European Commission

DG Environment

Economic assessment of groundwater protection

Groundwater restoration in the potash mining fields of Alsace, France

Case study report N. 1.

A project financed by the European Commission

ENV.A.1/2002/ 0019

May 2003
BRGM/RC-52324-FR

European Commission

DG Environment

Economic assessment of groundwater protection

Groundwater restoration in the potash mining fields of Alsace, France

Interim Report

A project financed by the European Commission

ENV.A.1/2002/0019

Jean-Daniel RINAUDO

May 2003

BRGM/RC-52324-FR

Géosciences pour une Terre durable

Keywords : Chloride. Cost-benefit analysis. Economics. France. Groundwater directive. Pollution.

This report will be quoted as follow :

Rinaudo, J-D. (2003) – Economic assessment of Groundwater Protection : groundwater restoration in the potash mining fields of Alsace, France. Case study report No. 1. BRGM/RC-52324-FR, Orléans: BRGM.

Abstract

The field site under study consists of a specific section of a large water body (the upper Rhine valley aquifer) which is affected by intense point source pollution, originating from potash mining waste dumps. Two large pollution plume have progressively developed and affected an area of more than 180 square kilometres, out of which 80 hectares are characterised by chloride concentrations.

Significant groundwater protection restoration measures have already been implemented since the late 1970's, resulting in a reversal of the pollution trend and a progressive decontamination of the aquifer. The cost of these measures is estimated at 67 millions € from1976 to 2001. Additional water protection and restoration measures should cost another 43 millions € between 2002 and 2010. Overall, more than 82 millions € have been spent on measures aiming at reducing pollution at source and 28 millions € on measures aiming at removing pollutant from the aquifer.

In spite of these efforts, and because the measures have been implemented belatedly, the pollution has generated significant economic damage for the drinking water sector, agriculture and industry. Using available data, these costs are roughly estimated at 30 million €. It is also expected that the pollution will entail an additional 8 million € in the future two decades.

The report then analyses the effectiveness of the measure currently implemented. Using an hydrogeological simulation model, it shows that these measures will not be sufficient to achieve the good chemical status in the aquifer by 2015. A scenario consisting in intensive clean-up measures is then defined and its costs assessed at 50 million €. The report then identifies the benefits generated by this accelerated clean-up scenario and their total economic value assessed at 16 to 21 million € (depending on the discount rate used). The report concludes with a discussion on possible options for water management of this field site, representative of many other industrial pollution cases situations in Europe.

Table of content

List of figures

List of tables

Introduction

The case study presented in this report focuses on a highly polluted area of the upper Rhine valley alluvial aquifer. This aquifer is a transboundary water body which extends over 4200 square kilometres in Germany and France (see map 1 below). With a reserve of approximately 45 billions cubic meters of water, that is approximately half of the volume of the Lake Geneva, this aquifer is one of the largest fresh water reserves in Europe. Groundwater from the Rhine alluvial valley fulfils 75% of the drinking water needs and about half of the industrial water needs. More than three millions inhabitants of the Alsace Region (France) and the Land of Baden-Württemberg (Germany) directly depend on its quality.

Although remaining usable for drinking purpose without prior treatment in most locations, groundwater has progressively been affected by diffuse and point source pollution. Nitrate concentration exceeding 50 mg/l have been reported in a large number of monitoring points. Pesticide pollution problems are also reported. High concentrations in chlorinated hydrocarbons have also been detected downstream of certain industrial areas. And a large area is affected by chloride pollution, originating from the potash mining industry, both on the French and German side.

This case study focuses on the chloride pollution problem on the French side of the border. The area under study is located in the south-eastern part of the Alsace region, close to the industrial city of Mulhouse in France. The area affected by chloride pollution extends over approximately 180 square kilometres. The main objective of the study is to assess the economic costs and the benefits of groundwater restoration measures implemented during the last 3 decades.

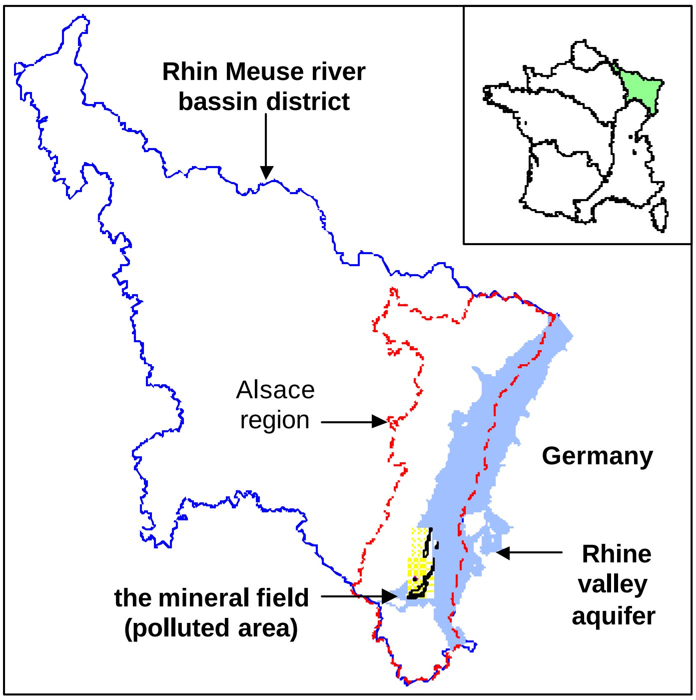


Figure 1 : Location of the field site.

This report is organised as follows. The first section presents the pollution sources (pressures), their impact on groundwater quality and the groundwater protection and restoration measures that have been implemented since the mid 1970s. The effectiveness and the cost of these measures are assessed. The second section investigates the nature of the economic damage generated by the chloride pollution and assesses their value in monetary terms. The third section assess a scenario consisting in intensive clean-up measures to achieve good chemical status by 2015. The cost and the benefits generated by the accelerated clean-up scenario are then assessed.

1. Pressures, impact and restoration measures

1.1. THE POLLUTION SOURCES

Potash ore started to be extracted in the region of Mulhouse in Alsace in the early 1910. The ore extracted from the mines was processed close to the mining site to separate the potash from its impurities and the salt (sodium chloride) it contains. Tailings from the ore processing plants were piled up into huge waste dumps. Fifteen such waste dumps, characterised by high salt contents, were erected in the potash mining fields between 1910 and 1933 and two other later in the 1950's and 60's.

For decades, the waste dumps have been leached by rainfall. Water percolates through the waste dumps and it almost reaches the saturation point, with salt concentrations frequently reaching 200 g/l of chlorides. It then infiltrates in the aquifer, which has progressively been contaminated by this point source pollution. As a result, two huge pollution plumes have progressively extended over time following the flow lines in the aquifer. Today, chloride concentration in groundwater can be very high, reaching 50 g/l in certain areas close to the waste dumps. Chloride concentration then decreases with the distance from the source.

After 1934, the industrial process has been gradually improved in order to leave less and less salty insoluble tailings, the soluble residue being pumped as a chloride-rich brine into the Rhine river through a pipeline (see map below). The salt contents of the solid waste produced decreased and the waste dumps erected after this date are characterised by smaller contents of salt. Overall, it is estimated that approximately 18,5 millions of tons of salt were deposited in the waste dumps (Chabart and Elsass, 2001).

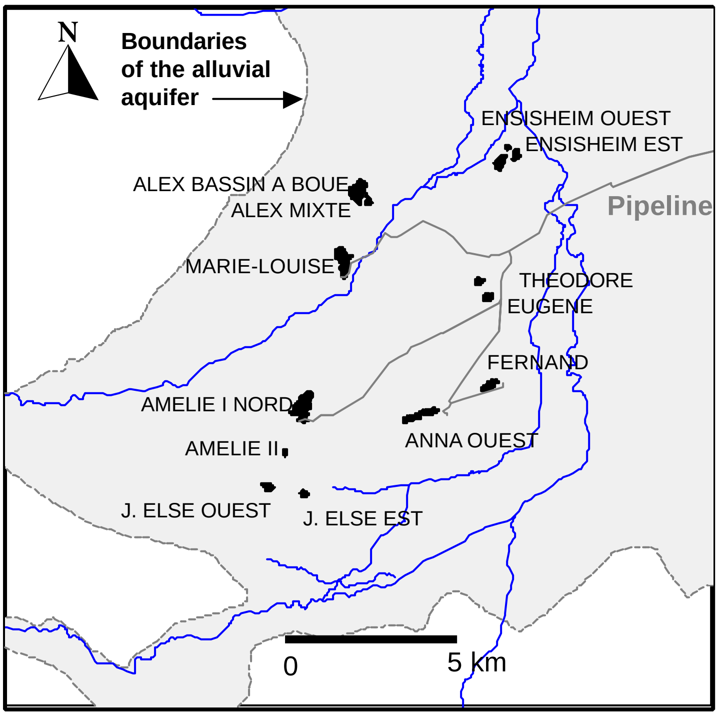


Figure 2: Location of the waste dumps (in black) and pipeline evacuating the brine to the Rhine.

