CENTRE OF DOCUMENTATION, RESEARCH AND EXPERIMENTATION ON ACCIDENTAL WATER POLLUTION

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Contamination of water bodies and wetlands due to damaged pipeline (Sainte-Anne-sur-Brivet, Loire-Atlantique)

On 5th April 2016, during levelling work in a hamlet in the municipality of Sainte-Anne-sur-Brivet (Loire-Atlantique), a trencher accidentally pierced a pipeline (Ø 320, 45 bar pressure) which runs from Donges refinery to the storage facility in Vern-sur-Seiche (Ille-et-Vilaine). The 20 by 50 cm breach released an estimated 400 m^3 of diesel fuel containing an additive (7% FAME – Fatty Acid Methyl Ester).

The biodiesel spread through the hamlet, then out into the natural environment. It first flowed through the rainwater drainage systems and roadside ditches, and reached a stream flowing into two successive ponds, surrounded by wooded wetlands. It then spread downstream towards the river Brivet, whose drainage basin is composed of a vast area of wetland of great ecological interest (as it is located within the Brière Regional Nature Park).

The pipeline's intermediate pumps and valves were shut off by the operator (Total Raffinage France) to isolate the leaking section and the pipeline's contingency plan was activated.

After being informed of the incident, the authorities of the Pays de la Loire and Loire-Atlantique areas mobilised the relevant services (fire brigade, police, environment directorate, regional health board, etc.). An on-site command post led by the Loire-Atlantique fire brigade was set up in Pont-Château, alongside that established by the operator, who agreed to conduct the necessary clean-up operations and to cover the costs. Instigated by the authorities, regular reviews were organised between response operators and representatives of the local authorities.

As a priority, the emergency measures initially implemented aimed to ensure human safety. In this respect, as an explosion/fire risk had been identified, the fire brigade deployed extensive resources (35 response vehicles and 70 fire-fighters) and set up a safety zone pending confirmation that no petrol was present in the fuel released from the pipeline. The 11 homes in the hamlet were evacuated, mostly for three days, and the hamlet was closed to the public, road traffic was prohibited and mains and well water consumption was also banned. Air and water quality measurements – for mains water and private wells – were rapidly implemented.

The pipeline operator immediately mobilised its own resources and technical experts to initiate spill response operations to supplement the emergency response actions implemented by the fire brigade. The coordination of clean-up operations in the various areas affected was soon handed over to Total Raffinage France, which contracted specialised companies to conduct the operations. The operations had two main aims: to protect sensitive sites downstream (Brière Regional Nature Park) and to remove oil from the watercourses and water bodies where it had accumulated, in order to reduce the time for which it was in contact with the environment.

The protective measures for the aquatic environment focused on limiting the spread of the pollution downstream:

- at the leak source, a bund was built and a vacuum truck was used to pump up the oil so as to prevent it from entering the drainage system, while bulk sorbents and sand were spread on the road.
- 900 m from the leak point, where the majority of the biodiesel had been naturally trapped in the two man-made ponds, which featured walls and water level regulation systems, containment was reinforced by (i) increasing the overflow height of the downstream pond and (ii) laying a containment boom and sorbent booms around the outflow.
- 1.5 km from the leak point, at the confluence with the Brivet, a major preventive system was set up. This two-fold system included a shore-sealing boom, completed with bales of straw and sorbent booms laid both on the water body and inside a wire structure. The wire structure was backed up against a small road bridge, where its role was to filter residual oil while not disrupting the flow. Pumping and storage equipment was pre-positioned here and the site was supervised 24/7 by the fire brigade and refinery fire-fighters.

Filter system (straw and sorbents in a wire structure) 1.5 km downstream of the leak (Source: Cedre)

In addition to, then to take over from, the fire brigade and Donges refinery fire-fighters, the Fast Oil

Spill Team (FOST, Total Group's response team) and two specialised companies, Triadis-services/Séché and Le Floch Dépollution, contracted by the operator, conducted clean-up operations for almost a month in the case of the first two and three months in the case of Le Floch Dépollution.

Several agents from Cedre were mobilised from day one by the Loire-Atlantique authorities and were present on site on a rota system throughout operations to assist the fire brigade, State services and local authorities. Cedre provided its expertise in terms of surveys, technical recommendations, clean-up site monitoring and environmental sensitivity considerations. It also helped to assess the type and fate of the pollutant (behaviour, biodegradability/persistence in the environment) by taking and analysing samples of water and sediment. The PAH concentrations in the ponds and streams were monitored using the Stir Bar Sorptive Extraction (SBSE) technique (50 water samples taken and processed the same day in a field laboratory before being analysed by Cedre).

In addition to the ponds, the gardens and houses close to the leak point were the most contaminated areas. In the hamlet, the fuel infiltrated deep into the ground through technical networks and ducts and accumulated in septic tanks. Major restoration operations were performed (pumping of accumulated fuel, evacuation/replacement of contaminated soil in gardens, rehabilitation of contaminated house walls, road repairs). Two houses remained unoccupied for several months.

In the ponds, natural containment of the pollutant was reinforced in order to protect the hydrographic network downstream:

- in the first pond, a bund made of sand bags and pipes was built at its weir to contain the floating diesel while letting the clean water travel downstream via an underflow.
- in the second pond, 4 high speed centrifugal pumps were positioned on the wall along the downstream bank to prevent overflow in the event of heavy rain which would cause the pollutant to spread downstream. A 24/7 duty team was mobilised to supervise the water level, in order also to prevent the emergence of submerged banks which would be liable to be oiled.

From the onset, the layout of the private estate on which the contaminated ponds and wetlands were located created serious difficulties in terms of access and for setting up recovery and fuel evacuation sites, given:

- the thick layers of fuel (several centimetres thick on the water in certain areas)
- the fragile environment (undergrowth, vegetated banks, low load-bearing capacity in places)
- the lack of track suitable for vehicles around the ponds and the availability of only a single access point to the estate for trucks
- the narrow primary waste and equipment storage area, set up on the edge of the estate's residential home, behind (but close to) the clean-up sites.

*Photos: Major accumulations of biodiesel trapped on the edges of the wooded banks, with difficult access (**left**); Floating hose to transfer the fuel collected from the downstream shore to the upstream shore of the second pond (**right**) (Source: Cedre)*

In the second pond in particular, the main skimming and pumping site was set up at the downstream end where the floating fuel had gathered: 2 Fastanks with a 5 m^3 capacity were deployed but could not be reached by trucks, as they were located 350 m from the primary storage area. To prevent the environmental impact that opening up an access point would have caused, a floating line was made on site, composed of a hose fixed to floats (polystyrene boards) which was drawn across the pond. This system was used to transfer the fuel from the 2 tanks on the downstream shore to 2 other tanks on the upstream shore, from which the fuel was then discharged into primary storage skips at the rear of the clean-up sites. This system incidentally provided 2 additional settling stages prior to evacuation of the liquid waste from the site by tanker trucks.

First pond: containment using floating booms and sorbent booms; recovery using mechanical weir skimmers. Note the ground protection with geotextile. (Source: Cedre)

On the water, the free diesel was contained by laying light floating booms, sorbent booms and skirted sorbent booms.

Pumping operations were implemented in the areas where the floating fuel had accumulated, due to the wind and water flow, partly promoted by various techniques (trawling using small boats, pushing with hoses and blowers in shallow areas).

Skimming was performed using small mechanical weir skimmers[1] (Mini Foilex, Desmi Minimax) together with diaphragm pumps, as well as oleophilic grooved drum skimmers (Elastec TDS 118) or disc skimmers (Vikoma Komara 20), which are selective and less sensitive to plant debris.

From the first week of weathering in the natural environment, the biodiesel took on a major transformation with phase separation, emulsification and formation of an extremely adhesive residue which formed amalgams. For a few days, these amalgams prevented both mechanical skimmers (clogging of weirs) and oleophilic skimmers from functioning correctly.

*Area of natural accumulation of free pollutant (northern wall of second pond): deployment of oleophilic drum and disc skimmers (**left**); manually unclogging a Mini Foilex weir skimmer (**centre**) clogged with weathered biodiesel, amalgamated with plant debris (**right**); (Source: Cedre)*

Generally, during clean-up operations, the transport and movement of equipment and responders were defined and channelled (walkways, wharfs, marked out access points). At the equipment storage areas, clean-up sites and pathways, the ground was protected to prevent (i) excessive trampling/puncturing and (ii) secondary contamination due to run-off/dripping (boards, polythene, geotextiles, three-dimensional polyamide matting).

On the banks and wetlands surrounding the ponds, the choice of clean-up techniques was based on the need to avoid damaging vegetation and burying the pollutant. Flooding and flushing operations were implemented for two months, to dislodge the fuel trapped in cracks in the banks, in the forest litter and in the vegetation (wooded areas, wetlands, horsetail marshes).

Low pressure flushing of fuel trapped in vegetation (horsetail) (Source: Cedre)

The contractor *Le Floch Dépollution* deployed various specially made low pressure systems designed to suit the conditions in each area: flooding using a "manifold" with a low pressure flow rate of 100 m^3/h; perforated pipes laid on the ground; flat jets or sprinkler jets with varied ranges.

Flushing was conducted either from the water body, from small boats working in waters a few dozen centimetres deep, or from the banks. The remobilised fuel was driven towards recovery points (pumping or sorbents) at the water surface using hoses (flat jet) or blowers.

In a few oiled areas, surfaces (pond walls, grazing meadows) were manually scraped and oiled, dead vegetation was cut back in places.

[1] These skimmers are sensitive to floating debris, which tends to be present in large quantities in such environments (branches, leaves, etc.). A strainer must therefore be fitted to the weir lip.

Alongside these operations on the water bodies, upstream ditches and streams were also cleaned up. The diesel, which had flowed several hundred metres along natural roadside ditches, accumulated in dips and was trapped in plant debris.

