December 2016 Version

Strategic Environmental Action Plan against lindane waste contamination in Aragón

GOBIERNO DE ARAGON

Strategic Environmental Action Plan against lindane waste contamination in Aragon

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"All truth passes through three stages.
First, it is ridiculed.
Second, it is violently opposed.
Third, it is accepted as being self-evident."
Arthur Schopenhauer. (1788-1860)

December 2016

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EXECUTIVE SUMMARY

The accumulation of Persistent Organic Pollutants (POPs) at the North of the Autonomous Region of Aragon, from the activity of an old lindane factory, is a potential determinant of the river Ebro water quality and represents a serious risk to human health and ecosystems.

Lindane, also known as gamma-hexachlorocyclohexane, (γ-HCH), is the commercial isomer of HCH and has been one of the most used pesticides worldwide in recent times. Due to its toxicity and persistence in the environment, lindane and several isomers of HCH have been included in the list of persistent organic pollutants of the Stockholm Convention.

The INQUINOSA factory synthesized lindane from 1975 to 1988 and stopped its trading activity in 1992. During this period, it is estimated that more than 150,000 tons of waste with high content of HCH and other organochlorine compounds were produced. In fact, every kilogram of lindane manufactured produced about 10 kilograms of toxic waste. These powdered and liquid wastes were dumped at the Sardas landfill, and later on at the Bailín landfill.

This same problem exists in many other parts of the world. However, the case of Aragon is specially interesting due to the large disposal volumes and the geological uniqueness of the sites, among other reasons. Therefore, its resolution is very useful to achieve the technological and institutional innovations required for such a global problem.

The Government of Aragon, which accumulates a technical, administrative and political experience of 25 years and € 54 million investment in the fight against lindane, proposes to institutions and society in general, to address its ambitious goal of solving the lindane problem as a pilot project through which to generate community added value and to contribute to smart, inclusive and sustainable growth.

The action of the Government of Aragon also represents an ambitious financial challenge to the extent that it is necessary to deal with a total investment of € 550 million over the next 25 years, which is 10 times the investment done over the past 25 years. This is an effort that the Government of Aragon cannot assume alone.

The support of European and Spanish institutions to the project is justified by the complexity of the problem, the guarantees offered by the Autonomous Community, as well as the potential importance of economic, social and environmental benefits of the experiences and solutions intended to be implemented in Aragon and which may be transferred globally.

The present Strategic Plan to address the pollution caused by lindane and other isomers of HCH, has been developed in accordance with the mandate of the Parliament of Aragon in November 2015 in the IXth legislature, expressed in Motion 158/15-IX, on the remediation of lindane in Aragon and the industrial revitalization in Sabinanigo, and in Motion 140/15-IX, on measures against lindane contamination in the affected areas.

Main ideas of this Strategic Plan:

- *The remediation actions to be developed must require little energy, i.e. low temperature and pressure in order to reduce risks and increase the sustainability of the solutions.*

- *Actions should preferably be carried out in situ, in order to reduce environmental risks and to apply the solutions where the challenges lie.*

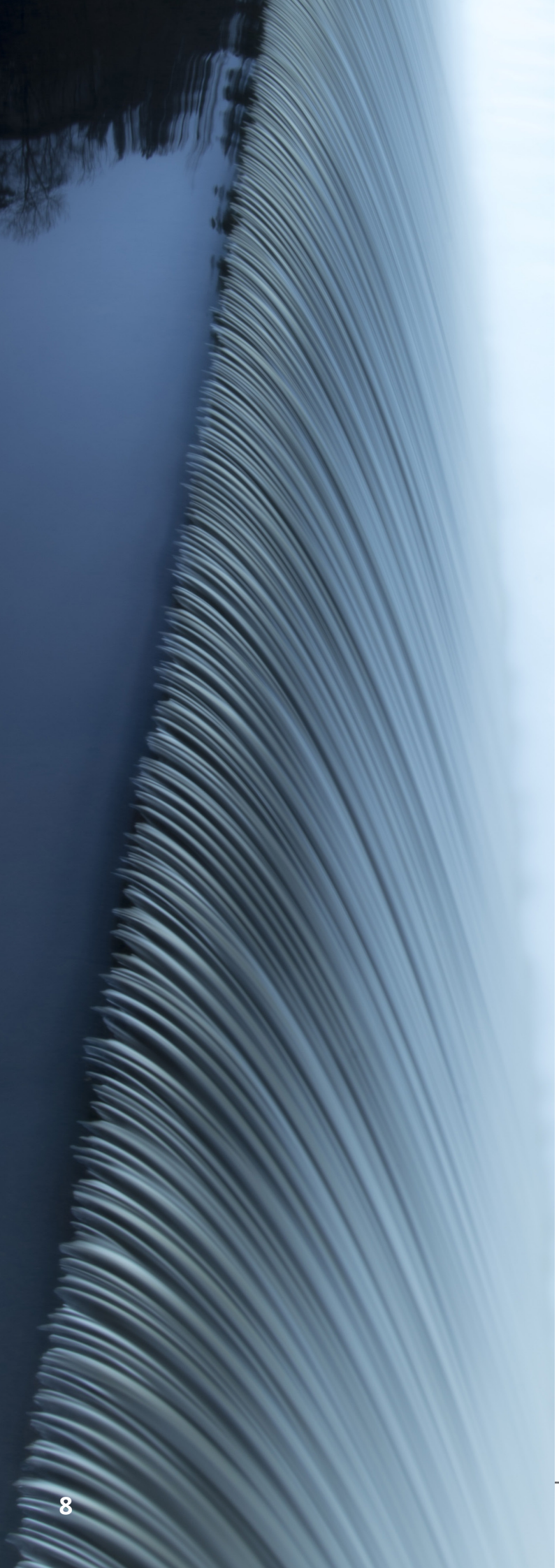
- *The final products of the remediation have to be less hazardous than the original ones, of shorter life and low mobility.*

- *Determined commitment to biological methods as main solutions, assisted with technological solutions.*

- *Remediation process modelization to predict the evolution and determine the efficiency of the results.*

- *This Strategic Plan is a dynamic tool, object of improvement and permanent revision. A minimum of an annual addendum with updates are required.*

- *This document is incorporated as an annex to the GIRA 2017-2022 Plan, in development, and will therefore be submitted to the Strategic Environmental Assessment procedure in accordance with Law 11/2014, of December 4, on Prevention and Environmental Protection of Aragon.*



RESUMEN EJECUTIVO

La acumulación de Contaminantes Orgánicos Persistentes (COP) al norte de la Comunidad Autónoma de Aragón, procedentes de la actividad de una antigua fábrica de lindano, es un condicionante potencial de la calidad del agua de la cuenca del río Ebro y representa un grave riesgo para la salud humana y los ecosistemas.

El lindano, el isómero comercial del hexaclorociclohexano (HCH), también denominado γ-HCH, es decir, gamma HCH, ha sido uno de los pesticidas más usados en todo el mundo en épocas recientes. A causa de su peligrosidad y persistencia en el medio ambiente, el lindano y varios isómeros del HCH han sido incluidos en la lista de contaminantes orgánicos persistentes del Convenio de Estocolmo.

La fábrica de INQUINOSA sintetizó lindano desde 1975 hasta mayo de 1989 y cesó su actividad de comercialización definitivamente en 1992. Durante este periodo se estima que produjo más de 150.000 t de residuos con alto contenido en HCH y otros compuestos organoclorados. No en vano, por cada kg de lindano producido, se generaron aproximadamente 10 kg de residuos peligrosos. Los residuos de la producción de lindano, en forma de polvo y de líquido, se vertieron en el vertedero de Sardas de forma incontrolada y posteriormente en el vertedero de Bailín de forma prácticamente incontrolada.

Este mismo problema existe en otros muchos lugares del mundo. A causa de diferentes razones, como los grandes volúmenes vertidos o la singularidad geológica de los emplazamientos, el caso de Aragón presenta un especial interés, por lo que su resolución resulta de gran utilidad para lograr las innovaciones tecnológicas e institucionales que exige un problema de naturaleza global.

El Gobierno de Aragón, que acumula una experiencia técnica, administrativa y política de 25 de años en la lucha contra el lindano en la que se llevan invertidos 54 M€, propone a las instituciones y a la sociedad en general, que contemplen su ambicioso objetivo de acabar con el problema como una acción piloto a través de la que generar valor añadido comunitario y contribuir al crecimiento inteligente, inclusivo y sostenible.

La acción del Gobierno de Aragón supone también un ambicioso reto financiero en la medida que es preciso afrontar una inversión total de 550 millones de € durante los próximos 25 años, que es 10 veces lo invertido durante los últimos 25 años. Un esfuerzo que el Gobierno de Aragón no puede asumir en solitario.

El apoyo de las instituciones europeas y españolas al proyecto del Gobierno de Aragón se justifica por la complejidad del problema, por las garantías que ofrece la Comunidad Autónoma, así como por la importancia potencial de los beneficios económicos, sociales y ambientales de las experiencias y soluciones que pretenden implementarse en Aragón y que podrán transferirse a escala global.

La redacción del presente Plan Estratégico de lucha integral contra la contaminación por lindano y otros isómeros de HCH, se realiza de acuerdo con el mandato de las Cortes de Aragón expresado en las proposiciones no de Ley núms. 158/15-IX, sobre la descontaminación de lindano en Aragón y reactivación industrial de Sabiñánigo, y 140/15-IX, sobre medidas contra la contaminación de lindano en las zonas afectadas, de noviembre de 2015 en la IX legislatura.

Ideas motor de este Plan Estratégico:

- *Las acciones de descontaminación a desarrollar han de ser de bajo requerimiento energético, es decir, de baja temperatura y presión, como garantía para minorar los riesgos y aumentar la sostenibilidad de las soluciones.*

- *Las actuaciones han de ser preferentemente in situ, para reducir los riesgos ambientales y aplicar las soluciones en donde se encuentran los retos.*

- *Los productos finales de la descontaminación han de ser menos peligrosos que los originarios, de vida más corta y baja movilidad.*

- *Apuesta decidida por los métodos biológicos como protagonistas del tren de soluciones, catalizados con soluciones tecnológicas.*

- *Modelizar los procesos de la descontaminación para prever su evolución y determinar la eficiencia de los resultados.*

- *Este plan estratégico es una herramienta dinámica, objeto de mejora y revisión permanente. Este carácter se sustancia en el compromiso de un mínimo de una adenda de actualización anual.*

- *Este documento se incorpora, como anexo, al Plan GIRA 2017-2022, en redacción, y por tanto, se someterá al procedimiento de Evaluación Ambiental Estratégica conforme a la Ley 11/2014, de 4 de diciembre, de Prevención y Protección Ambiental de Aragón.*

Strategic Environmental Action Plan against lindane waste contamination in Aragon

1

Lindane:

A global problem

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1

LINDANE: A global problem

The great boom of the commercial use of chemical synthetic products which occurred during the 20th century has contributed to human welfare but also presents ecological consequences never planned nor desired.

Many of these substances have shown to be beneficial for the control of pests and diseases, both in crops and in the industry. However, some of these compounds cause toxic reactions, persist in the environment for years and travel long distances through water, the air and the food chain from the place where they were produced or used, threatening the health of people and the wildlife (UNEP, 2005).

Persistent Organic Pollutants (POP) are a class of substances causing particular concern. Many of them pose important threats to the health and the environment. Thus, on 22nd May 2001 an international treaty was adopted, the Stockholm Convention on Persistent Organic Pollutants. It was intended to restrict and, ultimately, to eliminate the production, use, discharge and storage of these type of substances. The mentioned Convention aims to reduce and eventually eliminate the release of 12 particularly toxic persistent organic pollutants. Among them there is the hexachlorocyclohexane (HCH), one of which isomers is lindane, a pesticide massively used throughout the world.

Persistent Organic Pollutants POP

Persistent Organic Pollutants (POP) are chemical substances with the following characteristics: They are persistent in the environment due to their high resistance to degradation; they are bioacumulative, sitting up in the tissues of living beings and increasing the concentration through the food chain; they are highly toxic and cause serious effects on human health and the environment; and they have the potential to be transported over long distances, arriving to regions where they have never been produced or used.

The POP are volatile at average mid-latitude conditions of temperature.Transported by the atmosphere, they condense and deposit in the cold high-altitude areas or at high latitudes. Due to their persistence, they can be deposited and volatilized again in successive cycles depending on the ambient temperatures, producing the "Grasshopper effect".

The Autonomous Community of Aragon is seriously concerned by the constant release of persistent organic pollutants to the environment. These chemical substances cross international boundaries far from their place of origin and remain in the environment. The bioaccumulation occurs through the food chain and pose a risk to the human health and the environment. Therefore, additional measures should be taken to protect the human health and the environment from those pollutants (OJEU, 2004).

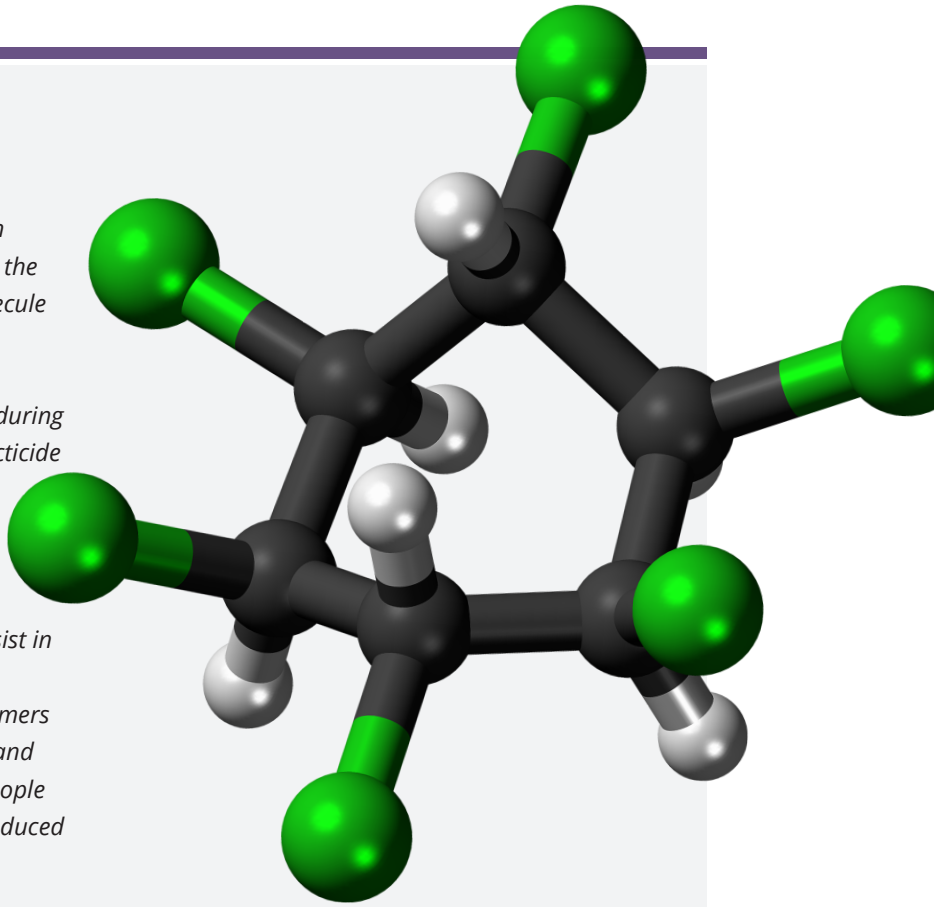
At the 13th International Forum on HCH and pesticides held in Zaragoza in November 2015 and promoted by the Department of Rural Development and Sustainability of the Government of Aragon, which was attended by more than 150 experts from 35 countries of the five continents, it was revealed that contamination by lindane and its associated waste is a global problem. There are numerous sites throughout the world where this type of contaminants accumulate, and there are no technically-viable and economically-acceptable solutions in a short term view. Those solutions definitively depend on the effort and success of coordinated I&D&I processes.

Lindane and HCH

Lindane, the gamma isomer of hexachlorocyclohexane (HCH, $C_6H_6Cl_6$), is an organochlorine compound which – same as the rest of the HCH isomers – is a synthetic molecule which does not exist in nature.

Lindane was widely used around the world during the second half of the XX century as an insecticide in agriculture and for the treatment of parasites in humans and livestock.

Lindane as a global problem.
HCH isomers are bioaccumulative, they persist in the environment and produce toxic effects.
This is a global-scale problem since HCH isomers can be transmitted through the food chain and transported by wind and water, affecting people and wildlife away from where they were produced and released.



Strategic Environmental Action Plan against lindane waste contamination in Aragon

2

The challenge of Lindane in Aragon

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2 THE CHALLENGE OF LINDANE IN ARAGON

Perspective of the Sardas landfill

Lindane was produced in Spain in four factories: two of which were located in the Basque country; a third in Galicia and the fourth in the province of Huesca, the old factory called INQUINOSA. The latter remains – even today – in a ruined state, being located some 15 m away from the Sabiñánigo reservoir.

Maximum permitted levels of HCH in drinking water:

- ***According to the EU:*** *0.1 microgram/litre for individual isomers and 0.5 for the sum of isomers.*
- ***According to the WHO:*** *2 micrograms/litre for the individual isomers, which is the existing criteria in the United States, Canada and other countries.*

Royal Decree 817/2015 on standards of environmental quality in the field of water policy: *preferential or priority substances.*

Note:

- *1 microgram / liter = 1 part per billion (ppb)*
- *Limit of current analytical detection: 0.005 microgram / liter.*

The concurrence of a number of key factors led to the current situation, where the production waste of lindane accumulated in landfills of Sardas and Bailín, as well as at the old INQUINOSA factory, constitute the most important environmental problem in Aragon and one of the most important in Spain.

All these factors have led the Aragon Government to be in face of a great challenge with multiple technical, economic, social and political aspects. The key factors can be summarized as follows:

- Characteristics of the contaminants. Toxic, carcinogenic, bioaccumulative, biomagnificable and persistent in the environment.
- Multicomponent and multicontaminating pollution.
- Huge waste volumes.
- Presence of dense organochlorine non-aqueous phase liquid (DNAPL).
- Poor isolation of historical landfills where waste was disposed, along with bad historical practices.
- Complex and unfavorable geology at the impacted sites.
- Proximity to sensitive receptors (Gállego river, Sabiñánigo city center).
- Characteristics of the Gállego river as a preferential way of migration for potential pollutants.
  - Downstream capture of water for human consumption.
  - Presence of the Gállego river irrigation system.
- Extremely low reference admissible concentrations in waters, in accordance to applicable regulations.

The minimization or elimination of environmental risks are great technical challenges, due to the characteristics of both the contaminants and the affected sites. To difference of others contaminants, the great chemical stability of the HCH and other associated organochlorine compounds, together with the large waste volumes which exist, pose the impossibility of applying many "traditional" techniques of treatment and removal.

On the other hand, the technical difficulties of the control, treatment and/or removal of waste, the large waste volumes, as well as the presence of an important transporting vector - the Gállego river, situated very close to the sources of contamination - make any action to be taken a true technological and economical challenge of a large dimension.

Additionally, the events of contamination of water supply in several localities, as well as of the irrigation water from the Gállego river, which took place in 2014, called the attention of the citizens to the lindane pollution problem, which is a great social challenge for Aragon.

Therefore, the sum of technical, economic and social aspects of the problem becomes a major political challenge. The Government of Aragon has to perform the management and coordination of different agencies, institutions, operators and administrations to deal with this threat.

The Gállego river

The Gállego river is one of the main tributaries of the Ebro river along its left bank. The river length is 200 km and has several short tributaries. The basin's surface is 4,020 km^2, stretching in N-S direction. The Gállego course is very complex. It passes through a variety of landscapes with different geological features as it cuts through the Pyreneean Cordillera from its Axial Zone, and then dissecting the central zone of the Ebro Depression. Its regime shows an intense dry season and is subject to intense floods. Along the course, several reservoirs and major derivations are present.

The Gállego river as it passes through Sallent de Gállego, Aragon.
Photo: Grand Parc - Bordeaux, Wikimedia Commons

A 60% of the area of the basin is used for agricultural purposes. It is further subject to a high hydroelectric exploitation with 21 power stations, 10 of them located downstream of Sabiñánigo.

On the other hand, there are dozens of municipalities downstream Bailín which capture waters directly from the Gállego river or from its channels or ditches. Among them, Villanueva de Gállego is a prominant village with more than 4,000 inhabitants. If we add to these municipalities those connected to the Monegros Channel System, the number increases considerably. There is also a very important use of irrigation water, mainly through the derivation leading to La Sotonera reservoir which nourishes - together with volumes of flow from the Cinca river - the Alto Aragón Irrigation System, the biggest within the whole Ebro Basin.

Finally, the river is also subject to fishing and recreational uses including bathing in Santa Eulalia, sailing in La Sotonera and rafting in Murillo de Gállego.

Sabiñánigo reservoir as seen from the Sardas landfill. INQUINOSA in the background.

Multicomponent pollution and multiple alterations:

The pollutants existing in the Sabiñánigo sites are mainly benzene, polychlorinated benzenes, polychlorinated phenols, HCH isomers, methanol and other alcohols, fatty acids, dioxins, furans, etc.
Contamination is present in different media as groundwater, runoff water, soil and rock.

Waste	Soil	Groundwater	Runoff water
INQUINOSA	Factory of INQUINOSA and its surroundings	Alluvial aquifer of the Gállego river at INQUINOSA	Bailín ravine
Sardas landfill	Foot of the Sardas landfill and its surroundings	Alluvial aquifer of the Gállego river Foot of the Sardas landfill	Gállego river
Bailín ravine	Surroundings of the Bailín landfill	Surroundings of the Bailín landfill	

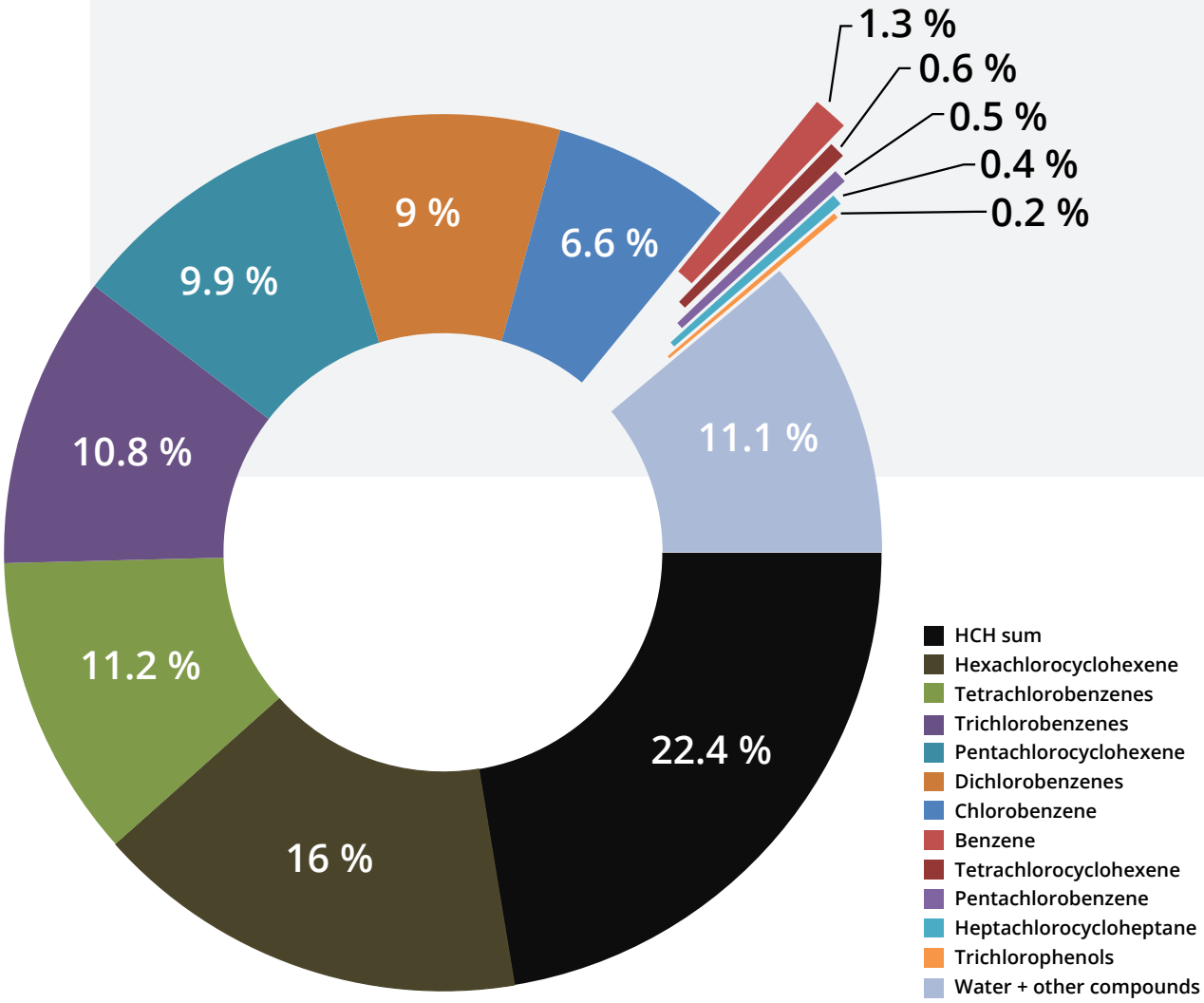
Dense, free phase or DNAPL

In the subsoil of the landfills where wastes from the INQUINOSA factory were deposited, a dense, free phase - or DNAPL (dense non-aqueous phase liquids) – accumulated. This is a residue of failing reactions and tails of distillation of the lindane production process.

