THE RIVER IS DEAD

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London Mining Network (LMN) is an alliance of human rights, development, environmental and solidarity groups working in support of communities around the world who are badly affected by mining companies based in, or financed from, London.

One such company is BHP (formerly BHP Billiton), the largest diversified mining company in the world, listed on the London and Australian Stock Exchanges, and in which many British financial institutions invest.

BHP owns 50% of the Samarco iron ore operation in Brazil. Samarco is an open-pit mine with 4,000 million tonnes of iron ore resources. It is exploiting itabirite, a low grade ore. The useful mine life was estimated in 2005 at 50 years if it were to continue production at the level it reached then. But it had expanded its production in the period leading up to November 2015, when a disastrous tailings (fine wastes) dam collapse occurred. The increase in production may have been because the quality of the ore was actually lower than the company had previously estimated.

Mining takes over large areas of land in Brazil. The two main mined and exported minerals - iron ore and bauxite - yield both profits and taxation. But communities suffer as companies 'externalise' costs. Brazil's former left-leaning government and other such governments in Latin America have been accused of trying to 'rebrand' mining to make it seem more advantageous and less destructive than it really is. Now it appears that, under a right-leaning coalition government, Brazil wants to expand mining even further, particularly by moving to environmental self-regulation and depriving protected areas of legal safeguards, and to increase mining taxation.

It was in this context that the November 2015 catastrophe occurred. It is usually said that 19 people were killed in that disaster. Community representatives who attended the 2016 AGM of BHP in London prefer to say that 20 were killed, as one woman who was heavily pregnant lost her baby when she was thrown around by the flood.

Impacted communities inhabiting the corridor of destruction and waste deposition along the Rio Doce - consisting of as many as 1.4 million people - are seeking urgent action to remediate ecosystems and restore nature-related livelihoods in the face of delays by the Samarco partnership and their Renova Foundation.

This report, by researcher Paul Robson, examines the immediate and continuing impacts of this disaster and the efforts of Samarco and its multinational corporate owners to tackle those impacts.

It is a measured and judicious report, but it nonetheless conveys something of the grief and horror experienced by those who lived through the disaster and the appalling continuing impacts on people's lives through loss of loved ones, homes, communities and livelihoods.

LMN has been working with Brazilian organisation Movimento dos Atingidos por Barragens (MAB), the Movement of People Affected by Dams. MAB has a number of demands as a result of the 2015 disaster.

1 The Renova Foundation, established by the mining companies to repair the damage caused by the collapse of the Fundão Dam and provide compensation to those affected, must act in good faith and transparently, and not restrict the independence or autonomy of community processes.

2 All the families affected along the Rio Doce must be granted emergency rights and participation in the compensation process. The mining companies must not be the ones who decide who is and who is not affected. Many people living slightly further away from the dam breach were still affected, but have not received any compensation.

3 The process of general repair must be speeded up. This is especially urgent in the construction of housing, provision of health services and support for the resumption of local production. Further, permanent solutions must be sought for the economic reactivation of areas along the Rio Doce. Water insecurity is leading to a precarious situation for the provision of adequate food.

4 Affected communities continue to denounce the inefficiency of the Brazilian justice system, which MAB says benefits companies but not people. In March 2016, after disagreement over judicial jurisdiction, the criminal investigation conducted by the Civil Police was suspended, which delayed the investigation into management responsibility for the dam breach. Communities seek accountability of those responsible.

We at LMN hope that Paul's report will make a contribution to the quest for social and environmental justice and reparation for those whose lives were devastated and continue to be significantly affected by the 2015 catastrophe.

> The corporate response to what is documented here by the London Mining Network remains denial and avoidance. What London Mining Network have done with this remarkably insightful and eloquent study is take over community control of the narrative on consequence and duty to take responsibility." - Lindsay Newland Bowker
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> *Lindsay Newland Bowker is the founder and head of her own Public Interest Research group, Bowker Associates Science & Research on The Public Interest, in Stonington, Maine, USA, and has partnered with scientist and global leader in responsible mining, David M Chambers, to focus on tailings failure trends and root causes. Two of their partnered works are cited in our conclusions section. Dr. Chambers is founder and head of the Center for Science on Public Participation, Bozeman, Montana.*

> **People affected by the impacts of the dam collapse do not know what their future will be as they have lost their livelihood: people do not see how they can continue living without their land or the livelihood that they have followed for many years. People feel a devastating experience of the loss as their settlement (or its economic basis) no longer exists and the references which structured routines and social organization were abruptly destroyed. People who have been previously impacted by major changes to their lives (such as the Krenak indigenous people who were dispossessed of their land and then returned, or communities who were displaced by hydro-electric dams) know that adapting to making a living in a new location is a long and painful process.**

CONTENTS

Researched and written by PAUL ROBSON

Photos:-

- NILMAR LAGE (IPATINGA, BRAZIL)
- PAUL ROBSON (LONDON, UK)

Works quoted as references in short form in brackets throughout the text are listed at the end of this report.

INTRODUCTION

This is an assessment of the present and likely future impacts of the catastrophic failure of the Fundão tailings dam in the state of Minas Gerais in the Federal Republic of Brazil on the 5th November 2015. The Fundão Dam was a holding structure for waste material from the processing of iron ore of the Samarco Mining Company. SAMARCO is, at present, a joint venture between the Brazilian company Vale S.A. and British-Australian BHP. The dam collapsed on 5th November 2015, eventually releasing 45 million cubic metres of mining waste into the Rio Doce river system and also affecting an area of the Atlantic Ocean over 600 km from the dam.

This report is based on the available Brazilian literature in Portuguese about the collapse of the Fundão dam and its impacts, discussions with Brazilian researchers and experts about the disaster, and a three week visit to the Rio Doce region in June 2017 to observe the impacts and interview people along the river whose lives have been transformed by the impacts of this disaster. The report aims to fill a gap in the literature in English about the impact of the collapse of the Fundão Dam. It also aims to show what can be the effect of the catastrophic failure of a tailings dam and serve as a guide to Environmental Impact Assessments (EIAs) of tailings dams: Environmental Impact Assessments of tailings dams usually only consider the possible local effect of tailings dam accidents and rarely take into account the possibility of a failure of this magnitude that can affect a large area and have long-term effects.

The report begins by describing the flow of mining waste into and down the Rio Doce system in the immediate aftermath of the collapse of the Fundão Dam and the deposition of mining waste in the river basin. It then describes what has been done since to contain the mining waste and remove some of it, and what is planned to be done. It goes on to look at the environmental impacts of the spill of waste into the river system, and the effect of this on the economy, health and society.

For the purposes of this report the area of the Rio Doce basin affected by the release of mining waste has been divided into the following zones:-

I. CORREGO SANTAREM

II. BENTO RODRIGUES AREA

III. DOWNSTREAM OF BENTO RODRIGUES

IV. BICAS, PARACATU DE BAIXO, GESTEIRA

V. BARRA LONGA AREA

VI. CANDONGA RESERVOIR

VII. CANDONGA DAM TO BAGUARI DAM

VIII. BAGUARI DAM TO LINHARES

IX. ESTUARY OF THE RIO DOCE

X. OCEAN SURROUNDING THE ESTUARY OF THE RIO DOCE

The help of the Movimento dos Atingidos por Barragens (MAB) is acknowledged: without their help, it would not have been possible to visit localities along the Rio Doce, contact so many affected people and see directly the impacts. A number of specialists and researchers were also interviewed in Brazil and their help is acknowledged.

