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**Physical and Biological Remediation Of Oil-Polluted River Bed And Hillside Sediments Resulting From A Ruptured Oil Pipeline In Northwestern Italy**

By: I. Bonfà and M. Gambera
Groundwater Technology Italy

By: Richard S. McIntosh
Groundwater Technology, Inc.
Norwood, Massachusetts U.S.A.

## 1. Site History

A few years ago, the rupture of an underground pipeline caused the spill of a large volume of fuel-oil on a hill slope, located next to the Rio Barca, a mountain stream. The Rio Barca is a torrential watercourse, situated on the southern border of the Province of Alessandria, Piemonte region, in the north of Italy. Approximately 500 meters of the stream was affected by the loss from the pipeline rupture to where the stream joins the main river, Rio Lemme.

The spill occurred during a time when the Rio Barca was almost totally dry, therefore allowing the fuel-oil to saturate the sandy-silty-gravelly sediments, which form the bed of watercourse. Several tens of thousands of liters of oil was spilled into the Rio Barca.

The impact of the stream bed contamination was evident during periods of moderate to high water flow in the Rio Barca. Droplets of oil from the stream bed sediments would periodically rise to the water surface and produce sheens of oil which were carried down to the Rio Lemme. Physical agitation of the sediments, such as a fisherman walking through the stream, would produce a large sheen of oil. In essence, a large volume of oil, adsorbed to the sediments and partially filling the pore spaces lay trapped beneath the flowing waters of the Rio Barca. Small volumes of oil were being continually released where it would ultimately flow into the Rio Lemme, which is used for drinking water downstream of the Rio Barca.

The pollution also saturated the detrital soil and rock covering the pipeline, which is found on the slope where the leakage took place, and the underlying shales, which also form the substrata for the sediment of Rio Barca.

## 2. Site Assessment

As a follow up to the fuel loss, Groundwater Technology was asked to establish the feasibility of conducting an in situ remediation. In order to define the full extension of the contaminated area as well as the relative hydrocarbon concentration, a water and soil sampling program was conducted both for the stream bed and the hill slope, where the accident took place.

The assessment results showed that about 6,000 $m^3$ of sediment in the stream bed and 700 $m^3$ of soil on the hill side were significantly contaminated with hydrocarbons.

Considering the absence of Italian regulations or norms regarding the admissible concentrations of residual hydrocarbons within the soil, Groundwater Technology, in consultation with the local authority, adopted the Dutch standards as reference for mineral oil concentration limits at the site (reported in Table 1).

Laboratory analytical results of the soil samples indicated a discontinuous distribution of hydrocarbon concentrations, showing average values of 10,000 mg/kg for the stream and 25,000 mg/kg for the hill side. Physical evaluation of the impact in the field indicated the presence of free product trapped in the sediments within the stream bed and the hill side. (These physical observations indicate that impacted areas exceeded 100,000 mg/kg.)

Due to physical constraints and the large volume of soil to be treated, the technical aspects of the comprehensive remediation project considered the feasibility of applying an in situ remedial action. The scope of the entire project was therefore to treat the impacts without removing soil from its original location.

As a preliminary step, a number of tests were executed to verify the feasibility of the clean-up operation based upon two separate methods:

a) Physical recovery of separate phase oil (free product).

b) In situ treatment of residual hydrocarbons using an Enhanced Natural Bioremediation (END$^{TM}$) technology.

Field tests on stream bed sediments revealed that large quantities of oil could be liberated via physical agitation thereby significantly reducing the residual concentration of oil. The main technical problem would be to recover the liberated oil before it flowed into the Rio Lemme.

Additional tests revealed a healthy population of hydrocarbon degrading bacteria existed in the stream bed sediments and the hillside soils at the spill location.

## 3. Operation Plan

### 3.1 Comprehensive Site Remediation (CSR$^{TM}$) for the stream bed sediments of Rio Barca.

The strategy developed by Groundwater Technology was a two step approach to remove the hydrocarbons in the stream. The residual hydrocarbon contamination in the hillside (spill source) soils were addressed in a separate plan.