The hamlet's ditches were purged using vacuum trucks then scraped out. Outside of the hamlet, small accumulations of fuel were pumped off. Sorbent booms and pads were laid along the entire length of ditches and filter barriers made of wire mesh and loose sorbent strands or bales of straw were built to collect the fuel remobilised by rainfall. As the rainfall proved insufficient, rinsing operations were ultimately conducted (water supply provided by tanker trucks).

Series of custom-made devices (sorbent strands and wire mesh) to capture the residual pollution along a roadside ditch which the fuel had entered (ditch purged and scraped prior to installation of the devices) (Source: Cedre)

We also note that, for several kilometres downstream to Brivet, similar filtration/sorbent devices were fixed in place in the watercourse, some of which were left in place once clean-up operations had finished as "sentry points" to check that no residual contamination remained downstream of the clean-up sites.

In terms of impacts, mortality was observed very early on, during the acute contamination phase, affecting various taxa of fauna (oligochaetes, nematodes, etc.) in the streams and, in the ponds, several fish species (1 pike, around 30 eels and some 50 kg of small white fish), as well as a few amphibians (including one protected species - the palmate newt *Lissotriton helveticus*), wetland birds (including 2 protected species: the common kingfisher *Alcedo atthis* and the little grebe *Tachybaptus ruficollis*) and rodents.

In terms of vegetation, the aerial parts of species which had already grown were burnt by contact with the floating fuel, but new shoots were observed a few weeks later and mortality was low. Several aquatic species developed in the ponds from which the accumulations of fuel were removed during their growth period. Monitoring of ground and surface waters showed water contamination by the dissolved fraction of diesel which decreased with each new series of samples.

Following the clean-up operations, the environmental monitoring ordered by the authorities (29th August 2016) for a renewable one-year period took over from the contamination measurements launched immediately after the spill to monitor the air (volatile organic compounds - VOCs), ground and surface water, as well as sediment (BTEX, polycyclic aromatic hydrocarbons - PAHs and total hydrocarbon content). In addition, monitoring of the aquatic environment, and the flora and fauna of the riparian environment was launched. The monitoring of the aquatic environment comprised: hydro-biological surveys (physical and chemical characteristics of surface waters, studies of diatom populations via the Biological Diatom Index - BDI) and macro-invertebrates (Standardized Global Biological Index); an inventory of fish populations and PAH concentrations in fish flesh. The monitoring of riparian environments covered the vegetation and flora, odonates (in particular dragonflies), birds and semi-aquatic mammals.

A post-clean-up residual health risk assessment was conducted in the affected homes and gardens.

Diffuse pollution due to flooding in north-east France

In early June 2016, successive episodes of heavy rainfall led to swollen rivers and flooding affecting the French Centre, Ile-de-France, Picardy and Burgundy regions in particular. The rainfall caused oil, among other products, to overflow from many different facilities: storage facilities for new or used oil, fuel tanks and other reservoirs, etc., in factories, warehouses, garages, residences, etc. The pollutants spread across vast flooded expanses, including the riverbeds of many watercourses in spate, across very varied areas in terms of their amenities – natural and urban, public and private areas – contaminating many buildings and infrastructures (houses, blocks of flats, etc.), including underground facilities (carparks, cellars...) on their way. The local authorities and fire brigades – already heavily mobilised in responding to this exceptional flooding and managing the damage and risks generated, with human rescue being the number one priority, – had to face this "diffuse" pollution issue.

Cedre was called out and sent agents on site as of 5th and 6th June: in Seine-et-Marne at the request of the fire brigade; in Essonne at the request of the authorities (*Préfecture*); in Yonne at the request of the city hall of Charny Orée de Puisaye. These missions lasted from a few days to a few weeks.

In addition to attending meetings, the agents from Cedre handled many requests for support in the field.

- **Situation assessment: varied sites and types of pollution**

The first requests were for assistance in assessing the situation: in Yonne, one main source of pollution was identified and flooded cellars with an overflowing heating fuel tank were also reported; elsewhere many scattered sources were identified and were often difficult to locate. Certain sites or homes were closed off or shut down, others were difficult to access due to the flooding.

The pollution had spread very widely, carried by the flood waters as the water levels rose then fell. Helicopter overflights were conducted to monitor its spread along the watercourse, observe the containment systems (floating booms) deployed and recommend alterations to optimise the set-up.

Very soon, these investigations were further supported by surveys conducted on land, or even by boat when the streets were flooded. New recommendations on containment techniques and equipment were issued to support emergency response operations, in particular with advice on setting up custom-made barriers and filter systems, as classic booms were unsuitable for certain sites.

Many individual homes were affected by the oil, meaning that "door-to-door" visits had to be organised to obtain an accurate estimation of the extent of the pollution and to define ad hoc technical recommendations. These surveys, conducted jointly with the city halls and local authority staff, fire brigade personnel and other services, proved to be particularly time-consuming, given that these were private properties where the pollution, due to the circumstances, was only one consequence among many other just as significant impacts caused by the flooding. This task took several weeks and mobilised up to 4 Cedre agents at a time. In total, over 70 sites were surveyed in Seine-et-Marne, and over 20 in Essonne and Charny (Yonne).

In Seine-et-Marne, Cedre drew up a daily note for the fire brigade, civil protection and defence service and State services, reporting the surveys and observations made and suggesting priority actions for the following day.

The pollutants observed were mainly light fuels, in particular diesel or home heating oil, and oils such as engine oil, possibly used, while many other products present in cellars, sheds or workshops had also been released, although the exact type or quantity could not always be specified. Seveso-classified sites were protected and did not appear to have suffered any leaks or significant damage.

Another urgently needed action was to pump up the large volumes of contaminated water at flooded sites (cellars, underground carparks). Cedre assisted the Seine-et-Marne fire brigade in designing and building custom-made filtration systems (bins with a perforated base filled with loose sorbent), in order to evacuate the water from these sites and release it into the natural environment. Technical datasheets were also produced by Cedre and distributed.

Health concerns rapidly emerged. A memo jointly produced by the Ile-de-France regional health agency (ARS), the Seine-et-Marne authorities, the Seine-et-Marne fire brigade and Cedre was released on 8th June for the general public and provided instructions on what to do in the case of response actions in flooded and contaminated properties and cellars.

Cedre also helped to define a sampling plan, managed by the Seine-et-Marne unit of the Regional and Interdepartmental Directorate for the Environment and Energy (DRIEE), so as to characterise the main types of pollution observed:

- Very heavily polluted areas of ground (with pollutant liable to be remobilised)
- Oiled embankments
- Areas of ground with visible traces of oil
- Areas of ground with no visible traces of oil but located on premises where oil was reported during flooding
- Recently emerged areas of ground with traces of oil on the water still adjacent to this area
- Areas of ground which were flooded but believed not to be contaminated ("white 1")
- Areas of ground not subject to flooding ("white 2").

- **Oil pollution: actions and recommendations**

When possible according to the site configuration, and more specifically when sufficiently thick layers of floating oil were contained, this oil was recovered by pumping, sometimes used in combination with skimmer heads. However, in more open areas, the high degree of spreading of the product at the water surface meant that sorbents were the only viable option. Sorbent booms were also laid as "sentry" devices, or near to points of pollution resurgence, or indeed in a protective capacity for certain sites. Very quickly, the quantity of sorbents required, and their installation, surveillance, renewal and treatment once oiled became an issue in itself. This came in addition to the problem of storing and processing the large quantities of litter and debris, whether oiled or not, generated by the flooding. Improvised storage areas were set up locally, sometimes in very restrictive conditions given the complex circumstances, in certain cases for instance without ground protection, creating a risk of secondary contamination.

In terms of the pollution deposited when the water level dropped, Cedre was questioned on the clean-up techniques to be implemented in homes and gardens, the equipment to be used and the available contractors. These recommendations were used to conduct clean-up, but also as supporting documents for insurance claims. Some of the questions asked did not fall within Cedre's field of expertise, in which case the enquirers were referred to the French geological survey BRGM (for probing and sampling polluted soil) and the regional health agency ARS (for questions relating to health).

The main concerns were in connection with:

- the techniques and equipment for cleaning walls and other hard surfaces, according to the material and coating (paint, render, etc.)
- the clean-up of oiled objects, furniture, ornamental or fruit trees
- whether or not fruit and vegetables grown in the gardens (in 2016 and the following years) would be fit for consumption, whether children should be allowed to play in the gardens, whether barbecues could be lit, etc.
- the health risks posed by oiled basements
- oiled waste management.

Within the limits of its field of expertise in relation to these concerns, Cedre drafted an observation record and recommendations for each site visit. Furthermore, Cedre produced a general framework memo, originally intended for mayors in Essonne but which was rapidly generalised to apply to the other areas affected.

This memo included:

- advice and key terms for use by the authorities, explaining the background to the pollution, the behaviour of the products involved and their impacts on soil and vegetation
- recommendations for treating oiled gardens and plant debris, according to the type of site (lawn, trees, vegetable garden, etc.) and the extent of the pollution
- recommendations for treating contaminated cellars.

The techniques recommended for gardens are similar to those used during the "botanical clean-up operations" implemented in oiled natural vegetated areas: scything, selective cutting, scraping, or even removal of a few centimetres of soil. In terms of the clean-up of hard surfaces, the emphasis was on the urgent need to contain, recover and treat washing effluents.

Cedre completed its field mission at the end of June, but continued to provide support from Brest to the BRGM and the authorities, in particular by fine-tuning the initial recommendations made and mapping the visits made. Among the lessons and questions Cedre drew from this response, we note the benefit of the surveys conducted jointly with the fire brigade or representatives of the local authorities. In the case of this incident, this made it easier for Cedre responders to access the various oiled sites, a crucial factor in obtaining a full understanding of the issues at stake and in providing suitable technical guidance.

• Main oil spills worldwide

Submersion and drift of a slurry oil spill in a river (barge *MM46*, Mississippi, US)

On 21st January 2016, on the Mississippi, the oil barge *MM-46* (operated by Magnolia Marine Transport), was part of a convoy of 6 barges attached to the pusher tug *Amy Francis*, when it collided with the Natchez-Vidalia Bridge, near Natchez (Mississippi state, US). Two of the barge's tanks cracked, releasing their cargo of slurry oil – a heavy oil residue –, of which the barge was carrying approximately 3,800 m^3.