A THE COLLAPSE OF THE FUNDÃO TAILINGS DAM

On 5th November 2015, the Fundão tailings dam in the Mariana District of the state of Minas Gerais, in the Federal Republic of Brazil, operated by the SAMARCO mining company, burst, releasing a total of 45 million cubic metres of mining waste. At an altitude of about 1200 metres above sea level, the Fundão Dam was a holding structure for waste material from the processing of iron ore of the Germano Unit of the Samarco Mining Company. It was one of the megastructures of the Germano mining complex. There are two other dams in the complex, Santarém and Germano, the latter being the highest dam in Brazil, with a height of 175 metres and a projected volume of up to 160 million cubic metres of tailings (Carmo et al., 2017, page 2)

A view over the tailings ponds near the Germano Mine, showing their size and what is behind a tailings dam. (Nilmar Lage)

The Fundão dam began operating in 2008 and was designed to contain a total of 79.6 million cubic metres of fine tailings (mud) and 32 million cubic metres of sandy tailings during its 25-year lifespan. In November 2015, Fundão Dam contained 56.4 million cubic metres of iron ore tailings deposited in just seven years of operation, a result of the high production level from 2013 to 2015. (Carmo et al., 2017 page 2)

The Samarco iron mine is located in the area of the Alegria mineral deposits, part of the large-scale Itabirito deposits of the "Iron Rectangle" (a series of iron deposits close to the surface, south of Belo Horizonte, that form a more-or-less rectangular form). The Alegria deposits are made up mainly of hematite (iron) and quartz.

SAMARCO was founded in 1977 and at present it is a joint venture between Vale S.A. and BHP. The mining complex is made up of two mines, mineral processing plants (to increase the percentage of iron ore by removing waste material), waste reservoirs (held back by tailings dams), mineral pipelines (to Ubu on the coast in the state of Espirito Santo), pellet plants, and a port on the coast for export of iron ore. The water for this operation comes from the Rio Santa Barbara and puts pressure on the

water resources of the region (Terra Arrasada, 2016, page 7). Water is used in the processing plants to remove the waste, and in the transport through the pipelines.

Floating booms were deployed as the pollution approached the mouth of the Rio Doce, in an attempt to prevent water polluted by mining waste spreading into creeks and some parts of the shoreline. This failed because the waste was in suspension and passed under the booms. The booms are designed to prevent the spread of surface oil pollution, not pollution in suspension. (Nilmar Lage)

The method of processing of iron ore used by SAMARCO had the objective of concentrating the iron through crushing, milling and flotation of the extracted material. The product from the processing meets the technical specifications needed to enter into the industrial processes of pelletizing carried out at the Ubu Production Unit. The process of flotation creates a material with a lower level of iron, and with no economic value, which is disposed of as waste in dams. The waste from the processing by SAMARCO was deposited in the waste reservoirs of Fundão, Germano and Santarém dams as a pulp in the form of large-sized waste particles (sand) and fines (mud), after a reduction in the level of water and removal of ultra-fine particles. There is evidence that the Fundão reservoir contained waste from other Vale mines and not just those of SAMARCO (Justiça Global, 2016).

On 5th November 2015, at about 15.30 hours, there was a catastrophic failure of the Fundão tailings dam releasing mining waste, in a viscous liquid form, from the reservoir behind the dam. The mining waste passed cascaded over the Santarem Dam, immediately below the Fundão Dam, forcing the passage of a tidal wave of waste material that entered the Corrego Santarém and the river system below generating mud waves 10 metres high (Carmo et al., 2017 page 2). As the wave of waste material flowed through the streams and rivers, other materials were eroded and carried along, including soil, sediment from the river banks, vegetation and other material, and then deposited on flood plains and stream channels.

There is evidence that the catastrophic failure of the Fundão tailings dam (as with other tailings dam collapses) came about because declining prices for iron ore on the world market were compensated for by higher throughput volumes without investment in additional waste management capacity (Kiernan 2016) The mineral boom of post-2003 had led to rapid investment in mining capacity to meet the rising demand. From 2011 onwards there has been a decline in demand, and thus a decline in prices, but production continued at a higher level (to pay for the previous investment) (Leitão, 2017, page 51).

The Fundão Dam was an "upstream" tailings dam. It is a common method of tailings disposal, with the greatest economic advantage. However, it poses a significant challenge to the geotechnical engineer and is considered to be an "unforgiving structure". Dams using the upstream embankment method represent up to 66% of the reported failures of tailings dams globally. The main limitation of this tech-

nology is that the foundation of later heightening of the dams is on unstable tailing slime, with the possible presence of water, which can cause instability. It requires a high level of monitoring using good instrumentation throughout operation and beyond. It is recommended that tailings dams should be heightened by no more than 5 metres per year (Carmo et al., 2017 page 2).

Since the beginning of the operation, in 2008, the Fundão Dam had presented several anomalies related to drainage defects, upwelling, mud and water management errors and saturation of sandy material. In some cases, emergency measures had been required. One of the measures, a retreat of the dam axis, was begun in 2013. According to SAMARCO, the retreat represented a temporary solution but was maintained until the collapse of the dam (Carmo et al., 2017 page 2).

Regulatory bodies in Brazil hardly ever consider turning down mining projects, since they regard them as vital to economic development, and mining corporations are highly influential in the political domain and on decision-making organizations. Rejecting projects is thus exceptional: EIAs are seen as a bureaucratic step, not a real check. Projects are almost always approved, though with conditional requirements that make the assumption that risks identified during the licensing process can be prevented, mitigated or compensated for at a later date. The use of conditional requirements speeds-up the licensing process but in practice it is difficult to ensure the conditional requirements are met once the project is under way, and responses to conditional requirements are procedural, without solving identified problems (Santos and Milanez, 2017).

I CORREGO SANTARÉM

In the first 5 km below the dams there is a steep and narrow valley of the Corrego Santarém. ('Corrego' means stream.) The large volume of viscous liquid, at a high velocity, forced a passage through this valley. It eroded the sides and bottom of the valley and carried away this additional soil and vegetal material.

II BENTO RODRIGUES AREA

After about 5 km, the Corrego Santarém stream meets the Corrego Mirandinha. The large volume of viscous liquid continued to flow down the Santarém but also flowed back up the Mirandinha, because the narrow sections of valley beyond the Santarém restricted the immediate flow of material downstream. Flowing down the Santarém the tidal wave of mining waste passed through the settlement of Bento Rodrigues, where the valley is wider and less steep.

A Samarco worker telephoned her family in Bento Rodrigues to warn of the tide of mining waste. Otherwise there would have been no warning for the people of Bento Rodrigues, as there was no alarm or other early-warning system (Terra Arrasada,2016, page 4). Some of the people of the village managed to escape by running up the valley slopes. When they looked back, they saw their houses being knocked over and other people being swept away. The body of one child from Bento Rodrigues was found at Ponte da Gama, 70 km below the Fundão Dam: she had been caught up in the wave of mud with her father and brother and, though the others had managed to escape with the help of neighbours, she was swept away. On top of the mud there was a large rock, rotating as it was carried along by the tide of waste material (Terra Arrasada, 2016, page 4). Some corpses were found 110 km from the accident (Leitão, 2017, page 55). An early warning system was installed only after the collapse of the dam, because of the risk of collapse of the other tailings dams associated with the Fundão Dam. But local people question whether this would give time for them to escape.

III DOWNSTREAM OF BENTO RODRIGUES

Below Bento Rodrigues the Corrego Santarém stream meets the Corrego Camargo, where they join to become the Rio Gualaxo do Norte, approximately 7 km after the dam of Fundão. The tidal wave of mud flowed back up into two arms of the Camargo for approximately 4 km, while also continuing into the narrow and steep section of the Gualaxo do Norte below. This section is uninhabited. As had happened in the Corrego Santarém, the flow of mining waste eroded the sides and bottom of this valley and carried away additional soil and vegetation.

> We stood on the hillside watching the sea of mud going past, making a terrible noise. It was unimaginable. There were boulders and masonry and bits of machinery carried along on top of the mud and the noise was horrific. We spent the night scrambling round on the hillside in the dark, trying to find each other.