Today, the waste dumps still contain significant quantities of salt as shown in Table 1 below and they continue to be a pollution source threatening the aquifer.

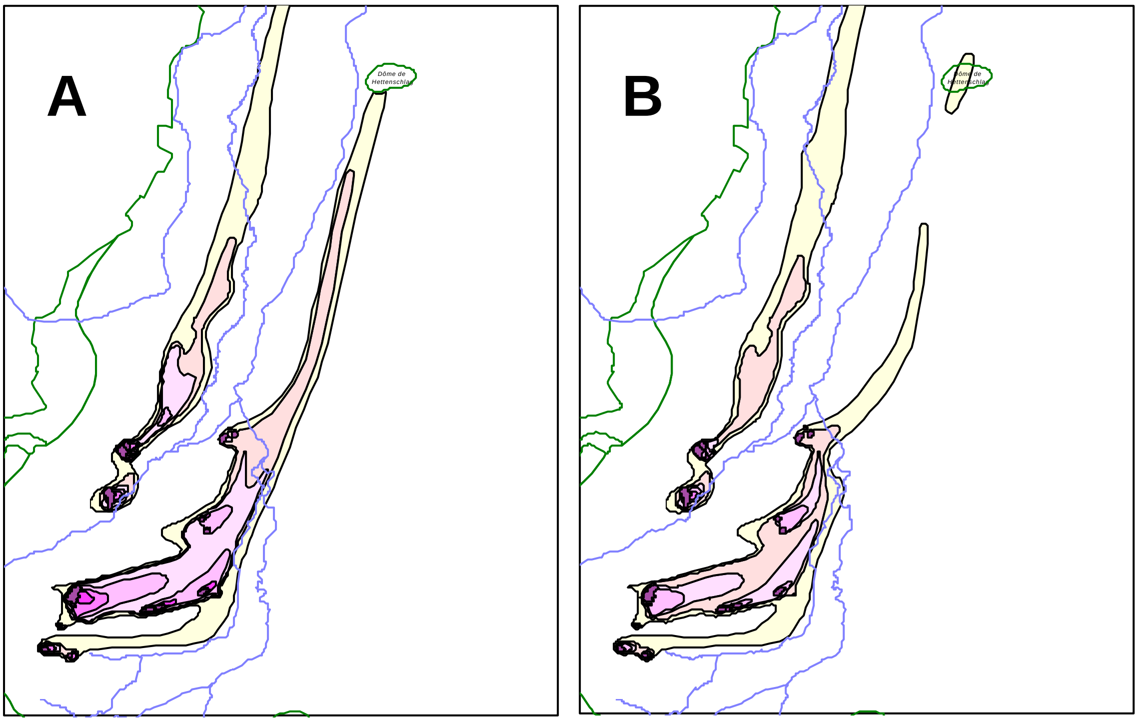
Name of waste dump	Starting date of deposit	Ending date of deposit	Area occupied by the waste dump (ha)	Material deposited from the beginning (in tons)	Total NaCl deposited from the beginning (in tons)	Total NaCl in place at the end of 2000 (in tons)
ALEX Terril ancien	1913	1933	3.0			
ALEX Terril mixte	1913	1969	6.8	4 860 000	1 470 000	0
RODOLPHE	1930	1976	7.3	2 895 000	665 000	259 200
ENSISHEIM Est	1923	1932	1.0	1 385 000	1 165 000	2 200
ENSISHEIM Nord	1926	1961	1.6	280 000	150 000	35 600
ENSISHEIM Ouest	1920	1975	3.8	900 000	440 000	189 500
ENSISHEIM bassin à boues	1932	1964	7.0	1 920 000	130 000	-
MARIE-LOUISE	1920	1999	30.9	18 477 900	3 450 800	1 487 600
AMELIE Nord	1924	on going	34.5	13 701 000	3 077 100	1 319 500
Amélie Est	1913	1929	2.7	1 160 000	950 000	281 500
AMELIE II	1913	1953	2.6	400 000	220 000	50 100
JOSEPH-ELSE Ouest	1912	1969	7.0	2 850 000	1 200 000	485 500
JOSEPH-ELSE Est	1959	1969	6.2	2 120 000	1 110 000	293 400
FERNAND	1913	1968	10.6	3 385 000	1 477 000	63 300
ANNA	1923	1974	16.7	4 780 000	1 515 000	763 500
EUGENE	1960	1986	5.9	3 615 000	635 000	248 000
THEODORE	1913	1959	4.4	1 550 000	925 000	50 100
TOTAL			**158.5**	**64 278 900**	**18 579 900**	**5 529 000**

Table 1: Major characteristics of the waste dumps.

1.2. THE EXTENT OF THE POLLUTION (IMPACT)

From the mid 1970's onwards, a water quality monitoring network was established and progressively extended. In 2000, this network counted 463 monitoring points used to follow the evolution of the salt concentration at different depths of the aquifer.

Using the monitoring data, the French Geological Survey (Brgm) has mapped the pollution of the aquifer, taking into account geological information and water flow directions. The latest maps produced in 2000 show the extent of the pollution (see Figure 3 below). The chloride concentration exceeds 100 mg/l in approximately 187 square kilometres and 200 mg/l in more than 80 square kilometres. The maps also highlight that, because of the higher relative density of saline water, deep layers are more affected more than surface layers.



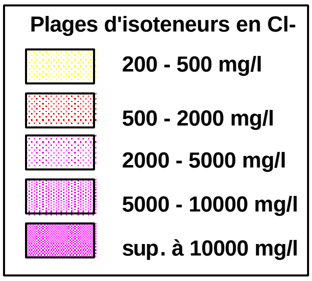


Figure 3 : Map of chloride concentration in the aquifer

A*: Deep layer (> 20 m in the potash field, > 40 m downstream)*

B*: Upper layer (< 20 m in the potash field, < 40 m downstream*

Source : BRGM (Chabart & Elsass, 2001).

1.3. GROUNDWATER PROTECTION AND RESTORATION MEASURES

Without any action, the waste dumps would continue to be a major source of pollution for more than one hundred and eighty years (see table 2 below). The volume of the aquifer affected by the pollution would thus increase year by year.

However, since the middle of the 1970's, three types of measures aiming at preventing any further degradation of the aquifer have been implemented:

- between 1976 and 1985, a number of water wells have been drilled immediately downstream of the mining deposits in order to intercept the salt infiltrated in the aquifer; the salt and water pumped by these wells is evacuated to the Rhine river though a pipeline; the discharge of salt in the Rhine river is kept compatible with the quota defined by the Bonn Convention.
- after 1989, a number of waste dumps characterised by a low salt content (less than 33%) have progressively been covered by a geo-membrane and/or a vegetal cover

in order to make them watertight and reduce infiltration; other waste dumps (containing more than 33% salt) have been artificially dissolved through intensive leaching with high pressure water guns (accelerated dissolution); in such cases, the highly concentrated water is recovered with a system of ditches and drains and evacuated to the Rhine river through the pipeline. As a result, the pollution sources are progressively suppressed and the inflow of salt into the aquifer is reduced. Since this pollution source dismantling programme will not be completed before 2010, fresh salt continues to enter the aquifer.

Name of Waste dump	NaCl leakage to the aquifer (tons/year)	End of NaCl emission date without measures	End of NaCl emission date with measures
ALEX Terril ancien		-	1994
ALEX Terril mixte	4 000	2080	2000
RODOLPHE	2 400	2130	2002
ENSISHEIM Est	600	2050	2001
ENSISHEIM Nord	800	2040	1999
ENSISHEIM Ouest	800	2080	2000
MARIE-LOUISE	16 000	2110	2006
AMELIE Nord	15 000	2140	2008
Amélie Est	5 300	2055	2008
AMELIE II	200	2020	1999
JOSEPH-ELSE Ouest	9 500	2130	2004
JOSEPH-ELSE Est	3 100	2160	2005
FERNAND	5 000	2060	2001
ANNA	7 900	2090	2006
EUGENE	5 600	2180	2005
THEODORE	6 800	2050	2001

Table 2 : Duration of the pollution emission by waste dumps with and without groundwater protection measures.