A dense, free phase or DNAPL is a liquid substance which is denser than water and immiscible in it. In contrast to a light phase or LNAPL (light non-aqueous phase liquid) - such as oil, which floats on water -, the DNAPL tends to descend down to impermeable horizons, its migration in the underground environment being driven by the gravity force. For this reason, the location and removal of DNAPL are very complex tasks. The density of DNAPL prevents conventional pumping techniques to be effective, since its movement barely responds to groundwater flows. Moreover, its downward migration into deeper zones makes the extraction difficult.

The graph presents the approximate composition of DNAPL which is present in the Sabiñánigo sites; organochlorine compounds account for nearly a 90% of the mixture.

Composition of organochlorine compounds



Types of pollution:

The pollution with negative environmental and health impact may occur due to the presence of elements that when in their free form and at very low concentrations are harmful and affect negatively the environment. For example, lead, mercury, arsenic, radon and uranium. In these cases, the remediation consists of promoting the synthesis of salts, chelates, polymers and/or other chemical compounds which prevent the free mobilization of the pollutant compound and its contact with life forms. Therefore, the aim must be the immobilization of the pollutant.

Another form of pollution is due to compounds formed by elements which are either neutral or of low aggressiveness, the environmental damage of which is due to the form in which those elements are present.

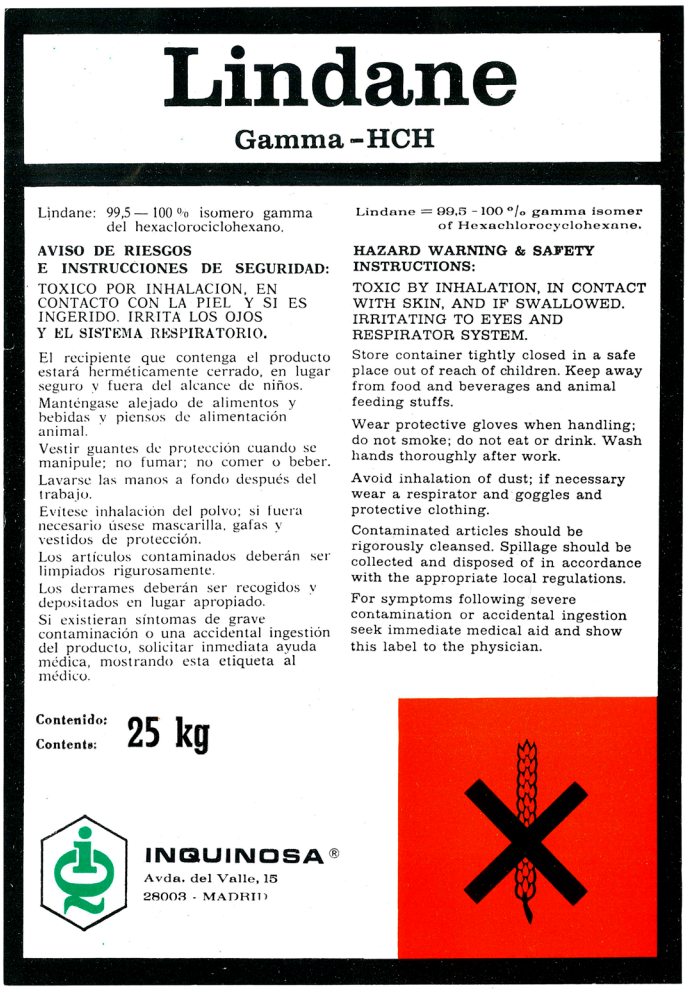
Fortunately, as for the matter of concern here, residues produced after the manufacture of lindane are composed of carbon, hydrogen and chlorine. Its formula is $C_6H_6Cl_6$, and the structure of the hexachlorocyclohexane is cyclical, bearing six carbons. Carbon and hydrogen are part of the human body in ca. 18 % and 10 % respectively, while chlorine is present in the form of salts in a 0.02 %. On the other hand, chlorine constitutes around 2.5 % of the oceans' mass.

In this case, the objective of the remediation entails breaking the six-carbons cyclic structure, by means of either oxidation or reduction, and mobilizing the resulting compounds, so that they can be incorporated into the ordinary bio-geochemical cycles.

Characteristics of HCH

*Chemical formula of hexachlorocyclohexane: **$C_6H_6Cl_6$***
and graph with the main physical and chemical properties of its isomers.

Characteristic	Isomer				References
	α-HCH	β-HCH	γ-HCH	δ-HCH	
Molecular weight	290.8	290.8	290.8	290.8	Prager, 1995
Density (kg L^{-1})	1.87	1.89	1.85	$^{-1}$	Prager, 1995
Boilling point (°C)	288	60	323	60	Prager, 1995
Melting point (°C)	157 – 160	309 – 310	112.5	138 - 139	Suntio y col., 1988
Vapor pressure (Pa, 20°C)	5.3 10^{-3}	4.3 10^{-5}	2.9 10^{-3}	2.3 10^{-3}	Manz et al., 2001
Henry's law constant (Pa m^3 mol^{-1})	0.870	0.120	0.130	0.073	Suntio et al., 1988
Solubility:					
In water (mg L^{-1})	10	5	7.3	10	Prager, 1995
In organic solvents (g L^{-1})	1.6	0.32	6.2	9.0	Manz et al., 2001
Acetone	139	103	435	711	Fabre et al., 2005
Ether	62	18	208	354	Fabre et al., 2005
Methanol	23	16	74	273	Fabre et al., 2005
Toluene	90	21	276	416	Fabre et al., 2005



Lindane

Gamma-HCH

Lindane: 99,5 — 100 % isomero gamma del hexaclorociclohexano.

AVISO DE RIESGOS E INSTRUCCIONES DE SEGURIDAD:

TOXICO POR INHALACION, EN CONTACTO CON LA PIEL Y SI ES INGERIDO. IRRITA LOS OJOS Y EL SISTEMA RESPIRATORIO.

El recipiente que contenga el producto estará herméticamente cerrado, en lugar seguro y fuera del alcance de niños.

Manténgase alejado de alimentos y bebidas y piensos de alimentación animal.

Vestir guantes de protección cuando se manipule; no fumar; no comer o beber.

Lavarse las manos a fondo después del trabajo.

Evítese inhalación del polvo; si fuera necesario úsese mascarilla, gafas y vestidos de protección.

Los artículos contaminados deberán ser limpiados rigurosamente.

Los derrames deberán ser recogidos y depositados en lugar apropiado.

Si existieran síntomas de grave contaminación o una accidental ingestión del producto, solicitar inmediata ayuda médica, mostrando esta etiqueta al médico.

Lindane = 99,5 - 100 % gamma isomer of Hexachlorocyclohexane.

HAZARD WARNING & SAFETY INSTRUCTIONS:

TOXIC BY INHALATION, IN CONTACT WITH SKIN, AND IF SWALLOWED. IRRITATING TO EYES AND RESPIRATOR SYSTEM.

Store container tightly closed in a safe place out of reach of children. Keep away from food and beverages and animal feeding stuffs.

Wear protective gloves when handling; do not smoke; do not eat or drink. Wash hands thoroughly after work.

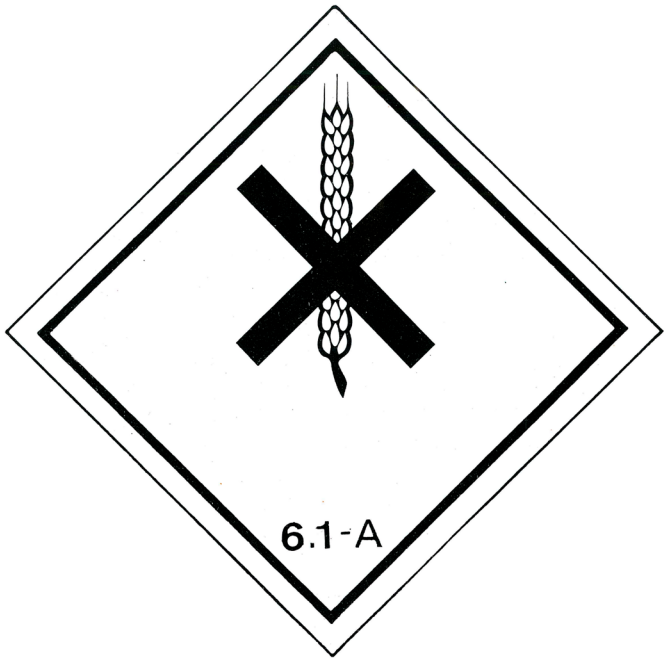
Avoid inhalation of dust; if necessary wear a respirator and goggles and protective clothing.

Contaminated articles should be rigorously cleansed. Spillage should be collected and disposed of in accordance with the appropriate local regulations.

For symptoms following severe contamination or accidental ingestion seek immediate medical aid and show this label to the physician.

Contenido:
Contents: **25 kg**

INQUINOSA®
Avda. del Valle, 15
28003 - MADRID



CIEL PRODUCT

INQUINOSA safety data sheet for lindane

It is possible to degrade the residues of lindane production:

Hexachlorocyclohexane and those contaminants accompanying it, are mainly artificial compounds which result from industrial synthesis in a chemical reactor. Therefore, at first sight, it may seem as if nature had no means to integrate them into its bio-geochemical cycles. Recent studies have shown that some very similar compounds are produced in nature since there is vegetation on Earth.

The presence of forests near the sea and winds that can drag the seawater drops towards the inner parts are necessary conditions for this process to occur. The dry residue of seawater, rich in sodium chloride, will be depositing on the leaves of the trees.

If an ordinary fire is produced in a shrubs and forbs forest, the average temperature reached is only 450 to 600 ° C. Nevertheless, if there is fire on top of the trees, with less than 40% of humidity and wind speed above 40 km per hour, the average temperature reached may be 800 to 900 ° C. Under these conditions, the dry chlorine salt residue deposited on leafs is transformed into compounds with a cyclic structure of six carbons. These compounds will fall to the ground in the form of ashes. There are communities of bacteria, yeast and fungi able to degrade it and metabolize for energy.

Strategic Environmental Action Plan against lindane waste contamination in Aragon

3

Characterization of contaminated sites

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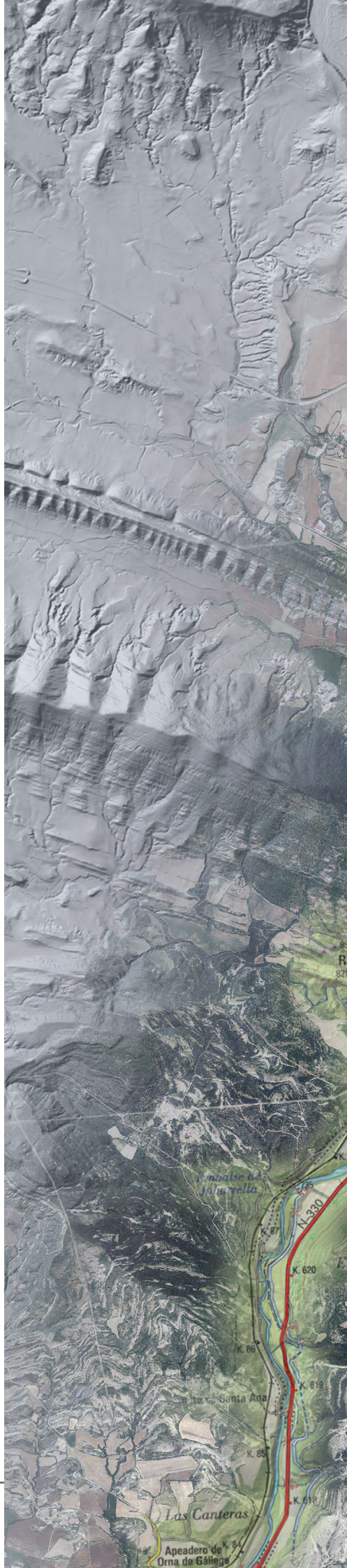
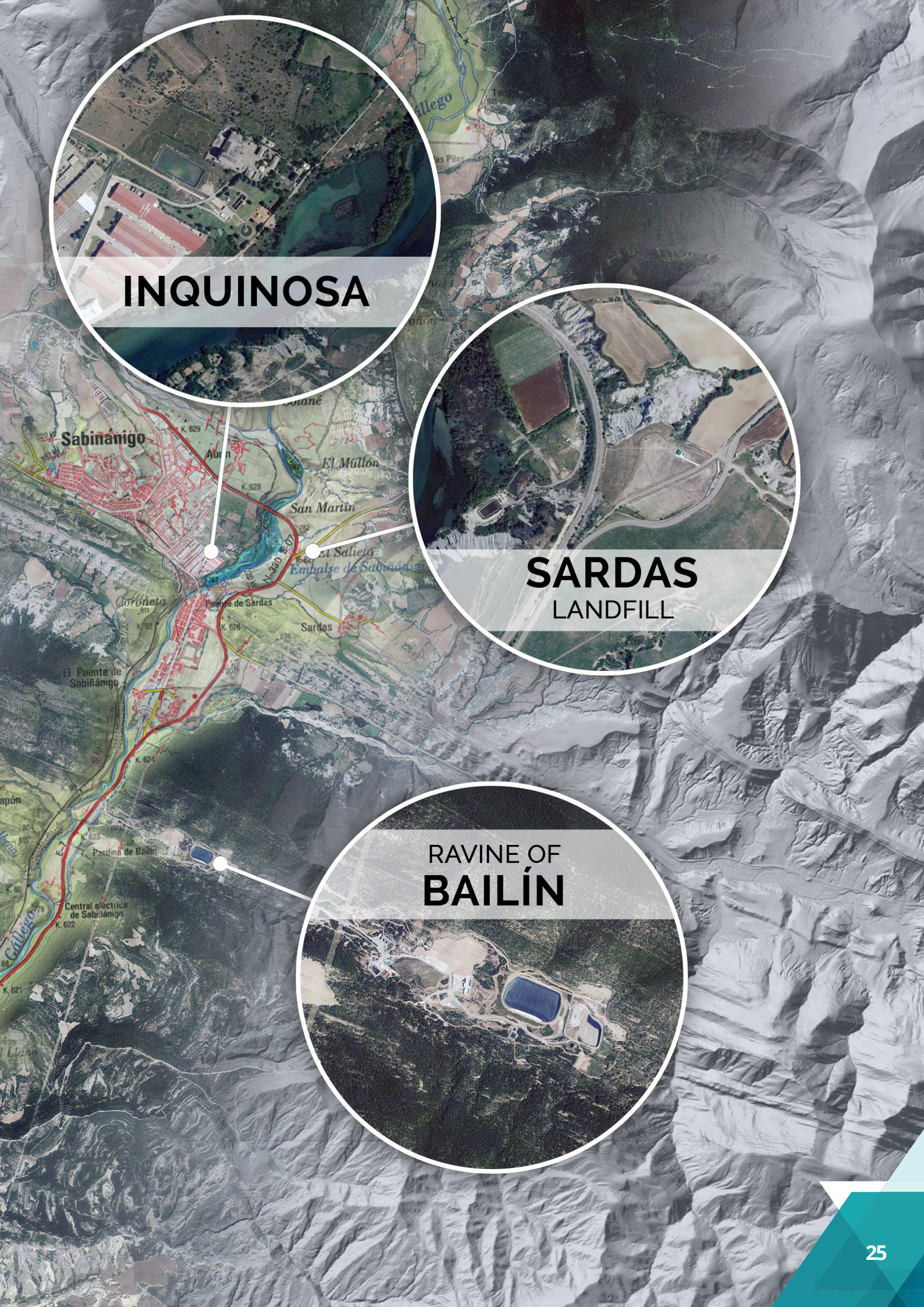
3

CHARACTERIZATION OF THE CONTAMINATED SITES

There are three sites affected by the production of lindane and associated waste: the old factory of INQUINOSA, the Sardas landfill and the ravine of Bailín.

The factory and the Sardas landfill are located next to the Gállego river and very close to the urban area of Sabiñánigo; the ravine of Bailín is located some 2 km to the South of the urban area.




INQUINOSA
SARDAS
LANDFILL
RAVINE OF
BAILÍN
Sabiñánigo
El Mullón
San Martín
Puente de Sardas
Sardas
El Puente de Sabiñánigo
Pardina de Bailín
Central eléctrica de Sabiñánigo
Gállego

PNOA, with permission of © Instituto Geográfico Nacional

3.1 THE OLD FACTORY OF INQUINOSA

The name of the old factory INQUINOSA responds to an acronym of Industrias Químicas del Noroeste Sociedad Anónima (Chemical Industries of the Northwest Corporation). The upper zone of the facility sits on the terrace of the Aurín river, while the lower area is located on the alluvial of the Gállego river and is separated from the Sabiñánigo reservoir only by the access road.

The factory began its activity of production and trading of lindane in the year 1975. From the year 1978 until 1984, the factory employed the Sardas landfill for discharging the production waste, and later, from 1985 to 1992, the landfill of Bailín was used.

Between 1989 and 1992 INQUINOSA imported lindane and elaborated commercial formulations. INQUINOSA ceased definitively its activity in 1994, and the factory was abandoned. From its opening until the moment of closure, the factory faced a strong social opposition by ecologist groups.

There are no reliable data on the production of INQUINOSA, however it is estimated that it generated ca. 7,000 tons of solid waste per year and between 300 and 500 tons of liquid waste.The greater volume of generated waste are alpha, beta, delta, and epsilon isomers of HCH, as well as purification sludges, packaging, lindane production surplus, etc.
As for the waste liquids, they were conformed by distillation tails and the remains of failed reactions.

The INQUINOSA factory

Location: *Adjacent to a sensitive receiver, the Sabiñánigo reservoir. Next to the urban area.*

Surface: *1,7 ha.*

Industrial ruins

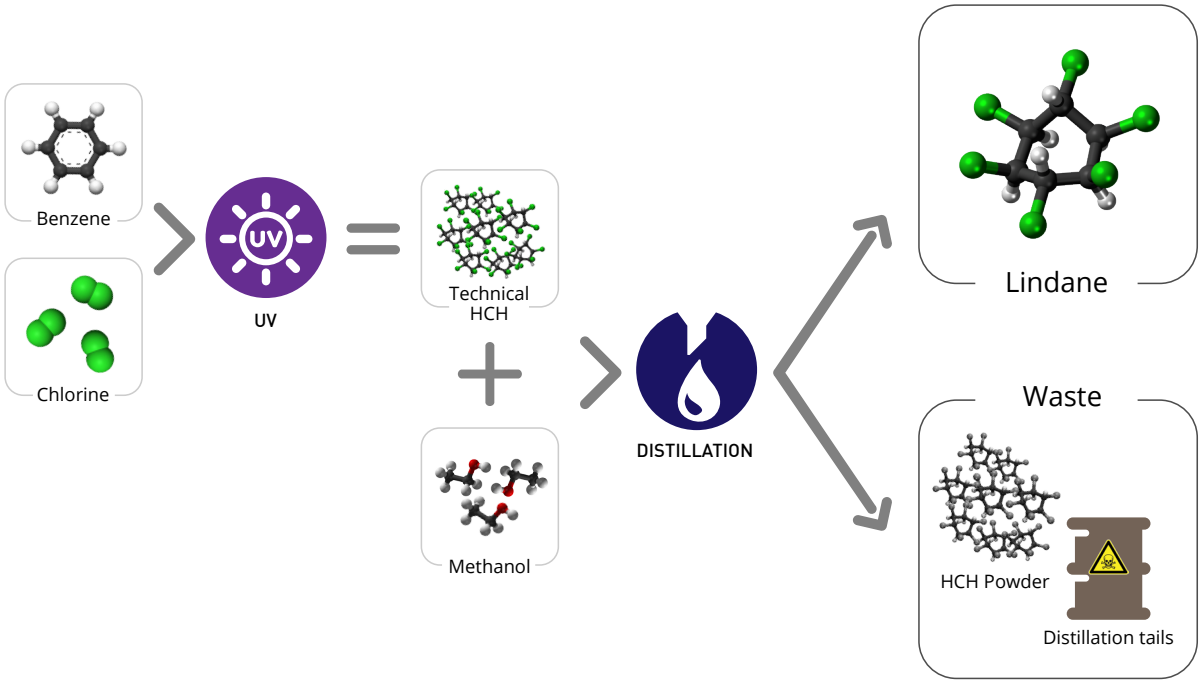
Contamination: *Structure and components of the plant, soil and aquifer of the Gállego river, presence of DNAPL.*

Hazardous waste

Geology: *Quaternary terraces of the rivers Aurín and Gállego.*

Legal status: *Thanks to recent judicial decrees, the Government of Aragon could begin characterizing the degree of pollution of the facilities and subsoil.*

Lindane production process scheme



The INQUINOSA factory
Work strategy

Either executed or ongoing.

- **Establishment of a solid conceptual model.**
  - -Historical study, current and historical cartography, geology, geomorphology and geophysics.
  - -Environmental characterization: borehole cores, trial pits, sampling, etc.
  - -Hydrogeological control: Sampling and analyses, physical and chemical data.
- **Environmental risks control.**
  - -Hydrogeological monitoring.
- **Elimination of accumulated hazardous waste.**
- **Drafting of preliminary project of demolition.**

Yet to be executed.

- **Drafting and implementation of the project of demolition of industrial ruin.**
- **Start of small-scale tests, in association with the University of Santiago de Compostela, on the use of catalyzed biological methods to remediate soil and water.**
- **Study of surrounding soils.**
- **Application of funding to the Environment and Climate Action Programme (LIFE), in order to design large-scale catalyzed biological methods of remediation.**
- **Transportation of contaminated soils to the new Bailín safety cell, and/or in situ remediation.**
- **Remediation of soils and the aquifer.**
- **Restoration of the site.**

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3.2 | THE SARDAS LANDFILL

The Sardas landfill is located less than 1 km east of the Sardas urban area, occupying a surface ca. 4 ha close to the Gállego river. Road N-330 crosses the site.

This site is composed of the following facilities and elements:

- The landfill body
- The plots at the foot of the landfill
- Hydro-geological monitoring network
- Drainage and pumping facilities for leachates and DNAPL.
- Two leachates ponds
- Sewage treatment plant

Historically, various types of waste were discharged into the existing gully next to the Gállego river, including industrial waste of lindane production and other chemical industries; among the latter there were solid and liquid waste of HCH, mercury, caustic soda, hypochlorite, dichromates, dithiocarbamates, solid urban waste, construction and demolition wastes, etc.

Discharge of lindane manufacturing waste was discontinued in the Sardas landfill by 1984, while urban waste disposal ceased in July 1987. The estimated figures of discharge made at the Sardas landfill are 50,000 to 80,000 m^3 of solid waste of HCH isomers in form of dust, and 3,000 m^3 in liquid form (DNAPL). After the abandonment of the Sardas facility, a new landfill located nearby the Bailín ravine started to be employed in order to discharge the waste generated during lindane production.

View of the Sardas landfill in the 1980's.

In the 1980's, the Sardas landfill was completely filled up, with a waste volume above 400,000 m^3. Between 1985 and 1988 the alternative road N330 was built and its trace cut off the front of the landfill. Because of these works, approximately 50,000 m^3 of waste from the landfill were moved to the bottom of the site.

Subsequent to the construction of the alternative road N330, the top and lateral surfaces of the landfill were sealed. The sealing consisted of the construction of perimeter and frontal slurry walls made of bentonite-cement. The surface of the landfill was sealed using a heat welded, high-density polyethylene lamina, which was covered by a drainage layer of gravel and, finally, covered with topsoil. The approximately 50,000 m^3 of residues deposited at the bottom of the site after the construction of the alternative road, were not included in the sealing process and remained located next to the reservoir adjacent to the site.

Sardas landfill

Location: *Adjacent to a sensitive receiver, the Sabiñánigo reservoir.*

Infrastructure: *The road N-330 cuts through the site.*

Surface: *4 ha, landfill body of 3 ha; plots at the foot, pools and water treatment plant account for 1 ha.*

Volume of waste:

400,000 m, up to 40 m in thickness:

- *Urban solid waste.*
- *Waste of construction.*
- *Industrial waste.*

(oil-hydrocarbon, dross, filter cakes, chlorine-potash, purification sludge, mercury, dichromate, HCH residues).

Partial, top and side sealing, without waterproofing at the base.