Resident of Bento Rodrigues

IV BICAS, PARACATU DE BAIXO, GESTEIRA

This section of river is less steep, more open and less narrow, and includes a number of settlements such as Paracatu de Baixo (40 km from Bento Rodrigues), Bicas and Gesteira. The wave of mining waste arrived at Paracatu de Baixo four hours after it hit Bento Rodrigues; at about 20.00 hours, a police helicopter landed in the middle of the football field and told those playing that they had 15 minutes to get out of the village (Terra Arrasada,2016, page 4). The people of this settlement managed to escape by running up the valley slopes, in the dark. In Gesteira, few people lived near the river banks, most people having moved their residences to higher ground after a serious flood in 1979, and people were not in their fields by the river at that time of day. Those people who lived close to the river had a few minutes' warning to run up the valley slopes in the dark to safety.

V BARRA LONGA AREA

Barra Longa is a small town 26 km from Paracatu de Baixo, just after the junction with the Rio Carmo. The wave of mining waste arrived in the middle of the night, at about 03.30 hours. People knew that mining waste had escaped into the river, but it was just before it arrived that the police came to warn of the magnitude of the flow of mud and how serious it was likely to be. Those living closest to the river had to run away from the river to escape. The mud rose rapidly and was already entering people's houses and flooding the square near the river as people escaped (Terra Arrasada, 2016, page 4). There was backwash of the wave of mining waste into the upper Rio Carmo, and the extensive fields alongside the river, both below and above the confluence of the rivers, were covered with mud.

VI CANDONGA RESERVOIR

The Candonga Dam is a hydro-electric dam, with an extensive reservoir, just below the junction of the Rio Gualaxo do Norte with the Rio Piranga to form the Rio Doce. (The official name of the dam and reservoir is Risoleta Neves.) At this point, there was a significant reduction in the velocity of the flow of

mud, and thus large-scale depositing of mining waste in the reservoir of the dam. Ten million cubic metres of waste were trapped behind the Candonga Dam.

Water had to be allowed to pass over the spillway of the Candonga Dam, and this contained significant quantities of finer waste material in suspension.

VII CANDONGA DAM TO BAGUARI DAM

This is a long section of the Rio Doce, which includes a National Park and several larger towns. On 8th November 2015 the flow of water, containing finer waste material in suspension, reached Baguari Dam. The Baguari Dam probably trapped some of the mining waste in the aftermath of the dam collapse, but considerable amounts of fine particles flowed past it (and some continue to do so). The flow reached Ipatinga on 8th November and the Baguari Dam on 9th November.

VIII BAGUARI DAM TO LINHARES

On 9th November, water had to be released from the Baguari Dam. Below Baguari is the important town of Governador Valadares with a population of 280,000 people. The flow of water with mining waste in suspension threatened the water supply of the town, which was from the river, and on 10th November a State of emergency was declared in Governador Valadares.

> We moved here when we lost our land with the building of the dam. It took almost 10 years to get the farm working again. There are still people near here who get water by lorry for their cattle to drink, because the different sources of water that were tried didn't work. It takes a long time to get a small business going again if your circumstances change. My Mombassa Grass improved pasture died because I stopped irrigating it with river water in late 2015 due to the mining mud in the river. I have re-seeded and started irrigating again but it isn't growing like it used to.
>
> *Farmer near Aimores Dam*

This stretch of river Includes further hydro-electric dams at Aimores and Marcarenhas. The brown water reached the town of Conselheiro Pena on 13th November, and then crossed the border from the state of Minas Gerais to the state of Espírito Santo and reached Aimorés on 15th November, Mascarenhas on 16th November, Itapina on 18th November and Linhares on 20th November. By this time, people living along the river had some time to take actions to mitigate the effects of the contaminated water. The mayor of Baixo Guandu moved the water supply equipment from the Rio Doce to a tributary stream. People had also turned out, and travelled to the area, to witness the arrival of the brown water.

IX ESTUARY OF THE RIO DOCE

Below the town of Linhares is a delta zone of the Rio Doce before it enters the Atlantic Ocean. This is a zone of deposition of sediments brought down by the Rio Doce. The course of the Rio Doce has changed over the centuries as the sediments changed the form of the delta. The delta is flooded occasionally, such as during the serious 1979 Rio Doce floods.

SAMARCO deployed floating booms in an attempt to prevent mining waste entering into the side channels of the river in the delta, but this failed as the booms were designed to prevent flows of surface pollution, such as oil, and not sediment in suspension. Contaminated water flowed under the booms and into the side channels and some low-lying areas such as Entre Rios (where farmers build their houses on stilts in case of floods). Fields were thus covered by a thin layer of sediment, and local people believe that the mining waste has infiltrated the sub-surface water.

X OCEAN SURROUNDING THE ESTUARY OF THE RIO DOCE

In the period leading up to the collapse of the Fundão Dam, there had been a drought in some parts of the catchment of the Rio Doce, and river flow was low. A sand bar had built up at the mouth of the river, separating it from the ocean. SAMARCO deployed earth-moving machines in an attempt to open the sand bar to allow the wave of material out. The flow of brown water and mud reached the sea at Regência on 21st November 2015 and crossed the sand bar (Terra Arrasada, 2016, page 4). A plume of sediment fanned out into the ocean in subsequent days and affected nearby coasts, including the turtle conservation area near the mouth of the river.

B WHERE THE WASTE WENT

The most important, and noticeable, impact of the collapse of Fundão Dam, is the presence of sediment in the streams and rivers downstream from the dam, and the deposition of mining waste in certain river-bank areas.

The historic Estrada Real (the Royal Road built by the Portuguese crown in the early 18th century) passes through Bento Rodrigues. One of the marks of the Estrada Real is surrounded by the devastation one month after the dam collapse.

(Nilmar Lage)

In general, larger-grained waste material was carried as far as the Candonga Reservoir and was retained in that location. Larger-grained waste material is therefore found in zones I to VI. Above Candonga Dam, the waste materials are composed mainly of quartz (about 60% by weight) and haematite (about 35% by weight), essentially fine sand, and are usually close to river banks. As a result of this the material lacks cohesion and is highly susceptible to erosion. When it is remobilised by erosion this material moves directly in the water courses. When it is disturbed by remedial works, it also tends to flow into the water courses or creates clouds of dust.

A month after the collapse of the Fundao Dam, just the roof of a house is showing above the mud in Paracatu de Baixo. (Nilmar Lage)

Fine-grained mining waste was transported in suspension. At the Candonga Reservoir, finer material flowed through the spillway and was deposited in the main channel of the Rio Doce. Some was retained in the Baguari Reservoir but suspended particles and colloids continued to flow through the Rio Doce to the middle and lower parts of the river, arriving at the mouth of the river and into the ocean (zones VII to X). The estimates by RENOVA suggest that about 20 million cubic metres of mining waste passed the Candonga Dam and thus are flowing into the sea, are deposited on the river bed or (occasionally) deposited on land beside the river. (RENOVA PRAI) (RENOVA is a Foundation created by the mining companies for the purpose of repairing the damage caused by the collapse of the Fundão Dam and providing compensation to those affected. It is a nominally independent foundation but is believed by many people to be heavily influenced by the mining companies.) Some of this mining waste will have been trapped by the other dams downstream of Candonga Dam, while some has been deposited on land near the river (especially Entre Rios in the delta of the Rio Doce and upstream of Governador Valadares). There is sediment on some parts of the river bed (which is remobilised from the river bed under conditions of strong winds or river currents) and there is a plume of waste flowing into the ocean. At the confluence of the streams and rivers leading from the dam with others, it can be clearly seen that there is a heavy load of sediment in the former while the latter are clear.

A month after the collapse of the Fundao Dam Paracatu de Baixo is a scene of devastation. (Nilmar Lage)

In the period leading up to the failure of the Fundão tailings dam, it was holding 54.4 million cubic metres of mining waste and water. On 5th November 2015, about 32 million cubic metres of mining waste and water were released into the river system. A further 11.7 million cubic metres were released before the flow of material was brought under control, giving a total of 43.7 million cubic metres released into the river system. According to estimates in the RENOVA Foundation's Plan for Environmental Recuperation, the following quantities of waste material have been deposited in different areas (RENOVA PRAI). (Various estimates have been published about deposition of waste material based on analysis of satellite imagery and field measurements; this appears to be the latest estimate.)

