The extreme flooding of the Rhône valley in December 2003 (South east France): Consequences on the translocation of sediments and the associated contaminants over the flooded areas

Frédérique Eyrolle, Christelle Antonelli, Céline Duffa, Benoît Rolland

Institute for Radioprotection and Nuclear Safety, IRSN/DEI/SESURE, BP 3, 13108 St Paul Lez Durance, France

Abstract: During the extreme flood of the Rhône River and consecutive flooding that occurred at the beginning of December 2003 in the South east France, sediment mass and associated contaminants were transferred from the river to the agricultural soils of the region. Our results show that, generally, the pollution of the soils flooded in 2003 remains unchanged regarding radioactive and stable contaminants.

Key words: floods, flooding, Rhône River, contaminants, sediments

Introduction

Over the last few years, worldwide environmental protection policies have led to a significant reduction in industrial emissions of radioactive and other pollutant substances. However, we know now that certain build-ups such as fluvial sediment deposits are delayed sources of contamination. For river areas, one-off flooding episodes are major factors in remobilising contaminants which had previously built up in the sediments.

In early December 2003 unusual weather conditions led to a major flood of the lower Rhône valley. The extreme flooding downstream of Valence in December 2003 was the most significant flooding ever recorded on the Rhone. Its peak flow was faster than in the two most significant floods in history in 1840 and 1856. In the night of 3rd December 2003, the Rhône had a record flow of 13,000 m^3 s^{-1} at the Beaucaire gauging station. The December 2003 flooding was moreover exceptional in its rapidity. In less than 30 hours the Rhône went from 2,400 to 10,000 m^3 s^{-1} at Beaucaire between the 1st and 2nd December. This exceptional speed resulted from an intense and generalised rainstorm across the south-eastern quarter of France. This is a relatively well-known Mediterranean phenomenon linked to a perturbation stemming from a collision between cold air masses and warm, saturated air from the Mediterranean Sea. As a result of this extreme weather an area of roughly 500 km^2 of the lower Rhône valley was affected by flooding as the Rhône broke its banks and as dykes burst (Figure 1). When it floods, the Rhône carries large masses of solid matter in suspension as well as potentially associated trace contaminants from soil drainage

Short scientific paper

in the catchment area, by re-uptake of sedimentary matter. To give an example, the floods of September and November 2002 (8,000 and 9,500 m^3 s^{-1} respectively) carried $7.6x10^6$ metric tons of suspended matter to the sea in 20 days, that is 90% of the total quantity carried out in 2002; and 115 ± 10 GBq of ^{137}Cs, that is 83% of the annual flow in 2002 (ROLLAND ET AL., 2004).

Flooding causes extreme matter flows to the sea but also towards the soils in the alluvial plain. This study sets out the results obtained on the translocation of sediments and associated contaminants onto the most flooded areas of the lower part of the Rhône valley during the extreme event of December 2003. We determined the quantities and spreading of sedimentary deposits and associated stable and radioactive contaminants. Finally, the consequences of such extreme flooding on the contamination of the food chain are estimated.

RESULTS AND DISCUSSION

The least thick deposits and the finest sedimentary textures were found in the areas furthest from the dyke burst (distant zone), in accordance with well-known fluvial geomorphological mechanisms.

In the near zone, the sediments deposited by the floodwaters are mainly coarse and fine sands due to the drastic reduction in the