In 1995, this programme of technical measures was backed up by a decree specifying that measures have to be implemented to restore drinking water quality standards in the entire aquifer (200 mg/l) [1]. This quality objective has also be confirmed in the Water Management Plan (SDAGE) of the Rhin Meuse Basin District, elaborated by representatives of water users, elected politicians and government agencies in 1997.

[1] In France, the maximum chloride concentration acceptable for producing drinking water was 200 mg/l until the new drinking water directive (1998) was implemented in 2000 (bringing this threshold value up to 250 mg/l). After this date, it has been maintained as an objective in view of keeping a safety margin for drinking water producers.

In addition to these restoration measures undertaken by the Mining Company, the local authorities (Conseil Général du Haut Rhin) have invested in the restoration of a system of ancient canals that divert water from the Rhine and recharge the main river crossing the polluted area (the Ill river). The discharge of the Ill river in low flow period is thus artificially increased (+10 m3/s), which in turn increases the recharge of the aquifer and the dilution of the pollution.

1.4. EFFECTIVENESS AND COST OF THE MEASURES

- **Effectiveness**

The first effect of the measures has been to reduce the quantity of salt yearly infiltrated in the aquifer. Brgm has estimated that the sodium chloride inflow had fallen from 110,000 tons per year in 1996 to 70,000 tons in 2002 (see figure 3 below). The salt inflow should totally stop in 2010, after the last waste dumps have been covered with geo-membranes or artificially dissolved.

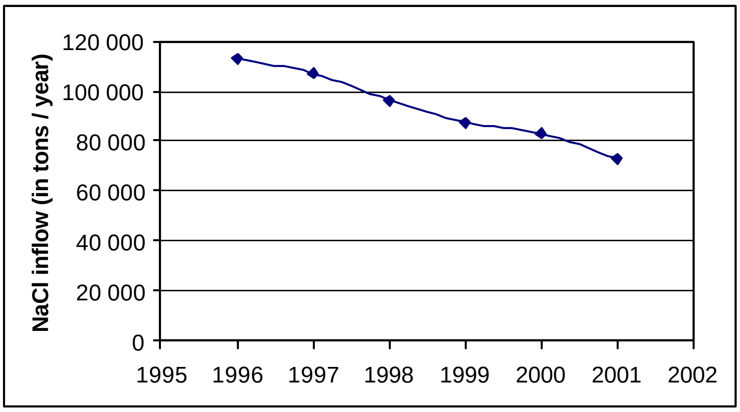


Figure 4 : Evolution of the total quantity of NaCl leached yearly from waste dumps.

The overall effectiveness of the measures has been assessed using a hydrodynamic model. This model, developed by Brgm as part of a previous study, is used to simulate the evolution of the chloride concentration in the upper and lower layers of the aquifer[2].

The simulation results (see maps below) show that if the measures already implemented are maintained ***until 2027***, the chloride concentration will fall below 250 mg/l in the entire polluted area and approximately 96% of the salt present in the aquifer in 2002 will be removed[3]. In other words, the measures implemented are sufficient to restore the good status of water in the whole area but, since the good status can not be restored in 2015, a time derogation has to be justified.

[2] For a detailed presentation of this model, see Rinaudo, Petit and Arnal, 2001.

[3] It is however possible that pockets of intense pollution, trapped in the lower section of the aquifer, remain after 2027, the model being too simple to account for such localised phenomena. It is assumed here that the presence of such pockets of pollution can be neglected.

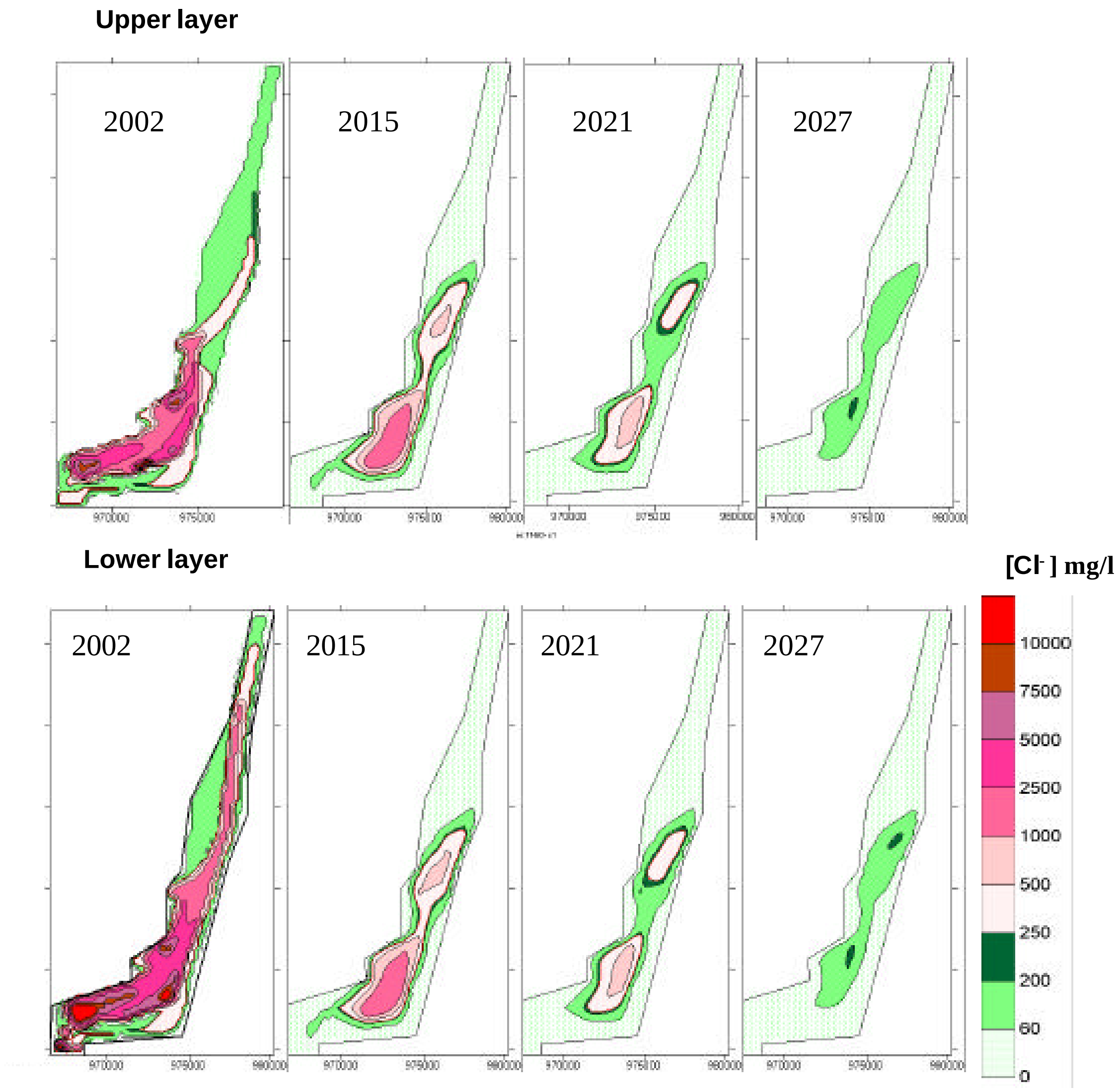


Figure 5 : Maps showing the simulated evolution of the chloride concentration in the upper and lower level of the aquifer (east plume only). The good status is achieved in 2027.

1.5. COSTS OF EXISTING GROUNDWATER PROTECTION AND RESTORATION MEASURES

♦ **Nature and decomposition of the costs**

The cost of the protection and restoration measures implemented since the middle of the 1970's have been investigated, as part of this study, using figures obtained from the Mining Company MDPA and the different public agencies involved in groundwater protection activities (namely the *Agence de l'Eau Rhin Meuse* and the *Région Alsace*).

Two main elements of costs were identified : <u>investment costs</u> (construction of pumping wells, infrastructure to artificially dissolve waste dumps, watertight covering of waste dumps) and <u>operation and maintenance costs</u> (energy used by wells, maintenance of the pollution control infrastructure, financing of a team in charge of the pollution control programme).

Overall, the total cost is estimated at over € 67 millions for the period 1976 to 2001, with over € 27 millions investment and close to € 40 millions operation and maintenance costs. **Additional measures which will be implemented between 2002 and 2010 should cost another 44 millions €**, split into 30 millions investment and 14 millions operation and maintenance costs.

The analysis of the detailed expenditures of the MDPA environmental programme (see table below) shows that the suppression of pollution sources (accelerated dissolution of waste dumps and waterproof covering) account for more than 70% of the total cost during the 1987 –2001 period. This percentage is likely to be raised above 85% in the coming decade. The other elements of cost are:

(i) the repair and maintenance of the pipeline which brings effluents from the ore processing plant and polluted water recovered through depollution wells to the Rhine river;

(ii) the installation and operation of depollution wells and monitoring piezometers;

(iii) studies and experiments (for instance those undertaken prior to installing a well or piezometer).