Behind Santarém Dam	**2.0 million cubic metres**
Corrego Santarém (Zone I)	**1.5 million cubic metres**
Area of Bento Rodrigues (Zone II)	**0.9 million cubic metres**
Below Bento Rodrigues and Above Candonga Reservoir	**8.9 million cubic metres**
Candonga Reservoir	**10.5 million cubic metres**

These official estimates do not state the amount of material that flowed past the Candonga Dam, but imply that about 20 million cubic metres of waste flowed downstream from Candonga Dam as suspended particles.

I CORREGO SANTAREM

In this initial stretch of the river above Bento Rodrigues there were large flows of highly viscous waste at a high velocity. This had a high erosive power, and the valleys were narrow with long longitudinal slopes. In these conditions the large, moving mass of waste material led to the complete removal of the soil profile and consequent exposure of the base rock along extensive stretches of the slopes of the valleys and the upper part of the soil profile. After the initial flow of waste material, as the flow rates and velocity fell, part of the waste material was deposited on the valley slopes, on small plateaus and in recesses where such materials could be trapped. The load of sediments was much higher than the capacity of the Fundão and Santarém streams, leading to the complete blocking of the channels by sediments. As a result, the whole of the flood plain was covered with waste, creating deposits more than 20 metres thick in some places, and changing the stream courses. There was reflux of material into small tributaries, including back up to the Germano dam.

II BENTO RODRIGUES AREA

In the area of the settlement of Bento Rodrigues, the speed of the flow of mining waste material after the dam burst was less than in areas just below Fundão Dam, and thus there was less erosion. In the final phases of the movement of waste material there was a high rate of deposition of mining waste material, leading to thick deposits on plateaus, terraces and flood-plains and even on less steep adjacent slopes. At Bento Rodrigues there is an area of deposition 80 metres wide. The deposits are made up of non-cohesive material and are very susceptible to erosion, leading to considerable erosion in the months after the formation of the deposits. The majority of houses in Bento Rodrigues were destroyed by the flowing mud, as were the community buildings in the centre of the settlement. Bento

Rodrigues had been an agricultural settlement but all its agricultural land became covered thickly by the flow of mining waste. Bento Rodrigues, just 6 km from the Fundão dam, was the most damaged district with 84% of the affected buildings totally destroyed (Carmo et al, 2017).

The reflux of waste material into the Corrego Camargo and Rio Gualaxo do Norte led to the destruction of the banks of the stream and then, as the waste material returned to the main stream, deposition on the stream bed and banks.

III DOWNSTREAM OF BENTO RODRIGUES

This narrow steep section of the Rio Gualaxo do Norte suffered erosion of the sides and bottom of the valley and removal of soil and vegetation. After the initial flow of waste material, part of it was deposited on the valley slopes, on small plateaus and in recesses.

IV BICAS, PARACATU DE BAIXO, GESTEIRA

In this zone from the confluence of the Santarém and the Gualaxo do Norte, there are extensive deposits of waste material in the central river-bed and the immediate stream banks, and this has sometimes reached the wider river-bed and led to changes in the morphology of the river plain. However, in this zone there has not been a loss of the natural form of the drainage channel that has occurred in zones I to III. The dissipation of some of the kinetic energy of the flow of material reduced the amount of erosion. However, the flood wave generated by the mud flows promoted a flood across the fluvial plain, which was severely affected by deposits. Deposits in the river bed and on the river bank are capable of being remobilised by stronger currents or rain.

The small hydroelectric plant of Bicas was also damaged. Houses in the lower areas of the settlements of Paracatu de Baixo (where 40% of the buildings were destroyed) and Gesteira were destroyed by the rapidly-flowing sediment, and mining waste was left on most valley-floor agricultural land in deposits on average more than 50 cm, and in some places estimated at more than 3 metres, thick (Carmo et al 2017).

V BARRA LONGA AREA

In the vicinity of the urban centre of Barra Longa, the entire river plain was covered by sediments, surpassing 250 metres wide in some stretches (especially at confluences with small tributaries). Steeper stretches of the river, with higher fluvial energy, had a higher rate of sediment transport and lower deposition of waste on the river at the margins; stretches of lower energy, such as river confluences and backwaters, have received larger, thicker deposits of material.

As a result, buildings in the lower part of the town of Barra Longa were invaded by mud. Agricultural lands near the river, both above and below the town, were also covered by the flow of mining waste. The pipes and sewers of the town of Barra Longa were blocked by mud. When the mud dried, it formed solid clay but, when disturbed, this creates clouds of dust (Brasil de Fato, 2016).

VI CANDONGA RESERVOIR

The reservoir of the Candonga Dam is the first point of significant entrapment of sediments of the fluvial system below the Fundão Dam. It is officially estimated that this amounts to 10 million cubic metres of deposits in the reservoir. These deposits are on the floor of the reservoir (where they are

believed to have led to a significant heightening of the bed of the reservoir) and in the mouths of side channels.

The capacity of the reservoir is 54.4 million cubic metres, though this has been reduced by silting since the start of operations of the dam in 2004. The texture of these deposits is mainly silt (between 60% and 80% by weight) with the rest being equal amounts of fine sand and clay. The operation of the generating plant is stopped at present because a significant percentage of the remaining volume of the reservoir has been occupied by mining waste.

VII CANDONGA DAM TO BAGUARI DAM

Below the Candonga Dam, mining waste was less dense and less viscous, because of the loss of solids and larger particles through deposition, and by the addition of water from other rivers.

Its flow has led to no major morphological changes. There has, however, been a covering with waste material of some sand bars in the river, deposition in backwaters and side channels, and some flooding of river margins. There was no alteration of the course of the river channels.

There are some areas where land near the river was flooded immediately after the dam burst and where mining waste has been deposited. For example, a farm on an island near the confluence with the Rio St Antonio at Naque was flooded and the channel separating it from the land to the west has been filled in with waste material. There is also sediment in some parts of the main channel, especially where normal flow rates are low (encouraging sedimentation): 1.5 metres was measured in the main channel near the above-mentioned island. When there are strong winds or strong currents, sediment from the bottom is remobilised. However, it is noticeable at the confluence of the Rio Doce and the Rio St Antonio that the Rio Doce water is much browner than the water from the Rio St Antonio.

There are, however, significant changes in the turbidity of the river and in the depth and nature of the stream bed. In some places the river is believed to be much shallower than before and the stretches with a sandy or stony stream bed are now covered with mud deposits. There are probably considerable deposits of sediment behind the Baguari Dam.

VIII BAGUARI DAM TO LINHARES

As some sediment has been trapped by the Baguari Dam, the turbidity of the river decreases slightly below the dam. The river is still turbid, however, and there are still deposits in environments, such as behind dams and in backwaters. The turbidity of the river fluctuates. At times of high wind when the river is disturbed, or after heavy rains, sediment is remobilised and brought up from the river bed.

IX ESTUARY OF THE RIO DOCE

The area near the mouth of the Rio Doce is a delta in which sediment has been brought down by the Rio Doce and deposited. The deployment of floating booms did not prevent waste entering into side channels, as the booms were designed to prevent flows of surface pollution, not sediment. Some land areas were also covered by a thin layer of sediment.

X OCEAN SURROUNDING THE ESTUARY OF THE RIO DOCE

A plume of waste material flowed into the Atlantic Ocean beginning on the 22nd November 2015. The area of this plume, and its temporal variation, is shown graphically on the website of IBAMA, the Brazilian environmental agency. The area of the plume varies between about 700 square kilometres and 7000 square kilometres. The area of greatest concentration varies between 100 and 1000 square kilometres. Monitoring of water turbidity shows that the greatest concentrations of sediments are near the sea bed, and to the north of the mouth of the Rio Doce (IBAMA maps of plume at the mouth of the Rio Doce).