Contamination: *Soils, the Gállego aquifer, leachates, presence of DNAPL, 50,000 m^3 of waste out of the sealed area.*

Geology: *Larrés Marl and alluvial of the Gállego river.*

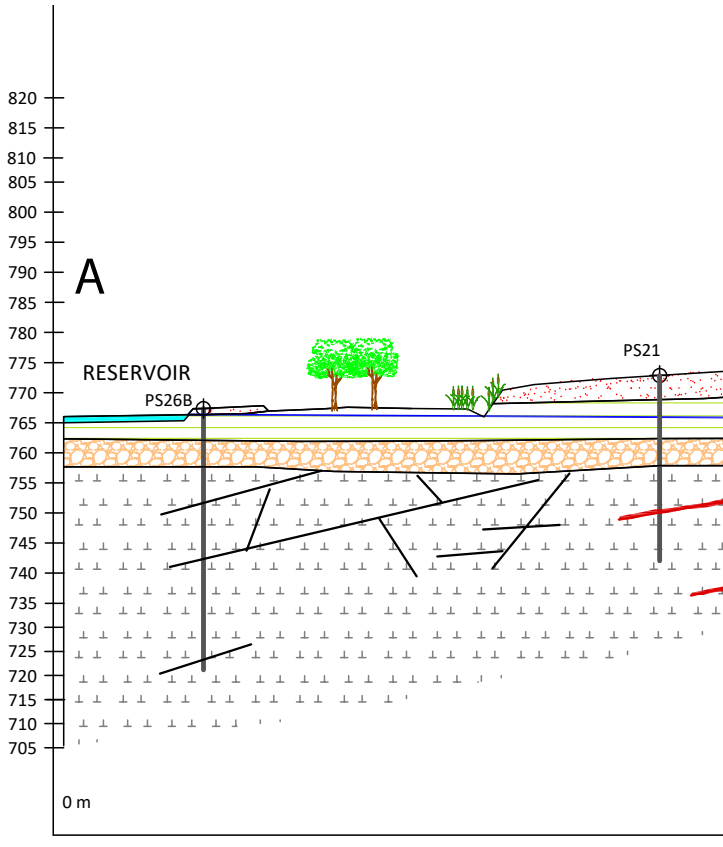
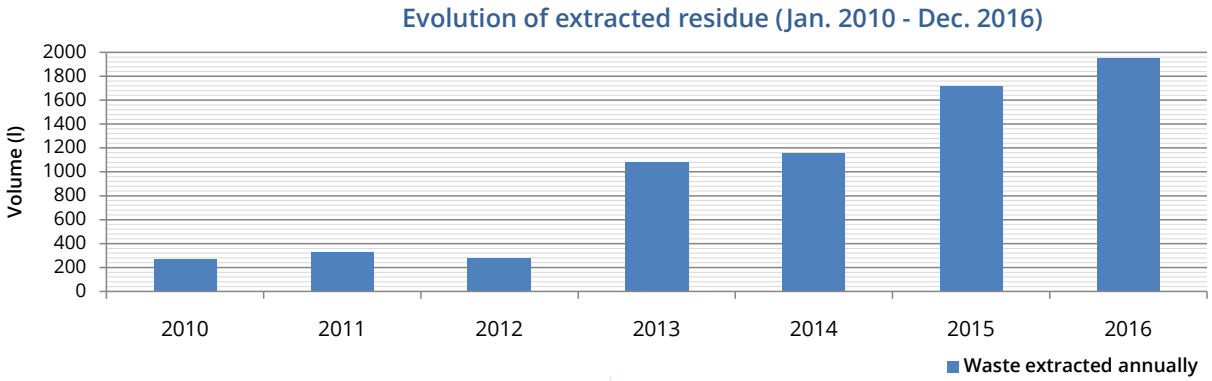


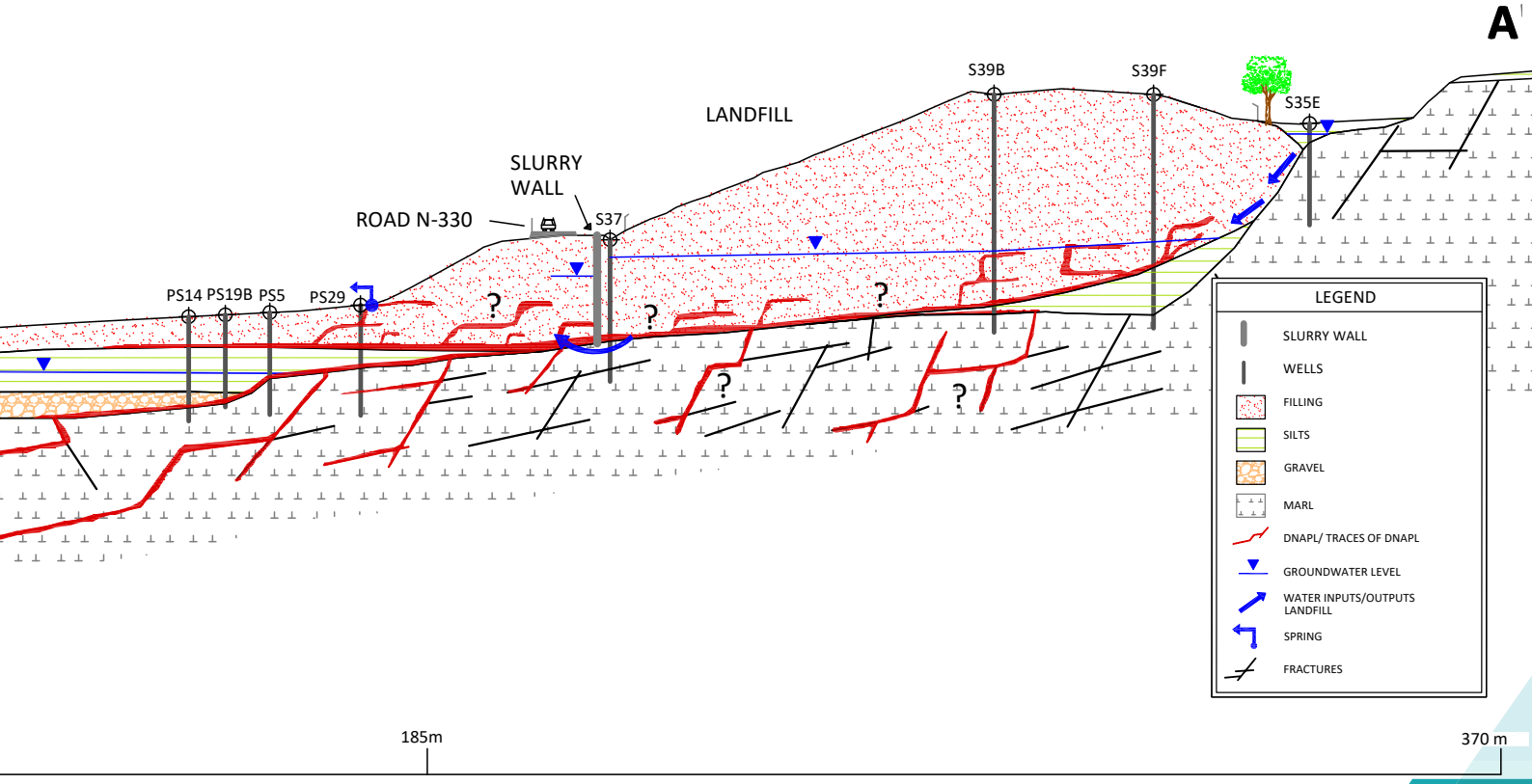
Diagram of the conceptual model of the Sardas landfill



The landfill body seemed to be sealed correctly until 2009, when staff of the Government of Aragon detected leakage of DNAPL at the foot of the landfill front. Since then, both the groundwater and leachates have been under permanent environmental monitoring and control. Controls included the commencement of the environmental and hydrogeological characterization of the site, as well as DNAPL pumping.

The works on characterization and remediation completed until today have resulted into the establishment of a hydrogeological control network composed of nearly 100 monitoring wells. There are 14 pumping wells connected to two pumping stations dedicated to the removal of the dense, free phase. A total amount of 6.79 m^3 of DNAPL has been extracted up to the year 2016. After its decantation, the dense, free phase which has been pumped is managed externally as a waste and is incinerated. The aqueous phase (groundwater and leachates) is transferred to two leachate pools located at the lower part of the site, from where the sewage plant is supplied. The sewage plant is equipped with physico-chemical treatment and activated carbon filtration.

On the other hand, a drainage network has been built for contaminated leachates being collected and conducted to the pools for their treatment. In addition, leachates are pumped from inside the landfill in order to maintain their levels at a reasonable height, avoiding leakages in the area of the road N-330.



Sardas landfill
Work strategy

Either executed or ongoing.

- **Prevention of pollution migration.**
  - Pumping of DNAPL.
  - Collection and treatment of leachates and groundwater (dissolved phase).
- **Establishment of a solid conceptual model.**
  - Historical study, current and historical cartography, geology, geomorphology, geophysics.
  - Environmental characterization: boreholes, trial pits, sampling, etc.
  - Hydrogeological control: Sampling and analyses, physical and chemical data.
  - Mathematical flow models.
- **Environmental risks control.**
  - Hydrogeological monitoring.
  - Containment and drainage works.
- **Intervention at the focus of contamination.**
  -Design of an isolation project.
- **Remediation of soil and groundwater.**
  - Laboratory tests. Aggressiveness, SEAR, MERC, Fe (0) nanoparticles, ISCO, thermal desorption.
  - Pilot testing. SEAR, Fe (0) nanoparticles, thermal desorption.

Yet to be executed.

- **Improvement of the leachate pools and the purification system.**
- **Intervention at the focus of contamination.**
  - Execution of isolation project.
  - Application of in situ waste biodecontamination technique at the foot of the landfill.
- **Start of small-scale tests together with the University of Santiago de Compostela, on the use of catalyzed biological methods to remediate sediment, soil and water, as well as designing a bioreactors barrier to control the contamination plume.**
- **Application of funding to the Environment and Climate Action Programme (LIFE) in order to design large-scale catalyzed biological methods of decontamination.**
- **Agreement with the University of La Coruña for the development of a numerical simulation model describing the flow and transportation of pollutants.**
- **Remediation of soils and the aquifer.**
  Application, on a field scale, of the successfully tested techniques.
- **Separation of HCH residues from other hazardous waste and land.**
- **Waste disposal.**

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3.3 THE RAVINE OF BAILÍN

The landfill and waste management facilities complex of Bailín occupies an area of approximately 40 ha in the homonymous ravine. It is located about 2 km south of the urban area. The Bailín facilities, related with the management of wastes generated after the manufacture of lindane, are interconnected by a main road which has an access from the old trace of the road N-330, passing under the current Mudejar road. It consists of the following main elements:

- **Former landfill of HCH.**
- **New safety cell for HCH waste.**
- **Facilities for the hydrogeological control of the pumping process of the dense, free phase (150 borehole sites, at 10 of which DNAPL is being pumped).**
- **Sewage treatment plant 1 for leachates (and premises such as deposits, storm tanks, etc.), associated to the HCH landfills.**
- **The sewage treatment plant 2 form the treatment of Bailín ravine waters in the lower part of the area.**
- **Soil and water analysis laboratory (ca. 400 samples are analyzed monthly).**
- **Facilities and offices for control and environmental monitoring.**

Current appearance of the old HCH landfill

The old HCH landfill was used between the years 1985 and 1989 to accommodate the former INQUINOSA factory waste, occupying an area of approximately 31,000 m^2 and housing waste in a volume of ca. 210,000 m^3.

The use of this landfill without an adequate refurbishment and insulation, as well as deficiencies during its operation, caused a major environmental issue in the area. After the cessation and several initiatives to adequately contain the landfill, it was decided to proceed to its dismantling. Dismantling was conducted during the summer of 2014, transferring the waste to a new safety cell located 800 m away from the landfill.

After dismantling, the surface where the old landfill body was based currently appears as a naked, inert hillside covered by an extensive network of emerging leachates collection. Two dams have been built at the foot of the slope, and concrete has been projected throughout the lower area of the old landfill. All the waters collected in the area are transported to the storm tanks with a capacity of 8,900 m^3, for their treatment at the Sewage treatment plant 1. From the year 2005 to 2016, 21.8 m^3 of DNAPL were extracted. In the year 2016, it was possible to extract only 0.38 m^3, by means of 31 boreholes. It is estimated that 2 to 3 m^3 of DNAPL are present in the basement of the old landfill.

Former HCH landfill at Bailín (dismantled in 2014)

Location: *Ravine of Bailín, 200 m away from Paco stream and 800 m away from the Gállego river.*

Surface: *3 ha.*

Mass of waste: 429.000 t (210.000 m³).

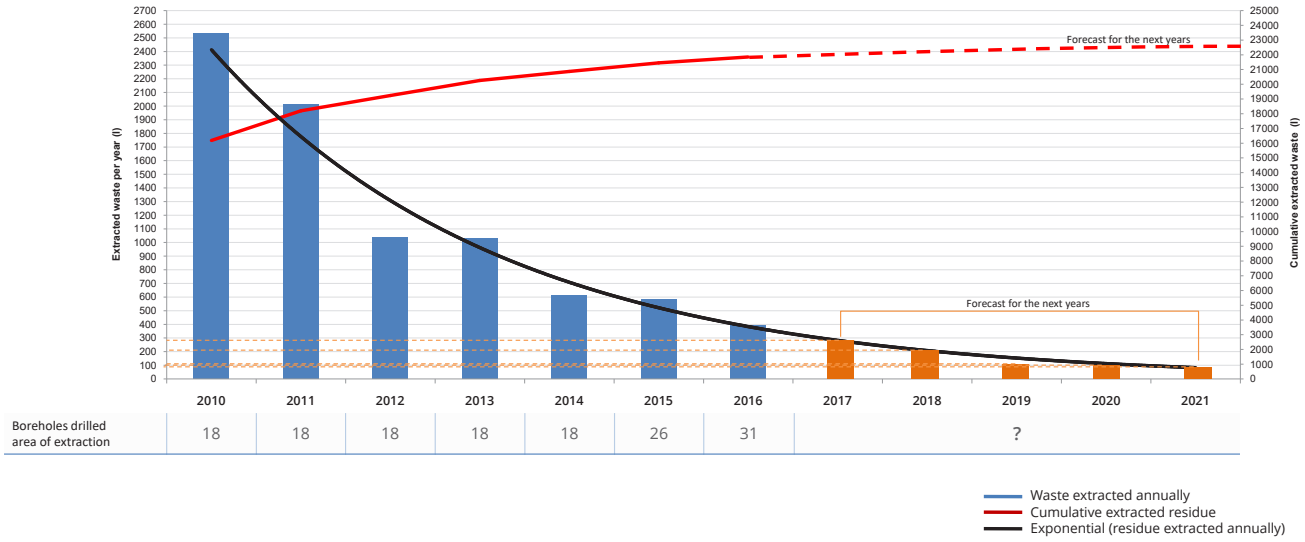
- *65,000 t of residues of HCH (31.000 m³).*
- *342.000 t of contaminated land (167.000 m³).*
- *Other. Solid urban waste, bulky waste, etc. 22.000 t (11.000 m³).*

Surface sealing and partial lateral sealing. With no waterproofing at the base.

Contamination: *Soil and sediment, aquifer (rocky massif), runoff water (2014 Gállego river contamination), presence of DNAPL.*

Geology: *Vertical succession of alternating sandstone, conglomerate and siltstone beds.*

Graph of DNAPL extractions at Bailín
Evolution of extracted waste volumes (from January 2010 through December 2016)



Graph of the dense phase extraction

Liquid wastes from the manufacture of HCH are denser than water and, as a consequence, they descend as there is a hollow to fill. Since the year 2010, dense, free phase (DNAPL) is extracted by pneumatic pumping. The phase accumulates in the 2 to 5 mm-wide fissures of the sandstone and conglomerate vertical beds. Although some six new boreholes are made annually at the former site of the Bailín landfill, pumping performance is decreasing every year. It follows therefore that the free phase available through pumping is next to its depletion, and that most of the remaining free phase is immobile, being attached to the rock fissure walls. Removal of pollutant remains attached to the fractures is important, since water will move through the fissures emptied of dense phase, being likely to be contaminated during circulation. It will be necessary to apply a new technology in order to clean the rock from dense phase attached to it. The ISCO-LIFE test pursued the elimination of dense phase micro drops from the groundwater, present in these fissures of the rocky formation.

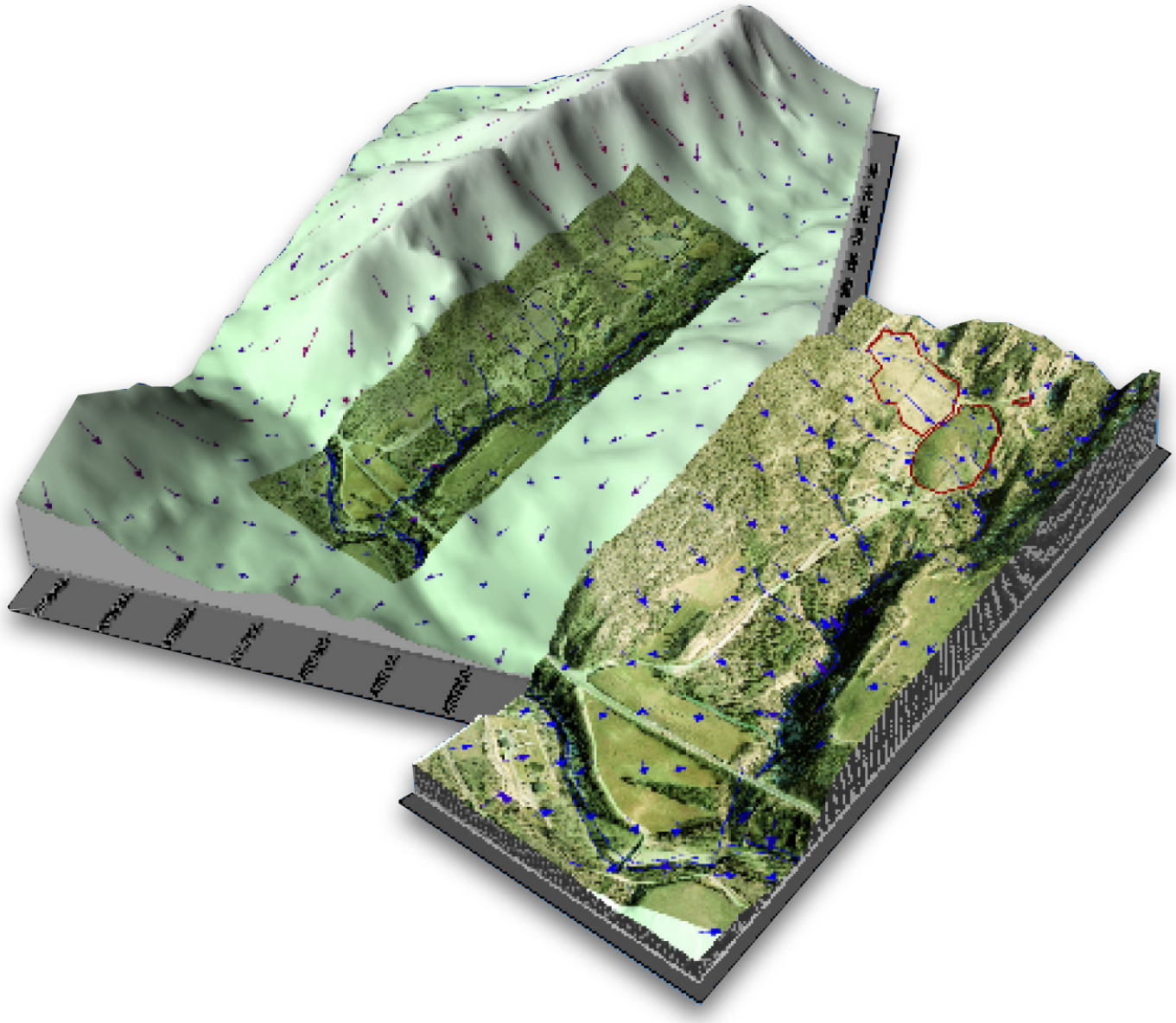
Bailín landfill
Work strategy

Either executed or ongoing

- **Prevention of pollution migration.**
  - Pumping of the free phase (DNAPL).
  - Collection and treatment of leachates and surface water and groundwater (dissolved phase).
  - Bypass at the creek of the ravine of Bailín (CHE).
- **Establishment of a solid conceptual model**
  - Historical study, current and historical cartography, geology, geomorphology, geophysics.
  - Environmental characterization: boreholes, trial pits, sampling, etc.
  - Hydrogeological control: Sampling and analyses, physical and chemical data.
  - Mathematical models of flow.
- **Environmental risks control.**
- **Hydrogeological monitoring.**
  - Containment and drainage works.
  - Atmospheric dispersion models.
- **Intervention at the focus of contamination.**
  - Design of an isolation project.
  - Execution of isolation.
  - Transportation of waste to the new safety cell (210,000 m^3).
- **Remediation of soil and groundwater.**
  - Laboratory tests. Aggressiveness, SEAR, MERC, ISCO, ISTD (discarded), ISCR.
  - Pilot testing. SEAR, Fe (0) nanoparticles.
  - Cleaning of the Bailín ravine.

Yet to be executed.

- **Preliminary market research for "Remediation of the Bailín ravine", as a prelude to a Public Procurement of Innovation.**
- **Application for obtaining a grant through the 2020 Horizon program, for the elaboration of prototypes through Public Procurement of innovation on "Remediation of the Bailín ravine".**
- **Reach to an agreement with the University of Zaragoza and the Institute of Chemical Synthesis and Homogeneous Catalysis (iSQCH), for the investigation on the design and elaboration of prototypes of techniques leading to either the destruction or the irreversible transformation of wastes into harmless materials.**
- **Prevention of pollution migration.**
  - Final sealing of the safety cell, completing the filling with waste of INQUINOSA.
  - Drafting and execution of the project of derivation of surface water (Bypass) undertaken by the CHE.
- **Intervention at the focus of contamination.**
  - Decontamination and environmental restoration of the old landfill's surface.
- **Remediation of soils and the aquifer.**
  - Application, on a field scale, of the successfully-tested techniques.
- **Separation of residues of HCH from its mixture with the soil.**
- **Waste disposal.**



During the dismantling of the old landfill and the transfer of waste to the new safety cell, a contamination event occurred associated to very strong storm episodes, the Gállego river being affected.

This event caused a decline in the quality of the Gállego waters from Bailín up to its confluence with the Ebro river and entailed the cut of potable water supply in various locations downstream of Bailín.

Likewise, it was avoided the inlet of Gállego river waters into La Sotonera reservoir, which feeds the Alto Aragon irrigation system and numerous localities downstream.

Justification of the transfer of the old HCH landfill at Bailín to the new safety cell.

In the year 2008, during the drilling of boreholes for hydrological characterization of the subsoil, the dense, free phase was found in a vertical substrate of sandstone and conglomerate at a depth of ca. 35 m, some 300 m away from the old Bailín landfill. Up to then, it had been suggested that the surface waterproofing undertaken in 1994 had induced the dense phase to remain in the subsoil of the landfill. The landfill substrate is composed of lutite in a 90% of its surface. The lutite is an indurated, fine-grained clastic rock composed of clay and silt particles. That is to say, the subsoil is of a very low permeability.

As it was evident that the dense phase had leaked underground through the fissures of a vertical sandstone bed of ca. 5 m in thickness, additional boreholes were performed in order to pump from several points and to stop the progress of the dense phase towards the Gállego river. Having analysed the situation, it was estimated that the most convenient action was the simultaneous pumping of the dense phase of the sandstone strata and removal of the waste from the landfill, since the latter were overloading the dense phase. Hence the need to transfer the old landfill to a new safety cell appeared.

Draining the vertical sandstone strata through the bottom drains at the new safety cell meant a significant reduction in the groundwater input to the old Bailín landfill and, therefore, an increase in security.

Reasons justifying the location of the new safety cell in Bailín.

The transfer of the old HCH landfill of Bailín, undertaken in the summer of 2014, entailed 20,127 truck travels and the mobilization of 64,908 tons of HCH isomers and 342,074 tons of soil contaminated with HCH isomers. Estimating the concentration of HCH in soils as 10% (i.e., 34,207 t), the mass of transferred HCH isomers amounts a total of 99,115 t.

Locations which are geologically optimal to accommodate a new safety cell are located in the Hoya de Huesca. But it did not seem logical to extend the problem to other municipalities, and also not to undertake a long transfer by a national road having to cross the Monrepos pass at 1,262 masl.

The main reason in favour of the Bailín location for the new safety cell is the transfer needed, which is the shortest possible, without affecting national roads or other pollution-free ways. On the other hand, the seismic risk in the area is low.

A factor against it is the singular geology of the area of Bailín, with steeply dipping strata of alternating lutite (indurated silt and clay), sandstone and conglomerate. The levels of sandstone and conglomerate occupy 10% of the ravine surface, intercepting the infiltrated water and generating springs at half hillside, which are of rapid response and short-lived.

In the light of this situation, it was decided to build a new safety cell, 400 m away in straight line, communicated by a 950 m paved road. The new cell has additional protective measures in accordance to the Royal Decree 1481/2001, of 27th December 2001, which regulates the disposal of waste by landfill deposit.

Image of the two drainage ponds

Additional measures for the Bailín safety cell.