1. Mechanical liberation and recovery of the free-phase hydrocarbon trapped in the sediments;

2. In situ treatment via an Enhanced Natural Bioremediation (END$^{TM}$) program.

### 3.2 Free Phase Oil Recovery

By physically tilling the stream bed sediments with an excavator during the optimum hydrological conditions, it was possible to liberate a large volume of the free-phase product. The liberated product would then float to the surface of the water and flow down stream. To capture and recover the liberated oil two (2) dams were constructed in the Rio Barca, one at the mouth of the stream where it joins the Rio Lemme and one dam located at the approximate midpoint between the spill location and the mouth. Settling basins were dug on the upstream side of each dam and siphons were installed to transfer the stream discharge through each dam. The intake depth of the siphons was 2 m below the surface. Oil booms were installed upstream of each dam to capture floating oil. Floating oil skimmers pumped off the collected oil into an oil water separator. Recovered oil was transferred to storage drums. Recovered water was treated then returned to the river.

In order to prevent the discharge of hydrocarbon-coated suspended sediment to the Rio Lemme, two clear-flocculation basins were constructed at the end of the Rio Barca stream, near the confluence with the Lemme river (Fig. 1). As the mechanical sediment-tilling was accomplished, the decanted contaminated solids settled in the stream bed up-stream the dams and into the basins themselves. These oil-coated sediments had to be removed and were subsequently treated biologically on-site in a soil pile, constructed adjacent to the watercourse.

3.3 Enhanced Natural Degradation of Residual Hydrocarbons (END™)

The END™ process is based on the principal of creating the best possible conditions for the proliferation of naturally existing soil bacteria, which are apt to utilize hydrocarbons as a food source. To accomplish this, a balanced mixture of essential nutrients is added to the soil and necessary oxygen supplied, so that the process of aerobic digestion may develop. The bacteria metabolize the organic and mineral substances thus converting hydrocarbons to carbon dioxide and water.

3.3.1

The remediation of the watercourse presented notable practical difficulties. The process coincided with periods of intense and heavy rains: several times the flow of the river rapidly increased from a few hundred liters per second to 10-20 $m^3$/sec.

The in situ bioremediation of residual hydrocarbons in the stream bed sediments was carried out after the physical liberation and recovery of separate phase hydrocarbon was completed.

Nitrogen and phosphorus-containing nutrients were mixed into the sediments in solid, pelletized form to provide a steady time release of nutrients. Oxygenation pipes were buried at 1 m depth in the stream bed sediments, perpendicular to the flow direction at 10 m intervals. The oxygenation pipes were manifolded to a series of blowers which pumped air into the sediments thus providing ample oxygen to support the microbial activity. The combination of this continuous oxygen supply plus the constant release of essential nutrients increased the indigenous bacteria population by several orders of magnitude and thereby greatly accelerated the biodegradation rate of the residual hydrocarbons.

3.3.2

Sediments which collected in the settling basins behind the dams and from the flocculation basins were excavated and treated in above-ground biological treatment piles (biopiles). Due to the fine grain size of these sediments, bulking and drying agents were added to increase permeability. Nutrients were mixed into the sediments and a network of oxygenation pipes was installed as the pile was constructed. Air blowers drew atmospheric air through the pile which provided ample oxygen to support the biodegradation process.

3.3.3 Hill side remedial action, source of the leakage.

The original plan to treat contaminated soils from the hillside where the leak occurred was to excavate the soils and treat them in an above-ground biopile. It was learned, through geotechnical investigations, that the hillside sediments were inherently unstable as a result of local geologic conditions. The risks were analyzed and it was decided to treat the contaminated soils in situ rather than risk destabilizing the pipeline during an excavation exercise.

The in situ remediation incorporated air sparging below the water table, soil vapor extraction of the vadose zone and nutrient addition to the soils via infiltration trenches.

## 4. Results

During meetings and planning with the governing agency and the client at the time of the environmental evaluation of the site conditions, the project goal was a decrease in hydrocarbon concentration to 5,000 mg/kg (Tab. 1).