The response to this incident and the resulting pollution was managed by a Unified Command (UC) coordinated by the U.S. Coast Guard (USCG) and involved representatives of the Mississippi Department of Environmental Quality (DEQ), the Louisiana DEQ, and the responsible party (Magnolia Marine) and their contractors. Priority was given to preparations to remove the oil from the barge, whose cargo remaining in the tanks was transferred to 2 other barges 2 days after the incident.

At this stage, the first surveys estimated that some 290 m^3 (76,000 gallons) remained unaccounted for, however later estimates knocked this quantity down to around 95 m^3 (24,600 gallons). The Unified Command called on the expertise and numerical models of the National Oceanic and Atmospheric Administration (NOAA) to shed light on the fate and potential impact of the pollutant on the resources at risk. With a relative density higher than that of water (and especially higher than freshwater) the product sank without forming any visible floating slicks. Side scan and multibeam sonars were mobilised to attempt to locate the submerged or sunken pollution but in vain: no significant accumulations were detected around the barge (see below § **Feedback from past spills**).

23/01/2016: Lightering operations on the tanker barge MM-46 (pumping and transfer to a barge brought alongside) (source: USCG)

According to the NOAA, this unexpected result can be explained by the high flow rate and turbulent waters in the river at this time of year, causing the heavy slurry oil to sink, be buried and break up into elements of varying dimensions, some of which are believed to have been carried and disseminated downstream.

Pipeline spills

A series of spills in the Amazonian basin from a pipeline (Norperuano pipeline, Peru)

On 25th January 2016, following a landslide near Villa Hermosa in the Amazonian Province of Bagua (Amazonas Region) in Peru, the Norperuano pipeline operated by the State-owned company Petroperú released (at km 441)[2] an estimated 320 m^3 of crude oil (operator estimation), affecting the Inayo and Chiriaco Rivers, both tributaries to the Marañón River. Little information is provided in our sources on the response, however we know that there was a certain delay (3 days according to various press sources) before action was taken and that certain difficulties were met, notably difficulty accessing the banks as well as heavy rainfall which, by increasing the flow rate and causing the affected watercourses to burst their banks, jeopardised the efficiency of containment systems (floating booms). The leak was plugged on 28th January, 3 days after the incident.

On 4th February, another section of this pipeline, this time at km 206 in the Province of Dátem del Marañón, suffered a leak of 200 to 500 m^3 (according to press sources) of crude oil once again affecting the Marañon basin. This leak was suspected to have been caused by sabotage. This incident prompted a 90-day state of emergency for public health, affecting districts across two regions (Amazonas and Loreto). Details of environmental impact monitoring are not, to the best of our knowledge, readily available either. What can be said is that an organisation representing several indigenous communities in the Upper Marañón indicated that wildlife had been greatly affected by this spill, leaving many fish dead in the rivers, and that the Peruvian Ministry of Environment and Ministry of Health decided to have water and soil quality tests carried out at different points along the tributaries to the Morona and Marañón Rivers (Regions of Amazonas and Loreto).

View of the leaking section of the Norperuano Pipeline (Source: OEFA)

Manual clean-up operations (Source: OEFA)

Although it did not result in the reopening of the pipeline, the breach was repaired a week after the incident, while manual clean-up operations involving paid volunteers were implemented. At this point in time, 90% of the oil had been recovered according to the authorities (although no further detail was given).

A third rupture occurred in June 2016, further up the pipeline but still in the Province of Datem del

[2] This 40-year old pipeline transports oil extracted from wells in the Amazonian basin across a distance of around 1,100 km, through the Peruvian forests then the Andes, as far as the Bayovar terminal on the Pacific coast.

Marañó (Loreto Region), resulting in the release of around 90 m^3 during pump tests, during which the section of pipeline was not transporting oil according to the operator. The volume of oil which contaminated the watercourses due to this release is not specified in our information source, although Petroperú (whose president was dismissed following this incident) claimed that the spill did not reach any of the watercourses.

In total, the Environmental Evaluation and Oversight Office of Peru (OEFA) estimated that over 1000 m^3 of oil had been spilt in the 7 incidents which occurred on this pipeline in 2016 (for a variety of reasons: lack of maintenance, vandalism, dilapidation, etc.). In October 2016, the company managers announced that the pipeline should resume operation "4 to 5 months after the end of repair work", i.e. after being shut down for over a year (from February 2016). This timeframe was necessary to replace the faulty parts, as ordered by OEFA. Petroperú was fined over €3 million by OEFA for "repeated and systematic failure" to meet its environmental obligations.

Heavy crude oil leak and river pollution (Husky Energy 16 TAN Pipeline, Canada)

On 21st July 2016, 220 km from Maidstone (Canadian province of Saskatchewan), a leak from the 16-inch (40 cm diameter) TAN pipeline operated by Husky Energy, triggered by a landslide, led to a 200 to 250 m^3 spill of sulphur-containing heavy crude oil (HLU Blended LLB Heavy Crude Oil)[3] of which approximately 40 % (somewhere in the region of 100 m^3) reached the North Saskatchewan River.

Response operations were implemented by the operator and contractors, under the supervision of the relevant province and federal agencies, within a command centre which included Husky Energy, the Saskatchewan Ministry of Environment (MoE) and Environment and Climate Change Canada (ECCC, which provided support in terms of scientific expertise). This structure was deactivated in mid-September 2016 and the operator took charge of the continued response through its own crisis unit, which was in turn demobilised in October.

Following the actions taken to control the leak and ensure safety around the pipeline (closing valves, isolating the leaking section, depressurisation), the response focused mainly on assessing the health risks generated by the spill, in particular given that several municipalities were supplied with drinking water from plants whose intakes were located further downstream on the river.

Monitoring of the contamination of the aquatic environment was therefore immediately initiated, first by the Saskatchewan Water Security Agency (WSA) and very soon after by a company contracted by the operator (although WSA also continued to monitor several sites to compare the results with those of the responsible party)[4]. These monitoring programmes aimed to rapidly assess the need for and duration of (i) restrictions on the uses (recreational, agricultural, etc.) of the water of the river for local inhabitants and (ii) closure of water intakes at treatment plants located downstream. These restrictions mainly affected 3 municipalities, where the bans on water usage were lifted between August (for Prince Albert and Melfort) and early September (North Battleford). On 16th September, WSA indicated that, given the levels of contamination, the water treatment plants could safely resume operation. In the meantime, various measures were taken to provide drinking water to over 60,000 inhabitants (temporary overground pipes from other municipalities/catchment areas; supply of bottled water; recommendations on reducing consumption to a bare minimum, etc.).

In terms of spill response operations in the river, the initial actions aimed at restricting the spread of the spill downstream, by laying containment booms. However, their hold and effectiveness were impaired due to the strong currents (which also hampered navigation); thereafter, response actions mainly focused on the banks, starting with pollution surveys conducted by several teams of experts trained in the standard SCAT (Shoreline Cleanup Assessment Technique) procedure, prior to clean-up operations. Two canine detection teams[5] (K9SCAT) were also involved in these surveys, which was a first in a post-spill context. The use of detection dogs, thus far only tested on old spills, was proven successful (shorter detection times and increased reliability for localised deposits of oil).

Ten days after the accident, the Government of Saskatchewan estimated that 38 km of banks had

[3] This oil is a blend of a conventional crude and a condensate, inaccurately referred to in various sources of information as a dilbit (diluted bitumen), until a press release from Husky Energy specified its exact nature a week after the incident.
[4] By the end of 2016, these monitoring programmes totalled over 5,000 water samples and over 1,000 sediment samples.
[5] A service jointly proposed by the US companies Owens Coastal Consultants and K2 Solutions, Inc. (See http://www.k9scat.com/); On this topic, see also LTEI n°24.

been oiled, however sheen was reported on the water up to 450 km downstream of the leak. In late 2016, the Government of Saskatchewan indicated that 800 km of banks had been investigated using the SCAT procedure.

Initially, the clean-up operations involved (i) collecting pockets of free oil (by skimming/pumping or using sorbents) which had accumulated locally along the river banks and recovering the largest deposits which could potentially be remobilised from the banks (including removing oiled vegetation), before (ii) a final clean-up phase aimed at reaching the endpoint criteria established jointly by the operator and the public agencies.

Clean-up operations were carried out on 130 to 140 km of river banks. Around two months after the spill, the quantity recovered was estimated at over 200 m^3, i.e. 90 % of that released by the pipeline.

Surveys were scheduled for 2017, following the remobilisation in August 2016 of a share of the pollutant during an episode of flooding.

In this regard, Husky Energy presented a corrective action plan to the MoE set to start in May 2017 which included a continued programme of SCAT surveys (with 4 canine detection teams), environmental risk assessment and, if necessary, local clean-up operations:

- the 2017 surveys were partly revised in light of the 2016 data on the pollution of sediment, analysed by the Submerged and Sunken Oil Working Group. In 2017, clean-up was carried out in 21 segments, out of a total of 61 surveyed.
- In May 2017, based on the surveys conducted to search for possible signs of environmental impact, no significant risk was identified. We recall that in the short term (mid-August 2016), these impacts proved to be moderate, with just under 100 specimens of oiled fauna found (unspecified species, a third of which were seabirds, half fish and over 15 mammals).

In February 2017, i.e. before these additional actions were implemented, the operator announced that it had spent $107 million on the response to this spill.

Major petrol leak at a remote site (Colonial Line 1, Alabama, US)

On 9th September 2016 in Alabama (US), a leak from one of the United States' main underground petrol (gasoline) pipelines, operated by Colonial and running from the Texan refineries to the storage facilities in the north of New Jersey, caused an estimated spill of 950 to 1,300 m^3 of gasoline. The majority of the spill flowed across the ground and was contained in a man-made pond, a former mining effluent retention basin, located 150 m from the leak point, where the majority of clean-up operations were carried out.