	Period 1987 -2001	Period 2002 - 2010
Accelerated dissolution of waste dumps	65 %	47 %
Waterproof covering of waste dumps	7 %	39 %
Brine pipeline (repairs and maintenance)	10 %	5%
Wells and piezometers	10 %	5 %
Studies and experiments	8 %	4 %

<u>*Sources*</u> : MDPA, service Environnement. No data available between 1976 and 1987.

♦ Funding of the measures

From 1976 to 2001, 27% of the total cost has been covered by public subsidies. The operation and maintenance costs, which amount to about € 40 millions, have been entirely paid by the mining company. Subsidies have been allocated to finance the development of infrastructures, they represent 65% of the total investment made between 1987 and 2001. The same public support is granted to groundwater protection and restoration measures

Period		Total cost (M€)	Public subsidies (M€)	Public subsidies in %
1976 - 1986	Investment	not estimated	-	-
	O&M	16.7	-	-
1987 - 2001	Investment	27.6	17.8	65
	O&M	22.8	-	-
	Total	*50.4*	*17.9*	*35*
2002 - 2010	Investment	30	18.2	61
	O&M	13.7	-	-
	Total	*43.7*	*18.2*	*42*
1976 - 2010	Investment	57.6		
	O&M	53.2		
	Total	*110.8*		

Sources : Agence de l'Eau Rhin Meuse, Région Alsace and MDPA.

2. The cost of delayed action

The groundwater protection and restoration measures described above have been implemented relatively late after the beginning of the pollution. This delay has resulted in a large scale contamination of the aquifer, which in turn, has generated significant economic damage. This section presents an attempt to assess the economic value of the damage that can be attributed to delayed action. A distinction is made between three different types of economic damage. The first one includes all damages related to consumptive uses of water, such as agriculture, industry and the drinking water sector for which chloride pollution represents an additional production cost (treatment cost, new investments needed, etc.). The second type includes all environmental damages caused by groundwater pollution to other ecosystems which are dependent on groundwater (wetlands, forests, rivers). The third type consists in the loss of patrimonial (or non use) value of the aquifer for citizens who consider it as part of their natural common heritage. In the paragraphs that follow, various methodological frameworks and data have been used to assess each of these benefits. Although a significant uncertainty is attached to the figures estimated, they nevertheless give an idea of the magnitude of the socio-economic impact of the pollution described above.

2.1. DAMAGE TO SURFACE ECOSYSTEMS

Because groundwater interacts with surface water bodies and related ecosystems, chloride pollution of the aquifer could theoretically have a negative ecological impact. However, in the area where the two pollution plumes extend, river beds are significantly higher than the water table. As a consequence, rivers tend to recharge the aquifer and there is no flow of water (and pollutant) from groundwater towards surface waters.

Furthermore, according to specialists in biological sciences of the National Scientific Research Center (CNRS) of Strasbourg, local Environmental Protection Associations, the Government Fish Department (CSP) and the Regional Administration for

Environment Protection (DIREN), most of the aquatic species present in rivers and wetlands of the area are not sensitive to chloride. Aquatic life could only be disturbed if chloride concentration would exceed 100 mg/l in surface water, a very unlikely event given the fact that water flow coming from the Vosges mountains represents a significant percentage of river discharge all year round.

This general statement has to be complemented by mentioning two cases where environmental damages have been observed:

- Firstly, a small wetland located immediately downstream of a waste dump (called the Rotmoss) is affected by salinity. Due to high salt concentration in surface water, a specific vegetal population has developed in this wetland, which surprisingly is now classified as an area of specific biological interest. In other words, the artificial salinity has led to the development of a new adapted ecosystem which is now considered as a positive impact by ecologists. Whether this should be considered as a cost or a benefit of the pollution is a subject of debate.
- Secondly, the growth of forest has been negatively affected by the salinity of groundwater, as tree roots may be in contact with high chloride concentration waters. According to local people, trees have even withered in certain areas in the past. However, it seems that the damage affected only a few hectares located very close to waste dumps before pollution control wells where installed.

☛ ***Conclusion :*** *chloride pollution of the aquifer has no significant ecological impact on surface waters and ecosystems of the same area.*

2.2. DAMAGE TO THE DRINKING WATER SECTOR

♦ **Financial costs for drinking water utilities**

Due to high chloride concentration, several drinking water wells located in the pollution plumes have probably been abandoned between the 1910's and 1975. We conducted a search in the archives of the *Département du Haut Rhin* and *Département du Bas Rhin* but it did not return any information on cases of well abandonment older than 1990.

After that date, we found two Drinking Water Utilities (DWU) which have been forced to undertake significant investment programs to cope with the increase of chloride concentration in the water withdrawn by drinking water wells:

- **The case of the Syndicat des Eaux de Ensisheim-Bollwiller et Environs (EBE):** the six wells of this DWU, supplying water to 7 municipalities and 17 628 inhabitants, are affected by the pollution since the late 1980s. Concentration of the water pumped in the wells range between 350 and 800 mg/l (significant fluctuations over time). In response to the pollution, the DWU constructed a pipeline in 1990 to import water from the neighbouring DWU of Guebwiller. The imported water is mixed with the polluted water in order to meet the Drinking Water standards (dilution rate 50% on average). The total investment cost amounts **to 1.93 million €** (constant €)[4]. This cost is partly supported by public subsidies (30%), the remaining 70% being paid by households (increase in water price).

[4] € 1.6 millions in 1990.

Moreover, the water imported, which comes from a dam in the Vosges Mountain, has to be treated (by Guebwiller DWU) and is sold to EBE a at fairly high price (over 0.5 €/m³). Overall, the price of water delivered by EBE DWU is raised by 0.35 €/m³. Knowing that EBE DWU sells approximately 700,000 m³ per year, the total cost for the water consumers (households and SMEs using water) is equal to 245,000 € per year. When we aggregate that cost for the period 1990 – 2002, the total cost supported by water consumers amounts to **3.185 millions €**.

Assuming that the pollution will continue to affect the drinking water wells for ten years[5], the water consumers served by EBE DWU will continue to support an additional cost of 0.35 €/m3, equivalent to 245,000€ per year (assuming no significant change in the water demand). That would lead to a total additional cost of **€ 2.15 millions** (with a 3% discount rate).

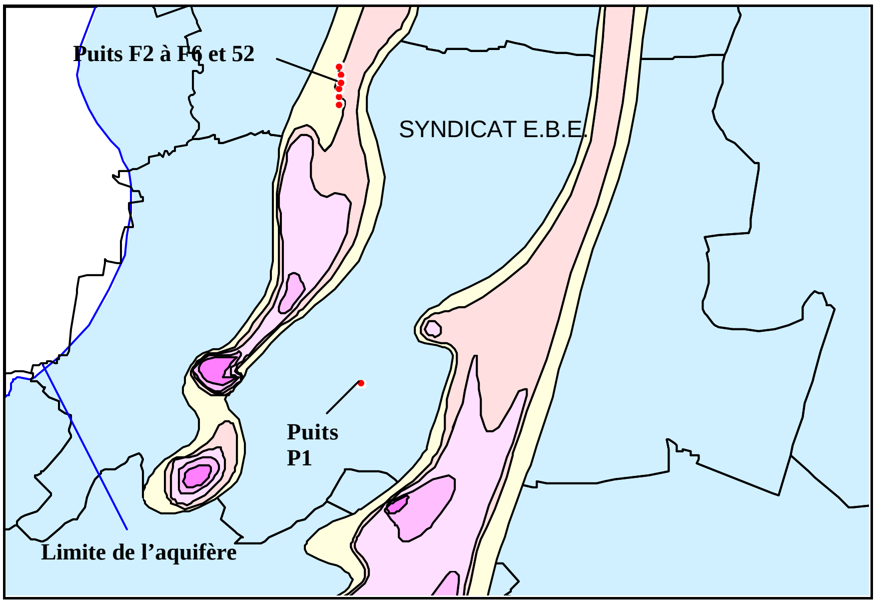


Figure 6 : Location of the wells of EBE Drinking Water Utility and groundwater chloride concentration.