After one year of treatment this goal was reached and surpassed, with the exception of the hill side area, for which a much longer time frame was envisioned, due to the physical conditions of HC-adsorbing soil and the slow degradation rates.

In view of the excellent results of the operation and the fact that remaining monies were still available, the client agreed to continue the process of stimulated biological degradation for the hill side. This was afforded to obtain the maximum cleaning in particular areas where residual contamination was still present in the soil.

The bioremediation action for the stream bed sediments and the soil pile is considered finished by the regulatory authorities (Fig. 2, 3, 4, and 5). Hillside treatment has been sufficiently effective to avoid the possibility that separate phase or dissolved hydrocarbons can migrate toward the stream. Further soil treatment and analyses at this time are under process.

The histogram on Fig. 2 shows the decrease in the percentage of the median concentration of TPH (Total Petroleum Hydrocarbon) on 19 sampled locations, considering 100% as a median value at the beginning of the operation. It is essential to note that initial concentrations reported by laboratories were far less. The discrepancies in laboratory results and field observations (lab results consistanly understated the concentrations of hydrocarbons in soil samples) are explained by several reasons:

- Wide variation in sediment matrix grain size distribution;
- Relative inexperience of local laboratory capabilities in soil analysis;
- Lack of standard analytical methods for soil analysis for hydrocarbons.

Laboratory analysis were, however, consistent in their reporting allowing Groundwater Technology to analyze relative changes in hydrocarbon concentrations over time.

Due to wide variations in the mass loading and distribution of hydrocarbons in the Rio Barca sediments the range of measured hydrocarbon concentrations varied significantly due largely to the grain size distribution of the sediment matrix. Figure 3 shows the range of stream bed sediment contamination in mg/kg before and after treatment. Data is from 19 designated sampling points distribution throughout the 500 m length of the Rio Barca impacted by the oil spill.

Two of the 19 sampling locations still show areas with some residual contamination: these are restricted areas, with irregular distribution and low permeability (e.g. silt and clay have strong affinity for adsorbing hydrocarbons). At these locations oxygen and nutrients transport, and therefore the whole bioremediation process develops more slowly.

The biodegradation rate in the above-ground biopile has been relatively slow but constant. An 80% reduction in hydrocarbon concentrations was achieved after 14 months of operation.

The fine grained matrix of the sediments reduce oxygen transport rates resulting in a slower rate of degradation than would be expected in a sandy matrix for example. Figure 4 shows the results of the biopile degradation progress.

In september 1991, the in situ biological treatment system which had been installed in the area of the pipeline rupture was activated. For this type of in situ operation longer treatment times were envisioned, due to the high initial contamination concentrations and because of the low permeability of the soil on the hill side. However, as the histogram of Fig. 5 shows, after one year of treatment a decrease of more than 60% from the initial concentration were achieved.

Regarding the operation costs, an intervention of traditional type, meaning the disposal in land fill, would have been not only very costly (over $5,000,000), but also impractical. Indeed, it is not thinkable that quantities of soil as voluminous as these should be completely removed and then replaced using clean soil in a mountain basin: problems connected to the stability of the slope as well as the hydrogeological and geotechnical equilibrium of the watercourse do not permit such an operation.

The choice of an intervention in situ, clearly compelling, proved to be notably efficient: the Comprehensive Site Remediation (CSR™) had a final cost of $1,500,000.