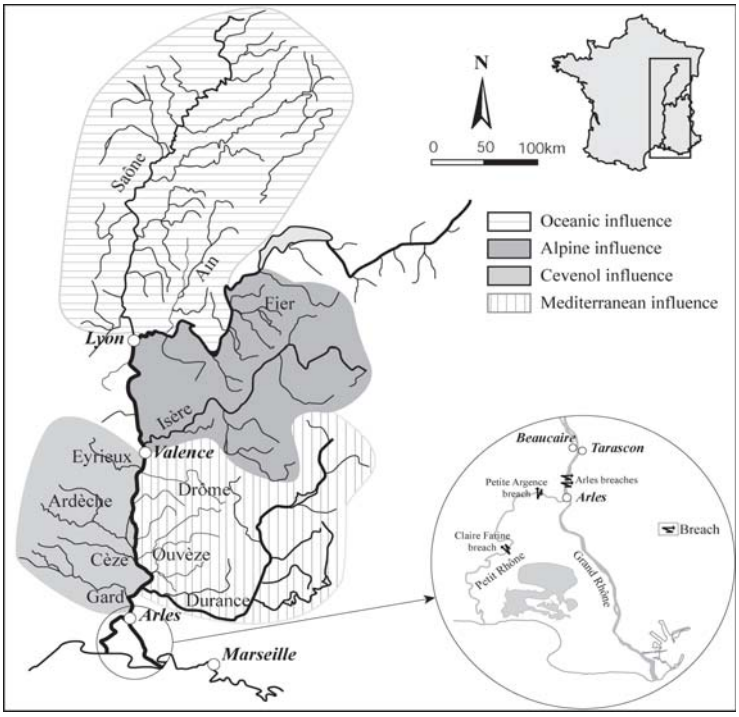

Figure 1. The Rhône watershed and main hydrological contributions – Localisation of breaches during the extreme flood of December 2003.

water's potential energy at the time of dyke breach. The maximum height of sand deposits measured is in the order of 1.20 m_{dry}. The sand deposits may cover a 3 km^2 area from the breached dyke. In the far zone the maximum height of clay and silt deposits measured is 0.05 m_{dry}. Silt deposits cover a wider area. The quantity deposited around the breached dyke at "Claire Farine" may be up to 1.5 metric $tons_{dry} m^{-2}$ for sand deposits (0.85 m_{dry}) and 40 $kg_{dry} m^{-2}$ for clay and silt deposits (0.025 cm_{dry}). Hence the sample deposits are heterogeneous in terms of water contents, the thickness and mass were adjusted to represent a unit of dry matter (at 80 °C) in order to make a comparative study.

The only artificial radionucleides detected by gamma spectrometry are ^{137}Cs and ^{60}Co. The ^{137}Cs was found in all the samples analysed (53/53). The ^{137}Cs comes from soil drainage in the Rhone catchment area affected by atmospheric fall-out from surface nuclear testing carried out in the past and by the Tchernobyl accident. This element is also emitted by nuclear installations in the Rhône valley, in particular the irradiated fuel reprocessing plant at Marcoule. The ^{137}Cs activity emitted by the nuclear industry is currently 2 to 3 times lower than the ^{137}Cs activity within soil drainage water from the Rhône basin, as a yearly average (Eyrolle and Duffa, 2002).

The region's agricultural soils falling within the area studied show ^{137}Cs activity of 4 to 30 Bq kg^{-1}_{dry}, that is surface activity between approximately 1000 and 8000 Bq m^{-2} (average density of agricultural soils in the Camargue area: 1050 kg m^{-3}, homogeneous over 0.25 m). The results of analyses on the deposits show that the sands contain in the order of 1 Bq kg^{-1}_{dry} of ^{137}Cs and the clay and silt deposits 25 Bq kg^{-1}_{dry}. In the environment, ^{137}Cs tends more often to fix on fine clay-like particles. It is thus consistent that higher ^{137}Cs specific activity should be found in clay and silt deposits. On the basis of our results, we estimate that the ^{137}Cs surface activity from the flood deposits is between 45 and 2100 Bq m^{-2} (for 1.20 m of dry sand) and between 75 and 2000 Bq m^{-2} (for 0.05 m of dry silt). These values are within the order of magnitude of soil ^{137}Cs activity in the region.