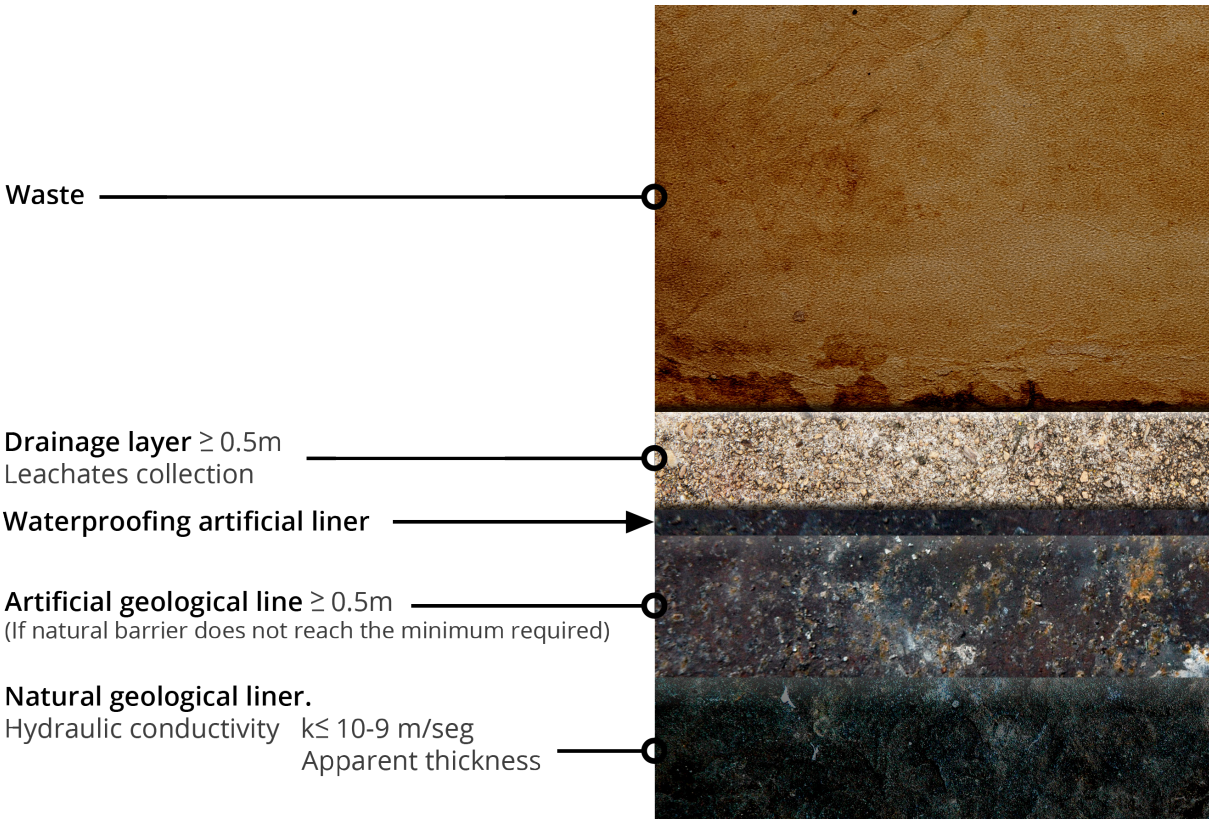
Drainage of ground water and sub surface water under the cell.

It has been undertaken a set of actions in order to avoid the risk derived from the presence of a certain level of water load on the basal waterproofing of the landfill. This ensures that, during the months of greater recharge the piezometric level stays depressed, in order to prevent subpressure or damage to the waterproofing materials. The drainage network is divided into a deep or primary drainage with big ditches several metres-deep and filled with gravel and drains, which aim is to evacuate the underground water under the cell; plus a drainage system for near-to-the-surface waters - or secondary drainage -, consisting of a general embankment at the bottom of the landfill body with a minimum thickness of 1 m, equipped with draining pipes and 1 m-deep ditches, different from the deep drainage ones. The aim of this secondary drainage is evacuating the near-to-the-surface water. Both drainages are independent and pour on two ponds of water control located at the foot of the cell.

Waterproofing of the cell, sealing of the base.

The lower waterproofing of the cell consists of two "sandwiches" with HDPE geomembrane + bentonite geocomposite + HDPE geomembrane, separated by a GeoDrain for leaks detection. In total, the sealing of the bottom of the cell consists of 14 layers, 6 of them are waterproof (HDPE and bentonite), 5 are draining ones (gravel and GeoDrain), 2 are geotextiles of separation and a final layer of soil on which the waste were disposed. As a result, the solid wastes from lindane production are stored in a secure and controlled location, isolated from pollution dispersion vectors such as water and air.

Section of a conventional landfill for hazardous waste, according to Royal Decree 1481/2001

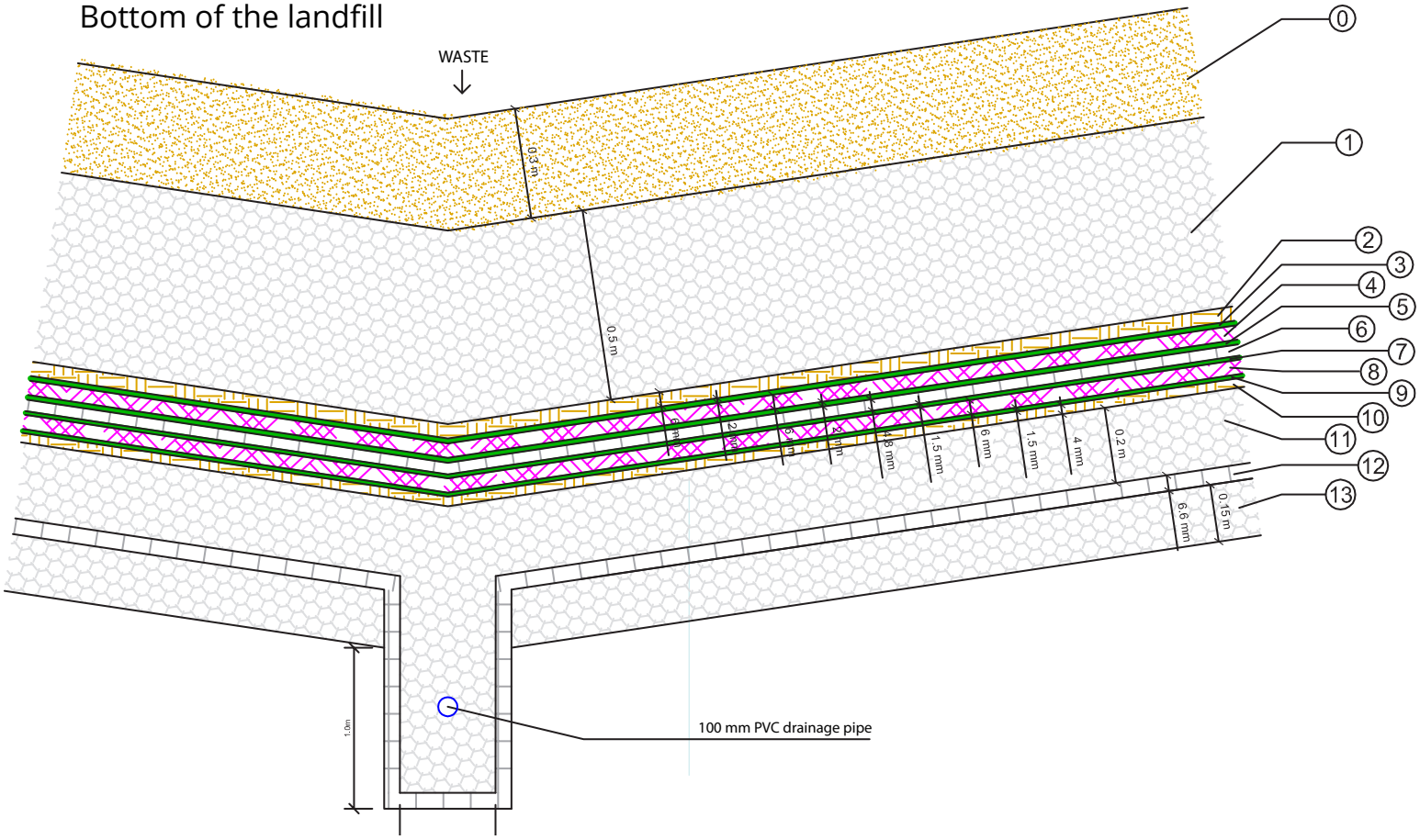


There is no option to transfer the old Bailín landfill

In the event that the landfill would have remained at its initial location, it is highly probable that the dense phase would have reached the Gállego riverbed within the term of a few years. The exclusive use of boreholes to intercept the dense phase flow towards the river, would have been insufficient because the difficulty to intercept 100 per cent of the sandstone fissures at 35 to 40 meters of depth, as they are 3 to 5 mm wide.

Today, the moving dense phase, removable by pumping, is very close to depletion at the Bailín site.

Section of lower sealing of the Bailín safety cell.



0 Washed river sand 0.30m

1 Gravel (20-40 mm) 0.5 m

2 Geotextile PP/PES 800g/m²

3 Geomembrane HDPE 2 mm double sided textured

4 Bentonite geocomposite 5500g/m²- needle-punched

5 Geomembrane HDPE 2 mm double sided textured

6 Geonet 1.5l/m/s (20kPa, i=1) subsurface water

7 Geomembrane HDPE 1.5 mm double sided textured

8 Bentonite geocomposite 5500g/m² needle-punched

9 Geomembrane HDPE 1.5 mm double sided textured

10 Geotextile PP/PES 800g/m²

11 Gravel (20-40 mm) 0.2 m

12 Geonet 1.5l/m/s (20kPa, i=1) subsurface water

13 Gravel 0.15 m

Bailín bypass

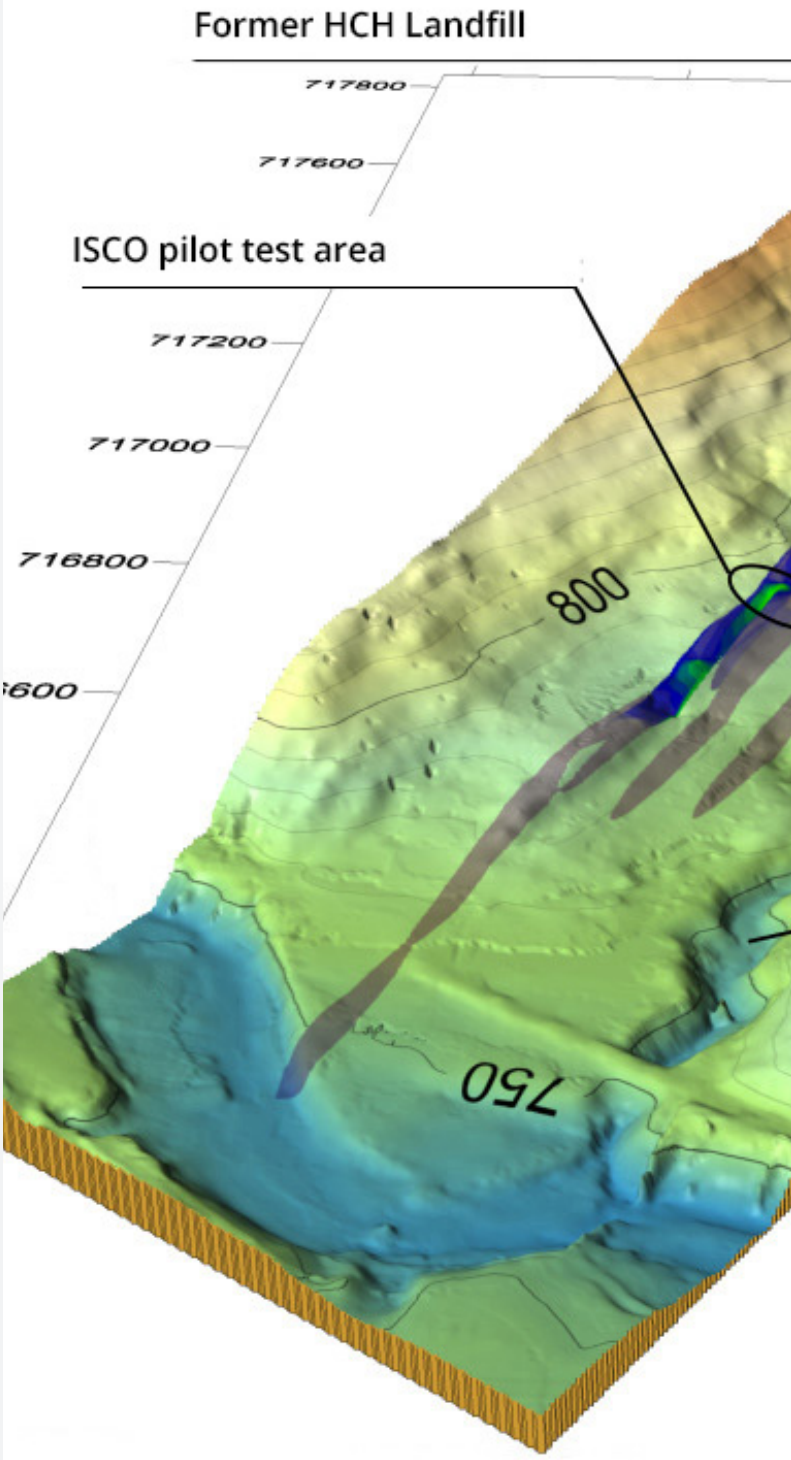
The Bailín ravine is a basin of about 472 ha, where the waste management facilities dedicated to the residues produced at the old INQUINOSA plant during the years 1984 to 1988 are located. The facilities occupy some 40 ha and they include:

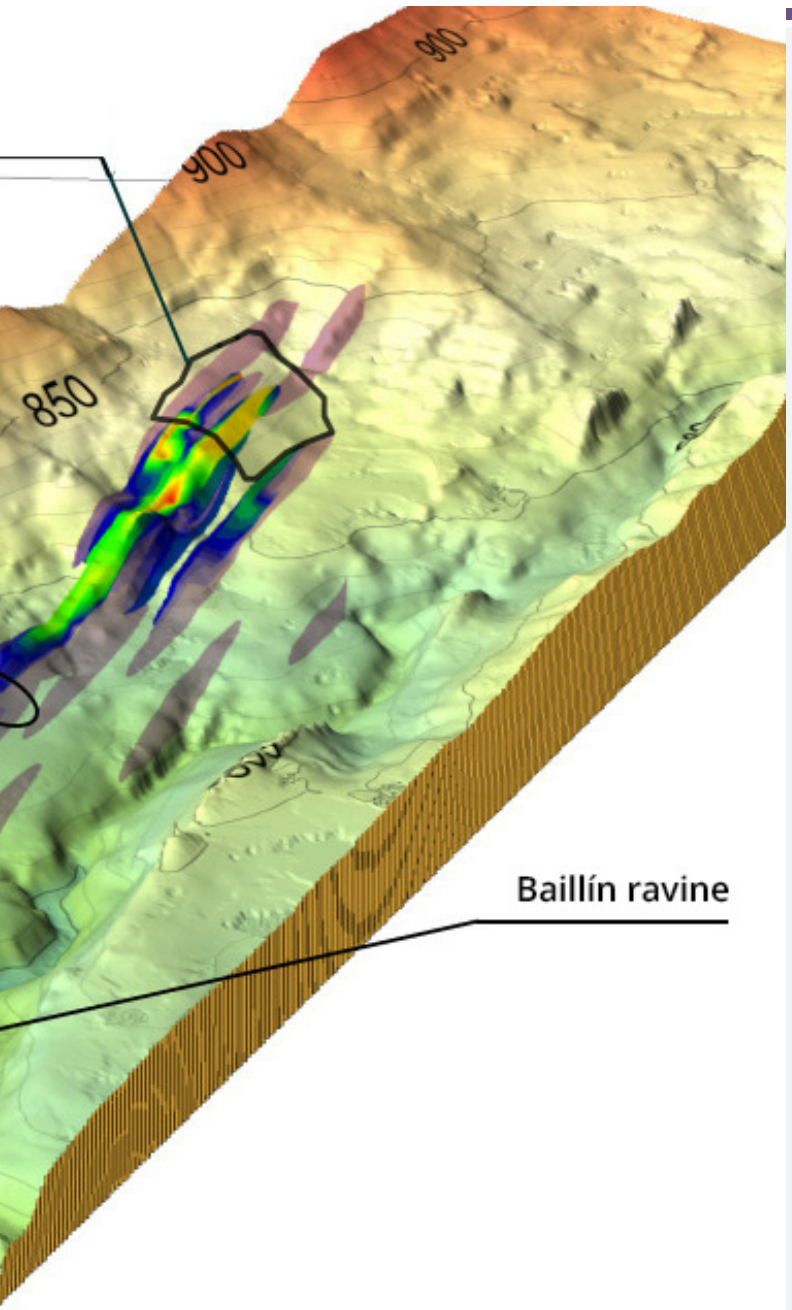
- *The location of the old Bailín landfill of HCH.*
- *A new safety cell.*
- *Four store tanks of 8,900 m^3 of capacity.*
- *The sewage treatment plant 1, capable to decontaminate the runoff water of the old Bailín landfill, pumpings and other leachates.*
- *The sewage treatment plant 2, with a capacity of 10 l/s, for decontamination of waters in the lower part of the ravine of Bailín.*

The Ebro Hydrographic Confederation (CHE) is editing the project for the performance of derivation of the ravine upstream from the affected area. Its construction will result in non-pollution of most of the flows generated in the ravine, the decrease of washing away towards the Gállego river and the correct functioning and increasing efficiency of the sewage treatment plant of the Bailín ravine, allowing to ensure that almost all of the circulating flows through the contaminated area are purged previously to its discharge into the Gállego river.

The action will consist of building a water capture, upstream from the contaminated zone, and later channeling the ravine waters along a path of ca. 1.2 km, down near the Gállego river. As well as the implementation of an area of dammed waters of the ravine to be treated according to the capacity of the sewage treatment plant 2.

The aim of the bypass is to derive 432 ha of upstream clean runoffs from the mentioned facilities, to a point downstream from the same. This way, the clean waters mixed with waters to decontaminate will pass through the sewage treatment plant 2, as happens today and will increase the efficiency of purification.





DISCOVERED LIFE

In the year 2010 the lab trials to select the best oxidizing agent for the present condition of aquifer in the old Bailín landfill began.

Trough the co-financing together with LIFE programme, in July 2016 the field tests for analysing the validity of in situ chemical oxidation have been run over. It was made within the train of usable technologies for the disposal of residues of lindane's manufacture from the aquifer which is fractured in the vertical strata of conglomerates and sandstone to about 40 meters deep. After constructing 10 boreholes with a separation of about 10 meters, injection tests and results monitoring were conducted at other boreholes located downstream. The tests have consisted of the creation of an alkaline front by injection of soda, to subsequently inject a persulfate solution to oxidize the waste from lindane's manufacturing, destroy them by releasing the chlorine and transform them into less dangerous, less soluble compounds with a shorter life.

Different pressures of injection and different amounts of injected mixture has been tested in order to verify the feasibility of the application of this method on a large scale to decontaminate the fractured aquifer associated with the old Bailín landfill. The challenge is focused on facilitating of contact between the oxidizing agent and contaminants in a surrounding of fractures in the rock of a few millimeters in width, saturated in water and about 40 metres deep. It is necessary to remember that the DNAPL is denser than water and tends to deepen until where the substrate allows.

The results will be available at the beginning of 2017. Preliminary data are promising.

Facing the future trails, it is analyzing the possibility of incorporate the biodegradable surfactants to facilitate the contact between an oxidant and a polluting. This LIFE project, that is currently running, has a budget of € 1.34 million, spread over four years.

More information at ***www.lifediscovered.es***

LIFE programme

Environment and Climate Action Programme (LIFE) is the financial instrument of the European Union dedicated to the environment for the period 2014-2020, in order to promote innovative technologies in the field of environment and climate change.

3.4 WATER ENVIRONMENT

Management of the Gállego river course and reservoirs is under the competency of the Ebro Hydrographic Confederation (CHE).

La Peña and La Sotonera reservoirs.

Lower reservoirs

On the 3rd and 4th December 2014 the Ebro Hydrographic Confederation (CHE) was doing the sediments sampling in reservoirs of La Peña and La Sotonera to identify a the possible repercussions of the transfer of waste from Bailín landfill to the new safety cell during during that very summer. One of the challenges of the study was the absence of reference values for fluvial sediments in the applicable regulations. For a legal framework about the evaluation of potential risks in contaminated soils, we find first, among comparative Spanish regulations, the Royal Decree 9/2005 on contaminated soils; as an international regulation related to the topic, there is the "Screening Quick Reference Tables" of the National Oceanic and Atmospheric Administration of USA (NOAA).

Data from superficial sediments

The high density of hexachlorocyclohexane (HCH), 1.8 g/cm^3, and its practical insolubility in water (between 0.005 g/l and 0.01 g/l, 20 °C), according to the isomers present, promote that these substances are present in a particulate form. *(1)*

This explains why it was found in a small quantity only, in superficial sediments near the tail of the first reservoir.

In the tail of a reservoir, water loses energy and particles settle. The sediments at ca. 50 cm of depth did not exceed the considered reference values in any case.

A link leading to the complete study is available at the website ***www.aragon.es/lindano***

Locality	Number of samples	Regulations	Alpha-HCH	Beta-HCH	Gamma-HCH
La Peña	10	Royal Decree 9/2005	Do not exceed	Do not exceed	Below the limit of detection
		USA	3 samples from the tail of the reservoir slightly exceeded	3 samples from the tail of the reservoir slightly exceeded	Below the limit of detection
La Sotonera	10	Royal Decree 9/2005	Do not exceed	Do not exceed	Below the limit of detection
		USA	Do not exceed	Do not exceed	Below the limit of detection

(1) A very soluble substance, as sucrose, dissolves at 1,330 g/l, at 20 °C.

Sabiñánigo reservoir

Originally, the reservoir had a profile composed of a substratum made of cemented marl and sandstone of a very low permeability, above which Quaternary alluvial deposits consisting of gravel and sand were found. Nowadays, by the effect of the reservoir's dynamics, the profile has been complemented with a third layered unit deposited at the top of the alluvial permeable gravel. The third unit is made of fine-grained sediments - clay and silt -, 0.5 to 8 meters in thickness, which is filling 86% of the reservoir capacity. In the year 2010, the Ebro Hydrographic Confederation (CHE) performed the environmental characterization of the reservoir and its immediate surroundings. For this purpose 23 boreholes were drilled, 17 of which through the reservoir profile. Some important conclusions of this study are:

- Analytical results showed that HCH leachates from the Sardas landfill are circulating underground through the terraces of the Gállego river until reaching the Quaternary gravels of the reservoir, where there are high concentrations of HCH, while sediments at the top of the third unit are recording low concentrations of this compound.

- The origin of the most significant detected metals is attributed to past industrial practices undertaken in the surroundings of INQUINOSA (arsenic, copper, lead, zinc and mercury), and in the surrounding of the facilities of Energía e Industrias Aragonesas (arsenic, copper, lead, zinc and mercury).

- Tests made at the surface layer of the sediments show that it is not ecotoxic, i.e., elements of the sediment are not affected significantly as to modify the biological balance of the ecosystem.

It can be interpreted that the wall of the dam and the reservoir filling - fine-grained sediments of the third unit - are holding back the historical contamination of the Quaternary alluvial.

On the website ***www.aragon.es/lindano*** the link to complete study is available.

It can be concluded that the mentioned low presence of lindane manufacturing residues in sediments of the Gállego river and its reservoirs - despite having been released in significant quantities for years - is due to the chemical characteristics of hexachlorocyclohexane compound. Hence the generic designation of "semi-volatile" to this compound, due to its practical insolubility in water and its low vapor pressure. Its low solubility - between 0.005 g/l and 0.01 g/l, at 20 ° C, according to isomers present - favours that the hexachlorocyclohexane powder is transformed into particles in contact with water, precipitating at the bottom of the riverbed.

Its low vapour pressure of 2.3 x 10-3 to 5.3 x 10-3 pascals, at 20 ° C, according to isomers, makes the compound to sublimate easily - i.e., it passes from the solid state into gas - as the temperature increases. It can also pass from gas to solid, if temperature decreases.

The Gállego river has a torrential regime, with very important flow variations. At its river mouth, the flow may change from 4 m^3 per second into 547 m^3 per second in a two-day term (15th-17th November 2016).

In addition, reservoirs at the Gállego river are subject to hydraulic exploitation, either for irrigation or for power generation, so that, at the end of the summer season, much of the accumulated sediment is exposed under the sun. Temperature at the reservoir bed can reach values above 50 °C. Sublimation increases exponentially with increasing temperature. In these conditions, the "Grasshopper effect" takes place massively, by means of which these residues form aerosols, gasify and move towards cold areas. In this way, they reach the soil and water bodies from local mountains up to distances of thousands of km, even to the poles of the planet.

The conclusion is that these contaminants have abandoned the riverbeds and become a part of the planetary background contamination, identified at the poles. It is necessary to remember that currently lindane production is still taking place in several countries of the world like Romania and India, and is used in equatorial countries.

Study of the ecological state of the rivers Gállego, Aurín and Basa, conducted by DGA.

Since 2006, a yearly "Report on actions aimed at determining the ecological state of the riverbeds in the Gállego basin (Bailín-Sabiñánigo)" is made, within the "Plan of monitoring and control of the Bailín and Sardas HCH landfills". The rivers Gállego, Aurín and Basa are being analyzed.