## TABLE 1

### DUTCH STANDARD FOR SOILS CONTAMINATED WITH MINERAL OIL

| TPH | CONTAMINATED LEVEL |
|---|---|
| <100 | CLEAN |
| 100 - 1,000 | ACCEPTABLE |
| 1,000 - 5,000 | RISK ASSESSMENT |
| >5,000 | TREATMENT NECESSARY |

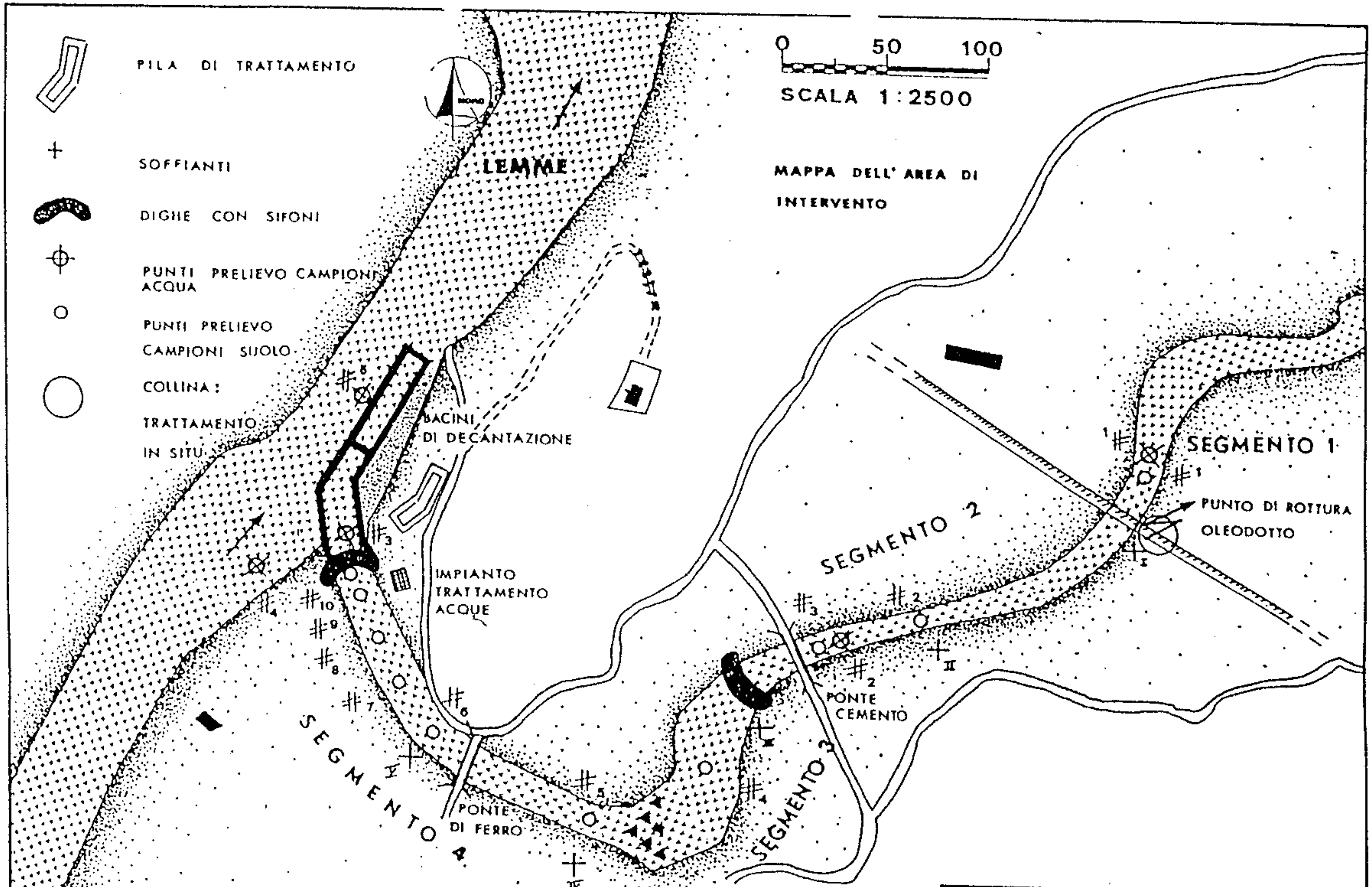


FIGURA 1

GROUNDWATER TECHNOLOGY ITALIA

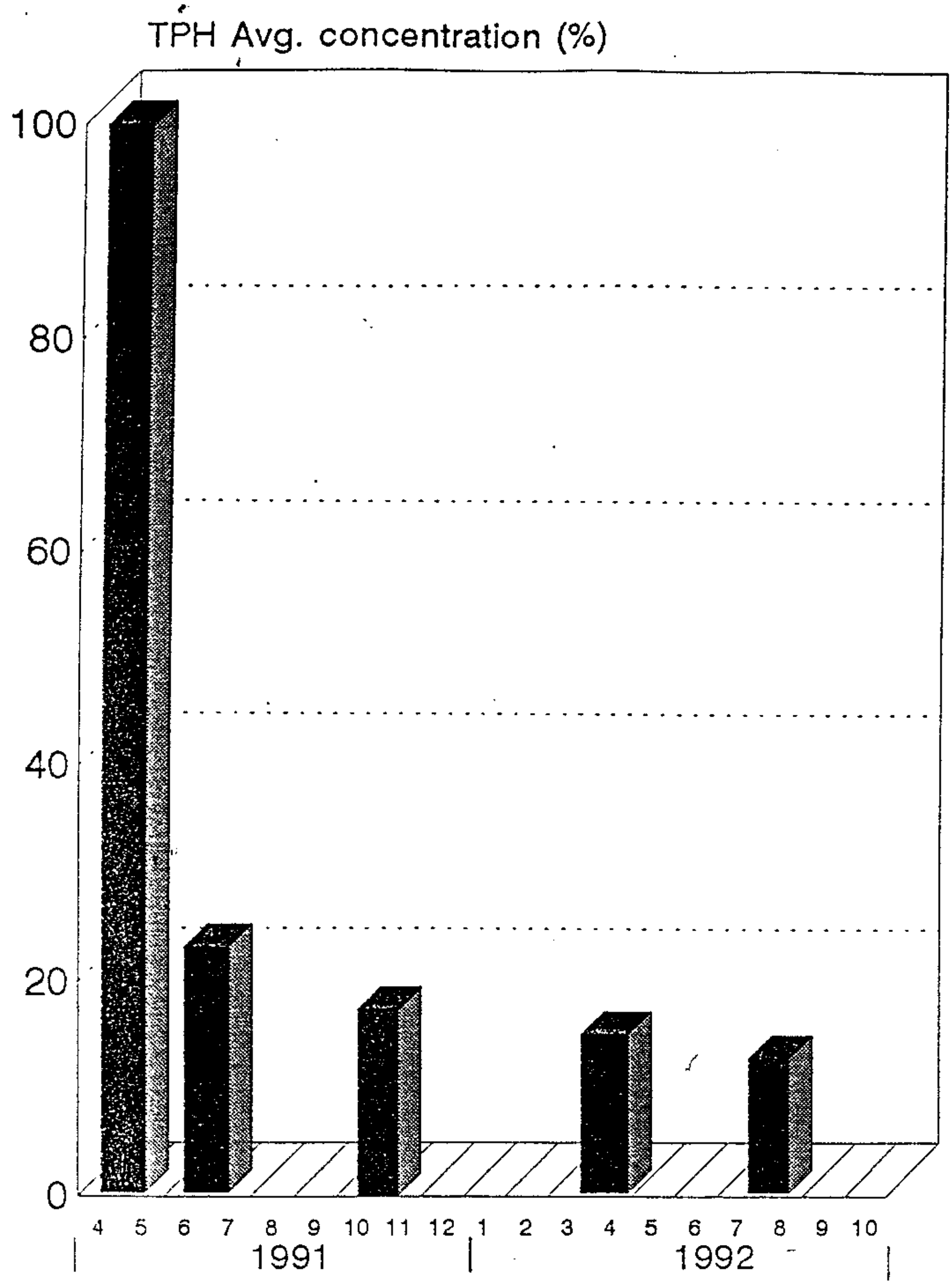


Figure 2: In situ Bioremediation of Rio Barca River (AL)