There is some deposition of waste on the shore and in other nearby river channels. During monitoring of sea water quality, it was observed that there was deposition of mud from mining waste in the Environmental Protection Area of Costa das Algas and in the Forest Life Refuge Area of Santa Cruz, both of which are Federal Conservation Areas (Bastos, 2017). A year after the dispersion started, 170 km of beaches were contaminated by mud, 110 km to the north of the Doce River mouth and 60 km to the south. The plumes have already spread over more than 770 square km (Carmo et al, 2017).

WHAT IS THE WASTE?

The mining companies have repeatedly stated that the waste is inert. This would appear to be based on the companies' monitoring of the waste reservoirs previous to the dam collapse, and on an analysis carried out by the University of Ouro Preto in 2003 (Piresi et al, 2003).

Other experts, however, advise caution. Local public health specialists and geologists who were interviewed for this report suggest that a more carefully planned analysis of the potential toxicity of the waste is required (which has not yet taken place), with a good sample of locations and levels of the river and sediments. As many experts and observers have pointed out, the mud and sediment that entered the river system is a mixture of material and not only inert rock. The ore-bearing geological strata can contain heavy metals that are inert when they are in the rock but are transformed during the processes associated with extraction of the ore and can be in the tailings ponds. Furthermore, as the large-scale flow of viscous material moved along at high speed after the dam collapse, it scraped up trees, animals, septic tanks, pigsties and drains. It swept away towns and villages. It swept away old gold mines and pans that used mercury. The gates of hydro-electric plants were opened completely to allow the wave of material to pass. The mud thus possibly contains both minerals and organic matter. Higher than normal concentrations of mercury, cobalt, iron, nickel, arsenic, barium, chromium, copper, manganese, lead and zinc have been found, either in sediments or as suspended particulate matter. Iron, arsenic, mercury and manganese exceeded sediment quality guidelines (Hatje et al 2016, Page 1).

There may be heavy metals that come down the river with the mud flow, in which case they are likely to have been deposited on the bottom of the river. Under certain circumstances this may be remobilised. The original mining waste has a tendency to absorb heavy metals, but these may be released in certain circumstances. Thus, any analysis of toxicity has to be not only of the river but its bed, and take into account where heavy toxic elements might be deposited and how they might be remobilised (Terra Arrasada, 2016, page 5).

In monitoring of the quality of water at the mouth of the Rio Doce (Bastos, 2017) during the arrival of the mud, it was observed that there was an increase in the levels of metals (principally iron, aluminium, manganese and chrome) and of nutrients (nitrites and nitrates) in the water. Subsequent monitoring has shown that there has been a significant increase in the level of metals in the marine

sediments, and a potential risk of an increase in the concentration of metals in the water (depending on the periods of flood of the Rio Doce and deriving from the re-suspension of sediments from the ocean floor of the adjacent coastal region). The significant quantities of metals that are typical of mining waste, such as iron and aluminium and others linked to the movement of the mud through the hydrographic basin of the Rio Doce (chrome, nickel, zinc, lead and manganese), have altered the quality of water affecting the marine environment and, presumably, the stretches of river through which the waste has passed and left deposits.

There are thus possible toxicological risks, such as possible changes in surface and groundwater quality due to contamination with trace metals; possible changes in the quality of soils and sediments due to contamination in situ; and the release of potentially polluting substances, such as trace metals, in soluble forms from biogeochemical processes acting on deposited waste materials.

C WHAT HAS BEEN DONE SINCE? - EMERGENCY MEASURES

Following the collapse of the Fundão Dam in November 2015, the Brazilian government obliged the mining company SAMARCO to carry out emergency work to stop the rupture of containment structures, prevent additional waste material moving downstream and start the removal of mining waste from the Candonga Dam reservoir (Campos, 2016, pages page 4). This was included in an agreement made in early March 2016 between SAMARCO and the Federal and State Governments. The responsibility was transferred from SAMARCO to the foundation RENOVA after its creation.

The Candonga Dam (a hydro-electric dam) trapped about 10 million cubic metres of the flow of mining waste (though possibly 20 million cubic metres of the finer sediments went over the dam and polluted the lower reaches of the Rio Doce). The reservoir of the Candonga Dam thus contains large amounts of the coarser sediments. SAMARCO (and then RENOVA) have been carrying out (since late 2015) a lot of work to try to remove some of this waste from the reservoir and to put in various forms of sediment traps. There is a lack of suitable places to deposit waste removed from the reservoir. Structures are being built to retain sediment in the side arms of the reservoir or to retain waste pumped out of the reservoir. (Paul Robson)

The emergency work to stop additional waste moving downstream involves stabilising material deposited on the stream banks in the stretches of river above the Candonga Dam, and reducing the amount of silt in the river in its upper reaches. The first phase of this was due to be completed at the end of December 2016 and appears to have been completed in January 2017. There does appear to have been a reduction in the turbidity of the river in its lower stretches as a result, though analyses show that turbidity in the lower reaches of the river are still higher than expected at this stage (Globo, 2017). Sediment flow has not ceased and there are still deposits of sediment that have not been stabilised. Waste material could still be remobilised and there is still a significant problem of erosion of deposited material outside the land of the mining company.

Stabilising material deposited on river banks has involved using earth-moving equipment to move it away from the river banks, planting rapidly growing species and covering with net. The banks of rivers and streams have been lined with stones or small fences to reduce the movement of sediment into

water-courses. Sediment weirs S3 and S4 have been constructed on the Corrego Santarém above and below the settlement of Bento Rodrigues. These are to reduce the amount of mining waste flowing downstream by acting as sediment traps. They have raised the river level so the agricultural lands of Bento Rodrigues are under water, and this makes it difficult for the former residents of Bento Rodrigues to imagine that they will be able ever again to have access to their lands. The construction of these weirs was opposed by the residents of Bento Rodrigues as they say that it was not discussed with them, they received no compensation, and they fear losing their property rights.

Construction of dam S3 at the settlement of Bento Rodrigues. S3 is a sediment weir, an attempt to reduce the amount of sediment entering the river system from the area of the mine and the collapsed tailings dam.
(Nilmar Lage)

At Barra Longa, 150,000 cubic metres of material have been moved from the centre of the town, though most of it has been deposited on the western outskirts of the town nearer the poorer neighbourhoods. The material will be used to construct a football pitch because analyses showed that this was the least bad option, in terms of impact on air quality: complete removal of this amount of waste would create greater problems.

> For weeks afterwards, the town was full of machinery and vehicles, moving the waste out of the riverside areas of the town and dumping it on the outskirts of town at the old exhibition ground. The vibration and dust was terrible, and everybody hung sheets over their doors and windows and filled the cracks with newspaper, to try to stop the dust getting in the house. Some people have cracks on the facades of their houses that they say was caused by the vibration from the machinery. It is said that the waste has been left near the town because moving it somewhere else would have caused even more disturbance. The new plaque in the town square says that the rehabilitation was carried out by SAMARCO, but it doesn't say that SAMARCO caused the damage in the first place.
>
> *Resident of Barra Longa*

The residents of the town feel that the workers of the companies contracted by SAMARCO or RENOVA dominate life in their settlements, as do the heavy machinery and lorries. When the waste has dried, this creates clouds of dust along with noise and vibrations (Terra Arrasada, 2016, page 4).

As part of the emergency actions, there is considerable work going on to remove mining waste sediment from the reservoir of the Candonga Dam. The removal of part of the deposits, closest to the hydro-electric plant, aims to allow the restart of electricity generation at some stage. Sediment is being removed by dredging, and by pumping, and by damming side arms of the reservoir where there have been sediment deposits (to retain it and to store material pumped from the main body of the reservoir). Booms and weirs have been being built across the reservoir to trap sediment and so minimise the amount of sediment passing over the dam. This is a large-scale undertaking with large numbers of earth-moving machines and lorries in operation around the dam creating large clouds of dust. The work at Candonga Reservoir is behind schedule; it has been complex and cost more than has been paid so far in compensation to those affected by the dam collapse. The rate of clean-up is much slower than after the failure of tailings dams in Spain (1998) and Hungary (2010) (Carmo et al, 2017, page 7).