These operations mainly consisted in protection (laying containment and sorbent booms) and recovery measures for floating slicks (by skimmers together with pumping equipment). A second pond and two watercourses located downstream (Peel Creek and Cahaba River) were not affected[6].

18/09/2016: view of the contaminated man-made pond (right) 9 days after the spill. The second pond (left) was not affected (Source: US EPA).

To respond to the emergency, the local fire services established an exclusion zone around the spill point, and a Unified Command was set up, coordinated by the US EPA (Environmental Protection Agency)[7] from an Incident Command Post based in Hoover (Alabama) and which included the local authorities (Shelby County Emergency Management, SCEM), State authorities (Alabama Department of Environmental Management, ADEM) and representatives of the responsible party (pipeline operator and its contractors).

Due to its natural containment in the man-made pond, the oil, which was light with a high volatile compound content, required atmospheric contamination monitoring to be rapidly implemented. To do so, a company was contracted by Colonial to control the risks (explosiveness and toxicity) for responders.

The implementation of response operations in the ponds was therefore almost entirely prevented for the first two days and heavily restricted over the following days due to high concentrations of Volatile Organic Compounds (VOCs) around the accumulations of petrol. Nevertheless, no inhabitants were

[6] We note that, while sheen was reported in the second pond downstream, it was shown to be of biogenic origin – a relatively common phenomenon in semi-enclosed freshwater environments, due to the bacterial degradation of organic matter.
[7] Representatives of the US Coast Guard Gulf Strike Team also contributed their expertise to the Unified Command.

required to be evacuated, as the site was over 3 km from the nearest home. Again in terms of public health, SCEM indicated very early on that there was no risk of the petrol reaching drinking water sources due to the location of the spill. The Federal Aviation Administration (FAA) issued a temporary ban on flights at altitudes of less than 2,500 feet above the spill site within a 5 km radius. The operators at clean-up sites were equipped with ad hoc protective gear (ATEX PPE, respiratory protection where necessary, etc.) and a site safety and evacuation plan, in case of explosion or fire, was defined by the operator and approved by the Unified Command.

In the contaminated pond, similarly to the situation encountered following the spill in France in April (see p.2), one of the challenges of the response was to control the spread of the spill, through effective containment measures, while preventing the risk of a water level rise in the event of precipitation and overflow downstream.

Left: Areas of high concentrations of petrol in the contaminated pond; Right: Construction of bunds with underflow pipes at a natural weir in the pond (Source: US EPA)

This was implemented by constructing bunds with underflow pipes at the outfall of the natural containment areas.

Among the main factors hindering the initial response, we note:

- poor access, due to the site's remoteness, wooded nature and lack of roads to reach it. This issue was exacerbated by the fact that operations were prohibited in all or part of the polluted area until the explosion and/or toxic risk had passed.
- difficulties in determining the quantities and in sourcing the equipment required for primary storage of the liquid waste collected. There are a number of reasons behind these difficulties:
  - estimations of the volume present in the environment appeared gradually. It was difficult for the operator to make an initial estimation due to the lack of information available via the leak detection system. Estimations were gradually pieced together based on field observations and measurements (such as the extent and thickness of slicks)[8] before more reliable data became available to support and fine-tune the figures.
  - before being interrupted (due to benzene concentrations and explosivity measurements), short-lived preliminary pumping operations resulted in the recovery of 60 to 70 m^3 of liquid waste on the day of the spill. When considered in light of the extent and depth of the ponds (and, let's not forget, the lack of accurate data on the volume actually spilt), this result immediately raised the question of how to manage the quantities of waste, expected to be high, in terms of mobilising sufficient storage capacities as well as evacuating waste from this remote area.

During the first days of the response, Colonial implemented various actions to prepare the site, in order to facilitate response operations and ensure safety: tracks were created to give access to relatively heavy vehicles; vapour recovery systems were mobilised to reduce VOC emissions near the pipeline (we also note that, around the leak, ground excavation operations were conducted, after spraying foam to control vapour emissions); a vehicle decontamination area was also installed to limit secondary contamination.

[8] On the first day after the spill, the petrol slick on the water body was between 8 and 8.5 cm thick. Six days post-spill, at the 2 main pumping sites, the slicks were 0.25 cm and 4 cm thick respectively.

At the skimming/pumping sites on the water, liquid waste was collected in collapsible tanks. It was then transferred by vacuum trucks to intermediate storage areas, set up behind the clean-up sites and composed of Frac Tanks[9] to store and settle the large quantities of effluent on site.

Left: Petrol containment/recovery sites along the banks; Right: Liquid waste storage in Frac Tanks, to the rear of the clean-up sites (Source: US EPA)

The initial recovery phase ended around 26th September, i.e. just over 2 weeks after the spill. By this stage, the operations, which had mobilised more than 700 responders, had resulted in the recovery of 330 m^3 of oil (settled volume). According to the operator's estimations in the situation reports (SitReps published by the US EPA), around 1,000 m^3 of the spilt petrol (i.e. the majority of the spill) had evaporated during this period[10].

Beyond this phase, clean-up operations were carried out on the water body, in particular with shoreline rinsing operations and recovery of the residual petrol at the water surface, not to mention the continuation of ground decontamination operations around the pipeline (40 tonnes of contaminated earth had been excavated by 26th September).

We note that the closure of the pipeline raised concerns over the petrol supply across 6 states[11]. It was therefore decided that a bypass segment would be built around the leak site, resulting in the line being restarted 12 days after the incident. In terms of visible environmental impacts, the situation after the first fortnight suggested that the overall impact would be low, reporting impacts (dead or oiled individuals, not specified) on 7 mammals[12], 4 turtles and 2 birds (duck and egret).

For further information:
https://response.epa.gov/site/site_profile.aspx?site_id=11818

Contaminated water leaks into remote watercourses (North Dakota, US)

On 5th December 2016 near Belfield (North Dakota, US), a leak was detected on a pipeline (Ø 15 cm) at an oil facility operated by Belle Fourche Pipeline, contaminating Ash Coulee Creek (a tributary to the Little Missouri River) with around 490 m^3 of oily water.

The leak (a total volume of nearly 670 m^3) was not discovered until a few days later, due to a fault (unspecified) in the detection system. The quantity of oil which reached the watercourse was naturally contained, and affected over 7 km of banks but did not reach the rivers further downstream according to the operator.

Clean-up actions included recovering floating oil by pumping, after rinsing the banks, and a few controlled in situ burning operations. A fortnight after the incident was reported, the oil company announced that it had recovered around 300 m^3 from Ash Coulee Creek.

10/12/2016: Oil spill naturally contained in Ash Coulee Creek (Source: North Dakota Department of Health)

A second spill of around 48 m^3 of oily water occurred 7 weeks later (late January 2017) less than 5 km from the first leak. It affected Frank Creek (another tributary to the Little Missouri River) where the spill was contained by constructing a dam as an emergency measure. Response operations (in particular pumping by vacuum trucks) were carried out by the responders (over 130) already mobilised for the response in Ash Coulee Creek.

In March 2017, the North Dakota Department of Health announced that the quantity released during the December incident could in fact be 3 times higher than initially indicated (530,000 gallons rather than 176,000 gallons, i.e. 2,000 m^3 instead of around 670 m^3), considering it to potentially be "one of

[9] Commonly used for various applications in the oil industry.

[10] Around half of this volume, i.e. around 500 m^3, evaporated during the first 4 days according to the updates provided by the SitReps.

[11] Alabama, Georgia, North and South Carolina, Tennessee and Virginia, whose respective Governors temporarily lifted the time restrictions on oil transport by trucks to limit shortages at petrol stations.

[12] 1 rabbit, 2 raccoons, 1 fox, 1 coyote, 1 otter, and 1 armadillo.

the largest spills in North Dakota's history", although no impacts on wildlife were observed. The Department of Health also indicated that it was likely that the leak had been caused by a landslide. Within this as a backdrop, on 24th March 2017, the Pipeline and Hazardous Materials Safety Administration (PHMSA) directed the operator to dig up the failed section of pipeline for further terrain testing and analysis and to assess the vulnerability of the pipes in this area.

• Main spills of other substances worldwide

Sinking of a barge carrying liquid nitrogen fertiliser (Mississippi River, US)

On 25th January 2016, a chemical barge with over 3,900 m^3 of liquid nitrogen fertiliser, a solution of urea and ammonium nitrate, began to list and sank (for an undisclosed reason in our information sources) in the Mississippi River, not far from Valewood (Mississippi). The incident was reported to the US Coast Guard which took charge of coordinating the response, aiming first and foremost to mitigate the risk of the contents of the tanks being released into the water. The use of acoustic sensors (side-scan sonar) immediately proved necessary to assess whether it was possible to implement response actions on the wreck. This technology showed that the wreck was lying upside-down on the riverbed, approximately 25 m deep, making it difficult to access. Given this position, together with the water pressure, responders considered it very likely that the entire cargo of liquid fertiliser would be released in the short term. In this respect, the National Oceanic and Atmospheric Administration (NOAA) was called upon by the US Coast Guard to estimate the fate of such a release and the related risk of impact. In light of the relative density of the product and its high solubility, it was expected that the fertiliser would sink into the deep layers of the water mass and rapidly dissolve. In such a scenario, few pollution control strategies (containment, recovery, etc.) were conceivable, other than, as is often the case for soluble chemicals, the monitoring of its concentration (and checking its dilution) in the environment.

To the best of our knowledge, and despite its volume, no impact related to this spill was reported, probably due to its rapid dilution in the river. We note that while nitrogen fertilisers can locally cause toxic effects on wildlife, algal blooms and/or a depletion in dissolved oxygen (due to the nitrification process by bacteria), such effects will only occur if concentrations remain high and, therefore, if the product is contained in the affected environment (e.g. shallow waters, semi-enclosed/sheltered areas).