- **The case of the DWU of Colmar and surrounding municipalities** : two of the four wells of the Colmar DWU ("puits du Neuland") are affected by the chloride pollution since the end of the 1980's (see map below). Chloride concentration of the water abstracted from these wells range between 200 and 260 mg/l. In response to this pollution, the Colmar DWU, which supplies water to 9 municipalities and close to 90,000 inhabitants, has modified the distribution network in order to mix water from these wells with the water abstracted through two other wells ("puits du Dornig", see map). In addition, to avoid corrosion of the distribution network provoked by high chloride concentration, the Colmar DWU adds polyphosphates to water before distribution (which forms a protection layer inside the pipes). However, this solution is not thought to be sustainable and the DWU is planning either to create a new well or to invest in a treatment plant (reverse osmosis). The investment cost would be close to 10 millions € for the first solution and 4.6 millions

[5] This assumption is based on the results of the hydrodynamic model simulation presented in a previous section.

€ for the second. Although creating a new well would be more than twice as high expensive as the treatment plant solution, the Colmar DWU is likely to go for it because it guarantees a lower water price. On the contrary, installing a treatment plant would lead to an increase of water production cost (operation and maintenance of the treatment plant), estimated at 0.08 €/m3. Knowing that the Colmar DWU distributes over 6 millions m^3 per year, the yearly additional variable cost (with the treatment plant option) would be equal to 480,000 € per year for the water users (households and industries). To summarize, we assume here that the cost of the chloride pollution for the Colmar DWU is equal to the cost construction of the new well, that is **€ 10 millions**. [6]

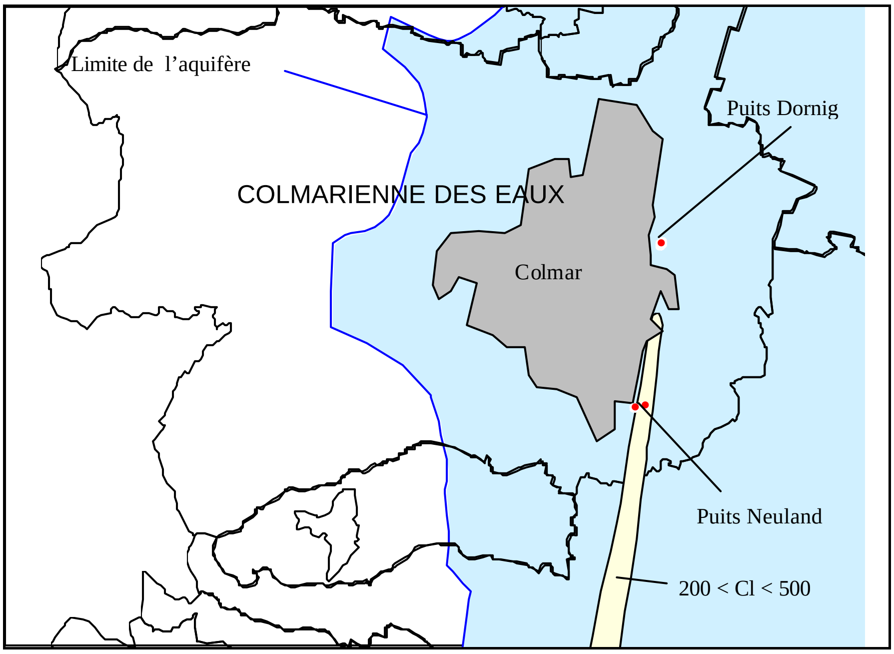


Figure 7 : Location of the wells of Colmar Drinking Water Utility and groundwater chloride concentration.

The costs identified above have been financed by:

(i) public subsidies allocated by the Rhin-Meuse Water Agency; these subsidies are in fact a redistribution of the water fees collected by the Agency at the river basin level, in all economic sectors;

(ii) public subsidies allocated by the Conseil Général (redistribution of the taxes collected at the local level);

(iii) public subsidies allocated by the National Fund for Drinking Water Network Development – FNDAE- (redistribution of the water fees for national solidarity)

(iv) the budget of two Drinking Water Utilities concerned, i.e. the local water consumer.

[6] No additional costs are expected after 2002 if the new well is constructed.

- **Indirect cost for households**

Although water distributed by the 2 concerned DWU complies with the European Drinking Water Standards, the chloride pollution reinforces the general decline of consumer confidence in tap water quality and safety. Indirectly, it contributes to increase the percentage of households who purchase bottled water. In other words, the chloride pollution generates additional expenditures for households which can be considered as an indirect cost of the pollution.

To assess this cost, we make the following assumptions :

- The chloride pollution problem is mainly perceived by consumers receiving water from the two drinking water utilities concerned, i.e. Colmar and EBE DWUs (total : 107,000 inhabitants).
- Approximately 60 % of this population drinks bottled water at least once a day[7];
- The average daily consumption of bottled water is half a bottle (0.75 litres) per person for a cost of 0.25 € per person;
- For a third of this population, the main motivation for purchasing bottled water is a lack of trust in the quality of tap water;
- 10% of this lack of trust can be attributed to chloride pollution; the remaining 75% are linked to nitrate, pesticides, fear of terrorism, etc.

These five assumptions are equivalent to saying that, in 2002, chloride pollution has generated additional expenditures for households worth **200,000 €**. In order to estimate the total cost born by the households over the last three decades and the additional cost up to 2027 (restoration of the aquifer), we further assume that:

- Bottle consumption started in 1975, grew linearly until 1990 (2% increase per year) and it will continue to grow linearly up to 80% in 2027.
- Consumers' perception of the chloride pollution has grown linearly from 1975 to 1990, then stabilised until 2002 before decreasing linearly and becoming nil in 2027.
- The assumed extra expenditure of households purchasing bottled water in response to chloride pollution is depicted in the figure below.

<u>Result</u> : the additional expenditure for households generated by chloride pollution is equal **to 2.6 millions €** for the period 1975 – 2002. An additional **3.53 millions €** corresponding to future bottle water purchase can also be attributed to the chloride pollution.

[7] Recent opinion polls conducted at the national level show that between 50 and 75% of the population drinks bottled water.

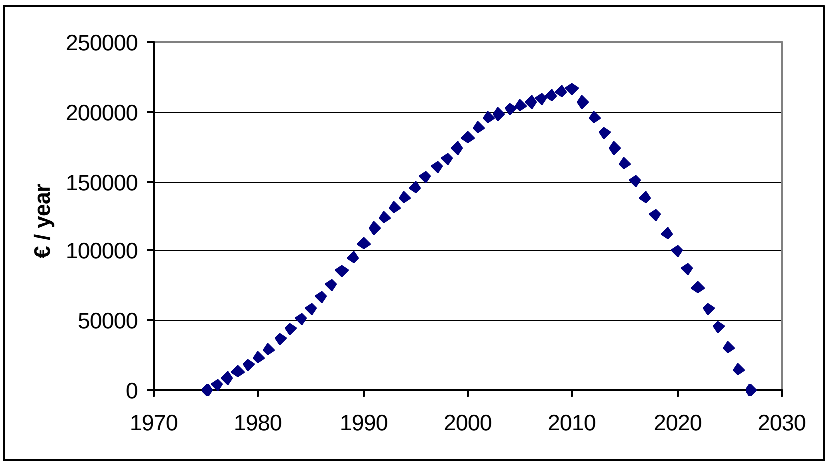


Figure 8 : Assumed evolution of the number of households drinking bottled water because of lack of trust provoked by chloride pollution.

2.3. DAMAGE TO THE AGRICULTURAL SECTOR

The chloride pollution results in two major types of economic costs for the agricultural sector: (i) the corrosion of irrigation equipment by polluted water; and (ii) the reduction of the quality of the crops irrigated with polluted water.

(i) Corrosion of irrigation equipment : depending on the chloride concentration of water, the useful life of irrigation equipment (tube and pumps of wells, irrigation pipes, centre pivots) can be reduced by a factor 2 to 10, especially when made of steel. The cost of corrosion was assessed by comparing the theoretical useful life of various equipment given by the constructor (noted ***d***) with that reported by farmers professional organisations (noted ***d'***)[8]. For a given investment noted ***I***, the annual financial loss due to rapid corrosion of the equipment is equal to ***(I/d') – (I/d)***. For instance, for a centre pivot dimensioned to irrigate 30 hectares, the investment is 55,000 €, the average useful life equal to 20 years and the observed useful life 7 years. Applying the above reasoning, the cost of corrosion is equal to 5100 € per centre pivot and per year. Knowing that only 5 centre-pivots are used in the area affected by chloride pollution, and assuming that this type of equipment was not used before 1975, the total cost is estimated to 714,000 € for the 1975 - 2002 period . Repeating the same approach with all the tube-wells located within the pollution plume (see map below), the cost of corrosion of wells and pumps is estimated to 700 € per year and per well, that is 980,000 € for the period 1975 – 2002 [9]. Overall, the cost of corrosion over a 28 years period is roughly assessed at **1.7 million €**.