Downstream of the Candonga Dam, most deposited material is fine sediment and there is no work at present on removing this from the river and the river banks. Forecasts showing that dredging in the Candonga Reservoir will have difficulty in keeping up with the amount of sediment still being brought into the reservoir in late 2016, and there is still likely to be sediment passing the dam. Areas to dispose of the waste are a bottleneck in the dredging of the reservoir of the Candonga Dam (Campos, 2016, pages 25 and 26).

D WHAT ARE THE LIKELY AND POSSIBLE MEASURES THAT WILL BE TAKEN TO ASSIST THE RECOVERY OF THE RIVER BASIN?

One of the aims of this report is to try to assess the long-term impacts of the collapse of the Fundão tailings dam and the subsequent release of large amounts of mining waste in the Rio Doce river system. Such an assessment requires some knowledge of what measures are being taken, and what actions will be carried out, to stabilise and/or remove waste material from the river basin. By mid 2017 the RENOVA foundation had produced a Plan for the Management of Waste Material which has been formally approved and adopted (RENOVA, 2017). Detailed implementation plans have not been prepared and it is difficult to assess the overall impact.

The confluence of the Rio Carmo and Rio Gualaxo do Norte on the outskirts of the settlement of Barra Longa. The water of the Rio Carmo, flowing from the left, is clear while the water from the Rio Gualaxo do Norte, flowing towards the camera, is brown with the mining waste it is carrying from the region of Fundão Dam more than 18 months after the collapse of the dam.
(Paul Robson)

It is clear that, as with the emergency actions already carried out, the actions involved in the removal and stabilisation of deposited waste material will have further impacts. Those mentioned include heavy traffic and presence of lorries and earth-moving machinery, a temporary increase in turbidity of the water courses due to earth-moving works and disturbance of the river banks, loss of agricultural and pastoral areas due to their use as deposits for waste or the construction of erosion-control structures, creation of dust in the air during earth-moving, and destruction of natural vegetation by access roads and work sites.

The confluence of the Rio Doce and the Rio St Antonio at Naque. More than 18 months after the collapse of the Fundão Dam, the Rio Doce is still brown and contrasts with the clear water of the Rio St Antonio (coming in from the right). (Nilmar Lage)

These documents of the RENOVA Foundation imply that, over the next four years, further work will be done in the stretches of the river above the Candonga Dam to remove waste from the river beds and stabilise it on the river banks. The plans do not mention plans for any works downstream of the Candonga Dam and tend to downplay the issue of the fine sediment deposited on the river bed in the lower reaches of the river. The removal of a relatively thin layer of fine sediment from a large area of river bed would be difficult and no means of doing this have been identified (RENOVA, 2017).

A creek with mining waste sediment in the delta of the Rio Doce near Regência

Detailed proposals have only been made for a pilot area just below Paracatu de Baixo (Zone IV), for the area of Bento Rodrigues and for further work on the reservoir of the Candonga Dam. In the pilot area, it is proposed to use mechanical draglines to remove sediment from the river-bed and use this

material to build embankments alongside the river. The embankments would be stabilised with netting and vegetation to prevent erosion from the rest of the flood-plain into the river. These would, of course, create a further barrier between the agricultural land and the river (in addition to the stones and fencing put in place during the emergency actions' phase) and make irrigation or access to the river by cattle more difficult. In addition, it is planned to divert some of the stream flow through settlement basins on the flood plain so as to reduce the turbidity of the rivers; this would transform some of the flood plains into wetlands and reduce the area available to agriculture.

The plan for further work on the reservoir of the Candonga Dam (phase 2) is expected to be ready by the end of October 2017 and has been delayed by the complexity of phase 1. Space to place the sediment removed from the dam in the second phase is, however, lacking, and there is not yet a plan for where all the waste material will be placed.

E IMPACTS OF THE DAM COLLAPSE ON WATER SUPPLY

The most important way in which the collapse of the Fundão Dam has affected life in the basin of the Rio Doce is through the impact of the mining waste, and the elements carried along by it, on the waters of the river.

The passage of the tidal wave of mining waste through the river basin caused the immediate interruption of water extraction from the river. This affected domestic water supply, irrigation, water for animals and water for industry. In Barra Longa, the wave of mud damaged water pipes and infiltrated wells in the flood plain. Below the Candonga Dam, the heavy load of sediment in the water led to the suspension of water availability in places where the supply came from the river as water treatment could not be carried out on water with such a heavy sediment load.

A tanker-lorry delivering water to Regência because of suspected contamination of the river and groundwater. The lorries come from Linhares, about 70 km away and cause damage to the roads.
(Paul Robson)

The town of Governador Valadares is the largest town on the Rio Doce, with a population of 280,000. It takes its water supply from the Rio Doce. Governador Valadares was already suffering from water shortages and restricting water use before November 2015 due to a drought, caused by one of the periodic droughts of the Sertões region to the north. Water extraction was interrupted on 8th November 2015 for Governador Valadares as water with a high sediment load had to be released from Baguari Dam. On 10th November 2015 a state of public disaster was declared in the town. Schools

and the university closed and people were encouraged to leave the town. Large queues built up in the streets at emergency water-supply points. There followed 13 days of chaos. Bottled water was delivered by lorry from distant parts of the country and water-lorries brought water from towns 50 to 70 km away. Tankers had to be sent from other parts of the country because all tankers in the region had been forced into use. Water extraction from the Rio Doce was re-established by using a polymer derived from the bark of Acacia Negra to accelerate decanting of sediment. (Many people do not trust this water supply and buy bottled water for drinking or drive to nearby towns to bring back barrels for water for other household uses.)

Bottles of drinking water are supplied in certain areas because of suspected contamination of the river and groundwater. (Paul Robson)

Given the risks of contamination of water supplies, the Brazilian Government ordered that the mining companies provide alternative water supplies to people at risk along the river basin. This has led to the supply of water to many rural communities (and some urban communities that have not been able to organise alternative sources of water) by tanker-lorry. The town of Regência at the mouth of the Rio Doce, and nearby rural communities in the delta region (for example) are supplied with water brought by tanker-lorry from Linhares, over 50 km away. This is presumably costly and one of the side-effects of this is damage to rural roads by the heavy lorries.

In most locations, residents are supposed to use the water supplied by lorry for drinking water, as well as other purposes such as washing or irrigation. In a few locations, arrangements have been made for supply of drinking water in bottles, delivered through local traders. In some cases, such as the delta region, arrangements have been made for bottles to be taken away when empty, but this has not been arranged in some cases (such as in the area of the Krenak people) and the empty bottles have become a pollutant.

Alternative water supplies rarely provide the level of service that was available before. Residents supplied by tanker-lorry point out that the amount of water available now is not sufficient for their needs. In the town of Baixo Guandu the water supply was moved from the Rio Doce to the tributary the Rio Guandu before the arrival of the wave of mining waste, and this alternative supply has been maintained. However, there are restrictions on the amount of water available, because the Rio Guandu is a smaller river which is heavily used for irrigation. There are also concerns about the amount of pesticides in the Rio Guandu and the implications of using it for water supply in the long-term.

F IMPACTS OF THE DAM COLLAPSE ON THE ENVIRONMENT

As yet there have been no systematic studies of the impact of the collapse of the Fundão tailings dam on the environment of the Rio Doce basin as a whole. This led one scientist to say that "Science cannot yet tell us what will be the environmental impact or on human health" (Globo, 2016). The volume of pollutants, and the extent of ecosystems affected, is significant and includes the Brazilian Atlantic Forest (one of the world's biodiversity hotspots) (Carmo et al, 2017).

Capybara are large rodents found in some areas of South America. They are semi-aquatic and were commonly found near the Rio Doce. They are reported to be very rarely seen since the pollution of the river in November 2015. (Nilmar Lage)

There has been, however, systematic monitoring of the environment at the mouth of the Rio Doce and the surrounding areas of the Atlantic Ocean by UFES (the Federal University of the State of Espirito Santo). There have also been individual studies of some areas of the Rio Doce itself by independent organisations (Greenpeace Brazil, GIAIA, SOS Mata Atlântico). These provide indications of possible environmental changes in the river basin and the surrounding ocean.