Molasses spill and river impacts (Magdalena River, Chalchuapa, El Salvador)

On 5th May 2016, in El Salvador, around 3,400 m^3 of molasses[13] were released from a sugar plant near Chalchuapa (Department of Santa Ana) and flowed into the Magdalena River, a tributary to the Paz River (marking the border between Guatemala and El Salvador). According to El Salvador's Ministry of Environment (*Ministerio de Medio Ambiente y Recursos Naturales*, *MARN*), which coordinated the incident management, the spill had occurred after employees had attempted to reduce the abnormally high temperature (around 200°C) of the molasses during the production process, by adding water containing chemicals (unspecified in our sources of information). This caused a reaction which finally resulted in the spill of hot, liquid molasses, which overflowed from the tanks, then burst out of the containment area, to flow off site and into the nearby Magdalena River.

A local inhabitant was severely burnt by the burning hot molasses and, again according to MARN, this spill caused fish mortality over at least a 5 km stretch of river, due less to direct toxicity than to a depletion in dissolved oxygen caused by this massive input of organic matter into the aquatic environment (confirmed by water analysis tests initiated by MARN). In terms of public health, the presence of chemical additives in the substance released caused the authorities to recommend that local resident temporarily refrain from using water from the river.

Although the spill was reported by MARN with a few photos and videos posted on various web media (Twitter, YouTube channel, etc.), little information was provided on this incident in terms of spill response actions: at the least, various photos suggest that manual techniques (collection, scooping, etc.) were used to recover part of the product, which became viscous once it had cooled down. Around 12 days after the spill, the Ministry announced that 95% of the volume released had been recovered and that the physical and chemical properties of the water had returned to normal.

13 Molasses is a syrupy liquid produced by refining cane sugar and is generally used in various industrial processes (biofuels, alcohols, animal feeds, etc.).



***Left** and **Centre**: Bed of the Paz River coated in molasses (source: MARN); **Right**: Manually recovering deposits of molasses along the banks (source: J. Henríquez / http://ecoviva.org)*

A second spill of molasses, whose extent and circumstances remain unknown to us, occurred a few days later (1st June) from a molasses storage facility in the north of the country, where it contaminated the Las Cañas River.

These incidents occurred against a backdrop of pre-existing criticism towards El Salvador's sugar industry (high consumption of groundwater; ground pollution due to the application of crop protection products; air pollution and soil impoverishment due to cane burning, etc.) and, following the spill of 5th May, several local residents had expressed their concerns over the potential long-term impacts on the freshwater ecosystem on which the subsistence of 450 families partially depended (fishing and drinking water supply). According to estimations by MARN, a large number of fish species (some commercial, other endangered) were affected, with 100% mortality in the first 12 km downstream of the spill point in the Magdalena River.

The government of El Salvador, which had declared a state of emergency following the incident, initiated legal proceedings against the operator. Thus, in late November 2016, the Environmental Court of San Salvador ordered the responsible party to pay almost €1.4 million to restore the affected site, as well as an additional €12K to cover the clean-up costs incurred by the state following the spill.

• Past spills

Coal ash storage basins: follow-up to the Dan River pollution (2014, US)

On 2nd February 2014 in Eden (North Carolina, US), the rupture of a dilapidated rainwater drain which passed under a thermal ash storage basin[14] in a disused power plant owned by Duke Energy caused the released of around 39,000 tonnes of mud containing coal combustion residues (coal ash, which includes heavy metals) in the Dan River (see LTEI n°22). The incident required 6 months of clean-up operations by the operator, under the supervision of the U.S. Environmental Protection Agency (US EPA), consisting mainly in dredging operations on local deposits and accumulations of ash along the banks and in the riverbed.

In early 2016, the North Carolina Department of Environmental Quality (NC DEQ) fined the operator $6.6 million (around €5.6M) after the firm had admitted to having violated the federal laws on water pollution. In addition, the company agreed to pay $120 million (approximately €86 million) in fines and damages, according to NC DEQ, and may be liable to face further fines over civil claims.

However we note that, over and above these fines, the Dan River spill was an incentive for North Carolina to demand that the operator stop storing coal ash in unlined pits – a practice apparently reported at numerous sites across the state (in which the coal industry has a heavy presence) – by 2029, in line with a recent change (2015) in federal regulations which, under the auspices of the US EPA, aims to promote the rehabilitation of this type of ash basins across the whole of the US.

With this as a backdrop, it was in June 2017 that, in response to the legal proceedings initiated against them 3 months earlier by Duke Energy Corp., some thirty insurance companies refused to cover the costs of cleaning up the coal ash storage basins (totalling several billion dollars), after the operator was ordered to do so in both North and South Carolina, claiming that the industrial firm had deliberately neglected to implement pollution prevention measures at these sites for years, despite being aware of the risks for the aquatic environment. Indeed, while the power producer considered that it should be reimbursed the costs related to the management of material damages "caused by an occurrence", the insurance companies on the other hand made the distinction between this case and

[14] North American alternative to the spoil tips found in Europe.

the operator's practices (here, storage in unlined ponds), which they considered to be "normal practice" by the company and hence "all damage" can be considered to have been "caused intentionally". Depending on negotiations between the two sides, this litigation can be expected to lead to a trial in mid-2019.

• Review of significant spills having occurred worldwide in 2016

This analysis is based on an inventory of incidents in 2016 recorded by Cedre having led to a spill of over an estimated 10 tonnes, for which sufficient information was available. We remind readers that, for a certain number of incidents, the volumes spilt are not known or were not available in our sources of information, although they clearly exceed the ten-tonne mark; these missing data and inaccuracies indubitably penalise the accuracy of the results presented below.

Spill sources

In 2016, 30 incidents followed by significant spills (≥ 10 t.) were identified in inland waters, a value slightly below the median for the period 2004-2015 (38), calculated based on annual data collected in a similar way, and below the medians calculated for 4-year periods[15]. The year 2016 would therefore appear to be a year during which the number of significant incidents identified by Cedre was lower than that of previous years, a result which could potentially point to a downward trend that remains to be confirmed.

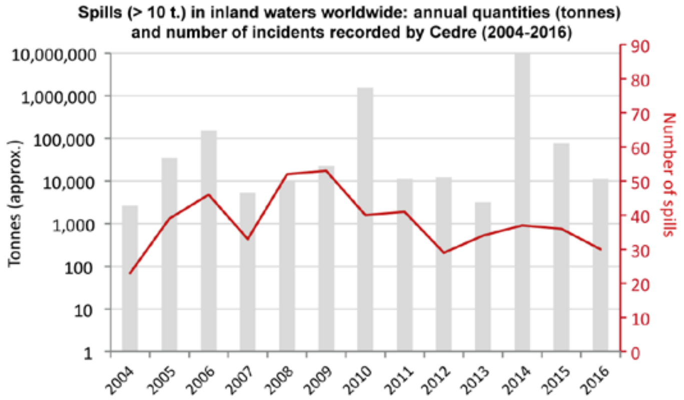

Figure 1

These incidents represented a total quantity of around 11,300 tonnes of oil and other hazardous substances spilt (Fig. 1), an estimation lower than the annual median expressed for the period 2004-2015 (around 17,350 tonnes).

The estimated median volume of spills for the year shows that the spills in 2016 were distributed around a median value between 90 and 100 tonnes. A dozen spills involved volumes of over 100 tonnes, including three in excess of the 1000-tonne mark.

Like for most of the previous years, but to a greater extent in 2016, **pipelines** were the most frequent source (50%) of significant spills in inland waters known to us (Fig. 2), well ahead of **onshore industrial facilities** which represented 13% of cases (half of which involved **chemical/petrochemical plants** and the other half **power plants** and **iron and steel plants**).

Various types of ships were responsible for 10% of incidents, divided between **tank barges** (7%) and **workboats** (4%), with a similar frequency to land transport – **tanker trucks** and **rail tank cars** – involved in 7 and 3% of incidents respectively (Fig. 2).

The other types of sources identified in 2016 (**factories**, various **SMEs**, etc.) were involved in less than 5 % of significant spills during the year. In approximately 7% of cases, the spill was connected to **unspecified onshore facilities** (Fig. 2).

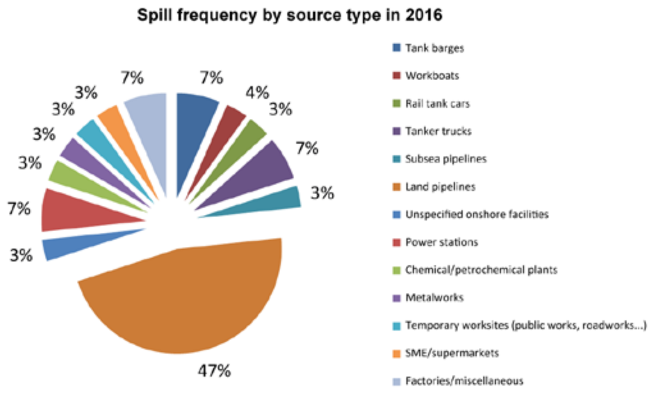

Figure 2

15 (median values of 38, 36 and 47, respectively for the periods 2004-2007, 2008-2011 and 2012-2015)

Given the patchy nature of the data identified, the relative shares of the overall total volume cannot be accurately established, with some of these shares evidently being underestimated (Fig. 3).

Bearing in mind this reservation, we note nevertheless the 35% share of tanker barges (around 4,000 tonnes), mainly due to the sinking of a barge on the Mississippi and the loss of its cargo of liquid fertilisers.

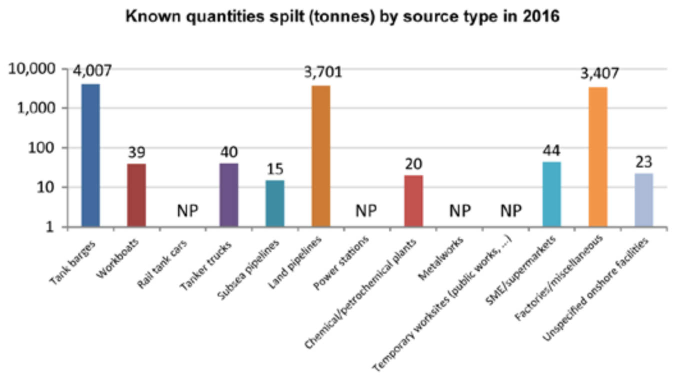

Figure 3

The second visible share is that of **land pipelines**, representing around 33% of the total quantity spilt, due to the high frequency of incidents on such structures (see above), generally causing spills in excess of 100 tonnes, or even 1000 tonnes (as was the case of the spill of nearly 1,200 m^3 of petrol from the Colonial Pipeline in the US in September, which alone accounted for nearly a third of this share).