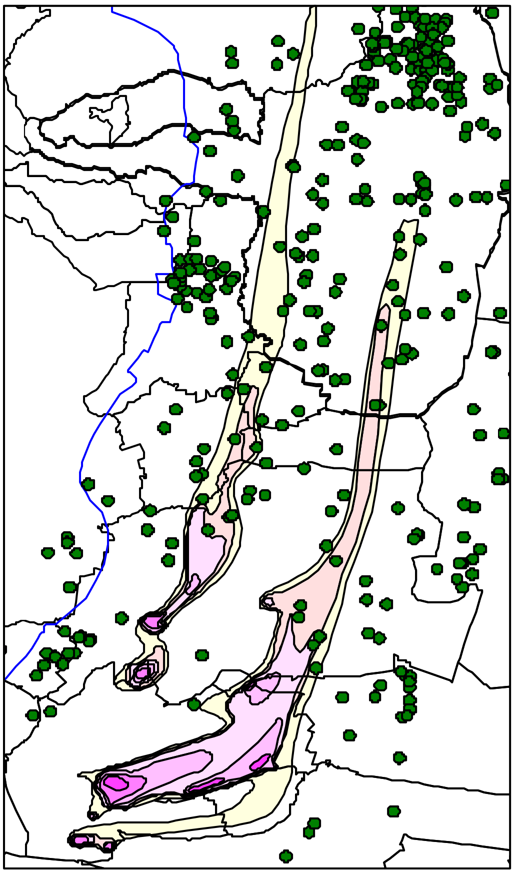
Assuming that the area where groundwater is used for irrigation will continue to be affected by chloride pollution until 2027, the farming sector is likely to bear additional costs due to the corrosion of irrigation equipment. Assuming that the area affected by

[8] Informations were obtained through interviews with engineers from the Agricultural Chamber of Haut-Rhin and from an irrigation association operating in this area.

[9] Assuming that: (i) the useful life of tube wells is reduced from 40 to 20 years and that of the pump from 15 to 7.5 years; (ii) the cost of a 20 meters deep tube-well and a pump are respectively 20 000€ and 3000€ and (iii) approximately 50 wells are –or have been- concerned by the pollution between 1975 and 2002.

the pollution (and the costs of corrosion) will decrease linearly with time, and taking a 3% discount rate, the total future cost is equal to **645 000€.**

<u>(ii) Impact on crop quality</u>: high added value crops such as tobacco and vegetables, which represent an alternative to maize cultivation, cannot be grown in areas where water shows a high chloride concentration. Irrigation of tobacco crop with such water leads to the formation of coloured marks on the leaves which reduces their marketable value; it also reduces the combustibility of the leaves [10]. As a result, certain farmers having a high ratio of labour per hectare, and who could have interest in cultivating tobacco (labour demanding crop), are forced to produce crops with lower added value such as cereals and maize. This generate a potential loss of income equal to the difference between the gross margins for maize and tobacco (respectively 1100 €/ha and 8000 €/ha) multiplied by the area where tobacco could be grown (20 hectares, taking into account soil constraints and the number of farms with high labour potential). The total annual income loss is thus equal to 136,000 €. Assuming that the relative profitability of tobacco (compared to other crops) has not evolved over time, the total loss of income would be close to **3.8 millions €**.



(source : BRGM and Région Alsace)

Figure 9 : Location of agricultural wells used for irrigation (green dots) and chloride concentration.

[10] Cigarettes made out of this tobacco won't burn, which could be considered as an indirect health benefit of groundwater pollution…

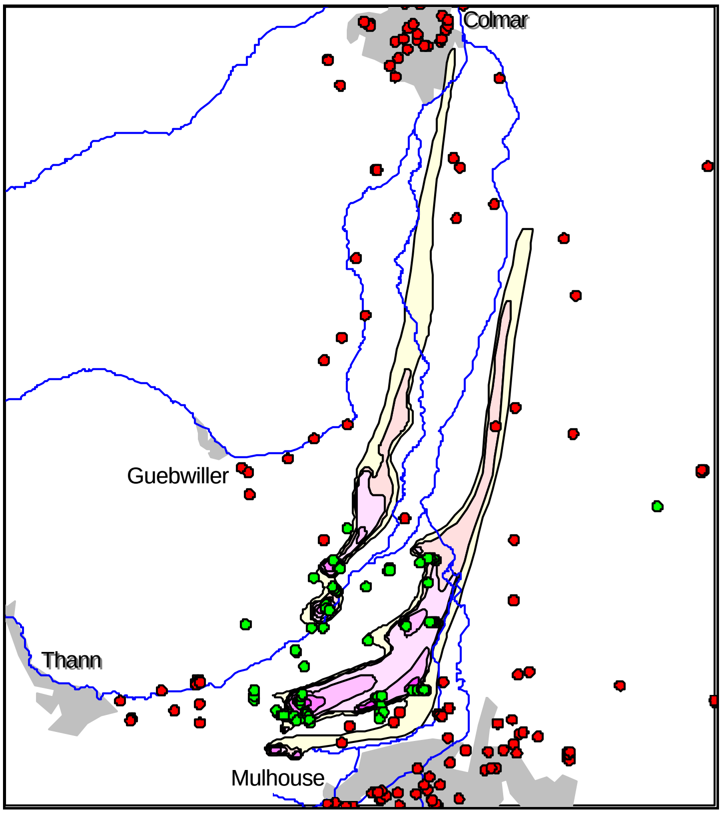
Assuming here again that (i) groundwater underlying the area potentially usable for tobacco production will not be restored before 2027, (ii) that the area affected by the pollution will decrease linearly with time and (ii) taking a 3% discount rate, the total income loss born by the farming sector is estimated at **1.46 million €**.

2.4. DAMAGE TO THE INDUSTRIAL SECTOR

The progressive extension of the pollution plume has forced many industries to abandon their own water well, mostly because of the corrosion problems caused by high chloride concentration. The costs induced are (i) those of the lost investment (abandoned well), (ii) the cost of connection to the drinking water network (fixed cost) and (iii) the additional cost of water per unit of volume (treated drinking water being generally much more expensive than water pumped in a private well). However, due to the historical dimension of the pollution, the experts [11] that we interviewed could not identify the concerned companies, some of which have probably disappeared today. Consequently, this cost is not assessed.

The experts interviewed also reported that many industries have installed small treatment units to purify water and remove chloride. However, treatment units have sometimes been installed in areas where the chloride concentration lies below 200 mg/l (in particular in the region of Mulhouse and Colmar, see map below). Also, they have not always been installed in response to the presence of chloride: in many cases, the treatment is imposed by technical constraints linked to the industrial process itself. Here too, the experts were not able to identify industries which have been forced to install treatment plants in response to the presence of chloride. In both cases, the damages provoked by the chloride pollution are not reversible and represent sunk costs.

[11] Association Alsacienne des Usagers Industriels de l'Eau (Alsatian Association of Industrial Water Users)



Source BRGM Underground Data Bank (BSS)

Figure 10 : Location of registered industrial wells (red dots). Pollution removal wells operated by the mining company are shown in green.

2.5. DAMAGE TO NON USERS

In Alsace, the preservation of the environment in general, and of groundwater quality in particular, is a matter of concern for the public concern. This environmental sensibility of the public results from the many awareness campaigns that have been conducted by regional authorities and environment protection associations, the latter being well established and structured in the region. Also, the aquifer is considered by the local population as an important part of the regional **heritage**. In other words, inhabitants attribute a value to the aquifer, independently from the fact that they use it or not (existence or non use value). Symmetrically, they consider that groundwater pollution reduces the economic value of what they consider to be a part of their natural heritage. In the paragraphs that follow, we try to assess in monetary terms the “loss of non use value” due to chloride pollution.

- **Historical evolution of the social perception of the chloride pollution**

In the potash mining fields as in many other mining regions in Europe, the public did not pay specific attention to the pollution of groundwater until the late 1950’s. In particular, it seems that chloride pollution, like land subsidence (the other major negative impact of mining), were long considered as necessary undesirable side effects and assumed as inevitable by the people whose jobs were directly dependent on this activity[12].

However, perception changed with the decline of the mining activity and the reduction of its weight in the local economy. Also, conflicts started to appear when the pollution plumes began to affect water users located outside the area where underground workers were recruited. The MDPA then started distributing financial compensations for the losses induced by the pollution. In the late 1970's, the MDPA accepted (and still continue) to reimburse the cost of the polyphosphate added to drinking water by the Colmar Drinking Water Utility (see above). A bit latter, some farmers obtained financial compensations for the corrosion of their irrigation equipment, in some cases after several years of legal action.