> We now are banned from fishing near the mouth of the Rio Doce, because of the pollution from the river and because we might churn up the mud that is on the shallow sea bed. But we don't catch enough fish in deeper water to justify the cost of the crew and oil and diesel. IBAMA (the Environmental Agency) come and look at our GPS logs and have helicopters, so they know where you have been fishing. I wonder if IBAMA control the mining companies so tightly.
>
> *Captain of fishing boat, Vitoria harbour*

The passage of large quantities of waste material down the river meant a prolonged period of a highly turbid and low oxygen environment, which appears to have led to the death of large numbers of fish and other riverine species. This also appears to have swept riverine species downstream, and even into the maritime environment. The result was a drastic reduction in the diversity of species and

number of individuals (and increasing the dominance of certain groups). During the arrival of the mud an increase was observed in the levels of metals (principally iron, aluminium, manganese and chrome) and of nutrients in the water, which led to an immediate change in the food chain and altering the community of organisms that makes up the base of the food chain (phytoplankton and zooplankton) (UFES, 2017, page 10).

Paracatu de Baixo is a settlement largely destroyed by the flow of mining waste. The tree was killed by the flow of waste, and the brown mark shows the height of the flow of mining waste.

Following this there has been the deposition of sediments on the river bed, and on river banks in the upper regions of the river and in the maritime environment around the mouth of the river. There is little information about the nature of these sediments over the river basin as a whole; however, the formation of a fine sediment layer on the rocky or sandy surface can be sufficient to alter its function as habitats for aquatic fauna. The deposition of sediments in some areas has also made the river shallower. (This may have long term implications for the hydrology of the river basin, and floods, such as those that occurred in 1979, may have a different intensity in future and have a more acute impact on areas such as the delta region that can be affected by flooding. The basin of the Rio Doce is forecast to have a lower average rainfall in future as a result of climate change, but heavier individual storms.)

In most environments there has been a gradual recuperation of the number of species and individuals. However, the presence of sediment on the river bed presumably presents a limit on recuperation, and sediment is available for remobilisation in certain conditions.

Analysis of the water and of sediment at the mouth of the river shows the presence of metal contaminants and nutrients associated with the flow of mining waste of November 2015 (though possibly not originating in the mining waste itself). The increase in these contaminants in subsequent periods of heavy rain shows that there is a large quantity of material that will, for a long time, release contaminants. There are thus chronic impacts that are enduring and are even putting at risk the ecosystem, which is still suffering from a chronic process created by the arrival of the waste material in the riverine, marine and coastal ecosystems. The structure of the ecosystem has been affected and the metals in the sediment can, eventually, be made bio-available and enter in the food chain (Bastos, 2017).

Observation by residents of areas along the river, and at its mouth, indicate that there has been a drastic decrease in the number of fish in the river and that there has hardly been any recovery in the populations of fish species of economic significance. Residents of stretches of river not directly affected by the disaster also report a decline in fish numbers, as migration routes have been disturbed. Fish are impacted by the fragmentation and destruction of habitats, contamination of water, erosion of (and deposition on) river beds, destruction of riparian and aquatic vegetation, interruption of the connection with tributaries and marginal lagoons, changes in estuaries and mangroves at the mouth of Rio Doce, damage to fish breeding areas and areas for feeding of larvae and juveniles, alterations and impoverishment of the food chain and interruption of the gene flow of species between bodies of water. (Minas Gerais para 3.1.2)

It has also been reported that bird and mammal species have left the area of the river, because of the reduction in the availability of fish as a food source, or because of contamination of drinking water and river bank habitats. The capybara, a semi-aquatic rodent formerly common along the Rio Doce, is now rarely seen.

G IMPACTS OF THE DAM COLLAPSE ON LIVELIHOODS AND THE ECONOMY

Former vegetable gardens near Ipaba, below the Candonga Dam. Part of the river bank was covered by mining waste in this area, though there is little mention of this in official reports. Small-scale farmers have given up cultivating the river banks, but have difficulty in being recognised as affected by the dam collapse as they are not registered businesses and do not have receipts for sales of vegetables.

In the region below the Fundão Dam, all the way to the sea, there are communities that rely on access to the river and streams for their livelihoods. There were immediate effects of the collapse of the dam and the release of mining waste - destruction of housing and infrastructure, interruption of transport, electricity and water supply, death of animals and impossibility of watering them; the loss of agricultural machinery and equipment and the destruction of annual crops, vegetables, fruit, eucalyptus, pastures and riparian forests. This led, for example, to paralysis in milk production and delivery in areas between the Fundão Dam and the Candonga Dam that had specialised in milk production.

(Minas Gerais page 243). There have also been longer-term effects caused by pollution and environmental changes.

The settlement of Bento Rodrigues, in Zone II about 5 km below the Fundão Dam, has had to be abandoned. Many of the houses in the settlement were directly destroyed by the flow of mining waste on 5th November 2015 as was community infrastructure such as the school and the church. The community's agricultural land was covered in mining waste material. Sediment weirs S3 and S4 have been constructed on the stream above and below Bento Rodrigues, and they have raised the water level so the agricultural lands of Bento Rodrigues are under water. At present most of the inhabitants are being lodged in Mariana and are unhappy with this situation. An area has been demarcated for a new settlement of Bento Rodrigues, a few kilometres from the original settlement, but there appear to be still many issues to resolve before housing construction begins. There is no clear vision of how they will gain access to their farming land again: they have had to abandon their way of life completely.

Barra Longa - a small town above the Candonga Dam, where the waste flow flooded part of the centre of the town - the waste was removed from the centre of the town and dumped on the outskirts near a poorer part of town

Houses in the lower areas of the settlements of Paracatu de Baixo and Gesteira, slightly further downstream in Zone IV, were destroyed by the rapidly-flowing sediment on 5th November 2015, as were community buildings in Paracatu de Baixo. Mining waste was deposited on the agricultural land of these settlements. The agricultural land is unusable as it has been covered with sediment or it has been reformed by RENOVA or SAMARCO for erosion control. Some people whose homes were destroyed are living in Mariana, while some are living in the rest of the village. There were few houses destroyed in Gesteira: only those near the river belonging to people who had not moved after earlier floods. However it is, at present and for the foreseeable future, impossible to farm in these agricultural communities.

Barra Longa in Zone V is a substantial settlement, the lower part of which was covered by the flow of mining waste on 5th November 2015. The best agricultural lands near the river in this area, used for vegetable-growing and animal production, were covered by the flow of mining waste and now produce poorly. Some land-owners have bought compost to begin improving the soil but this is expensive and they have only improved small areas of their land. A new layer of soil has been created which is practically inert and of low fertility, and in which seeds will have difficulty in germinating and

roots will have difficulty in developing (EMBRAPA, 2015). Corrective measures that insert organic material into the environment are critical to the recovery process (Minas Gerais para 2.1.2.6).

Downstream of the Candonga Dam, Zones VII to X, the contamination of riverside land by mining waste has been less significant than above Candonga; there are, however, some riverbank areas near Naque and Ipatinga (Zone VII) that were flooded by mining waste immediately after the dam burst and where there are mining waste deposits. These lands used to be perceived as the most productive areas and were used for vegetable crops, but are now producing only grass. Some farms had wells close to the river, that were used for irrigation of vegetables, and these were flooded by mining waste and are now unused, though other wells, at a higher level, are still used. A farm on an island near the confluence with the Rio St Antonio at Naque was flooded and the channel separating it from the land to the west has been filled in with waste material. There is also sediment in some parts of the main channel, where normal flow rates are low (encouraging sedimentation): 1.5 metres was measured in the main channel near this point. The presence of sediment in the water prevents its use for irrigation and means that water has to be fetched from the Rio St Antonio.