Despite its low frequency, the **factories/miscellaneous** category represented around 30% of the total quantity. This share can be accounted for by a single yet major spill which occurred at a sugar plant in El Salvador in May (spill of over 3,000 tonnes of molasses, see above).

The other sources represented a negligible (less than 1%), or unknown, proportion of the estimated total for 2016 (Fig. 3).

Types of substances spilt

Although figures are not available for certain categories of pollutant, the largest share of the 2016 total would appear to be oil, with almost 4,000 tonnes of oil products spilt, i.e. a total share (again underestimated) of around 35% of the annual total (Fig. 4). Among these oil products we can distinguish:

- **light refined products** (such as diesel and petrol), which represent the largest proportion (around 15% of the total), due to 7 spills including a petrol spill from a US pipeline which accounts for 2/3 of this share.
- in second position, the share of **crude oil** (most often of unspecified density), of which the known quantities totalled around 1,220 tonnes, i.e. around 11% of the overall total. According to the data at our disposal, this share was largely due to spills from pipelines in Peru (see above).
- **biofuels** represent 4% of the total quantity spilt (and 10% of the oil category), accounted for by a significant incident: that of the Donges – Vern-sur-Seiche pipeline in spring 2016 in the Loire-Atlantique area of France.

Chemical spills represent approximately 35% of the total quantity spilt in 2016, a share relatively close to that of oil. This share is almost entirely dominated by the **liquid mineral fertilisers** category, due to a single spill of over 3,900 m^3 of urea and ammonium nitrate when a barge sank in the Mississippi in January 2016 (see above).

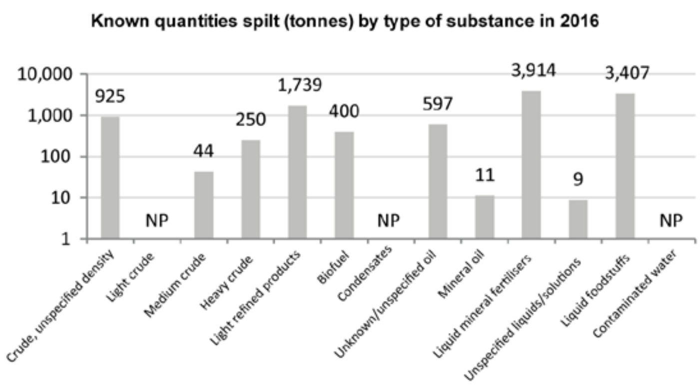

Figure 4

Finally, the organic matter category also significantly contributed to the overall total, representing 30%, due to a spill of 3,400 tonnes of liquid foodstuff (in this case molasses, spilt from a sugar factory) into a river in El Salvador (see above) (Fig. 4).

Events

The most frequently reported incidents in 2016 were **holes, breaches or ruptures** in various structures (approximately 70 % of the total, see Fig. 5):

- Most (54 %) of the incidents in this category were due to a loss of integrity, most often (in 11 out of 13 cases) on land pipelines. In terms of the quantities spilt, these incidents formed the third largest share of the overall total spilt, representing just over a quarter (with over 3,000 tonnes, i.e. around 27%) (Fig. 6). These were generally significant events, with spills of around 200 tonnes in 2016 (median value).
- **Overturning** incidents (mainly ships capsizing and – in the majority of cases in 2016 – overturning/derailment of rail tank cars or road tankers) represented 17% of such incidents (13% of the total in terms of the number of spills, see Fig. 5). Distributed around a median value of 20 tonnes in 2016, the quantities spilt during these relatively minor events however only represented a very low share of the total quantity (less than 1%, see Fig. 6).
- The third type of event identified in terms of frequency (around 10% of all cases, see Fig. 5) was **structure ruptures** which did not represent a significant share of the total quantity spilt in 2016 either.

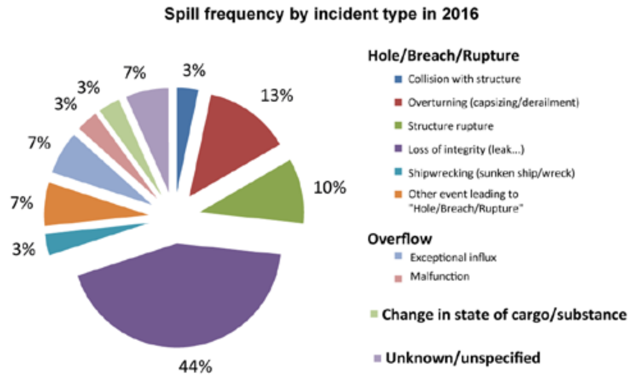

Figure 5

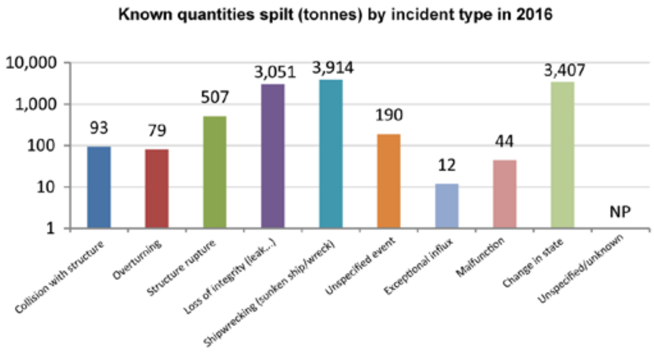

Figure 6

This share is mainly due to an incident in which a trencher accidentally pierced a pipeline transporting refined products between the Donges refinery and the Vern-sur-Seiche storage facility (spill of approximately 400 m^3, see above), while the other incidents in this category resulted in spills of less than 100 m^3.

- Few **ship losses** were recorded (approximately 3% of cases, see Fig. 5) however they represented a significant share (over 33%) of the total quantity spilt, due to the sinking of a chemical barge which sank in January in the Mississippi with its cargo of fertiliser (see above).

Finally, with the exception of spills due to **overflow** (**exceptional influxes** and **malfunctions**), totalling 10% of cases but representing a low share of the 2016 total given the small quantities involved, the frequencies of the other categories of events did not exceed 3% (Fig. 5). Among these categories, we note however the considerable share of the total quantity spilt (around 30%) occupied by the '**change of state of the cargo/substance'** category, accounted for by a spill in a watercourse following the incident at a sugar factory in El Salvador (see above).

Causes

Analysis of the frequencies of each cause shows that the cause was **unknown or unspecified** in the majority (around 60 %) of cases listed (Fig. 7). In addition, this category by far constitutes the greatest share of the total quantity spilt, accounting for 88% (Fig. 8). Indeed the causes of several major incidents in 2016 are unknown to us, some of which, for instance, resulted in spills of over 1,000, or even 3,000 tonnes (e.g. sinking of the MM501 barge; incident at Magdalena Sugar Mill, leak from Colonial Pipeline, etc., see above for details). It is therefore difficult to establish with certainty the main causes of these incidents, and the resulting analysis should therefore be taken with caution.

Among the causes identified, we note the prevalence in 2016 of **natural causes** (involved in around 20% of cases):

- two thirds of these causes were related to **flooding/precipitation**, in general resulting in relatively small spills (a few dozen m^3). The most significant such spill was from a pipeline in Pennsylvania (US), leaking after having ruptured due to flooding, following heavy rainfall. This spill represented over 80% of the modest share of this cause (around 240 tonnes) in the overall total (Fig. 8).
- despite being less frequent (7% of incidents), **landslides** represented a higher share (around 570 tonnes) of the overall total spilt, mainly attributed to two pipeline ruptures and spills of around 200 and 300 tonnes, respectively in January in Peru and in July in Canada[16].

Technical failures of facilities caused around 13 % of events recorded (Fig. 7). The most frequent such incidents (10 %) were due to **defectiveness/dilapidation** of various elements (of onshore facilities and pipelines in 2016, etc.), although these incidents only represented a small share of the annual volume (Fig. 8).

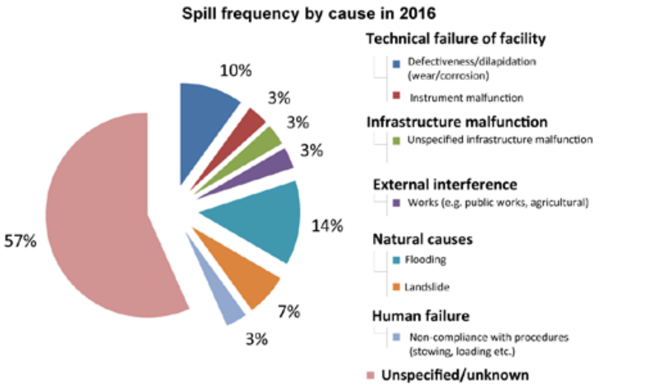

Figure 7

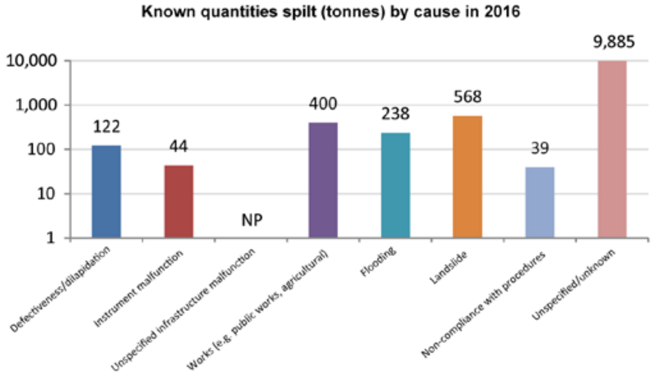

Figure 8

Finally, despite a low frequency (3%), **external interference**, in this case due to **earthworks**, accounted for 400 tonnes of the annual total due to damage to the Donges – Vern-sur-Seiche pipeline and the resulting spill of biodiesel in France in April 2016.