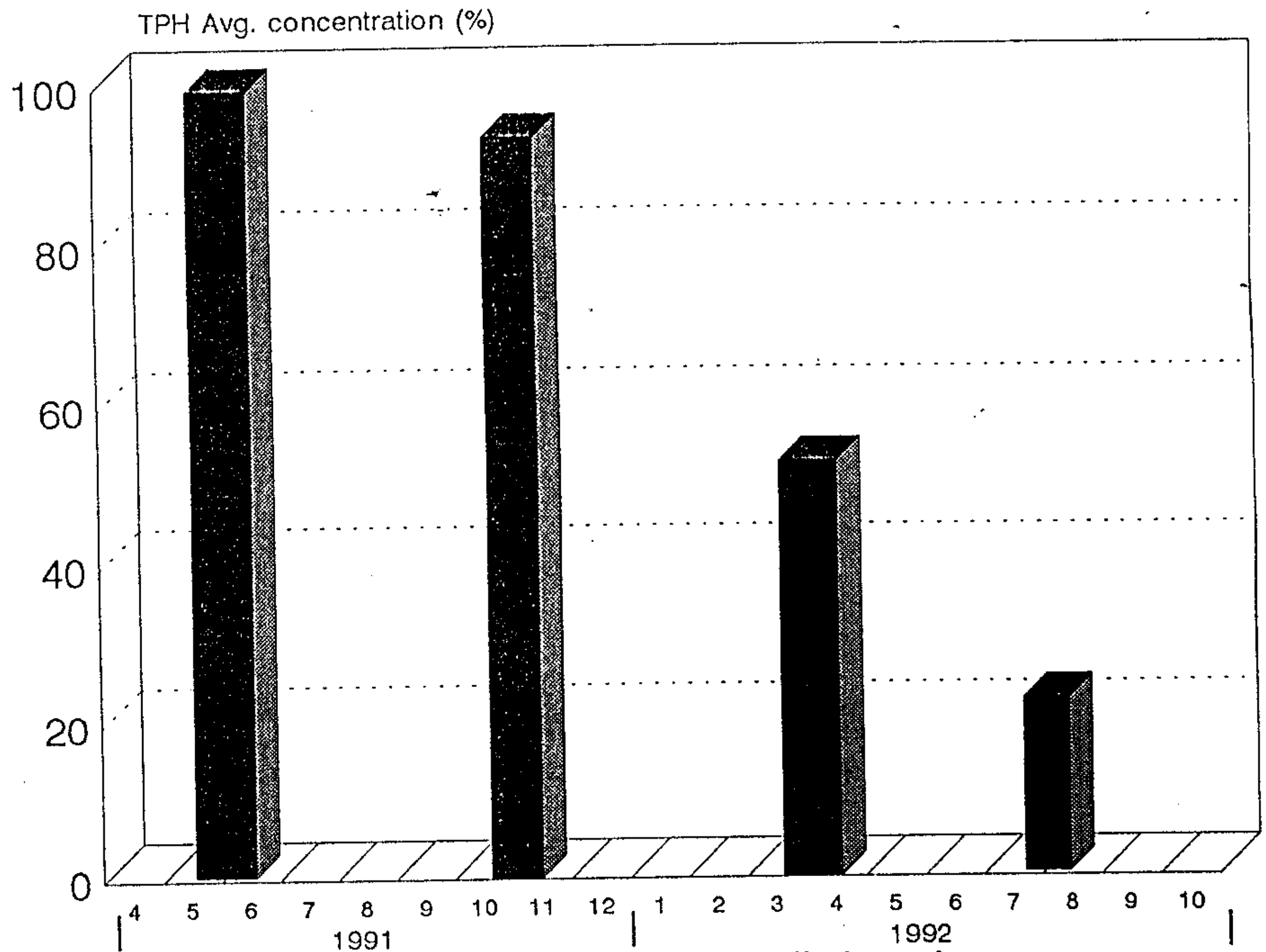


Figure 4: On site Bioremediation of the Rio Barca sediments with Soil Pile Treatment