- **Citizens' willingness to pay for groundwater protection**

More recently, the Regional Council (Conseil Régional d'Alsace) has supported a research project aiming at evaluating citizens' willingness to pay to protect the aquifer. The study was conducted by economists from Strasbourg University, using the contingent valuation method (Rozan et al., 1997). A sample of 817 French households depending on the aquifer as drinking water resource (users) and 159 depending on other resources (non users) were interviewed and asked to state their willingness to pay to protect the aquifer.

The results showed that households were willing to pay (on average) 93€ per households when the water they drink comes from the aquifer and 52€ when their water supply relies on other resources (surface water). The study also showed that willingness to pay depends on several variables such as household's income, price of drinking water, etc.

These answers were then aggregated to assess the total willingness to pay of the Alsatian population to protect the aquifer (Masson et al., 1999). These researchers found a total value of 64 millions € per year, split into 53 millions € for the use value (i.e. the value that citizen attribute to water because they use it directly for drinking of for other economic uses) and 11 millions € of non use value (i.e. the value that citizen attribute to the presence of good quality groundwater independently of the use they make – or intend to make- of it). It should be noted here that the use and non use values of the trans-boundary water body could not be assessed in absence of a similar study on the German side of the Rhine.

- **Assessment of the loss of existence value generated by chloride pollution**

What we now want to have is an estimate in monetary terms of the loss of utility (or satisfaction) [13] that has been (and will continue to be) felt by the citizens concerned by the pollution of the aquifer in the potash mining field, independently of the other costs they could bear as farmer, industrialist, drinking water consumer. This monetary value can be estimated using the results of the contingent valuation study presented above and making the following assumptions:

---

[12] Similar attitudes were reported in Spain (Loredo et al., 2001).

[13] Loss of non use value.

1- Citizens' willingness to pay to protect the aquifer reveals its existence (or non use) value for citizens.

2- WTP varies significantly over time; this is due to changes in the level of environmental awareness of the public and variations in the intensity of the pollution (the higher the pollution threat is, the higher the WTP)

3- As a result, we assume that the willingness to pay for groundwater protection against chloride pollution was nil 1975 and that it has grown (linearly) after that, reaching its maximum in 1990. It then remained constant until 2002 and it decreases afterwards, together with the area affected by chloride pollution (see figure below).

Results: the loss of satisfaction of citizens integrated over the period 1970 – 2002, represented by the area [ABCD] on the figure below, is equal to **6.6 million €.** Similarly, the loss of satisfaction generated by the fact that groundwater quality will only be restored in 2027 is equal to **3.96 M€**. However, given the number of assumptions made above and the uncertainty attached to the evaluation method used by Rozan et al. to quantify the willingness to pay, these values have to be taken as very rough proxies.

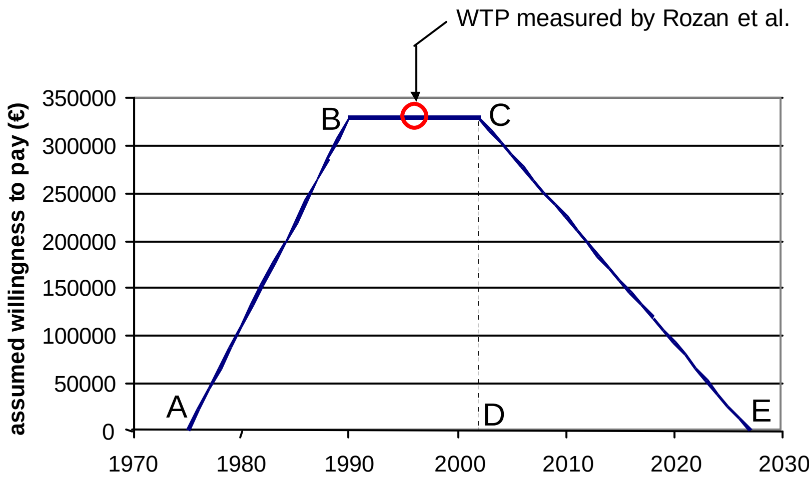


Figure 11 : Assumed evolution over time of the citizens willingness to pay for the protection and restoration of groundwater in the potash mining field. Only one value was actually measured in 1995.

2.6. SUMMARY

The case study presented in this section shows that pollution has generated significant economic damages because the groundwater protection measures have been implemented long after the pollution began. The value of the economic damage is assessed at 17.5 M€ for the drinking water sector (60% of the total cost) and 5.5 M€ for the drinking water sector. Also, the pollution of the aquifer, which represents a degradation of the common heritage of the population is felt by the public as a damage which economic value has been assessed at 6.6 million €, using the results of an existing contingent valuation.

Economic sector affected	Description of impact	Past cost (until 2002)		Future cost (2002 – 2027)	
		in M€	In %	In M€	In %
Drinking water supply	Investment - Pipeline EBE DWU - New well for Colmar DWU	1.93 10	40%	- -	- -
	Additional cost of water due to water purchase (EBE) Households expenditures on bottled water	3.185 2.6	20%	2.15 3.53	48%
Agriculture / irrigation	Corrosion of irrigation equipment. Loss of income (and employment) due to impossibility to irrigate tobacco crop.	1.7 3.8	18%	0.645 1.46	18%
Industrial sector	Polluted wells abandoned Construction of treatment plants: investment & increase of O&M costs	Not assessed		Not assessed	
All citizens	Cumulative loss of non use value due to groundwater pollution in the potash mining field.	6.6	22 %	3.96	34%
Total cost		**~ 30**	100%	**~ 8**	100%

Figure 12 : Main elements of cost due to chloride pollution in the potash mining field.

3. The costs and benefits of accelerated clean-up

In the second section of this report, we showed that the groundwater protection and restoration measures that have been implemented since the 1970's are not sufficient to restore the good chemical status by 2015. In this section, we investigate whether its is economically rationale to accelerate the clean-up of the aquifer by assessing and comparing the costs and the benefits of accelerated clean-up measures.

3.1. DEFINITION AND COSTS OF THE INTENSIVE CLEAN-UP SCENARIO

Using the hydrodynamic model presented in the second section, we have defined an intensive clean-up scenario (for more details see Rinaudo, Petit and Arnal, 2002). This scenario consist in installing additional wells to pump polluted water and prevent any further extension of the plumes. It enables the restoration of chloride concentrations below 250 mg/l in the entire area by the year 2015. It is therefore beneficial for water users, who will have good quality water 12 years earlier than if only the current measures were implemented.

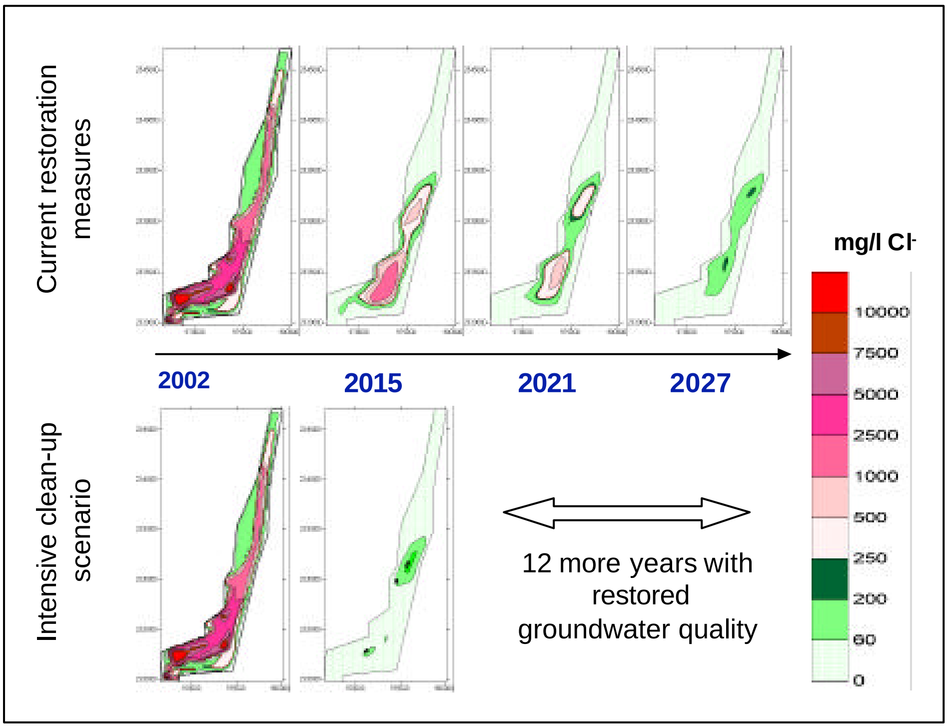


Figure 13: Maps showing the simulated evolution of groundwater chloride concentration with current restoration measures and with a more intensive cleaning-up scenario (case of the upper layer of the Eastern pollution plume).