• Statistics

BARPI: 2016 inventory of technological incidents in France

Since 1992, the French bureau for analysis of industrial risks and pollution BARPI has been collecting information on the technological incidents made known to it (reports by emergency services, press, etc.). BARPI recently published its annual analysis of incidents which occurred in France in 2016 at classified facilities, hydraulic works, transport structures for hazardous substances as well as for the transport and use of gas. Below is a summary of some of the key points for 2016:

- 1,455 technological incidents were identified by BARPI within the scope of this review, of which 66% involved classified facilities:
    - o according to the classification adopted by BARPI, the analysis of the phenomena associated with these incidents ranked the top three causes as "fire", "release of hazardous substances" and "explosions". "Releases of hazardous substances" showed a frequency of around 40% (a rate close to that estimated in 2015 based on the same criteria).
    - o These releases of hazardous substances occurred in various fields of activity, some of the most common being "Waste treatment", the "Chemical and pharmaceutical industry", the "Agrifood industry", "Metalworks and metal products" and "Transport and storage" (BARPI classification), far ahead of "Coking and refining" for instance.
- The number of technological incidents at classified facilities related to weather conditions saw a peak in 2016, with 85 incidents including:
    - o over 30 flooding incidents at factories and storage facilities between 29th May and 15th

[16] Incidents involving the Norperuano Pipeline (Petroperú) in the Amazonian province of Bagua (Peru) and a pipeline operated by Husky Energy in the province of Saskatchewan (Canada).

June.
- o over 20 incidents related to periods of high temperatures.
- o 5 incidents due to lightening and one forest fire (causing 8 incidents at industrial sites in southern France in August).

- BARPI's analysis of the frequency of the different categories of consequences showed their relative stability from one year to the next, with economic consequences in over 70% of cases (material damage and loss of production) and environmental consequences in 30% of cases – water pollution (surface and/or groundwater) being an outcome in around 10% of cases.

The review thus constitutes a complementary review of past incidents, for the other categories of structures (transport of hazardous materials etc.) and within the scope of BARPI's specialisation, in addition to that conducted by Cedre for its own needs (see above).

For further information:
https://www.aria.developpement-durable.gouv.fr/wp-content/uploads/2017/09/2017803_BARPI-Inventaire2017-Web.pdf?utm_source=Sendinblue&utm_medium=email&utm_campaign=Inventaire&utm_term=sept-oct&utm_content=LettreInfo48

Canada: increased risks due to crude oil transport

In the second half of 2016, Statistics Canada (StatCan, an agency of the Federal Government of Canada) publicly released the conclusions of a statistical analysis of accident data, which suggested (i) an upward trend in the number of incidents involving oil transport structures in Canada and (ii) the prevalence of oil among incidents involving hazardous goods.

Because of Alberta's tar sands, which are among the largest in the world, there is a particular focus in this review on the question of spills of non-conventional crude oil. The quantity of oil transported in Canada – by truck, boat, rail or pipeline – is constantly increasing, as is the number of incidents involving crude oil (despite a dip observed in 2008 due to the world economic crisis).

Following a peak of 283 incidents in 2013, the number of incidents involving crude oil exceeded that involving other types of hazardous goods.

In terms of the sources of spills which occurred during transport, StatCan estimated that an average of 55 pipeline incidents occurred each year between 2005 and 2014. In 84% of cases, these incidents resulted in an oil spill, with an estimated average volume of 36 m^3 (however information on the volume released is missing in 70% of cases, as it was not mandatory to report the quantity spilt until July 2014). Rail freight, with an annual average of 780 derailments between 2005 and 2014, of which approximately 31% involved hazardous goods, caused between 2 and 7 spills a year.

From a broader perspective, StatCan produced a review of these results against the current backdrop of Canada's growing oil production together with changes in methods of oil transport to oil facilities (refineries, storage facilities, etc.) and to the export market: new pipeline sections, conversion of certain pipelines, higher flow rate, three-fold increase in rail transport between 2005 and 2014... All these factors help to explain the increase in risks related to oil transport in Canada.

For further information:
http://www.statcan.gc.ca/pub/16-002-x/2016002/article/14629-eng.htm
http://www.statcan.gc.ca/daily-quotidien/160712/dq160712a-eng.htm

• Containment

Spills during transfer operations: VikoSeal Boom

The British manufacturer Vikoma has launched a containment and protection system baptised VikoSeal, designed to set up an oil containment area between ships, or between a ship and the dockside. Its primary purpose is to ensure safe cargo loading and unloading operations, bunkering operations – either in dock or at sea, etc.

It is composed of 3 sections of floating boom which, when deployed, form an H-shape. The two lateral bars of the H form a seal against the ship hull or dockside, creating a containment area with the crossbar, which also acts as a spacer.

According to the manufacturer, the device has high abrasion resistance and high tensile strength (in particular resistance to towing and compression) – vital given the conditions in which it is used – thanks to its vulcanised neoprene. The draught of this boom is around 90 mm.

View of the VikoSeal deployed between a ship and the dock (Source: https://www.vikoma.com/)

The Vikoseal comes in 2 lengths, approximately 3 m and 4.5 m wide. In addition to its preventive role, as described above, the manufacturer claims that this device can be used in emergency response as a spacer for conventional booms deployed for instance around a grounded, leaking vessel (in order to provide a recovery/skimming area for floating substances).

In either case (risk of operational or accidental release), Vikoma emphasises the fact that this system is quick to deploy, which is an important factor given that when a spill occurs in inshore areas – which are often sensitive environments – the effectiveness of containment is often a key factor in ensuring a successful response.

For further information:
https://www.vikoma.com/Oil_Spill_Solutions/Booms/VikoSeal.html

Floating debris and seaweed: the Elastec Beach Bouncer

The manufacturer Elastec recently launched a new model of barrier, the Beach Bouncer, initially developed to protect beaches against seagrasses such as Sargassum, which is relatively invasive and which washes ashore in massive amounts in the Caribbean where it has been known to occasionally affect tourism from Mexico to Florida.

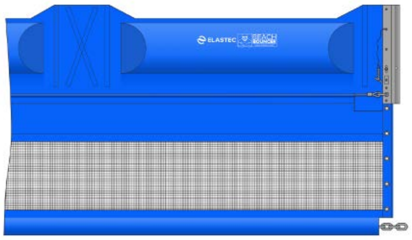

Diagram of the components of the Beach Bouncer (source: https://www.elastec.com)

In this respect, the Beach Bouncer was designed as a boom for floating debris, and it can also be used to contain (or deflect) litter, in the same way as other models proposed by the manufacturer such as the Brute Boom[17].

It is composed of permanent floats (Ø 30 cm foam cylinders) in a PVC casing, with a longitudinal steel load-carrying cable and, below, a 90 cm-high net, with approximately a 3 mm mesh. This net is ballasted with a galvanised steel chain along the bottom of the skirt to keep the boom upright.

The 30 m-long boom sections can be combined using standard ASTM connectors and feature mooring points every 7.5 m.

For further information:
https://www.elastec.com/products/floating-boom-barriers/invasive-aquatic-plant/beach-bouncer/

• Oil measurements and monitoring

SWARM buoy: a progressive, modular water quality monitoring system

In 2016, the first permanent SWARM buoys designed by VEOLIA Endetec were installed.

These buoys are composed of a mooring system, 4 main modules and a buoyancy compartment:

- An energy module, comprising a battery and an energy recovery system, allowing it to be self-sufficient.
- A wireless communication module (GSM, GPRS) which sends the data

Buoy set up in a river

[17] Heavy duty permanent containment boom with reinforced steel screen.

to a remote server.
- A measurement module with an electronic motherboard able to manage up to 6 multi-parameter probes as well as the communication and energy modules.
- Multi-parameter probes which measure environmental and water quality parameters: sunshine, wind speed, depth, water flow speed, turbidity, organic matter, water temperature, dissolved oxygen, conductivity. Only 3 of the 6 probe slots are currently occupied, meaning that new probes could potentially be installed to monitor additional parameters.

These buoys transmit the values of the parameters measured to a secure web portal which can be accessed by those concerned. According to requirements, a drop in one or more water quality parameters can be set to trigger an automatic alert by email or SMS, have a sample taken, a valve closed, etc. For more information on the equipment and services available, visit www.homeridersystems

Diagram of the buoy (Source: Veolia)

• Feedback from past spills

Detection of submerged oil: adaptation of techniques according to current (US)

Following two recent incidents involving the submersion of heavy oil spilt in the Mississippi, the National Oceanic and Atmospheric Administration (NOAA) published an article outlining the constraints and limitations of submerged oil assessment techniques according to the flow conditions in rivers and the benefits of technical improvisation.
Both these spills involved slurry oil following the collision of the *Apex 3508* tanker barge with a tug in the first case (September 2015, Kentucky; see LTEI n° 25), and between the *MM46* push barge and a bridge near Natchez in the second case (January 2016, Mississippi; see above).
While, in both cases, the oil, which was denser than water, was expected to sink, the US Coast Guard (response coordinator) remained uncertain as to the ultimate location of the sunken oil, as well as its behaviour and fate (e.g. sinking of the whole of the original slick, fragmentation/dissemination due to currents, burial, etc.) in the flow conditions, with low water levels in the river in the first case and high levels in the second.
In the case of the incident involving the *Apex 3508* barge:

- the oil deposits were able to be located and mapped using acoustic imagery by deploying both a side-scan sonar and multibeam echosounders (to simultaneously acquire data on the depth and nature of the river bed).
- once they had been mapped, the slurry oil deposits were recovered mechanically using a clamshell dredger.