These reports are part of the Integrated Environmental Assessment. Every year the same points of riverbeds are sampled and the same indicators are being used. Ten points are analysed, having been sampled for microphytes, macroinvertebrates, hydromorphological analysis (QBR index of quality of the riparian forest, and IHF index of the fluvial habitat), fish populations study, water analysis and sediment.

Therefore, these reports are a faithful reflection of the historical records of riverbeds. They are available at the website ***www.aragon.es/lindano.***

For example, in 2015, the conclusions of the report were as follows:

- For the microphytes, the quality varies between good and very good, according to the proximity of farms to the riverbed.

- For the macroinvertebrates the quality ranges from dubious to acceptable.

- As for the hydromorphological analysis, according to the QBR index, it varies from mediocre to deficient, with only one point with a good sampling. IHF index results are either medium or low diversity, with only one point being of high diversity.

- Regarding the study of fish populations, data are very heterogeneous and difficult to compare between the years.

3.5 | SMALL DUMPS

In different spheres, there are rumours about the existence of other points of discharge for the lindane production waste by INQUINOSA, in addition to the Sardas and Bailín landfills.

Today it has not been found any evidence of this. It should be noted that the INQUINOSA company was "acting at its own convenience" since 1975 to 1992. The company was discharging lindane production waste "at the lowest cost". The company discharged both solid and liquid waste in the two mentioned landfills. The possibility that the company did buy plots, rented digging machinery, poured residues and buried them seems to be remote.

It is likely to suggest that due to, perhaps, a truck breakdown or bad meteorological conditions some uncontrolled discharge could have happened in, for instance, a ravine.
In the area of Bailín, average rainfall is 750 mm per year and intense storms are frequent.
After 15 years, any off-landfill discharge will definitely not be at the original location anymore.

This hypothesis is based on the absence of residues related to the lindane production among the localised analyses carried out in areas such as the Basa and the Aurín rivers.

Sampling at the rivers Basa and Aurín		
Riverbed	**Period of sampling**	**Result**
Basa river	Quarterly	Sum of HCH isomers below the limit of detection in laboratory.
Aurín river	Annual	Sum of HCH isomers below the limit of detection in laboratory.

Another matter of concern is the suspected event of liquid residue pouring into abandoned gas boreholes located in the Serrablo region, reaching several km of depth. A geological reservoir which contained gas for millions of years does not seem to involve risk to aquifers located thousands of metres above.

In any case, the Department of Rural Development and Sustainability is open to perform research at any newly-appeared waste location, provided that evidences are provided. This does not rule out the possibility of the existence of disseminated waste, hence periodical, localised actions of analysis are still being made out of the Gállego river and the Bailín ravine. Results to date have all been negative.

The INQUINOSA company started its activity in 1975, and in 1978 began to use the Sardas ravine as a landfill. During these years the company claimed that generated waste was carried to a plant in Bilbao.

Therefore, a campaign of announcements at the Bulletin Board of several city halls is planned, requesting information on the whereabouts of possible isolated discharges.

Characteristics of lindane according to FAO:

"The half-life in soil ranges from 5 days (Kenya) to more than 400 days (temperate soils) depending on both temperature and microbiotic life of the soil (WHO, 1992)". According to the Decisions Guidance Document on Lindane, by the Joint FAO/UNEP Programme for the implementation of the principle of Prior Informed Consent (PIC), 1996.

Therefore, for a temperate zone, half of the initial amount of lindane will be vaporized in approximately one year.

Strategic Environmental Action Plan against lindane waste contamination in Aragon

4

Work carried out

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4 WORK CARRIED OUT

Perspective of the new safety cell of Bailín

> *The Aragon Government has made an important effort proving a high social and environmental commitment.*

The Government of Aragon has made a great effort in facing the ambitious task of controlling and minimizing the environmental risks linked to the presence of HCH residues, showing a high social and environmental commitment. The challenges encountered are of a technical, economical, political, institutional and social reach.

This effort has resulted into the accumulation of an important "know how", i.e. technical, administrative and political experience in the management of HCH and POP contamination. Además, tras los eventos de afección al río Also, after the events of contamination of the Gállego river in the summer of 2014, it has progressed notably in risk control of areas downstream Bailín, establishing a full and comprehensive system of surveillance and early alert to ensure the quality of potable waters and irrigation waters downstream Bailín.

The successive paragraphs summarize the main actions, progress and goals achieved in the management of HCH and lindane issues in Aragon.

4.1 INTERVENTION AT THE MAIN POLLUTION SOURCES

The level of progress in three main sites is different because of the economic investment, the time invested, as well as the legal and administrative situation.

The site of Bailín is, by far, the one where more time and economic resources have been invested, followed by the location at Sardas. The situation seemed to be under control at Sardas until the year 2004, when springs bearing free organochlorine phase were observed at the foot of the landfill. Only after recent judicial decrees, the Government of Aragon was able to characterize the INQUINOSA site, so that the progress at this location is delayed.

Knowledge of the environmental problems

The substratum of all the three main sites has also been characterized by means of hundreds of exploration boreholes, from which cores were retrieved. In total, thousands of metres were drilled. Thousands of samples from soil, sediment, runoff, surface water and groundwater, leachates, air and biota were analyzed. Advanced conceptual models are available now for all of the sites. Both in Bailín and Sardas, some mathematical models of groundwater flow have been developed, which allowed to support and improve the conceptual models. Intense works are being made now to improve the conceptual model at the old plant of INQUINOSA.

Management and isolation of waste

EIn this section, the transfer of residues from the old HCH landfill of Bailín (210,000 m^3) to the new safety cell is the most important advance. Thus, the free organochloride phase extracted from the subsoil, both at the Sardas and Bailín sites, is regularly transported to a last waste manager and destroyed by incineration. Moreover, the hazardous wastes collected on the surface at the old factory of INQUINOSA have been removed and managed. Also the content of existing underground tanks at the site was managed and remediated.

Control of leachates and runoff waters

Both at the Bailín and Sardas sites, facilities for the control and treatment of leachates have been built, including drainage systems which prevent, on one hand, that leachates and potentially contaminated runoff waters reach the sensitive receptor, and, on other, that clean runoff water come in contact with potentially contaminated areas. For the treatment of water and leachates, two sewage treatment plants have been built, one at Bailín and another one at Sardas.

Remediation

The most important remediation works carried out are removal of DNAPL from the subsoil and purification of leachates, both in Sardas and Bailín. In addition, contaminated sediments from the bed of the Bailín ravine have been removed in collaboration with the CHE.

Other activity associated with the remediation was the realization of dozens of pilot trials, both at the laboratory and the field, in order to advance in the study of techniques available for remediation of underground waters and leachates, as well as soils and bedrocks.

Treatment facilities at Bailín

4.2 SYSTEM OF SURVEILLANCE AND EARLY ALERT

In terms of control of environmental risks, the top priority for the Government of Aragon is to ensure the potability of the water and its quality for irrigation downstream Bailín.

For this purpose, an ambitious Protocol of Emergency and Early Alert has been implemented. This protocol ensures coordination between departments and administrations with staged competences, giving response to pollution events which could affect the whole hydrological system. It has been successfully completed the "Gállego river Monitoring Procedure in Face of Possible Lindane Pollution", coordinated by the Civil Protection Service of Aragon.

The System of Monitoring and Early Alert includes a daily sampling and analysis of surface waters from the ravine of Bailín up to Villanueva de Gállego. That is, more than 150 km of the Gállego riverbed. Waters from reservoirs and channels are also analysed.

The limits of application of the procedure are the following:

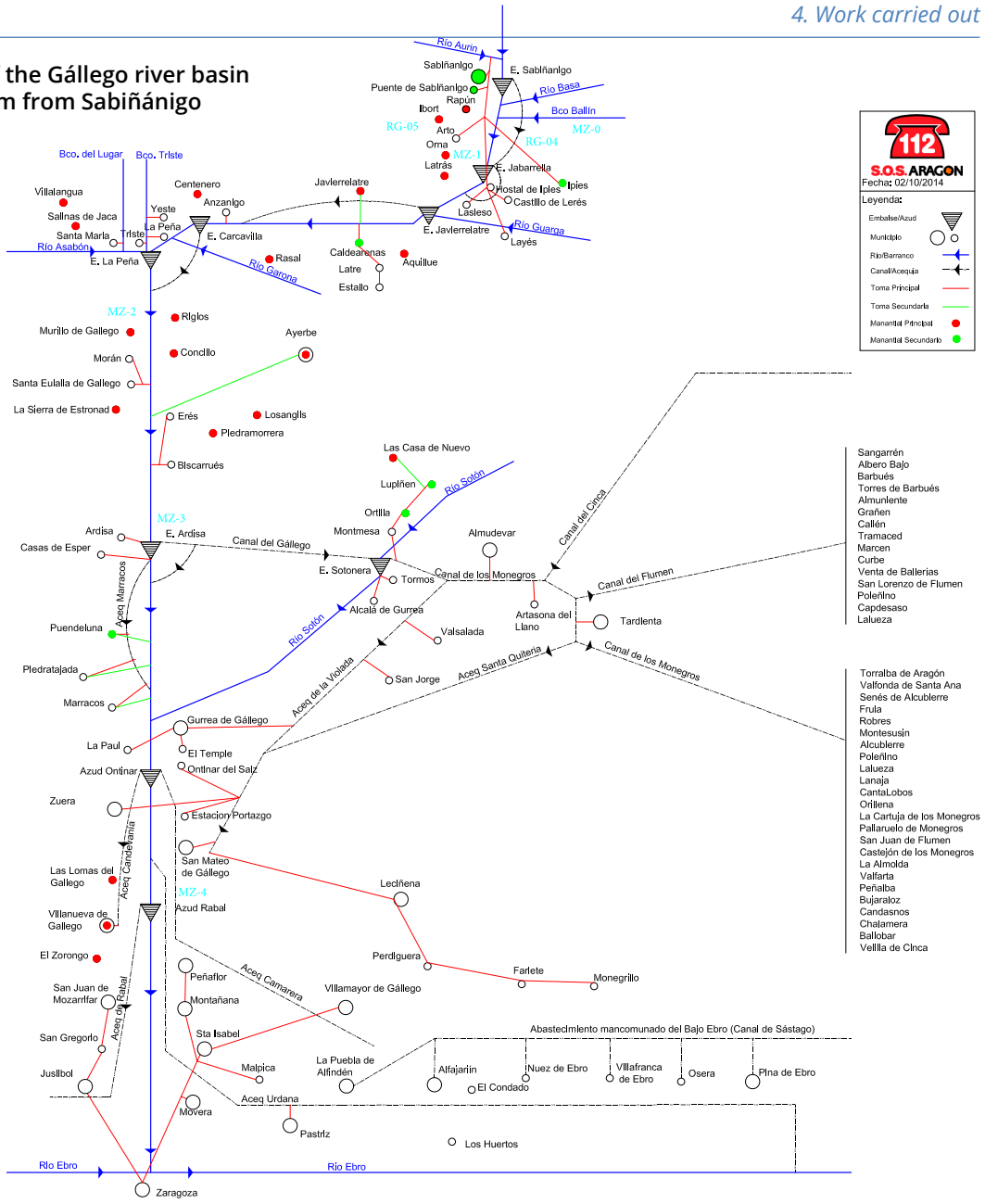
- Level of **'Normality',** below or equal to 0.1 micrograms per litre of any isomer of HCH.

- Level of **"To be transmitted to the IAA"**, greater than 0.1 and less than or equal to 0.5 micrograms per litre of any isomer of HCH. (IAA, Aragonese Institute of Water).

- Level of **"review of purification systems including activated carbon filters"**, greater than 0.5 micrograms per litre and equal to 1 microgram per litre of any isomer of HCH.

- Level of **"Non water catchment for potability"**, above 1 microgram per litre of any isomer of HCH.

Diagram of the Gállego river basin downstream from Sabiñánigo



The settlements listed in the mentioned procedure are a total of 20, divided into 4 zones. They are, from upstream to downstream:

- **Zone 1**. Between Bailín and the La Peña reservoir: *Caldearenas, Javierrelatre and Anzánigo.*
- **Zone 2.** Between the La Peña reservoir and the Ontinar weir: *Santa Eulalia de Gállego, Murillo de Gállego, Biscarrués, Ardisa, Puendeluna, Piedratajada and Marracos.*
- **Zone 3.** Between the dam of Ardisa and the channel of Gállego river: *Montmesa, Ortilla y Lupiñén, Tormos, Alcalá de Gurrea, Valsalada, San Jorge, Gurrea de Gállego, El Temple and La Paul.*
- **Zone 4.** Between the channel of the Gállego river and the Ebro: *Villanueva de Gállego, Zuera (El Campillo Industrial Park) and Pastriz.*

Each area has its own point of sampling:

- **Zone 1,** at the Jabarella reservoir.
- **Zone 2,** downstream the Carcavilla power plant.
- **Zone 3,**at the Gállego channel.
- **Zone 4,** at the Ontinar weir.

The system is redundant, since besides of three sewage treatment plants of activated carbon filters enabled by the Government of Aragon, each municipality has its own system of active carbon filter. Note that these filters are non-selective and may retain any other diffuse contamination present at the riverbed.

Scheme of the "Gállego river Monitoring Procedure in Face of Possible Lindane Pollution". Procedure 11/27/15						
Sampling point	**Ordinary sample**	**Event sample (a)**	**Any isomer of HCH into raw water**	**Action →**	**Action → Phone. + E-mail**	**Action**
MZ-0 Ravine of Bailín Daily average	Daily average	Snapshot sample > 100 microg/l sum. HCH		SARGA reports to the person in charge of the General Direction of Sustainability (b)	112	
MZ-1 reservoir of Jabarrella	Daily periodicity		≤0.1 microg/l	Normal		
MZ-2 Carcavilla power plant			0.1 ≤ 0.5 microg/l	SARGA reports to the person in charge of the General Direction of Sustainability (b)	IA Water (c)	
MZ-3 Channel of Gállego			0.5 ≤ 1 microg/l	SARGA reports to the person in charge of the General Direction of Sustainability (b)	112 (b)	Technician in duty notifies the person in charge at the Dept. of Justice and Internal affairs, General Direction of Public Health. IA Water and CHE. Review of the potabilization system (d)
					IA Water (b)	Municipalities of the region review the carbon filters (e)
MZ-4 Ontinar weir			>1 microg/l	SARGA reports to the person in charge of the General Direction of Sustainability (b)	112 (b)	Mayors in the region DO NOT capture water from the Gállego river
Meanwhile the automatic samplers are not installed; snapshot samples will be taken twice a week. If there is any problem, this frequency would be increased .						
(a) in case of spill or overflow (b) Notify: (c) To confirm correctly-functioning potabilization processes (d) General Direction of Public Health takes samples during the first 12 hours, and after that it notices 112. c-1 of any isomer of HCH is >0.1 microg/l in the tap water, in the 2nd analysis → notification to the municipality about NO potable water. c-2 notification to the Service of Prevention, Fire-fighting and Rescue or to SARGA for cleaning the water tanks and the potable water. c-3 notice to the Aragonese Institute of Water (IAA) to assist in the cleaning of tanks and systems of potabilization. c-4 after c-3, if raw water to fill deposits shows < 0.5 microg/L of any HCH isomer, the water of the Gállego is suitable for capture. (e) IAA recommends, for those who has dispensing filter, to ration active carbon in powder. If there is no dispensing filter, it is necessary to supervise the granulated active carbon, and even to avoid capturing water from the Gállego.						
1 microgram/litre = 0.000001 g/l. Solubility of HCH in water is very scarce 0.007 g/l a 20ºC						
Other data of interest. Authorization of discharge by CHE, sewage treatment plant of the Bailín ravine: < 50 microg/l total HCH. This small, 4.4 km-long ravine does not supply water to any settlement.						

The Aragon Water Institute has subscribed agreements with the city halls of Caldearenas, Santa Eulalia de Gállego, Biscarrués, Ardisa, Piedratajada and Marracos, in order to ensure the quality of water supply.

With the intention to give peace of mind and confidence to the population involved, the web site **"www.aragon.es/lindano"** of the Government of Aragon shows daily assessments of the analyses performed.

The Department of Rural Development has offered to all the municipalities from the middle stream of the Gállego river, viable and economically reasonable alternatives to increase the security in face of a potential water pollution event at the Gállego. Alternative solutions are from new water captures for supply to - in an extreme case - the construction of ponds for holding a temporary, alternative water supply for a period of 60 to 90 days. These ponds would be filled with water from the Gállego, good for potabilization. It is necessary to make clear that former events of concentrations increase in the Gállego have been sporadic and had a duration of 3 to 4 days as a maximum. These short periods of recovery of potabilization values are due to three causes:

- The existence of the "Gállego river Monitoring Procedure in Face of Possible Lindane Pollution", which establishes a protocol of action.
- The important average flow of the Gállego river along the stretch of the sites (12 to 20 m^3 per second).
- The presence of two important reservoirs at the headwaters of the Gállego. Drawoffs management at the Lanuza (17 hm^3) and Bubal (64 hm^3) rese rvoirs allows to perform operations of "washing" the river if the situation is required.

Alternative water supplies

Some municipalities of the middle stretch of Gállego river, claim the Yesa reservoir water supply.
This option is economically unacceptable.
Insisting on this option means deprive those involved in the implementation of alternatives, which would increase their security.

Regarding to alternatives supply to small localities with a quite high cost, is worth commenting that a solution may be technically feasible, but may not be so socially. Especially when there is a technical and socially acceptable alternative. It is necessary to take into account that all needs of Aragon are competitively fighting among them for limited economic resources.

Irrigation water quality

It is guaranteed by the "Gállego river monitoring procedure face of possible lindane pollution". The existence of these daily data allows paralyzing the derivation for irrigation where water is not purified.

It is interesting to emphasize that HCH residues have a low capacity for dissolution in water and higher density than this and tend to adhere to fine particles. The reservoir of La Peña acts as great decanter, as it has enunciated in paragraph "Lower reservoirs", restricting the access to the lower course of the river. In addition the irrigation system of Alto Aragon (High Aragon) has the reservoir of La Sotonera, which allows the autonomy during several months.

Automatic samplers

There is one automatic sampler installed at the Gállego river and another one at the Bailín ravine, four more being under construction.
They collect one sample every hour.
The composite sample which gives an integrated reflection of water at that point during the day consists on 24 partial samples.

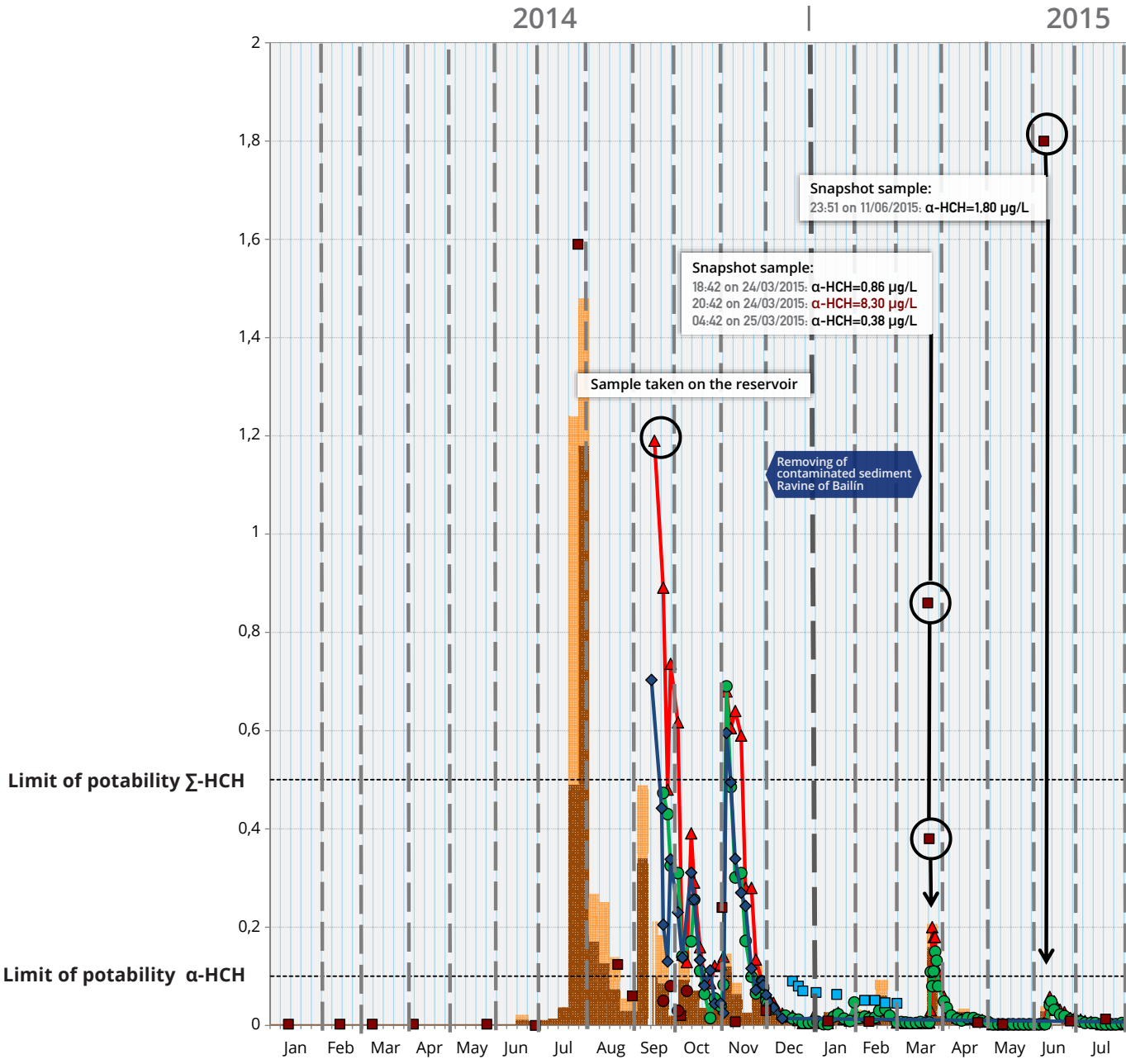
List of municipalities that capture water for purification downstream from Bailín.

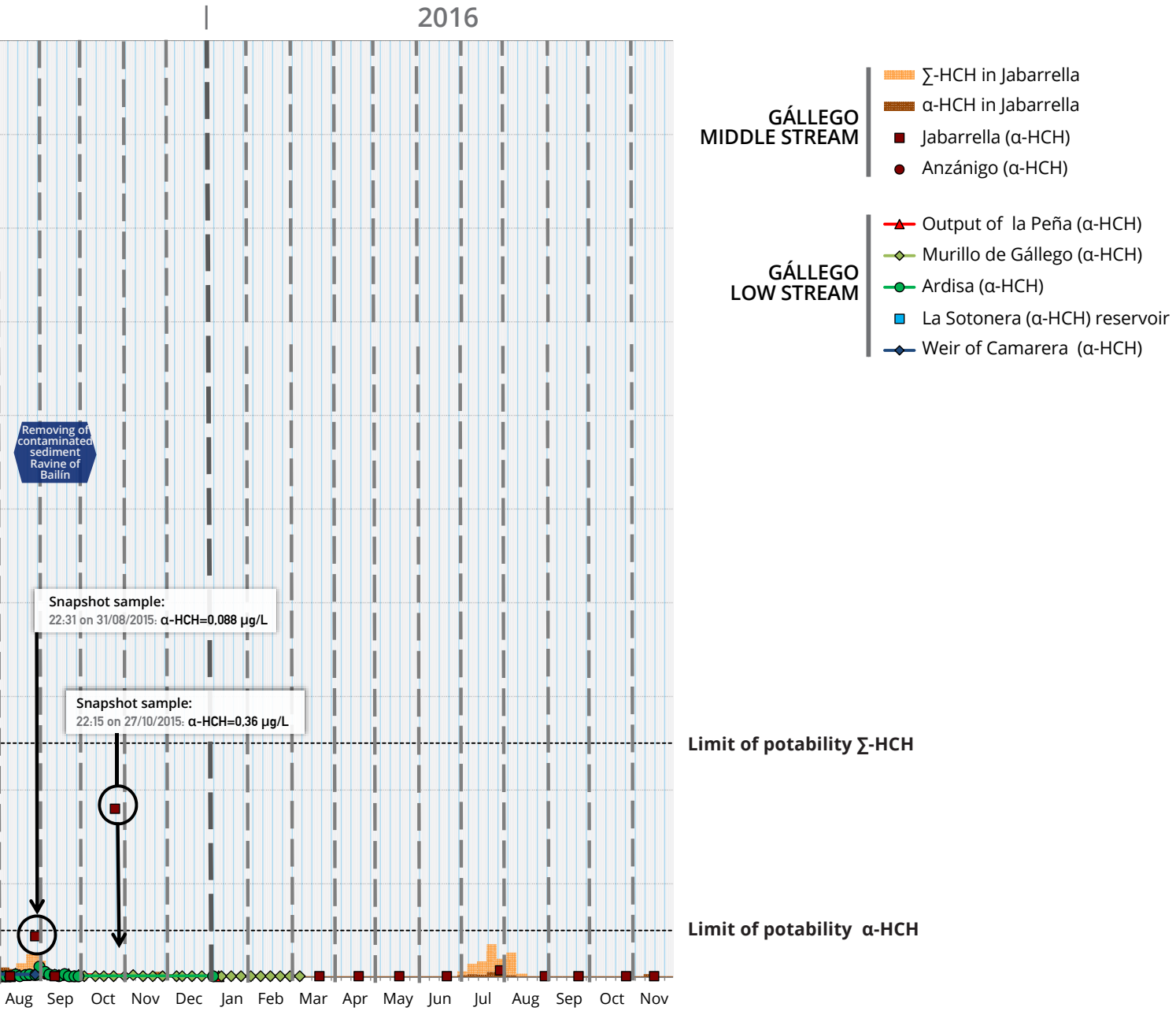
City council	Province	Hab.
Caldearenas	Huesca	210
Santa Eulalia de Gállego	Zaragoza	110
Ardisa	Zaragoza	74
Biscarrués	Huesca	202
Marracos	Zaragoza	94
Piedratajada	Zaragoza	114
Villanueva de Gállego	Zaragoza	4,614
	Total	**5,418**

Census 2015

Evolution of the concentration of ∑-HCH and α-HCH in the Gállego river.