The additional cost of the intensive clean-up scenario has been estimated at over 23 million € for the Eastern plume, taking into account investment costs (construction of new pollution control wells), operation costs (energy, labour) and maintenance costs. The *additional* clean-up cost for the two plumes is roughly estimated at **50 million €**, taking into account that the Western plume contains more salt that the Eastern plume.

3.2. BENEFITS OF ACCELERATED CLEAN-UP

♦ **Definition of benefits**

From a theoretical point of view, the benefits of the intensive clean-up scenario are the *additional* welfare accruing to water users as compared to the welfare they would derive from the current scenario. As shown on Figure 14, these advantages increase much more rapidly with the intensive scenario (green line) than with the current scenario (blue line). The additional benefits generated by the intensive restoration scenario are represented on the figure by the area of the triangle OAB.

In the case study, the benefits of the intensive groundwater restoration scenario are defined as the damage that can be avoided by a faster restoration of the aquifer quality. These avoided damage concern agriculture, industry and the drinking water sector, but also citizens at large since the scenario leads to a faster restoration of the common heritage.

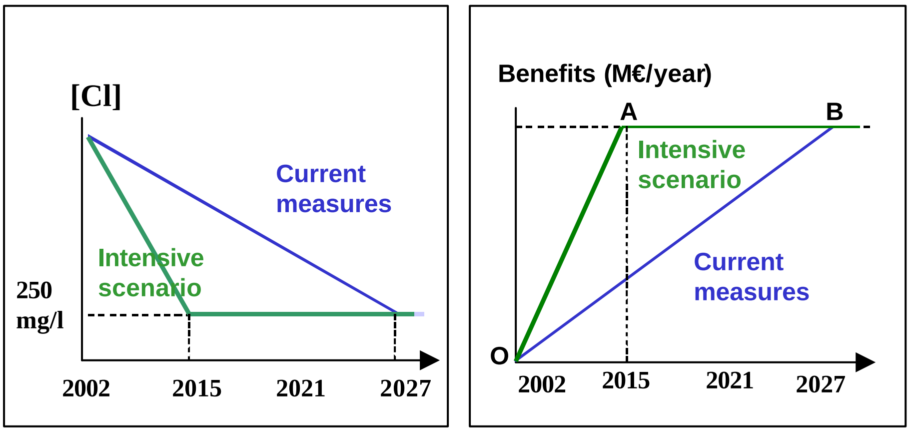


Figure 14 : Evolution over time of chloride concentration and related benefits.

- **Economic assessment of the value of the benefits**

The additional benefits generated by a rapid restoration of the aquifer have been assesses in monetary terms using the assumptions, data and methodology presented in the previous section. The economic value of the major benefits generated by accelerated clean-up measures, estimated with a 3 % discount rate (D.R.), are as follows:

- a reduction of drinking water production costs for the DWUs concerned over a 12-year period (10.7 million €) and a reduction of the amount of bottled water purchased by households whose trust in tap water is restored 12 years earlier than with the "current scenario" (1.4 million €);
- a reduction of the cost of corrosion of irrigation equipment over a 12-year period (0.4 million €) and an increase in farm income due to the fact that tobacco can be grown during an additional 12-year period (1.4 million €);
- an increase in the welfare of citizens who derive satisfaction from the rapid restoration of the aquifer, which they perceive of as being part of their common heritage. This benefit is assessed in monetary terms using the results of a contingent valuation study of citizens' willingness to pay for groundwater protection in Alsace (3.8 million €).

Overall, the total monetary value of additional benefits ranges from 16 to 21 million € depending on the discount rate that is used. This estimate is, however, only partial as other benefits have not been assessed in monetary terms. In particular, the fact that groundwater quality is restored might reduce the production costs of some industries. It might also increase the attractiveness of the area and thereby accelerate its economic development. Consequently the estimate of 16 to 21 million € should be perceived and used as a *lower boundary value*.

Finally, these benefits can be compared to the estimated cost of the intensive clean-up scenario (50 million €). Knowing that the estimate of the benefit presented above is a lower boundary value, the decision whether the benefits of implementing this scenario justify the costs is not trivial. The decision remains a political act that must be informed and backed up not only by the economic analysis but also by technical, social and environmental information.

Type of benefit	Estimate with D.R. 3 % (M€)	Estimate with D.R. 0 % (M€)
Drinking water sector		
Savings on production of drinking water	10.7	10.9
Reduced bottled water purchase by households	1.4	2.4
Farming sector		
Increased useful life of irrigation equipment	0.4	0.66
Increased income (tobacco)	1.4	2.44
Citizens (Protection of natural heritage: non use value)	3.8	6.6
Industrial sector (Avoided treatment costs)	not estimated	not estimated
Local territorial bodies Increased development potential (& related fiscal income)	not estimated	not estimated
Environmental benefits (rivers & wetlands, forests)	not estimated	not estimated
Total benefits	**> 16.5**	**> 21.1**

Table 3: Additional benefits generated (damage avoided) by the intensive clean-up scenario.

4. Conclusion

In the case study presented in this report, groundwater protection and remediation measures have been implemented several decades after the pollution source started to have an impact on the aquifer. It is this delay which has led to the formation of two large plumes of polluted water, which in turn have generated significant damage for various categories of water users. Also, the cost of remediation measures which have been implemented in the late 1970's is much higher than it would have been if measures had been implemented earlier.

If the groundwater protection measures, which consist in reducing pollution at its source (artificial dissolution, covering of waste dumps) had been implemented earlier, one can assume that the social and economic costs borne by water users would have been avoided (approximately 38 M€). The cost of groundwater protection (suppression of pollution sources) would have remained unchanged (approximately 82 million €) and the cost of remediation measures (28 M€) would have been reduced (as the volume of polluted water to be pumped from the aquifer would have been much smaller). [14]

This case study illustrates that benefits generated by intensive groundwater quality restoration in zones affected by point source pollution may be significant, although they depend on the type and economic significance of water uses in the polluted area. This suggests that an economic analysis of groundwater clean-up scenarios should systematically be done before deciding whether or not it is socially desirable to restore groundwater quality in such areas. In other words, derogation should not be systematically allowed but justified on a case to case basis.

[14] The damages that would have been avoided with early action (38 M€) are not equal to total the benefits of the measures. Indeed, if no measures had been implemented, the pollution plumes would have gone much further and caused other damages, in particular in the industrial area located downstream of Colmar (see map above).

Acknowledgement

The author would like to thank Jean-Pierre Rulleau, head of the Environment Unit at MDPA, for providing access to the financial data and technical expertise hold by MDPA as well as for organising a field trip. We also thank Philippe Elsass (Brgm) for his significant contribution to the analysis presented in this report and Benjamin Görlach (Ecologic) for the comments made on an earlier version of this paper. However, the responsibility for the mistakes that may remain in this report lies with the author.

References

Chabart, M. and Elsass Ph. (2001). Contrôle et surveillance de la salinité de la nappe phréatique d'Alsace dans le bassin potassique et à l'aval (68). Rapport de synthèse des mesures effectuées en 2000. Rapport No. RP-50943-FR. Orléan : BRGM.

Gaumand, C. (1984). La nappe phréatique de la plaine d'Alsace : une rente de situation pour les Alsaciens. Unpublished report. Agence Financère de bassin Rhin Meuse, Moulins-lès-Metz, France.

Loredo, J., Pendas, F, Ordonez, A. and Perez M. (2001). Environmental Regulation of Mine Waters in the European Union – National case studies: Spain. ERMITE project report. Escuela de Minas, Universitad de Oviedo.

Masson S., Verchere A., Willinger M., Llerena D., Stenger A., and Rozan A. (1999). Vers une évaluation de la valeur patrimoniale de la nappe phréatique d'Alsace. Rapport Final. BETA – Université Louis Pasteur : Strasbourg. 126 pages + annexes.

Rinaudo, J.-D., Petit, V. and Arnal, C. (2001). Test de la méthode d'évaluation économique du caractère disproportionné du coût d'un programme de mesures: application au bassin potassique de la nappe d'Alsace. Rapport No. RP-51619-FR. Orléans: BRGM. 73 pages.

Rozan, A. Stenger, A and Willinger, M. (1997) Valeur de préservation de la qualité de l'eau souterraine : une comparaison entre usagers et non-usagers. *Cahiers d'Economie et de Sociologie Rurales* (**45**).

BRGM

WATER DEPARTMENT

Resource Assessment and Discontinuous Aquifer Unit

BP 6009 – 45090 Orléans cedex 2 – France –Tél. : 33 (0)2 38 64 34 34