When the MM36 barge incident occurred however, the water level in the Mississippi was characteristically high (late winter), bursting its banks, with a flow rate of 8 to 13 knots (approximately 15 to 25 km/h) for a flow rate of over 50,000 m^3/second:

- on the riverbed, not far from the site of the collision, the side-scan sonar and multibeam echosounders proved, in these conditions, to be less useful for mapping the sunken oil than for identifying very intense and rapid sediment movements, in the form of hydraulic sand dunes around ten metres high and progressing at a rate of 5 m/hour. Based on this observation, it appeared unlikely that attempts to recover the oil would be successful.

- on the bank, then flooded and with a slower flow rate where the leaking barge was moored, the presence of many submerged objects (structures, tree trunks, etc., not to mention the barge itself) prevented the detection of submerged oil using acoustic techniques. The oil was detected using an improvised system, made of long rigid tubes with sorbents wrapped around each end (dubbed a "cotton swab", see photo on the right), used to probe the submerged ground around the barge through the debris and vegetation.

An effective "low-tech tool" for detecting sunken oil (Source: NOAA)

2005 hurricanes in the US and in situ burning: long term marsh restoration

Over 10 years ago, in August and September 2005, the hurricanes Katrina and Rita came in quick succession, inflicting major damage on many oil infrastructures in Louisiana (US) which resulted in many oil spills in the surface, inland and coastal waters of the state of the Gulf of Mexico (see LTML n°11).

The destruction of the roof of a storage facility at the Chevron Pipe Line Company oil terminal in Buras (Louisiana), one of the largest in the world, caused a crude oil spill into an adjacent ecologically sensitive marsh. The vegetation in this ecosystem acted as an oil trap and significant quantities of this oil remained across around 20 hectares due to very limited response possibilities. It was against this backdrop that, a month after the spill, a team of experts composed of representatives of NOAA and Chevron[18] recommended cleaning up the affected area by controlled in situ burning (ISB).

This recommendation was justified by (i) the remote location and difficult access to the site for personnel and logistical equipment, (ii) the lack of 'normal' wildlife due to post-hurricane conditions and (iii) the presence of drainage channels along 3 edges of the marsh acting as fire barriers.

The NOAA mentioned various types of difficulties encountered at the time in terms of the acceptance of ISB:

- technique less commonly used in marshes (despite previous scientific publications and studies) than in the open ocean (where it was better documented, even in these pre-Macondo times)
- the negative perception/image of burning following a natural disaster
- the belief, according to various responders based on their experience, that the oil had been exposed to weathering processes for too long to burn successfully. Burn tests were conducted on samples and indicated that oil burning showed good potential, thanks, according to NOAA, to the thickness of the oil and its protection by vegetation against the processes liable to cause the physical and chemical characteristics of the oil to evolve (hydrodynamics, photo-oxidation, etc.).

Approved by the Unified Command, ISB was carried out for 2 days, a month and a half after the spill, with burns lasting 3 hours and 4.5 hours respectively, and resulted in the elimination of 90% of the oil according to NOAA. Signs of vegetation regrowth were observed very shortly after the burns, visible from a few days to a few weeks later according to the species.

October 2005: Regrowth of the vegetation a few days after controlled burning operations.

*Comparative view of the oiled marsh following the spill caused by the damage to the Chevron storage facility due to the hurricanes of 2005: immediately after the burns (**left**) and 10 years later (**right**) (Photo source: NOAA)*

[18] As well as the US Coast Guard and public wildlife agencies (local and federal: Louisiana Department of Wildlife and Fisheries, U.S. Fish and Wildlife Service)

Provided ISB is implemented within a relatively short timeframe and subject to the verification of certain environmental data[19], the restoration process (which was reported in a number of scientific publications to have begun in 2006 and to continue to progress in 2007, see below) appears to be confirmed in the longer term, suggesting that the marsh ecosystem is resilient to ISB, which appears to have been an effective method in these circumstances for removing oil from a remote site.

For further information:
https://usresponserestoration.wordpress.com/2015/08/25/10-years-after-being-hit-by-hurricane-katrina-seeing-an-oiled-marsh-at-the-center-of-an-experiment-in-oil-cleanup/

Background reading:
Merten A.A., Henry C.B. & Michel J., 2008. Decision-making Process to Use In-Situ Burning to Restore an Intermediate Marsh Following Hurricanes Katrina and Rita. *International Oil Spill Conference Proceedings*, 2008, pp 545-550.
Baustian J., Mendelssohn I., Lin Q. & Rapp. J., 2010. In Situ Burning Restores the Ecological Function and Structure of an Oil-Impacted Coastal Marsh. Environmental Management, 46 (5), pp 781–789.

• Response preparedness

River spills: specificities, strategies... technical reports and operational guides from the API

The American consultants Research Planning, Inc. and QualiTech drafted a review, for the American Petroleum Institute (API), based on feedback from real spills, aiming to present useful information and knowledge for implementing a technical response in continental waters tailored to the sensitivity of the affected environments. Published in the last quarter of 2016 and entitled 'Options for Minimizing Environmental Impacts of Inland Spill Response', it replaced the 1994 version by providing additional information and amendments for the following aspects:

- An updated overview of the potential spill sources and related risks through data (products, quantities) illustrating, for instance, the increase in oil transportation by rail, the explosion and fire risks related to the transportation of light crude oils (such as Bakken crude oil), diluted bitumen products, etc.
- Organisation of the report into 5 oil groups based on their API gravity, a determining factor in particular in terms of toxicity, persistence, behaviour in the environment and, finally, the choice of techniques.
- Technical guidance summarised by oil group, in the form of "stoplight" matrices, indicating the potential impacts of different methods for different types of continental waters (lakes, ponds, rivers, streams), habitats and substrates (permeable/impermeable, forested land, vegetated wetlands).

In terms of spill control and containment strategies, as well as recovery, many specificities were addressed, such as protecting water intakes, responding to spills of ethanol-blended fuels, sheen, containment in strong current, etc.

The year 2016 also saw the release of two new API publications on the issue of sunken oil detection:

- The first (Sunken Oil Detection and Recovery) aims to review the current state of knowledge, drawing upon past incidents in marine and freshwaters, in terms of potentially appropriate techniques and equipment for sunken oil detection (sounders, subsea cameras, divers, samplers, ballasted sorbents, detectors, etc.) containment (air curtains, silt curtains, gabion baskets) and recovery (dredging, pumping/suction, sorbents, remobilisation, etc.). It also proposes research and development opportunities for a number of techniques identified as promising in this field, or conversely due to gaps being pinpointed, without forgetting the issue of management of the waste generated by these techniques (e.g. sediment dredging).
- The second is an operational guide which aims to provide decision support in terms of implementing response operations for sunken oil (choice of techniques), by weighing up the advantages and disadvantages of each method (e.g. operational limitations, logistical

[19] in particular the presence of surface water, to preserve root systems

prerequisites, etc.).

When considered in a wider context in terms of applications and based on feedback from incidents in inland waters, this issue is also of interest for offshore and inshore environments and ultimately concerns all aquatic environments in which submersion processes – in particular due to sediment load[20] – may lead, in the longer term, to the issues of response to sunken pollutants.

For further information:

American Petroleum Institute, 2016. Options for Minimizing Environmental Impacts of Inland Spill Response. *API TECHNICAL REPORT* 425, 112 pp.

American Petroleum Institute, 2016. Sunken Oil Detection and Recovery. *API TECHNICAL REPORT 1154-1*, 126 pp.

American Petroleum Institute, 2016. Sunken Oil Detection and Recovery, Operational Guide. *API TECHNICAL REPORT 1154-2*, 36 pp.

• Fines and legal proceedings

Kalamazoo spill: verdict, fines and preventive measures against future spills

In July 2016, a consent decree between the U.S. federal government and the Canadian company Enbridge Energy was approved, whereby the operator agreed to pay $176M (approximately €150M) following the incident which polluted the Kalamazoo river (July 2010, Michigan, US) with around 3,700 m^3 of dilbit, from an underground pipeline (see LTEI n°15, n°19 and n°21).

Six years after the incident, this settlement, concluded on a federal level (following that of May 2015 for the State of Michigan, see LTEI n°21), under violations of the Clean Water Act, drew a line under this incident which was considered to be the largest spill in the continental waters of the United States. In terms of the sum to be paid, the only settlement to exceed this has been the $20 billion agreement concluded in October 2016 between the U.S. government and BP in relation to the Deepwater Horizon disaster.

Through this settlement, the operator agreed to spend $110 million of this sum on a series of measures to offset damage done by the spill and prevent further disasters. This sum is earmarked to:

- improve the pipeline system inspection programme
- upgrade leak detection systems as well as information management systems at the control posts (with more specific requirements in sensitive sectors)
- establish a preparedness programme for major spills, with mandatory exercises to test the operator's response capacity
- develop an incident command system and to train personnel accordingly, to improve coordination with public agencies in charge of spill response
- contract an independent consultant for a critical review of the above-mentioned actions.

The settlement also includes:

- a $61 million penalty for violating the Clean Water Act. The Department of Justice decided that this fine would go into the Oil Spill Liability Trust Fund (OSLTF, managed by the U.S. Coast Guard).
- $5.4 million to reimburse the expenses incurred by federal agencies for spill clean-up.

According to the federal administration, the considerable sums concluded in this settlement should hopefully be an incentive, to Enbridge and other operators, to improve incident prevention measures.

[20] On this point, a report was published in 2015 by the U.S. Geological Survey (USGS) presenting the state of knowledge on the formation and fate (transport, sedimentation, resuspension, etc.) of oil-particle aggregates (OPA) in various environments (marine, coastal, estuarine, lakes, etc.) See Fitzpatrick, F.A., Boufadel, M.C., Johnson, Rex, Lee, Kenneth, Graan, T.P., and others, 2015. Oil-particle interactions and submergence from crude oil spills in marine and freshwater environments—Review of the science and future science needs: U.S. Geological Survey Open-File Report 2015–1076, 33 p., http://dx.doi.org/10.3133/ofr20151076.

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