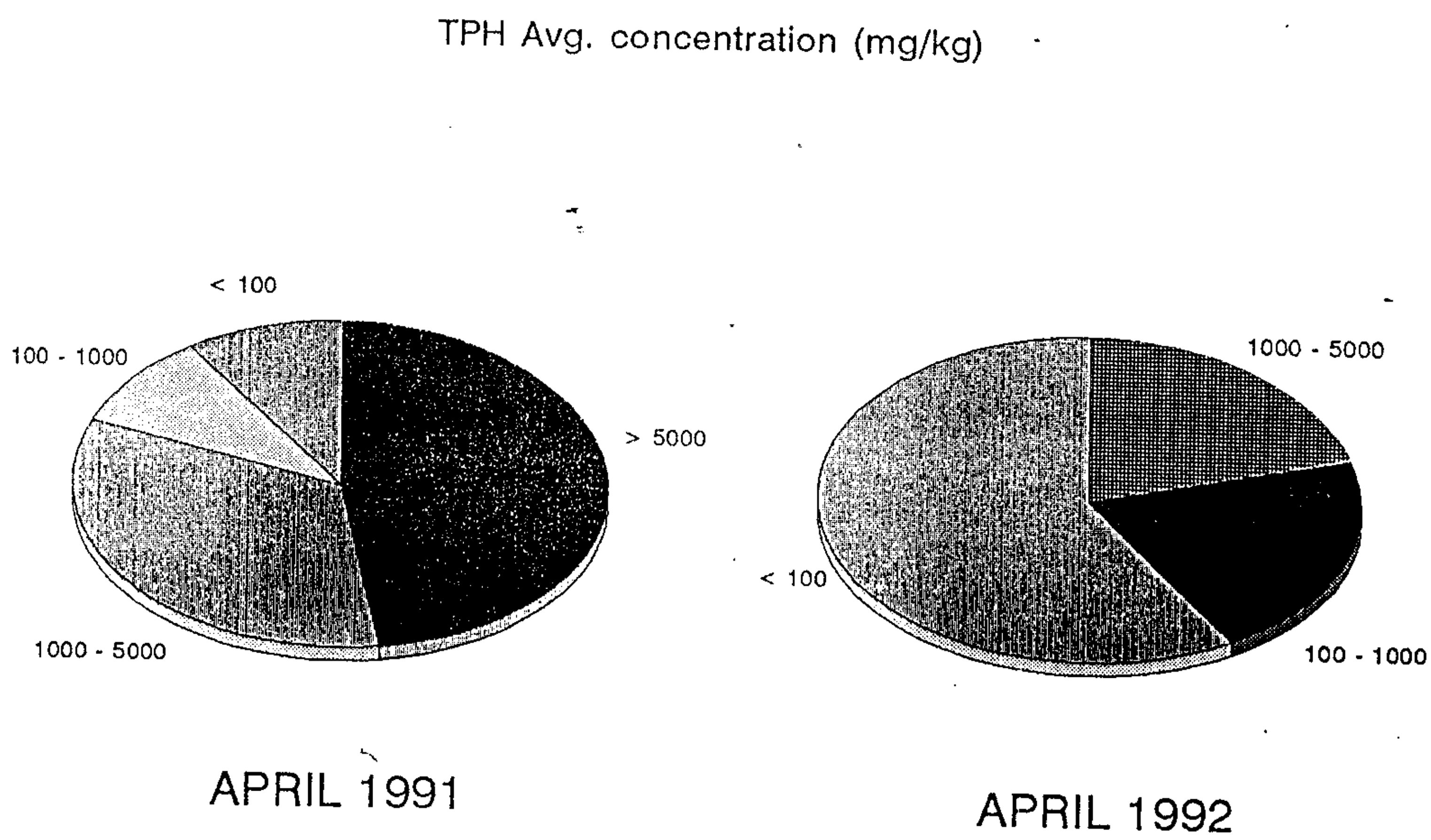


Figure 3 : In situ Bioremediation of Rio Barca River (AL) - TPH Area Distribution