Ebro Hydrographic Confederation data.
Continuous weekly samples at Jabarrella.
Rest of specific samples.





Graphic of the analyses carried out by the CHE.

he waters of the Gállego river stay over 750 days within the limits of purification and 99.9% of the days at concentration of HCH below the limits of laboratory detection.

This is has been achieved thanks to the investments made to contain and destroy the pollution and to the work of some 20 people giving service seven days a week.

4.3 | POLITICAL AND INSTITUTIONAL MANAGEMENT

In October 2015 the Governing Council agreed to create an Administrative Unit for Integrated Lindane Decontamination.

The Government of Aragon has taken a step to recognize the problem and deal with it as a management and innovation challenge. The importance of the problem of HCH in Aragon is especially highlighted due to technical evidence of potential risks to the environment, political and social significance and the great interest that raises in different actors such as social, politics, business, Administration of Aragon, central Government, etc.

On the other hand, the lindane in Aragon has had a great impact in mass media during the recent years, and not only locally in Aragon, but also at the national level. This impact has been translated in hundreds of articles in newspapers, with a presence even in cover pages of newspapers of national circulation, in broadcast programs in Aragon and national, on radio, digital media, etc.

Should be noted in this section, while it is true that the Government of Aragon leads the fight against the problem of lindane in Aragon for decades, testing of which are remarkable developments described above; starting from 2015 the Government of Aragon has led an institutional strengthening in coherence with the structural nature of the problem and its definitive and final solution to long-term horizon.

In October 2015 the Governing Council agreed to create a Administrative Unit for integrated remediation of lindane. This unit has the support of three committees:

• **Scientific Committee,** composed of experts of recognised prestige that underpins and improves the foundations and relevance of the objectives and the measures carried out in the different fields of action, including the processes of R&D&I requiring the final solution of the challenge. Its eight members cover the areas of hydrogeology, chemical engineering, biomedical and restoration of soils and agronomy.

• **Monitoring Committee,** which ensures coordination between the different areas of competence related to the challenge and its solution. It has twelve representatives of the Ebro Hydrographic Confederation (CHE), Department of Health, Civil protection, SEPRONA, local administration and Alto Aragón irrigators.

• **Social Committee,** which coordinates the participation of civil society and facilitates the flow of information as well as the process of communication. It consists on twenty-one representatives of environmental associations, trade unions, organization of agricultural producers, business associations and the Council of Protection of the Nature.

In July of 2016 the representatives of all Parliament groups have been incorporated to ensure the presence of all the sensibilities.
As an example of the progress in the institutional management and as a proof of the need for collaboration between the different agents involved, the collaboration agreement between the Ministry of Agriculture, Food and Environment and the Autonomous community of Aragon was signed in June 2015. It aims to define the actions for the integrated plan of Gállego river remediation for 2015.

The total amount of the agreement come to 17 M€ (8 M€ in charge of Aragon and 9M€ of the General State Administration) this Convention included works in the ravine of Bailín, analytics tracking, hydrogeological control , drafting of the INQUINOSA demolition project, studies of alternative water supplies for populations of the Gállego's basin, Zaragoza water supply project and its environment (4th phase) and drafting and implementation of the project of diversion of waters away of the ravine of Bailín. This Convention is currently being developed.

Institutes and agencies involved

- ***Government of Aragon***
  - *Department of Rural Development and Sustainability*
  - *Health Department*
  - *Aragonese Water Institute (IAA)*
  - *Civil protection*
  - *112*
- ***European Union***
- ***Ministry of agriculture, food and environment***
  - *Ebro Hydrographic Confederation (CHE)*
- ***City councils***
- ***Political Parties***
- ***Communities of irrigators***
- ***Environmental associations***
- ***Citizen association and citizens in general***
- ***Scientific community***
- ***Mass media***

GOBIERNO DE ARAGON

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MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE

European Union

Boreholes logging in the landfill of Sardas

Political refocusing. Transparency

Because of progress in detail knowledge of environmental problematic, object of this Plan, as well as lessons learned of the contamination events in the Gállego river on summer of 2014, the Government of Aragon has been underway a refocus politician, formal and explicit recognizing the importance of the issue and the inability to resolve it by itself on an exclusive basis.

Within this political refocusing, the Government of Aragon has self-inflicted a compromise of maximum transparency, fruit of which has developed this Strategic Plan and made it available to any interested party a lot of information in en ***www.aragon.es/lindano***.

This section of the web site of the Government of Aragon has the following parts:

1. Evaluation of HCH in the water:
It is daily presented the assessment of drinking water quality in five points of sapling within the "Gállego river monitoring procedure face of possible lindane pollution"

2. System of purification from HCH:
There is a description of three sewage treatment plants with active carbon filters as well as the physico-chemical pretreatment and the human resources involved.

3. Actions for HCH remediation:
Here the actions planned for three sites (already fulfilled or on going) are providing.

4. Related web sites:
There is the link to several web sites, a video and news of Environmental Digital Bulletin of the Government of Aragon.

5. Administrative acts related to the HCH:
The administrative acts such as environmental statements of contaminated soil or integrated environmental authorisations of the facilities are here.

6. Investments carried out:
in this chapter the investments made since 1992 intended to contain the pollution is related.

7. HCH Committees:
The functions of each of the three committees, committee's members and the organism they are representing may be found here.

The Aragon Court

The activity of the Aragon Court in the IX legislature compared to the challenge of the management of waste from the lindane manufacture has been intense, in fact it was treated in the debate on the status of the Autonomous region of Aragon on October, 5th and 6th, 2016

Among the parliamentary initiatives tabled by the various political groups the following can be noted:

PROPOSALS BILL NUMBER

- **PNL 158/15-IX, passed on 05/11/15 with the aim of:**

  1. Develop a technical plan for remediation, provided with necessary funding, which ensure the continuation of the actions aimed to locate the spots contaminated by lindane in Sabiñánigo and its surroundings. That plan should gather the actions planning to perform it in a calendar, and also must define the competent administrations and economic contributions for remediation and regeneration labours in all lots contaminated by INQUINOSA's waste.

  2. Develop a Plan for Territorial Compensation which alleviate the negative effects caused by pollution in such locations.

- **Motion 140/15-IX, approved on 05/11/15 with the aim of:**

  1. Leading and ensuring an effective institutional coordination in order to solve the problem of lindane in Aragon.

  2. Undertaking works on an alternative supply, in the shortest term possible.

  3. Promoting the creation of a technological park dealing with persistent organic pollutants and/or green chemical industry.

- **Motion 191/15-IX, adopted on 22/03/16 with the aim of :**

Facing the lindane analytic results from the Manubles river, and possible means to be applied whenever appropriate.

OTHER PARLIAMENTARY INITIATIVES

- **Appearance 05/11/15** of the Regional Minister of Rural Development and Sustainability in order to clarify the statement of the situation and new approaches.

- **Appearance** of Minister of Rural Development and Sustainability reporting the proposed bill of the Autonomous Community of Aragon for the year 2016 in regard to his Department.

- **Appearance** of Director General of Sustainability in order to inform about the Management Unit for Integral Decontamination of Lindane, 10/05/16.

- **Oral Question 366/16** on the functions and dynamization of the committees of institutional and social monitoring which will give support to the Management Unit for Integral Decontamination of Lindane.

- **"1/12/2016,** the appearance of Counsel of Rural Development and Sustainability to report on the progress of the Strategic Environmental Action Plan against lindane waste contamination and other HCH isomers in Aragon. Edition: November 2016."

Biomonitoring of the population

An initiative raised by social groups is the biomonitoring of the population which uses the Gállego river water downstream of sites.

The samples that easily can be obtained in the human body are the blood and urine. Nevertheless, these do not provide conclusive information. Experts indicate that the body fat is useful tissue for this aim. Samples of body fat are difficult to obtain annually from the group of people representing different strata of population. The target population is quite a small, this fact also complicates the representativeness of the results.
The experts quantifies that the minimum population of about 50,000 people needed to make a reliable study of these features.

The Executive:
"Aragon requests help from Europe to battle the pollution problem caused by lindane".

The President of Aragon, Mr Javier Lambán, has met representatives of the European Parliament and the European Development Bank (EIB) in May 2016, in order to obtain financial support and solutions to the problem of lindane in the Gállego river.

He said that another matter discussed during his meetings was dealing with "the quite real possibility" that EU budget for 2017 will contain "items being disclosed to start working on the lindane issue".

The Regional Minister of Rural Development, Mr Joaquín Olona traveled to Brussels last July, for interviewing with the Commissioner of Research, Science and Technology, Mr Carlos Moedas and for exposing the needs from the point of view of R&D&I, in order to solve the challenge of pollution produced by lindane production. He also met with the Director General of Environment in the European Commission, Mr Daniel Calleja, to expose the situation and to introduce a preview of the Comprehensive Plan for Decontamination of Lindane.

Mr Olona proposed that the European institutions include the problem as "an opportunity through which to generating added value for the European Community and to contributing to smart, inclusive and sustainable growth". He recalled, moreover, that lindane is not an exclusive problem of Aragon, but it has worldwide importance, since this product was extensively used as a pesticide during the 20th century.

The Director General of Sustainability travelled to Brussels last September for participating in the Conference "Management of agrochemicals: removal of blackheads and whiteheads-building", held in the European Parliament with the aim of analysing the situation of persistent organic pollutants (POP).
Ms Ortega rose awareness of the European institution about the situation and expressed the importance of "progressing into the development of technology and solutions for the remediation of Sardas and Bailín, which can be extrapolated to other territories and become global solutions for HCH (lindane) waste management at an European level".

Agreements by the Governing Council

It started with the presentation of amendments to the proposed bill on the budget for the year 2016, in order to assign a greater investment.

In October 27th, 2015 the Governing Council agreed the necessity to create an Administrative Unit for Integrated Decontamination of Lindane.

On 12th June 2016, the Governing Council agrees the authorization of multiannual expenditure, for the years 2017 to 2019, of €1,853,135 for the hydrogeological monitoring of Sardas and €1,843,096.20 for the hydro-geological monitoring of Bailín.

On 25th October 2016, the Governing Council agrees the authorization of multiannual expenditure of €3,394,914.60 for the purification, analysis, laboratory management and monitoring of the areas affected by HCH contamination in the Gállego river, for the period 2017 - 2019.

The Management Unit for Comprehensive Decontamination of Lindane

Environmental Control Service is integrating into a specialized technical centre, named Management Unit for Comprehensive Decontamination of Lindane, which is structured into several technical areas and deals with the management, monitoring, control, research and communication related to this remediation process.

Palace of the Aljafería, the headquarters of the Aragon Court

Calls of support committees for the management of lindane (HCH) waste

The Scientific Committee convened for the first time on November 26th, 2014 to evaluate the situation of pollution in the ravine of Bailín and Gállego river, to define actions to perform, and create the specific working groups.

February 3rd, 2016, the Scientific Committee visited the sites, along with social representation and parliamentary groups of the Aragon Court. In the afternoon, in Pirenarium, the challenge of the scientific assessment on such a complex topic as the present was raised.

The Committee for the institutional monitoring was create on April 20th, 2016.
This Act proposed the objective of coordination between different fields of competence in the subject of HCH waste management and its consequences and the possibility to transform this challenge into an opportunity for the territory.

The Committee for the social monitoring was create on April 27th, 2016. In this act it was putting forward (as a main commitment) the allowing of communication flow and the exercise of transparency, an orderly fashion, on the HCH residues management. In the course different demands and acknowledgments for this initiative of transparency were raised.

July 14th, 2016, is convened jointly Committee of Institutional Monitoring and the Committee of Social Monitoring, to inform about recent developments in management, to welcome to the representatives of the parliamentary groups to the Social Committee and expose the main estimations provided by the Scientific Committee to the management in course and future.

October 5th, 2016, is convened jointly the Committee of Institutional Monitoring and the Committee of Social Monitoring so the members could carry out the questions to the Scientific Committee members who were conducted the evaluations.

All workers from the three sites follow the safety and health protocols issued by different prevention services of the participating companies, in agreement to the Law of Prevention of Occupational Hazards and the Royal Decree 374/2001. Protocols are coordinated, following the Royal Decree 171/2004 and Royal Decree 1627/1997.

Also, according to their job position receive the specific training in the field of prevention, among other, training related to the management of chemicals, with the correct use of individual protection equipment and even the drills of spill and contact with contaminants are conducted.
Workers who develop the job in sites come under, at least, one annual medical review specific for this type of compounds with analysis of blood and urine. It is necessary to obtain the medical certificate confirming the suitability to develop their work prior to start and a medical recognition to finalize its tasks.

Also, the hygienic measurements in different posts of work is performed to assess the exposure to them different compounds and define them elements of protection necessary.

Additionally, continuous controls on the presence of organochlorine compounds in gases are made by means of four samplers installed at Bailín.

To this day, even in 2014 that were the work of dismantling of the old landfill body of HCH, all checkups of individual workers, have been suitable, hygienic measurements were below the daily exposure limits and values of air have located always below established occupational exposure limits.

Press

The management of residues from the manufacture of lindane has reflected on numerous times in the newspapers.
It's a sensitive topic, with many variables and angles in constant generation of news developments. From July 2015 to July 2016, the topic appeared 90 times in the Aragonese newspapers. All this despite that the communication on topics with a complicated scientific and technical basis is not simple.

Social sensitivity

The management of persistent organic pollutants is a global issue affecting to planetary biological systems by background contamination.
In this long chain, the first interested users are populations downstream the sites.

On numerous occasions they have made presence in the mass media to claim more actions and information of the situation.

"Recognition of a local NGO"

In 1986 it was accepted to proceedings by the Court of Jaca, a complaint submitted by Mrs Rosa María Paradinas, from the ecologist group ADEPA (Association in Defense of the Aragonese Pyrenees), on the waste management undertaken by the company INQUINOSA.

Main recommendations by the Scientific Committee in support of HCH residues (lindane) management, assumed by the Department of Rural Development and Sustainability:

Concerning the landfill of Sardas:

1. 1. *While techniques for waste elimination advance, it is necessary to improve the confinement with enhancement of the perimeter and surface waterproofing.*

1. 2. *To continue with the work of extraction of groundwater and dense phase from below the landfill by conventional inclined boreholes and large diameter inclined boreholes.*

1. 3. *To prioritize the remediation actions on the landfill itself.*

1. 4. *Speed up the extraction of dense phase, pasty residue of HCH, with the use of surfactants (fluidifiers). These surfactants should be biodegradable, easily recoverable from the emulsion and compatible with other physical treatment chemicals.*

1. 5. *It is totally discouraged the transfer of Sardas landfill to a safety cell in another location. **

1. 6. *SIt's recommended to carry out some specific studies on the Sardas landfill, in order to identify the areas for which the main inputs and outputs of water occur and quantify flows and water balance using hydrogeological, hydrological methods of balance and the use of tracers"*

1. 7. *SIt is recommended to improve the characterization of the alluvial area which is discharging the contaminated water into the reservoir and to improve the estimation of mass flows of contaminants into the reservoir, isolating hydraulically, if necessary, the contaminated areas of the alluvial of the reservoir by hydraulic screens, counting with the support of numerical simulation of the flow and pollutants transport models.*

2. Regarding the INQUINOSA demolition residues.

2.1. *The rubble of buildings and concrete screeds should be transferred to the Bailín safety cell, if the contamination level advises to act in this way.*

2.2. *Regarding the contaminated grounds of the terrace, it is necessary to complete the characterization and analysis:*
- Which part should be taken to the Bailín safety cell?
- Which part should be treated in situ or at the same lot to dispose it in the site itself?

2.3. *To give preference to the non-invasive (GPR) methods for characterising the residues of the old INQUINOSA factory.*

2.4. *As for the demolition of INQUINOSA, to build a double metal sheet piling with a system of extraction and purification of water between sheet pilings, as a prevention measurements for the extraction of deposits in it lower part of alluvial terrace.*

2. 5. *On the site of the factory of INQUINOSA it is necessary to perform a detailed characterization of hydrogeology and pollution of soils and groundwater. The piezometric data at the location and neighbouring areas must be completed, as well as the data of hydraulic conductivity, and to define the geometry of the wall of the fluvio-glacial terrace and the alluvial terrace in a bigger detail.*
The study should take into account the effect of the existing pond eastward of the facilities on the groundwater flow on the site.

3. Regarding the ISCO technique

When the extraction of dense, free phase is over, it seems suitable to analyze the ISCO technique plus biodegradable surfactants (fluidifiers) in order to act on the remaining dense phase attached to the walls of the rock fractures.

***** *Transferring the Sardas landfill is discouraged for the following reasons:*

1) The transfer could generate issues such as air, runoff water and underground water pollution.

2) It would not solve completely the problem of the pollution, since the underlying field of the landfill has shown evidences of contamination.

3) The technical, social and environmental difficulties to locate an appropriate geological site in the surroundings of Sabiñánigo. Furthermore, it would entail the elimination of the upper polyethylene sealing, therefore an input of rainfall during the time span (months) of operations. This would generate a high risk of pollution mobilization. HCH concentrations found in samples collected by CHE from surface sediments at the Sabiñánigo reservoir are below the detection limits of the measuring equipment.

4. Regarding the contaminated soils situated outside the main landfill:

4.1. *To move the waste from the old pool of the sewage treatment plant to the safety cell of Bailín, depending on the degree of pollution.*

4.2. *About the filling materials deposited at the foot of the landfill during the works of the road N-330: assessment of the appropriateness of in situ remediation using biodecontamination treatment, applied jointly and with adequate measures of confinement.*

4.3. *To study metabolic pathways of microbial consortia associated with HCH degradation.*
For soils and groundwater with residues of HCH, decontamination through the definition of a battery of chemical and biological solutions for successive and/or simultaneous application, as appropriate.

5. Regarding the Bailín site

5.1. *For the management of HCH residues in the soil of the Bailín landfill, it seems suitable to apply first the techniques of immobilization using colloidal nanoparticles of high specific surface area, and then move to eliminating in situ or ex situ by technosols of ad hoc composition or controlled reactors (digesters), depending on the concentration of HCH.*

5.2. *It is recommended to seal the old Bailín landfill to reduce the gas emissions and the infiltration of rainwater into the ground.*
The seal (temporary or permanent) should be compatible with other study and remediation activities.

5.3 To reduce the uncertainties remaining in the knowledge of the hydrogeology of the site of Bailín is recommended:

a. *Continue the drilling of specific boreholes to define the presence of free phase and of pollutants at different depths.*

b. *Apply extreme care when sealing the boreholes, so that they can not communicate the shallow levels with deeper ones.*

c. *To continue conducting specific studies to define the interactions of groundwater with the main ravines and streams.*

d. *To improve the geological and geometrical model of the area, allowing to define adequately the major fractures in the rock, their connectivity and spatial continuity, their hydrogeological significance and their parameters of flow and mass transport.*

5.4. *To reduce underground emissions of pollutants from the layers of sandstone towards the Gállego river is recommended:*

a. *To improve the quantitative estimation of the mass flow of pollutants towards the main ravines and the Gállego river.*

b. *To analyze the possible ways of capturing ground water flows in the sandstone layers upstream from its discharge into Gállego river by pumping and installing hydraulic barriers.*

6. Common to all sites:

6.1. *The solution is to define a train of chemical and physical treatments and biodecontamination measurements, according to the matrix that supports them and the concentration of waste.*

6.2. *The most suitable formula to boost the centre of research on Persistent Organic Pollutants is the one of Technological Centre, being a non-profit entity created in order to contribute to the overall benefit of society, supported by the Public Research Institutions (OPIs) (CSIC and CIEMAT) belonging to the State.*

6.3. *Advance in the understanding of hydrogeology, the quantification of the components of the hydrological cycle through models of water balance and the realization of numerical models of flow and transport of soluble contaminant and DNAPL and their interactions with the solid phases.*
Thanks are given to the members of the Scientific Committee for their disinterested contribution of appraisals for the improvement of the management and the refocusing of the approaches.

4.4 PUBLIC PROCUREMENT OF INNOVATION (PPI)

Decontamination of waste from the manufacture of lindane and its destruction, in conditions of low ecological footprint and social acceptance, requires the development of technologies through R&D&I.

The application of the procedure for Public Purchase of Innovation (PPI) is a priority of the Government of Aragon. This form for public procurement seeks the dedication on the part of the budget of administrations to carry out the investigation oriented to obtain goods and services. In its application, the public buyers encourage collaboration between enterprises, universities, research centres and SMEs with the task to investigate emerging technologies for the realization of prototypes aimed at the market or the development of emerging technologies for the specific case in a competitive environment.

The Government of Aragon is developing an active policy of dissemination of the PPI between the different departments. At the same time, and in view of the scope and possibility of this form of contract of R&D&I and innovative features, the Government has chosen the challenge of the decontamination from residues of HCH for the realization of a pilot contract of PPI in the Autonomous Region. Specifically it resulted in the "Ravine of Bailín remediation".

A consequence of this decision are ongoing the workshops for composing a Map of Early Demand. This dynamic concludes in the informal dissemination of details of the functional challenge, an outline of calendar and an advancement of intent of budget, between companies and researchers in the sector, thus they can be taking positions and form consortia for the moment when the bidding starts.

As relevant elements of the approach of PPI, in addition to the informal diffusion (pre-commercial) prior to contract publication, mentioned above, it is possible to find that public resources are invested to simultaneous investigation for several prototypes of different bidders, who aspire to meet the same functionality in a competitive environment. Also that the along the process of research and development there are generating patent in which the Administration is expected to be involved in some percentage. Thus, when this prototypes passed to commercial product, the contracting Administration has access to more favourable conditions than the rest of the market.

It is the first step in a change of paradigm where they pass from bidding of specific and predefined objects and services (purchase a boiler of 3,000 calories) to tender the specific capabilities (keep a building above 20 °C, in winter, in a determined locality and reducing the consumption of energy in minimum of 18%) where there are multiple solutions.

4.5 R&D&i ORGANISATION AND PARTICIPATION IN CONFERENCES AND FORUMS

Both in Bailín landfill and the Sardas one significant efforts to develop the effective decontamination techniques have been made. These efforts have focused in numerous trials of treatment, both in soil and groundwater as well as leachates in order to find the best available techniques for the treatment of soil and water. These trials can be summarized as follows:

- **Trials of treatability of soils with of zerovalent iron nanoparticles, both in the laboratory and field (Sardas).**

- **Trials in laboratory and on field scale of the thermal desorption (Sardas).**

- **SEAR's trails for tractability with surfactants (Bailín and Sardas).**

- **ISCO tests (Bailín).**

Moreover the Government of Aragon, together with SARGA and several collaborating companies, has been present at numerous congresses, professional and scientific forums, where the achieved progress was presented:

- ***Forum LIFE, CARESOIL.***

- ***Technical group MAGRAMA COP.***

- ***11th International HCH & Pesticides Forum. Gabala,*** Azerbaijan 2011.

- ***14th EuCheMS International Conference on Chemistry and the Environment.*** Barcelona. Junio 2013.

- ***12th International HCH & Pesticides Forum. Kiev,*** Ukraine, 2013.

- ***34th International Symposium on Halogenated Persistent Organic Pollutants.*** (Dioxin Madrid 2014).

- ***13th International HCH & Pesticides Forum.*** Zaragoza 2015, as organizers.

In these forums the Government of Aragon has had an active participation and have made numerous scientific articles on various gains made. Moreover, the Government of Aragon has presented to the scientific community the situation in sites in relationship with lindane. There is an active collaboration with the national scientific community, as well as with international groups specialized in POPs. This collaboration culminated in the organization by the Government of Aragon, along with the IHPA's of 13th International HCH & Pesticides Forum in Zaragoza in October 2015. This forum featured the participation of 150 experts from more than 35 countries.