The ^{60}Co activity levels in the deposits from the December 2003 floods are generally below detectable limits. This element was only detected in 4 out of the 53 samples analysed. ^{60}Co is an activation product that only ever comes from nuclear installations. The ^{60}Co activity emitted by the whole of the Rhone valley nuclear industry is currently significantly lower than the ^{137}Cs activity in the waters of the Rhône, as a yearly average. ^{60}Co was only detected in the sand deposits at levels in the order of 0.3 Bq kg_{dry}. These values are very close to the limits of detectability for sands (0.2 Bq kg^{-1}_{dry}). In the silts, the ^{60}Co activity is below the limit of detectability (0.6 Bq kg^{-1}_{dry}). ^{60}Co has only been detected very rarely in the region's agricultural soils. The presence of this element in the soil can only be due to inflows of river water from the Rhone, in particular via irrigation. Furthermore this element is mainly transferred into water in a dissolved and colloidal form. For the floodwater flows at Arles in the order of 4000m^3 s^{-1}, 30% of the ^{60}Co present in the water was associated with solid support matter whereas, for this same flow, more than 80% of the ^{137}Cs existed in particulate form. Finally, this element has a relatively short

radioactive half-life ($T_{1/2}$ = 5.2 years) and thus breaks down in the environment quicker than ^{137}Cs, whose half-life is around 30 years. The presence of ^{60}Co in the control soil sample, as in other soils in the region that were not affected by the December 2003 floods shows the effect of recent or continuing inflows of water from the Rhone from irrigation or previous flooding. $^{239+240}Pu$ and ^{238}Pu mass activity in muddy deposits are 0.3 Bq kg s^{-1} and 0.04 Bq kg s^{-1}, respectivelly, i.e., 2 to 3 order of magnitude lower than those of ^{137}Cs. Plutonium isotopes ratios underline a significant contribution of the previous reprocessing plant releases through contaminated sediment remobili-sation (EYROLLE ET AL., 2004).

As regards heavy metals analysed (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn), the highest concentrations are observed as expected within the finest sedimentary textures. The measured concentrations in deposits do not significantly differ from those generally observed in the soils of the same area and are far lower the values generally retained for polluted soils (BRGM, 2002). From the 287 organic molecular compounds that were looked for only 3% of the results show concentrations slightly higher than the specific detection limits. The few organic molecules that were detected belong to hydrocarbon and insecticides.

The level of activity measured in crops and prairie grass sampled in January 2004 are not significantly different from those measured in similar samples that have not been affected by the floods of December 2003. As regards the grass and the goat milk from a flock reared on affected prairie collected in June 2004, the results do not underline any significant transfer to the food chain as expected with respect to low contamination levels of the flood deposits.

CONCLUSIONS

During the extreme flood of the Rhône River and consecutive flooding that occurred at the beginning of December 2003 in the South east France important sediment mass were translocated from the river to the agricultural soils of the region. The maximum height of sand deposits was measured in the close zones from the dyke breaks and may reach 1.20 m_{dry}. Clayey and silt deposits cover a wider area. The maximum height of clayey and silt deposits measured was around 0.05 m_{dry}. The quantity deposited around the breached dyke may be up to 2 metric $tons_{dry}m^{-2}$ for sand deposits and 80 $kg_{dry}m^{-2}$ for clay and silt deposits. Generally, the pollution of the soils flooded in 2003 remains unchanged as regards radioactive and stable contaminants and the level of contamination measured in the vegetable crops was not significantly different to that measured in similar samples that were not affected by the December 2003 floods.

References

BRGM, (2002): Gestion des sites (potentiellement) pollués – Annexe 5C- Valeurs guides en matičre de pollution des sols et des eaux.

EYROLLE, F., DUFFA, C. (2002): Sedimentary beds as a delayed source of ^{137}Cs, ^{238}Pu and $^{239+240}Pu$ for the Rhône River freshwaters, 9th International Symposium on the interaction between sediments and waters, Banff Springs Hotel, Canada, May 5-10.

EYROLLE, F., CHARMASSONS, S., LOUVAT., D. (2004): Plutonium isotopes in the lower reaches of the river Rhône over the period 1945-2000. *Journal of Environmental Radioactivity*, Special issue, *74*, 127-138.

ROLLAND, B., ANTONELLI, C., EYROLLE, F. (2004): Fluxes of suspended Fluxes towards the Mediterranean Sea and sedimentary inventories. material and associated radionuclides to the sea during flood events of the Rhône River, ECORAD 2004, 6-10 Sept. 2004, Aix en Provence, France.