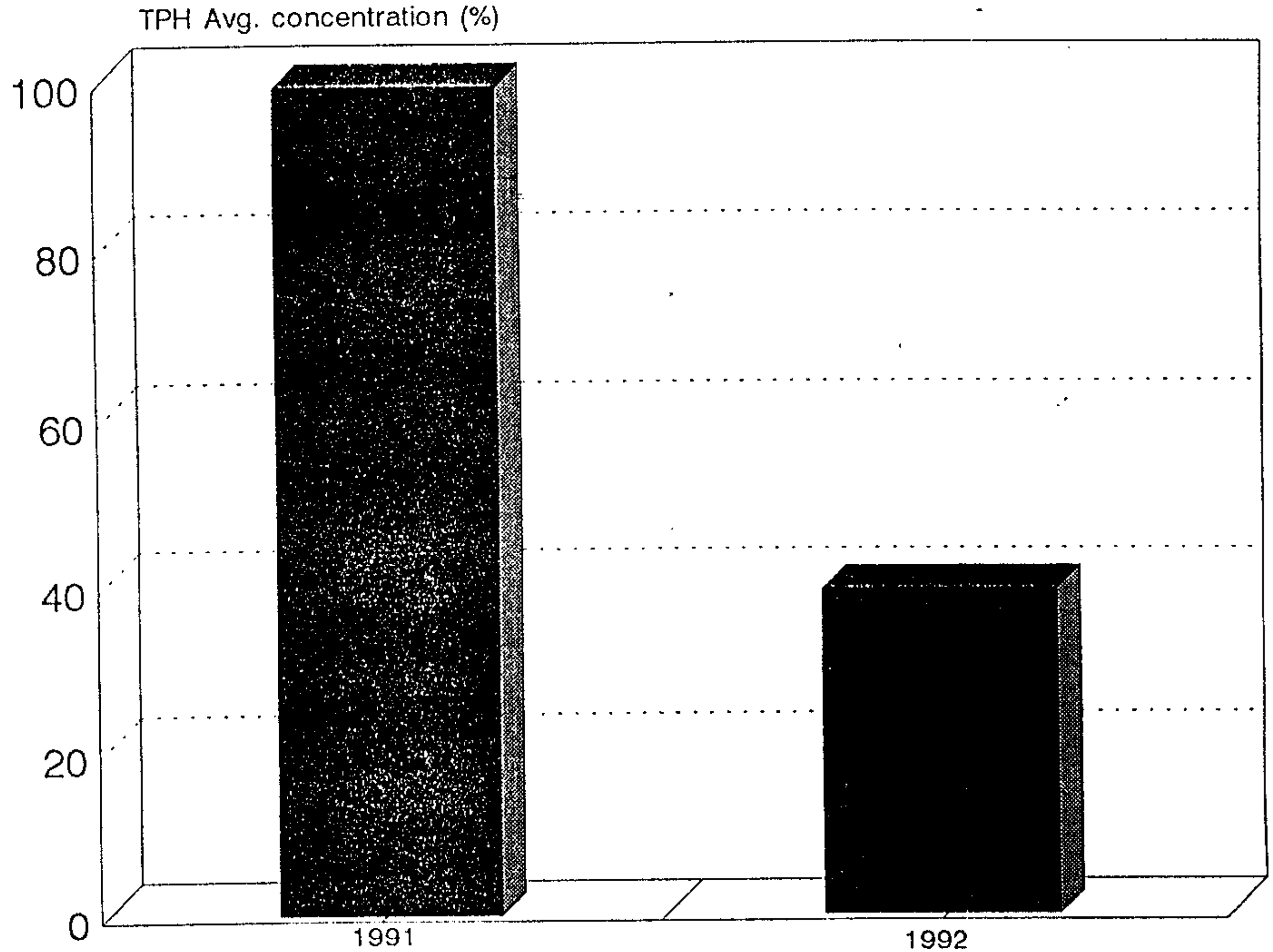


Figure 5: In situ Bioremediation
of the accident zone
Rio Barca (AL)

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