4.6 EU REPORT ON LINDANE

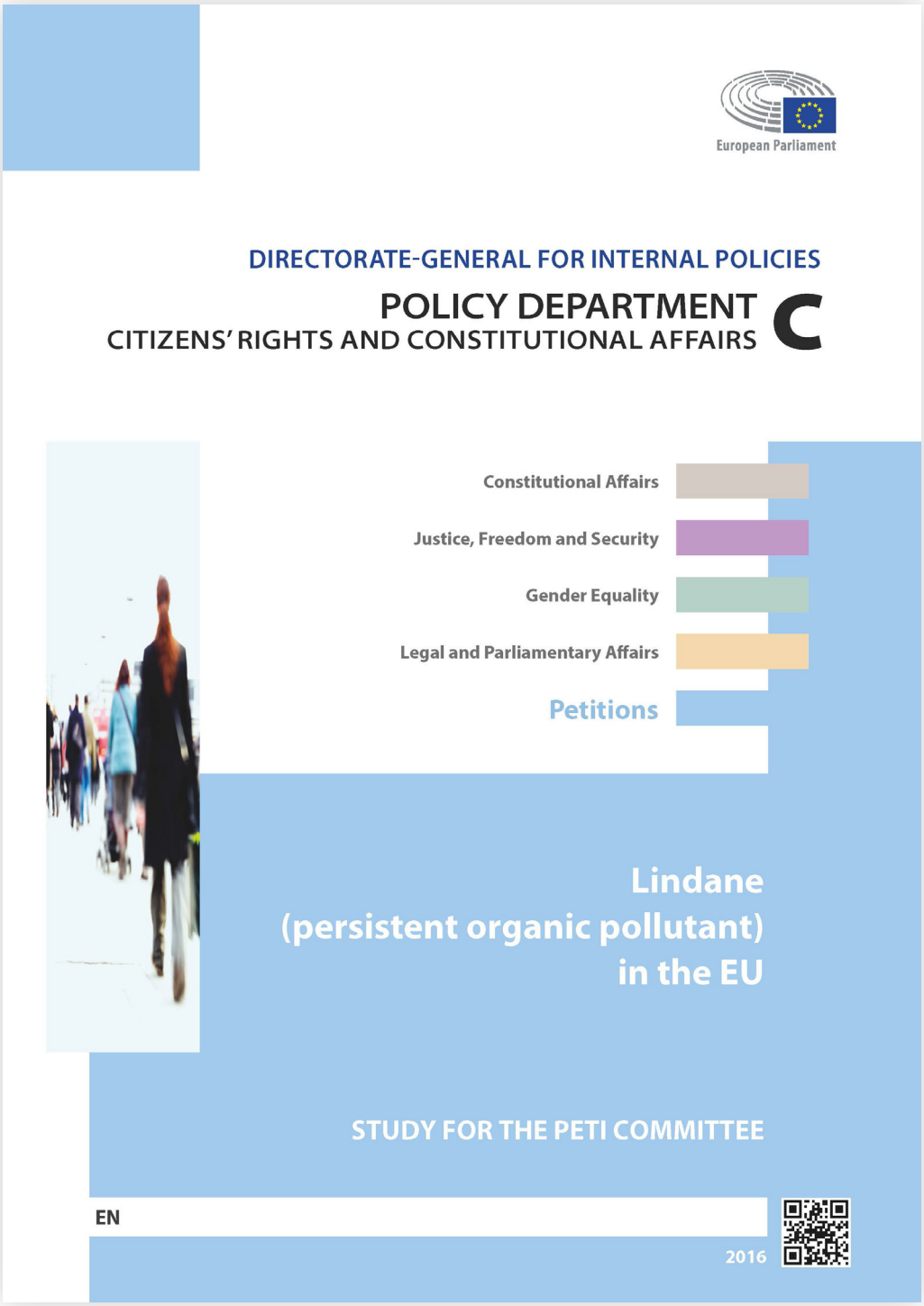
In November 2016, the EU tabled the Study "Lindane (Persistent Organic Pollutant) in the EU, Best practices of de-contamination exchanged", edited by the General Direction for internal policies, Department of Policy, Citizen Rights and Constitutional Affairs".

This document is a review of legislation on lindane residues, the state of the sites with waste from its manufacture in the EU and a introduction to the "state of the art" of their de-contamination.

Note that it has been included in the list of "Best practices" the creation of the three "Monitoring Committees" in Aragon, as a guarantee of coordination and participation in solutions search.

One of the ideas of background of the document, is the need of research applied to find viable solutions for the decontamination. Specifically the attention is drawn to the fact that in the "biological methods:" the biodecontamination of soil and water","... more research is needed, especially in field studies, to better understanding of factors affecting the biodecontamination and to improve their efficiency".

One of the objectives of the Government of Aragon, in this area, is to determine how much concentration of residues of the manufacture of lindane in water and soil can be degraded via catalyzed biological methods.



The cover page of EU Report on lindane

4.7 INVESTMENTS INVOLVED

Since 1992 an remarkable amount of resources has been invested due to the problem of the HCH production waste. This investment has been focused mainly on:

- **Characterization of the problem.**
  Environmental research of the sites.

- **Environmental risks control.**
  The hydrogeological monitoring of sites as well as the surroundings (surface water and groundwater). Realization of various infrastructures of containment, sealing of waste and surface water and leachates control.

- **Decontamination of soil and groundwater,** as well as purification of water and leachates.

- **Waste management.**

Drilling of boreholes in the ravine of Bailín

The following table summarizes the investment made by the Government of Aragon and by the General Administration of the State and the European Union between 1992 and 2015. This amounts is about 54 M€.

Year	Description	Millons of Euros		
		UE	AGE	DGA
1992	First Characterization study			1.10
1993	Completion of study and proposed actions			0.55
1994	Surface Sealing of Sardas landfill		1	1
1995	Surface Sealing of Bailín landfill		1.25	1.25
1996	Environmental monitoring of the sealed			0.1
1997	Environmental monitoring of the sealed			0.1
1998	Monitoring of both landfills and leachates treatment in Bailín			0.1
1999	Monitoring of both landfills and leachates treatment in Bailín			0.1
2000	Monitoring of both landfills and leachates treatment in Bailín			0.2
2001	Monitoring of both landfills and leachates treatment in Bailín			0.2
2002	Monitoring of both landfills and leachates treatment in Bailín			0.2
2003	Monitoring of both landfills and leachates treatment in Bailín			0.2
2004	Monitoring of both landfills and leachates treatment in Bailín . Discovery of the DNPAL in Bailín			0.6
2005	Monitoring of both landfills, treatment and DNAPL extraction net in Bailín			1.4
2006	Monitoring of both landfills, improvement of treatment and DNAPL extraction net in Bailín			2.6
2007	Monitoring of both landfills, improvement of treatment and DNAPL extraction net in Bailín			2
2008	Monitoring of both landfills, improvement of treatment and DNAPL extraction net in Bailín			2.4
2009	Discovery of DNAPL in Sardas, treatment and DNPAL extraction net on Sardas and Bailín, the beginning of the construction of new Bailín landfill	1.98	3.71	2.51
2010	Monitoring, purification and DNAPL network of extraction in Sardas and Bailín, commencement of construction of new landfill in Bailín	1.42	2.67	1.81
2011	Monitoring, purification and DNAPL network of extraction in Sardas and Bailín	0.7	1.31	0.89
2012	Monitoring, purification and DNAPL network of extraction in Sardas and Bailín	0.7	1.31	0.89
2013	Monitoring, purification and DNAPL network of extraction in Sardas and Bailín			3.4
2014	Monitoring, purification and DNAPL network of extraction in Sardas and Bailín Transfer of waste in Bailín			7.7
2015	Monitoring, purification and DNAPL network of extraction in Sardas and Bailín Complementary works for the transfer of waste in Bailín			6.6
	subtotal	4.8	11.25	37.9
	Total 53,95	9%	21%	70%

Strategic Environmental Action Plan against lindane waste contamination in Aragon

5

Strategic objectives and mission:

Comprehensive decontamination

GOBIERNO DE ARAGON

5 STRATEGIC OBJECTIVES AND MISSION: COMPREHENSIVE DECONTAMINATION

Rocky massif of Bailín ravine.
This vertical strata of sandstone and conglomerates has 5 meters of thickness.
Their fractures act as draining elements of the subsoil of the old Bailín landfill.

Because of the magnitude of the problems associated with the presence of residues of HCH production and the ambitious main objective, this objective cannot be achieved in a short period of time.

For this reason, it is necessary to prioritize and set partial objectives which, firstly, will contribute to effective control for identified environmental risks more immediately possible; and in second place, underpin and promote the accomplishment of the mission of the Government of Aragon.

5.1 MISSION

The Department of Rural Development and Sustainability of the Aragon Government assumes:

"The integrated decontamination of the locations affected by the manufacture of lindane, the destruction of waste generated and the transformation of this challenge into an opportunity, through the dissemination of the implemented research, development and innovation (R&D&I) ".

5.2 SHORT-TERM GOALS

The Government of Aragon has invested notable resources and is working since years in the achievement of the following short term goals:

- Ensure the potability of water supply of municipalities downstream Bailín and water quality for irrigation in all circumstances.

- Prevent the arrival of contaminants to the hydrological and hydraulic system and act with urgency and efficiency before possible pollution events.

- Setting up a dynamic Roadmap consensus by the different political, social, economic and environmental agents.

- Boost R&D&I oriented to explore the effective technologies. Promotion of public procurement of innovation (PPI).

- Search for financial resources in the national and EU framework.

5.3 LONG-TERM GOALS

This Strategic Environmental Action Plan against lindane waste contamination in Aragon is concrete and converges into clear and ambitious long-term goals:

- Complete and definitive elimination of the waste.

- Complete remediation of soils and rocky substrates.

- Statement of the current contaminated sites as pollution-free.

> *While these long-term goals are not achieved, the top priority of the Government of Aragon is to keep the environmental risks under control.*

Strategic Environmental Action Plan against lindane waste contamination in Aragon

6

Action Plan and Roadmap

GOBIERNO DE ARAGON

ACTION PLAN AND ROADMAP

Inside the factory of INQUINOSA before waste management

Once described the current situation, explaining in detail the work performed to date and defining the objectives, it is possible to propose a roadmap that will allow develop and achieve those objectives. The completion of the Roadmap intimately depends on the selection of alternatives, both for the minimization of environmental risks and for decontamination of sites, as well as for the environmentally reasonable disposal of waste.

The alternatives of environmental risks control for the decontamination of polluted sites as well as for the disposal of wast (as it was exhibiting in the present Plan) subject to various limitations and conditioning key factors. Among them, there are a large volumes of waste, the multicomponental character of pollution, mixing with soil, persistence, etc.

Taking into consideration the constraints factors, the Government of Aragon, in base of own experience in this field and with the support and cooperation of the Scientific Committee and the different social and institutional agents involved, has defined a series of technical alternatives that support the Roadmap.

It is referred to technically complex actions, and although their detailed development is not the object of this Plan, there is a summary of them.

Constraints of the actions to be developed

- *Large volumes of waste and contaminated soils.*
- *Multicomponent pollution.*
- *Mixture of pollutants with the soil and other hazardous waste.*
- *High persistence and stability of the contaminants.*
- *Direct discharge on the ground of HCH residues.*
- *Direct discharge of HCH liquid waste to the landfills.*
- *Inadequate geological sites.*
- *In the downstream from Sabiñánigo there is a water capture for human consumption (40,000 inhabitants) as well as for irrigation.*
- *Long term processes will bring several decades of performance.*
- *Large budgetary requirements.*

Main actions to develop

- ***Action 0***
  Ensure the supply of drinking water and the quality of the irrigation water.
- ***Action I***
  Isolation of waste.
- ***Action II***
  Pumping of the free phase (DNAPL) and decontamination of soils and the rocky substrate.
- ***Action III***
  Decontamination of surface soils and restoration.
- ***Action IV***
  Disposal of waste.

6.1 ACTION 0

Ensure the supply of drinking water and the quality of the irrigation water.

Keep the waters of the Gállego river and supply points of the various locations downstream of Bailín inside the limits of potabilization is a top priority. Below the Bailín site the water of the Gállego river stay 750 days as potabilizable, a 99.9% of the days with HCH concentration below the limits of detection of analysis devises. These results are a consequence of the 3 billion of Euro annually investing by Government of Aragon into contain of contamination in the area.

The "Gállego river monitoring procedure face of possible lindane pollution" for Civil protection, coordinates the administrations involved and establishes the early alert system, as it has reviewed in previous sections.

A new challenge within this action is in the decontamination of water with residues of HCH through systems that do not generate hazardous waste. The active charcoal filters situated in the populations, do not constitute a hazardous waste when they end their life, This fact is confirmed by analyses which show that the content of lindane there is below the legal limits. However the active carbon in disuse of three sewage treatment plant of the sites, does constitute a hazardous waste. It is planned the implementation of a prototype system of water purification without generating waste, using ultraviolet light in water, duct catalyst of titanium or another technique with the same goal.

6.2 ACTION I Isolation of waste

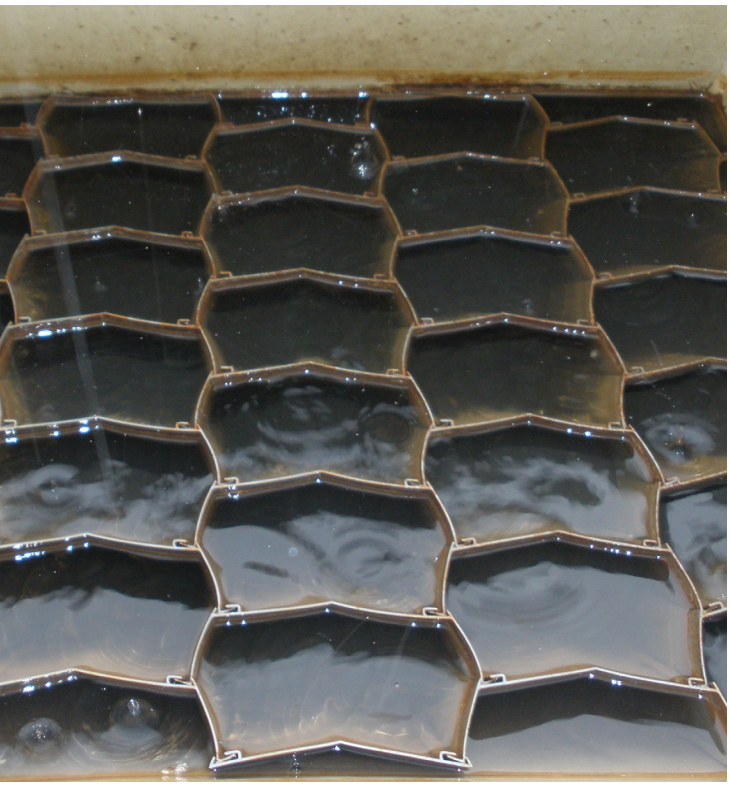
The isolation of waste allows that they do not come into contact with potential dispersal vectors, mainly air, and runoff and groundwater. Therefore the objective of minimizing environmental risks, both for the human being and ecosystems is achieved. It refers to a widely applied option in the sites with similar problems of all over the world, including sites in the Basque country and Galicia. It is also an alternative approved and accepted by international organizations such as the United Nations. The technical guidelines for the environmentally reasonable management of waste containing POPs edited by UNEP the specifically designed landfills is considered as a valid option in case where the destruction or irreversible transformation do not represent the environmentally acceptable option.

The isolation of waste is an action that in part has already undertaken in two phases in the locations of Sardas and Bailín. In a first phase in the 90's both landfills were partially isolated and although this fact largely limited the contact of residues with potential ways of dispersion, these isolates have been shown inefficient. In a second phase, in the year 2014 the old HCH landfill of Bailín was dismantled and moved to a new safety cell in the own Bailín ravine.

They are currently on study the possibilities for isolation of the landfill of Sardas. The alternatives referred to this location are the improvement of insulation present landfill with the construction of perimeter screens and groundwater drainage. Also it is possible that the wast associated with ponds of leachates will be moved to safety cell of Bailín. In all cases there are technically complex solutions, given the volume of waste, its multi-component nature, the proximity of the Gállego river and their interdependence.

On the other hand, it is planned to complete the volume of the new safety cell of Bailín with waste and part of contaminated soils from the dismantling and environmental restoration of INQUINOSA site.

Although it do not constitute an insulation sensu stricto, it should be highlighted in this section the derivations of water from surface runoff that have been developed both in the Sardas and Bailín sites in order that these waters do not come in contact with residues favoring its mobilization. These actions will receive a major boost in the near future with the construction of the bypass of Bailín brook.



Decanter of free phase of the Sardas landfill

6.3 ACTION II Pumping of DNAPL and decontamination of soils and the rocky substrate

Among the residues present at the contaminated sites, the free, dense phase is potentially the most dangerous one, as its mobilization capacity is very high in comparison to the solid waste.

Pumping of DNAPL and contaminated groundwater is being made at the Sardas and Bailín sites since years ago, and this is a first-order priority. This action can be divided into three stages:

Pumping of DNAPL.

Currently DNAPL is being pumped in dozens of wells in Sardas and Bailín sites by pneumatic pumping of total fluids. The free phase is managed externally as waste and leachates and waters are treated in the sewage treatment plant of Sardas and Bailín.

Improved pumping with surfactants (SEAR) or other techniques.

Currently in phase of study. Once exhausted the available DNAPL using the simple pumping, it is necessary to complete the removal of the residual free phase adsorbed on the particles from the underground. The trial treatment in laboratory and in situ have been conducted both Bailín and Sardas sites and is expected to move forward in the development of this technique, even combining it with oxidation.

Decontamination of the subsoil.

Once extracted the DNAPL, to achieve suitable quality standards both in soil and rock, as well as in groundwater, it is necessary to complete the process with final decontamination. With this aim the appropriate techniques of tailored decontamination have been developed on the sites. This is the line of work of the DISCOVERED LIFE project that is carried out on the site of Bailín and based in the on-site chemical decontamination. However is necessary to advance in this field through research, new studies with different techniques such as the combination of ISCO and surfactants or through public procurement of innovation in field of possible techniques of decontamination.

6.4 ACTION III
Decontamination of surface soils and restoration.

This section includes performances by treatment of areas belonging to the three main sites.

At the old HCH landfill of Bailín, it is necessary to decontaminate the topmost levels, as well as the rocky surface – now exposed – of the old HCH landfill, where springs of leachates – with high concentration of contaminant – can be observed.

At the site of the old INQUINOSA factory, the affected surface soil will be decontaminated – provided that soils are not being moved to Bailín – and restoration will be undertaken after the dismantling of the facilities.

The characteristics of three sites are very different, so the solutions, in all likelihood, it will also. The techniques to be applied must be studied and developed in detail, but in any case must proceed along the same line of in situ solutions. Preference will be given to the techniques such as the development of artificial soils or technosols that could contribute, both to the surface decontamination and the stabilization of contaminants as well as for final restoration. The techniques based on the biodecontamination or reactive wetlands are also likely to be studied in detail and applied.

6.5 ACTION IV
Elimination

The technologically available methods of elimination of POP in general and HCH in particular, with exception of those thermal methods, actually are methods of limited application and whose technologies not are very developed.

Technologies of waste liquids disposal are more evolved than of solid waste, in particular for PCB, but for the specific case of the DNAPL present in the sites there are no references dealing with removing aside from incineration. The incineration is already being applied in the free phase extracted in Sardas and Bailín, which is fulfilling in France for years due to the absence of appropriate facilities in Spain.

For the disposal of solid waste, the technologically viable techniques today are technologies based on thermal processes, e.g. incineration, co-incineration in cement plants and thermal desorption. While it is true that it is well known and developed viable techniques, the economic and social factors discouraged them. The application of these technologies would be a huge investment for a thermal treatment plant building and continuous treatment of large volumes of waste for years, with the risks that would be derived from the handling and transportation of waste, opening of the landfill, as well as emissions into the atmosphere including other factors.

Another possibility is the dehalogenation and rupture of the benzene ring in reactors with catalytic action to reduce energy and pressure needs.

For this reason, is clear that the final elimination of residues of lindane production is a complex goal and that its achievement requires a great effort in research and innovation where the public procurement of innovation can also play an important role.

The preferential research lines

Matrix	Characteristics	Possible Features of R&D&I lines
Pure solid HCH waste (when segregated)	**Sardas**: ca. **60,000 m³** **Bailín:** ca. **65,000 t**	**Technology of segregation of HCH waste** on the soil.
		Technology for separation of HCH residues from other another hazardous waste.
		Physico-chemical technologies: Waste packaging and application of fluid reactors and/or supercritical or subcritical water.
		Chemical technologies: Possible developments of catalysis for the destruction by dechlorination, polymerization, and/or generation of reusable byproducts.
	Bailín: ca. **342,000 t**	Development of **technologies of washing and extraction of pollutants.**
	Old factory: approximately **45,000 m³**	Improvement of **technologies of thermal desorption**
		Development of reactors of **physico-chemical digestion with catalysts**
Solid waste HCH mixed with hazardous waste	**Sardas:** ca. **350,000 m³**	Development of **technologies of segregation of contaminants.**
Solid HCH waste (when segregated)	**Sardas:** ca. **60,000 m³**	**Thermal technologies:** Plasma, pyrolysis, vitrification
	Bailín: ca. **65,000 t**	**Physico-chemical technologies:** waste conditioning and application of fluid and/or supercritical or subcritical water reactors
		Chemical technologies: Possible developments of catalysts for destruction by dechlorination, curing, and/or generation of reusable by-products
Contaminated soils and contaminated cracked rocks in Bailín	Zones between the surface and groundwater in the landfill site	**Technosols** development
	Sediments of sandpits and purification	Bacteria growth, fungi and yeasts
	Foot of the Sardas landfill	**Phytodecontamination techniques**
		Techniques of infiltration and washing in vadose areas
		Development of biopiles, tunnels or digesters combining treatment with nanoparticles, microparticles, surfactants and biodecontamination
Aquifers in presence of dense phase (DNAPL)	Presence at the three sites	**Application of surfactants + ISCO**
		Oxidation-reduction
		Bioaumentacion
		Improvement of location and modeling of dense phase systems
		Improvements of extraction of dense phase with surfactants or other complexing agents and fluidifiers
Contaminated water: includes surface water, runoff and pumpings	Presence at the three sites	Improvement of **water purification techniques**, such as photocatalysis, electroxidation, chemical catalysis, etc., which allow treating leachates by minimizing the generation of waste or byproducts, while optimizing energy consumption.

6.6 ROADMAP

The roadmap or long-term action plan, is going to establish the sequence of stages for the achievement of goals posed in this Plan. That is the transversal or common action in three main sites and in the specific actions in each of these sites. It contains stages and actions that are considered inevitable and whose convenience has a broad technical consensus. There are other more open alternatives which currently are pending to confirm its viability or even the development of new technologies.

> *The following is not exhaustively list of actions in the planned Roadmap,*

The following is not exhaustively list of actions in the planned Roadmap, which is open to modifications and improvements based on the future development of the evolution of performances and the technological developments Much of the phases of the roadmap are overlapping in time.

INQUINOSA

• Extension of the environment characterization and improvement of the conceptual model of the site.

• As a step prior to the demolition of INQUINOSA, it must be edited the corresponding draft project and the project for dismantling of industrial ruin.

• After that, the continuation demolition and dismantling of the former factory of INQUINOSA will run and the waste will be transferred to the Bailín safety cell.

• Once demolished the old factory is time to decontaminate, where appropriate, the remnants subsoil and restore the site. It will be studied whether the contaminated soil will move to Bailín partually or will be treated in situ or on its own site.

• If deemed necessary in their time or the signs of contamination are detected, it is possible to carry out a study of soils of the surroundings.

Sardas landfill

• Improvement of the treatment facilities of Bailín. Sewage treatment plant and leachates' ponds

• Improvement of mathematical models of flow.

• Acquisition of land by the Government of Aragon.

• Improvement of the insulation of the landfill.

• Prioritize the treatment of waste at the foot of the landfill by using in situ chemical and biological treatments.

• Remediation of soils and the aquifer.

• Treatment of the soil remaining in the foot of the landfill.

• Implementation of viable techniques for processing of waste or its destruction.

Ravine of Bailín

• Control and monitoring of the situation in the new safety cell.

• In situ chemical oxidation tests (Project DISCOVERED LIFE, currently in progress).

• Decontamination of the surface of the old landfill and restoration of surface using the biodecontamination methods.

• Decontamination of the aquifer and the vadose zone of the old landfill.

• Drafting and execution of the project of derivation of water of Bailín ravine (actually, undertaken by the CHE).

• Opening, filling and final sealing of new safety cell. The pending volume new safety cell, will be completed with materials from dismantling and restoration of the site of INQUINOSA.

• Implementation of viable techniques for destruction of waste.

General or common actions for all sites.

• Improvement of the Bailín laboratory and transfer to the Pirenarium facilities.

• Implementation of a center of research of POP.

• Protocol for monitoring and early alert of the Gállego river.

• Maintenance of the control and hydrogeological monitoring including pumping of DNAPL.

• Treatment of leachates in the Bailín and Sardas sites.

• Wast management (pumped DNAPL, used material, cleaning of chests and ditches, etc.).

• Research of decontamination techniques.

• Research of techniques of waste destruction.

• Applying techniques of monitored natural attenuation in the final stages of decontamination and monitoring of the residual contamination.

Scheme of the roadmap

2016-2020		2020-2025	2025-2040
Action I Isolation of waste	**Action II** Pumping of DNAPL. Decontamination of the subsoil	**Action III** Decontamination of surface soils and restoration	**Action IV** Disposal of waste

INQUINOSA

I
- **Dismantling of plant and transfer to Bailín the corresponding wast and soils**
- **Control of the atmosphere** Tents with nebulizers / aspiration
- **Sheet piling in buried tanks** (Gállego river's protection)

II *(To be determined after improving the characterization and carried out the dismantling)*

III
- **Decontaminate large vol. of water with low contamination** (withdrawal of deposits under groundwater level)
- **Installation of portable and stationary sewage treatment plant**
- **Other**

IV *(There are no volumes of waste significativos that may be outside the cell in Bailín)*

SARDAS

I
- **Avoid water inlets:** Screens and drains in the headwaters
- **Avoid water outputs:** Screens and drains
- **Transfer to Bailín:** (Correspondent waste from outside of seal)

II
- **Pumping of DNAPL**
- **Selection of surfactants**
- **Assessment of use of surfactants and oxidants**
- **Method of location of new surways (radon, other)**
- **Decontamination**

III (After removal of waste at the bottom)
- **Pilot testing treatment of mildly contaminated soils, restoration** (Fe0, bacteria, fungi, improve of substrate, aeration, etc.)
- **Technosols**

IV
- **Identification by ICC of the segregation system of waste** (HCH and hazardous)
- **Treatment:** Physical, chemical, biological

BAILÍN

I
- **Transfer to new safety cell** (executed)
- **Reception of waste of INQUINOSA and Sardas in the new cell**
- **Bypass (CHE)**

II
- **Pumping of DNAPL**
- **Selection of surfactants**
- **Method of large-scale selection of ISCO areas**
- **Method of location of new boreholes** (radon, other)
- **Identification by ICC for the system of decontamination of soil of the old landfill**

III
- **Decontamination of soil of the old landfill**
- **ISCO application to large-scale**
- **Pilot testing treatment of mildly contaminated soils, restoration:** (Fe0, bacteria, fungi, improve of substrate, aeration, etc.)
- **Technosols** (old landfill body)

IV
- **Identification by ICC of the segregation system of waste** (HCH and hazardous)
- **Treatment:** Physical, chemical, biological

GENERAL

- **ACTION 0: Application of early warning protocol. Assessment of water quality in the Gállego river and supplies**
- **Improvement and transfer of Bailín laboratory facilities of the Pirenarium and implantation of a research center of POP**
- **Hydrogeological control of the 3 sites, leachates treatment in Bailín and Sardas and waste management (DNAPL, EPIs, used material, etc.)**
- **Research of techniques for decontamination of soil and groundwater**
- **Research of techniques of waste destruction.**
- **Applying techniques of monitorized natural attenuation of end stages of decontamination**

Economic assessment of the roadmap (millions of €)

Site	Performance	2016-20	2021-25	2025-40	Total
INQUINOSA	Dismantling of the INQUINOSA plant, and restoration	14.65	1.40	1.90	**17.95**
Bailín	Pilot test of chemical oxidation in situ DISCOVERED LIFE	0.37			**0.37**
	Decontamination and control of the aquifer	5.30	6.00	8.00	**19.30**
	Opening and final sealing of new safety cell	3.00			**3.00**
	Decontamination of soil, rock and aquifer of the of the old landfill of HCH	4.00	7.70	6.20	**17.90**
	Hydrological adecuation (*Bypass* CHE)	3.50			**3.50**
	Methods of separation, analysis and simplification of the composition	1.00	2.50	1.50	**5.00**
	Development of catalytic recoverable systems on laboratory level	1.50	4.50	4.00	**10.00**
	Treatment of waste of the catalytic destruction	0.50	2.50	3.00	**6.00**
	Scaling at the level of pilot plant of the global process		5.00	10.00	**15.00**
	Commissioning of a plant for destruction of chlorinated waste (*)			115.00	**115.00**
Sardas	Decontamination and control of the aquifer	4.40	5.00	10.00	**19.40**
	Demolition of old pound of of leachates, improve sewage treatment plant and transfer of waste	4.00			**4.00**
	Reinforced insulation of the landfill and waste treatment on the foot	5.08	15.00	5.00	**25.08**
	Methods of separation, analysis and simplification of the composition	2.00	3.50	2.00	**7.50**
	Development of catalytic recoverable systems on laboratory level	2.50	5.50	4.00	**12.00**
	Treatment of waste of the catalytic destruction	1.50	4.00	4.00	**9.50**
	Scaling at the level of pilot plant of the global process		7.00	13.00	**20.00**
	Commissioning of a plant for destruction of chlorinated waste (*)			120.00	**120.00**
General	Leachates treatment and analytical control. Monitoring of the new landfill and technical assistance	15.00	15.00	45.00	**75.00**
	Managing of the free phase (DNAPL)	1.20	1.00	2.00	**4.20**
	Research of decontamination techniques and natural attenuation	2.50	2.50		**5.00**
	Technical studies of destruction of waste, Protocol of Surveillance of Gállego river, safety and health	1.33	2.33	1.48	**5.14**
	Impulse and coordination of R&D&I including the POP Research Center	5.00	10.00	15.00	**30.00**
		78.33	100.43	371.08	**549.84**

(*) *The start-up investment of a chlorinated waste destruction plant, estimated in a comparative way, with the investment of an incinerator of hazardous waste. There are two facilities built in Spain listed below:*

•Case 1 of incineration plant for hazardous waste with a capacity of 50.000 tons per year and that it was built between 1995 and 1998, the investment was about € 84 M. This number updated to the year 2016, 2 per cent per annum, is 122 M€.

•Case 2, is not comparable but indicative only. The incinerator built between 2006 and 2008, with an investment of 100 M€, that treat about 250.000 t/year. It is designed for non-hazardous waste, i.e. with less demanding environmental conditions, and therefore with a simpler equipment.

Research for the design and construction of prototypes of techniques of destruction or irreversible transformation of waste into harmless materials comprises the following areas.

• Methods of separation of the dry residue of the manufacture of lindane, which contains a great amount of different substances in fractions, which are more manageable from the point of view of the complexity of its composition. This phase includes also the separation of organic waste, chlorinated or not, soils that are mixed in the landfills, taking into account a different situations that occur in the landfills of Sardas and Bailín.

• Chemical methods for the simplification of the composition of the fractions obtained, transforming most of the compounds in a few families of molecules. This will enable a specific treatment by separate of each family of compounds, as well as reduce the total number of different treatments for acting upon each original family of chlorinated compounds.

• Design of effective catalysts for the segregation of chlorine from each of the families of compounds obtained from the stage of previous simplification. Eventually, the design of catalysts capable to brake the ring of six carbon atoms, although this is not the critical goal of the research.

• The design of systems of catalyst recovery, to be able to reuse it in the processes, facilitating the economic viability of the same.

• In previous processes, the special attention will be provided to the byproducts of catalytic decontamination, to be safe or much less dangerous than the initial ones, with less lifespan and/or of low mobility. For example, the potassium chloride, that can be one of these byproducts, is a raw material of the industry. Some organic byproducts can be easily biodegraded. Others may be polymers with zero volatility and solubility in water, so their polluting capacity is much smaller, and that could be added in the formulation of asphalt, for example.

• The case of using of organic solvents both in the initial stages of separation and the subsequent chemical processing, will get a special attention to the optimize these solvents to ensure a very high percentage recovering, as well as having the least possible environmental impact.

It is important to highlight that this research plan is completely modular, so is not necessary to have fully resolved a phase of the process, to be able to start the research of later phases. For example, it can be investigating the design of catalysts for chlorobenzenes treatment, at the same time that the investigation of chlorinated waste separation from the landfill ground or the transformation of a part of this waste on chlorobenzenes. This gives a great organizational versatility, time that he favors using more fast forward and collaboration between different research groups and specialists in different fields.

Strategic Environmental Action Plan against lindane waste contamination in Aragon

7

Reference centre of the fight against persistent organic pollutants

GOBIERNO DE ARAGON

REFERENCE CENTER OF THE FIGHT AGAINST PERSISTENT ORGANIC POLLUTANTS

Laboratory of Bailín

The realization of this initiative can be a pilot action in Europe, creating community added value and utility for other contaminated sites in different places of the world.

The municipality of Sabiñánigo has a population of 9,883 (data of 2014) inhabitants and an area of 586.8 km^2, which includes 73 towns. Sabiñánigo is the administrative capital of the region of the Alto Gállego and it experienced during the second half of the 20th century an important industrial development based on the chemical sector still present but, in the current context, it must be refocused on sustainability criteria.

Sabiñánigo is located at the foot of the Pyrenees and its immediate surroundings are located two important natural spaces such as the National Park of Ordesa and Monte Perdido and the Natural Park of the Sierra and Canyons of Guara. This fact highlights the importance and significance which has the resolution of the problem of HCH pollution and the need that the decontamination actions carried out with the highest environmental guarantee in all its extremes and conditions.

High environmental demands that imposes the surrounding, coupled with the fact that contaminated sites are located in the headwaters of the Gállego river, an important tributary of the Ebro river, limit the application of certain technologies based on heat treatments, such as incineration or thermal desorption, which are currently available. Volumes to be treated, as well as the heterogeneity of contaminants and other economic and social factors make unwise the usage of technologies based on the application of high temperatures and/or pressures as well as high energy consumption and high emissions. All above mentioned invites to seek the solutions based on the research and development of new chemical and biological approach to green technologies. New technologies to be developed both for the

treatment of contaminated water and soils and for the disposal of waste should be preferably of in situ application, so that to avoid or minimize transport and mobilization of the huge volumes of waste to treat. But also, because it is should be that the decontamination will help, itself, to socio-economic development of Sabiñánigo through the conversion of its conventional chemical industrial activity to the new approach of a green chemical industry: clean, sustainable and based on the principles of the circular economy.

To do so it is committed to implementing in Sabiñánigo of a research center with vocation of becoming International reference of the Elimination of persistent organic pollutants (POPs) in situ using the low cost technologies such as biodecontamination. Its mission should be focusing on set-up of such technologies in order to transfer them on a large scale for the elimination of this type of waste in the multitude of polluted sites in the world. To move forward in relation to this objective we work with the following approach:

1 Identification of preferred lines of research and development including its promotion and coordination, taking into account the high degree of interdisciplinarity and medium and long-term approach.

2 Framework agreement with the University of Zaragoza and the Higher Council of Scientific Research.

3 Award of the City Council for the extension of the analysis laboratory in Bailín in new facility of 497 m² in Pirenarium. This city offers a great potential.

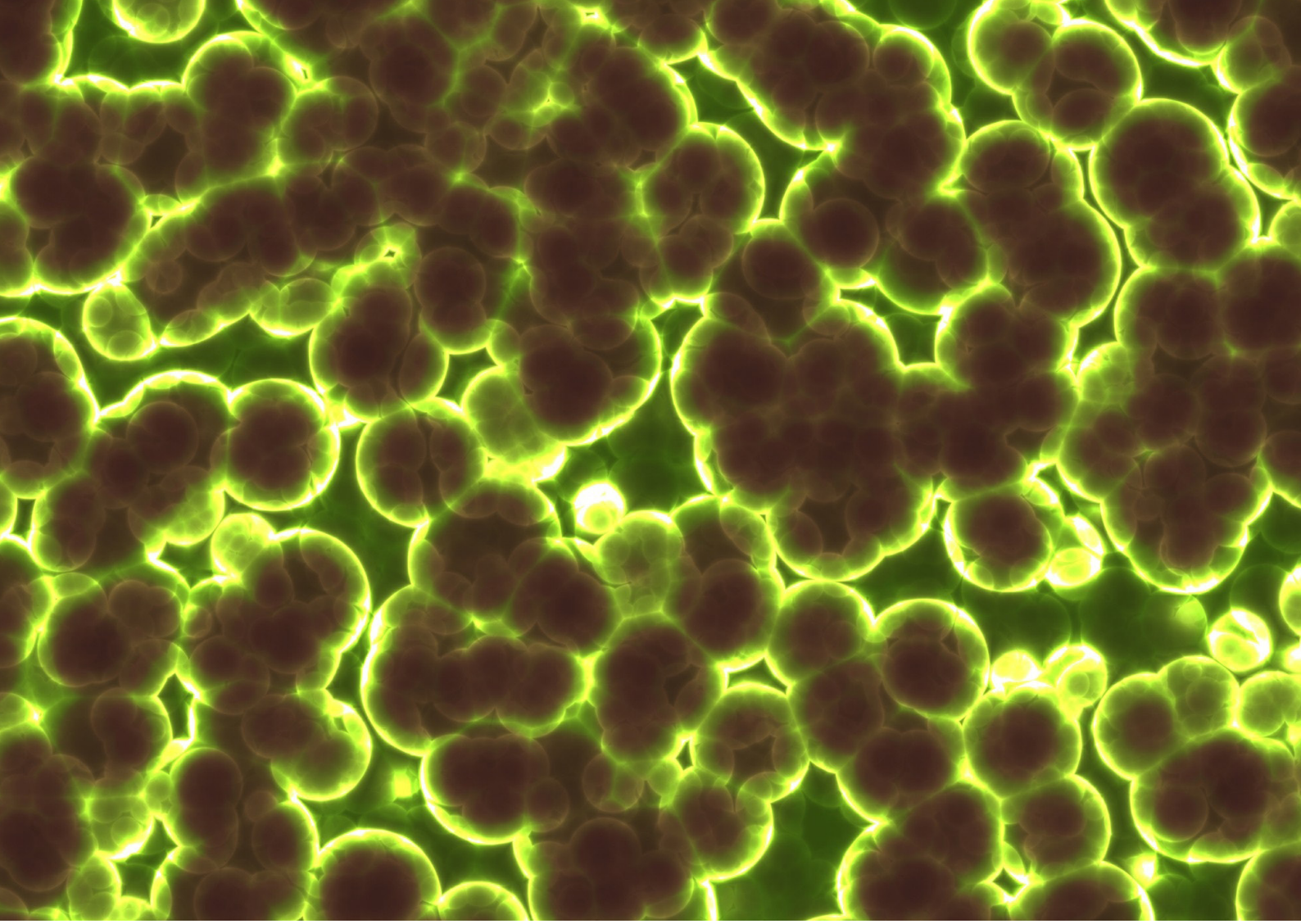
4 The Government of Aragon call for technical assistance, financial support to innovative procurement and innovation that enhances the interest of entrepreneurship, technological centers and research groups for the development of new technologies for the management and disposal of POPs.

5 Uptake of funds from the European institutions and the General Administration of the State that complements the financial resources of the Government of Aragon, which are insufficient in any case to deal with the problem by themselves.

- In 2016, the Government of Aragon has counted with a specific budget of 4.3 millions of €.
- The project DISCOVERED LIFE, currently underway, is focused on the pilot test of chemical oxidation technique in situ ISCO has 1.12 million €.
- On the horizon of 2020 the needs of 70 million of euro are estimated to deal with the containment of the contamination (analytical monitoring and control, purification, hydrogeological monitoring, control of pollution, extraction and treatment of liquid waste), activation, promotion and coordination of the R&D&I process.
- In the 2040 horizon, that is in which place the ultimate solution to the problem, it is estimated to be required a total investment of 550 million Euros.

*The expansion of the **laboratory in Pirenarium** can be the cornerstone of a focal point in the fight against the persistent organic pollutants and "Green Chemistry" development. The granting of the space has already been accepted by Decree 120/2016, 30th August.*

*The **Institute of chemical synthesis and homogeneous Catalysis (ISQCH)** is a joint Research Institute belonging to the Higher Council for Scientific Investigations (CSIC) and the University of Zaragoza (UZ), among other lines, highlights the research activity focused on the study of catalytic reaction mechanism. The catalysis allows to obtain results with reduced requirements of energy and pressure, making most economical and fast tarnishing: chlorine release processes. Thus, even transform HCH residues into other compounds that could enter the circular economy as raw materials. Circular economy is a priority of R&D&I in the European Union. The idea that we are living in a finite world, with limited resources and recyclable is becoming step.*



CATALYZED BIOLOGICAL METHODS

This may be one of the areas of work of the "Reference centre of efforts against the persistent organic pollutants", specifically the optimization of technology of catalyst for the case of the POP and the training of personnel in their handling.

One of the objectives of the Government of Aragon, in this topic, is to determine the limits of concentration of residues of the manufacture of lindane in water and soil which can be degraded via catalyzed biological methods.

The General Direction of Sustainability is working with the aim to start a small scale tests with the University of Santiago de Compostela, on catalyzed biological methods in 2017.

The objectives of the field work are to obtain data for modelling the remediation processes of the subsoil at the INQUINOSA plant, and for establishing a bioreactive barrier which betters the control on the contamination plume in the lower Sardas, along with the trial of catalytic methods. The conclusive results are not expected before 2019.

Catalyzed biological methods

They are grouped into two techniques: biodecontamination and phytodecontamination:

1. *At the same time, the biodecontamination consists of:*

1.1 The biostimulation is the improvement of the environmental conditions to increase the activity of microorganisms (fungi, bacteria and yeasts), as provide specific nutrients, improving C/N ratio, adjust the pH, the bioavailability of the carbon, conditions of oxidation reduction, etc.

1.2 *The bioaumentacion consists of select and improve indigenous microorganisms or incorporate allochthonous microorganisms degrading pollution.*

2. P*hytodecontamination involves the cultivation of higher plants in a contaminated matrix with the aim to facilitate immobilization or degradation of the pollution. What Act are The root exudations of higher plants and associated mycorrhizal fungi are acting here. As for example, the planting of poplars inoculated with mycorrhizae of Pleurotus eryngii (King oyster mushroom).*

The ability of Nature to 'do' is undeniable. Now, the times used may not coincide with the social demand. To speed up the nature required complementary technologies and human resources capacity to manage them.

3. *Some of these complementary techniques of the biological methods are the following:*

3.1 *Application of biocompatible surfactants, to facilitate access to the pollutants the substances secreted by bacteria, fungi and yeasts.*

3.2 *Use of techniques of pumping of leachates, and injection of them after pass by bio-digesters, that enrich it with selected colonies of bacteria, to facilitate the contact in the subsoil between contaminant and substances that it degrade, and also, generate aerobic conditions.*

3.3 *Use of biocarbones for the containment of the contamination in situ and increase the contact surface, making it more vulnerable to the microorganisms.*

3.4 *Generation of a positive "plume" through the use of irrigation systems in summer for the provided technosols with pretreated leachates, to generate cycles and accelerate the biological activity of the microorganisms degrading thewaste.*

Strategic Environmental Action Plan against lindane waste contamination in Aragon

8

Conclusion

GOBIERNO DE ARAGON

Monitoring and evaluation

This strategic plan is intended to make a characterization of the current state of the situation and redefine a path of action with objectives in the short and long term. Goodness of some of these marked work lines depends on the results of the implemented R&D&I , and execution of the budgetary availability in each time. Therefore, it will be necessary to evaluate and periodically redefine this plan, according to the course of events.

Gállego river next to the ravine of Bailín

CONCLUSION

Decontamination of sites affected by the presence of HCH and its associated waste located in Sabiñánigo, in the North of the autonomous community of Aragon, is a process of large-scale R&D&I and offers a significant potential for the development of technologies and transferable institutional solutions for the elimination of persistent organic pollutants, which is a world-famous environmental problem.

During the last 25 years, the Government of Aragon has accumulated an important technical, administrative and political experience in the management of the HCH pollution and associated waste. Having recognized and characterized by 2015 this pollution as the most serious environmental problem of the autonomous community, the Government of Aragon has decided to deal with the ultimate solution, which requires the complete removal of waste as well as remediation of affected soils, aquifers, channels and reservoirs.

Currently there is no economically and socially viable technology for the removal of the volumes of existing waste in landfills of Sardas and Bailín. The search for a viable solution for the disposal of waste as well as for remediation of sites, constitutes an action only affordable in a long term which, with a 25-year horizon, is an important and complex challenge of technological and institutional innovation (R&D&I).

The action of the Government of Aragon relies on an ambitious financial challenge. **An inversion of 550 M€ is needed for the next 25 years.** It is 10 times more than the already invested amount, during the last 25 years. An effort that the Government of Aragon can't afford itself.

The institutional and financial support which Aragon needs is justified by the complexity of the problem as well as the important potential added value associated with the development and transfer of innovations that requires the solution of the problem, including the improvement of the regulatory framework. Therefore, it is offered as a pilot action which serves as reference for other areas of Europe and the world with similar problems.

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ACRONYMS

CA.	Active carbon.
CHE.	Ebro Hydrographic Confederation.
DGA.	General Council of Aragon.
DGSP.	General Directorate of Public Health of the Government of Aragon
DNAPL.	Dense Non-Aqueous Phase Liquid.
GIRA.	Plan of comprehensive waste management in Aragon.
HCH.	Hexachlorocyclohexane.
IAA.	Aragonese Institute of Water.
IHPA.	Intenational HCH & Pesticides Association.
INAGA:	Aragonese Institute of Environmental Management
ISCR.	*In situ* chemical reduction.
ISTD.	*In situ* thermal desorption.
MERC.	Methanol Extraction Rock Chip.
OJEU.	Official Journal of the European Union.
PCB.	Polychlorinated biphenyl or polychlorobiphenyl.
PNUMA.	United Nations Environment Programme.
POP.	Persistent Organic Pollutants.
PPI.	Public procurement of innovation.
R&D&I	Research, development and innovation.
SARGA.	Aragonese society of agro-environmental management.
SEAR:	Surfactant enhanced aquifer remediation.
UE.	European Union.
USEPA:	United States Environmental Protection Agency.
WHO.	World Health Organization.

GLOSSARY OF TERMS

Natural attenuation:
Set of natural processes that eventually may contain or reduce pollution of the subsoil. Natural attenuation monitored as the last phase of a decontamination process is frequently used in the environmental field. The basic processes involved are dilution, diffusion, adsorption, drift, oxidation or degradation among others. Natural attenuation processes can be stimulated by giving rise to natural attenuation improved or stimulated, enhanced natural attenuation.

Active carbon.
Activated charcoal or activated coal is a form of very porous processing coal and with large surface reaction to its volume. Among many other applications it uses as a filter for water or gas, gas masks, extraction of metals, medicine, etc. Along with sand, is the most used filter media.

Stockholm Convention:
The Stockholm Convention on persistent organic pollutants (POPs) is an international agreement that regulates the treatment of toxic substances. It was signed on May 23th, 2001 in Stockholm and came into force on May, 17th 2004. Initially the agreement regulated 12 chemicals products, such as pesticides, PCBs, dioxins and furans. Currently there are 172 countries that have signed the Convention.

Tail of distillation:
Heaviest fractions of a distillation process. They often constitute the distillation residues.

Persistent organic pollutants. POPs.
They are chemical substances that pose a threat to human health and the environment due to: they remain in the environment being resistant to degradation, are bioaccumulative, are toxic to human health and the environment, and have the potential to be transported over long distances, causing them to regions where they have never produced or used.

Thermal desorption:
Process of non-destructive physical separation in warming of the soil at temperatures ranging between 90 and 540 ° C, in order to volatilize or break down organic pollutants and volatile heavy metals (such as mercury), without altering the structure of the soil.

Free dense phase (DNAPL)
Liquid, denser than water and insoluble at the same time in this substance. The free phase therefore tends to drop below the water table when a spill occurs in significant quantities, and stops when it reaches a waterproof bedding only. Its density and penetration in the subsoil make their location and extraction extremely difficult.

Technical HCH:
Intermediate product of the production of lindane that contains different isomers of hexachlorocyclohexane obtained from the reaction between chlorine and benzene. Through the distillation of this substance, the indane separates from the rest of the non-commercial HCH isomers. The relation between lindane and the rest of isomers is 1/10 approximately what is the generation of large amounts of waste.

R&D&I
Research, Development and Innovation. It is a term associated with the field of science and technology and in the context of the advancement of society. This concept surpassed the previous R&D&I by adding innovation.

Isomer:
Chemical compound that, with same molecular formula (not developed chemical formula), i.e. of the same relative proportions of the atoms that make up the molecule, different chemical structures, and therefore different properties. For example, ethyl alcohol or ethanol and dimethyl ether are isomers whose molecular formula is C_2H_6O.

Lindane:
Lindane, chemical name: 1, 2, 3, 4, 5, 6-hexachlorocyclohexane, 4 also known as gammahexaclorociclohexano (γ-HCH), is a alkyl halide with molecular formula C6H6Cl6 has activity of insecticide and is forbidden in all their formulations and applications for being harmful to human health and the environment in accordance with the Stockholm.

Piezometer:
It is an instrument that measures the pressure of a fluid at a point. Generally in the environmental and hydrogeological field, the piezometers are wells or holes in the ground with an installed filter pipe, used to measure the level of groundwater and water sampling.

Contaminant plume:
Volume either of subsoil or a fluid, water or atmosphere, with concentrations of contaminants. It can expand, keep stable or contract. They usually have narrow, long shape in the main source and oriented, in general according to the direction of flow of the medium in which it is developed (groundwater, for example).

Surfactant:
Comes from the word surfactant - "surface active agent". Substances that change the surface tension of a fluid. Detergents, soaps, foaming agents, humectants, among others are surface-active substances. In the environmental field are used to facilitate mobilization or dissolution of pollutants that are attached or adsorbed on the particles of the land.

Vadose zone:
The subsoil area between the surface and the phreatic level of the groundwater.

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