In all stretches of the river further downstream, the presence of sediment in the water of the Rio Doce has meant that irrigation has been interrupted. Farmers near Resplendor, whose livelihood is small-scale intensive cattle raising (for milk production), irrigate pastures with water pumped from the Rio Doce; they ceased irrigation in November 2015 just before the arrival of mining waste in the river and their pastures died without irrigation. Some water has been supplied by tanker lorries in compensation but this is not enough to irrigate all their pastures. Those who have started using river water again, for irrigation, say that their pasture does not grow as well as it used to.

Many of these farmers were previously displaced about ten years ago by the flooding of the Rio Doce valley when the Aimorés hydro-electric dam was constructed, and small-scale intensive cattle-raising was a new livelihood strategy that they were persuaded to adopt after being displaced. It has taken them ten years to establish their livelihoods with this strategy, because there were a series of practical challenges to overcome, and this has now been seriously disrupted. Among the farmers who have been affected in this way are the indigenous Krenak people, who were only able to return to their ancestral lands in 1999 and were then affected by the construction of the Aimorés hydro-electric dam. Cattle-rearing was a completely new activity for the Krenak and, as they began to adapt to this livelihood strategy, it has been disrupted.

In the river delta (Zone IX) farmers have been affected by the presence of mining waste sediment in creeks that are used for irrigation. They also say that their land was flooded by water with mining waste in November 2015, and that they suspect that ground water has also been contaminated. It is difficult for them to sell their crops, because customers suspect anything that has been possibly irrigated with water from the Rio Doce, but in any case yields are lower.

Disruption to fishing activities has been severe in the lower reaches of the Rio Doce and in the maritime region near the mouth of the river since November 2015 and, in Zones VII to X, those who used to fish report that this is now impossible. This affects whole families' livelihoods because family members processed and sold the fish. Fish were killed by the lack of oxygen in the river, due to the very high turbidity of the water in the aftermath of the dam collapse. There has been no noticeable re-population of the river by fish subsequently even though turbidity is now lower than it was immediately after the dam collapse (and depends on weather conditions). Fishing people believe that the water is still polluted and that the characteristics of the river have been changed by the sediment on the river bed: where there may have been sand or stones on the river bed there is now a layer of mud, so fish that were adapted to rivers with a sand or stone river bed will not re-populate the river.

Possibly 11,000 fishing people along the river are now inactive. The ban on fishing in coastal waters near the mouth of the Rio Doce affects fishing boats from as far away as Vítoria, the capital of Espírito Santo state, and families who fished and collected sea-food in other estuaries along the coast. Even if there were fish, fishing people believe that nobody would buy them because consumers refuse to buy fish that they believe has come from the Rio Doce. Fishing was, in fact, banned along the river and in certain maritime areas near the mouth of the river in November 2015, but even if it were to be permitted again, fishing people say that customers would not have confidence to buy fish from the area for many years to come.

South of the mouth of the Rio Doce, fishing was disrupted in the last decade by the construction of a naval yard on the coast, which involved disruption to a reef with subsequent disruption to fish movements. In compensation, those involved in fishing in this area were offered credit and training for a seaweed production project which was about to get under way in 2015. As the sea waters in which this was to take place have been affected by mining waste brought down by the Rio Doce, these projects are suspended and no new livelihood strategies have as yet been suggested.

Regência at the mouth of the Rio Doce, and nearby towns on the coast, have an economy that used to be linked to tourism. Bars, restaurants and hotels were important sources of employment. Individuals rented out rooms to visitors. Shops depended on tourists for business. But bathing and surfing were banned in November 2015, and since then tourists and surfers have stopped coming to the area. There is very much less tourism and this (and the crisis in fishing activities) has a knock-on effect on other economic activities in the town. Turn-over in shops is very much less and traders and shop keepers believe that people now only have enough money for basic survival and basic purchases (Leonardo et al, 2017).

H IMPACTS OF THE DAM COLLAPSE ON HEALTH

There has not yet been a systematic study of the impact of the collapse of the Fundão Dam, and the release of mining waste into the Rio Doce river system, on the health of the local population. Brazilian public health personnel who were interviewed said that a large, systematic study was required because of the apparent risks that such an event presents. Changes to the natural environment, contamination of the river and reduction of people's livelihood opportunities are the most obvious risks. There is believed to have been a study by the Ministry of Health that has not been published. Greenpeace funded a study of the impact on health in Barra Longa, while there are other reports of effects on health in reports from along the river.

One of the most widely reported effects on health from a disaster of this size is psychological. The health services in the Districts most affected by the dam collapse have taken on additional mental health staff. In the study financed by Greenpeace in Barra Longa, 23% of the respondents reported that they were suffering from anxiety, stress or depression, in addition to those reporting insomnia and mood swings (Vormittag et al, 2017).

Large disasters are tragic collective events in which there are sudden and involuntary losses and damages which disorganize the strategies, routines and way of life of a given groups of people. People affected by the impacts of the dam collapse do not know what their future will be as they have lost their livelihood: people do not see how they can continue living without their land or the livelihood that they have followed for many years. People feel a devastating experience of the loss as their settlement (or its economic basis) no longer exists and the references which structured routines and

social organization were abruptly destroyed. People who have been previously impacted by major changes to their lives (such as the Krenak indigenous people who were dispossessed of their land and then returned, or communities who were displaced by hydro-electric dams) know that adapting to making a living in a new location is a long and painful process.

In the long-run, the health impact of the collapse of the Fundão Dam will depend on whether the waste from the dam and the material it has eroded and moved into the river system contains any toxic elements, and whether this affects water quality or affects in other ways people who are in daily contact with the river or work on the river banks. As noted above, this has become a contentious issue and there have not yet been large-scale systematic studies of toxicity of the river and its environment. The Greenpeace study in Barra Longa notes that "reported symptoms are similar to those described in cases of intoxication by some metals: this is suggestive but does not permit affirmation of a cause-effect association of exposure to metals and illness." (Vormittag et al, 2017.) The study of sediments at the mouth of the Rio Doce finds evidence of metals and nutrients that could be a long-term health risk (UFES, 2017).

A noticeable effect of the release of mining-waste into the environment, especially in the areas where there have been extensive deposits on the river banks, is that the mud has dried and has created a solid deposit that turns to dust when disturbed. In Barra Longa there were significant movements by heavy lorries and earth-moving machinery that disturbed the solidified mud and created clouds of dust. The removed mud was deposited on the edge of the town. The health study in Barra Longa found that residents of the town reported symptoms that could be related to the presence of high levels of dust, such as respiratory problems. More than a third of respondents reported that their health was worse after November 2015 than before (Vormittag et al, 2017).

In addition, wider environmental changes may impact on health. The character of the river has changed and there are fewer fish, so this may have had an impact on disease vectors: there may, for example, be more mosquitoes as there are fewer fish in the river. In Barra Longa pipes and sewers were destroyed. This may have an impact on the incidence of diseases for which mosquitoes are vectors (such as dengue). These relations need to be studied, which is why most research studies conclude that there is a need for more systematic monitoring of heath along the Rio Doce, which has experienced a rapid, large-scale change in conditions.

J IMPACTS OF THE DAM COLLAPSE ON SOCIETY

As noted above, the Rio Doce and its tributaries were an important factor in the livelihood of people living nearby between Bento Rodrigues and the coast. It was also an important part of their social lives: at Regênica almost everyone bathed in the river several times a week, washed their clothes there and met their friends there at the weekend. This is no longer possible because nobody wants to bathe in the river (or the nearby sea) and riverside locations are no longer attractive. Fish was a central part of the diet (eaten several times a week) but is no longer eaten (Leonardo et al, 2017).

In the upper part of the river, residents reported that the river was an important part of social and recreational life and being cut off from it (by erosion control works) means a change in social life and relations. Fishing parties at the weekend were an integral part of village life and it is difficult to find a substitute activity around which to build a community. The Krenak indigenous people see the river (Watu) as an integral part of their life and their activities and ceremonies: they returned to their lands

less than 20 years ago after being forcibly displaced, and see the sedimentation of the river as a disruption of their re-integration with their history (CdH/UFMG, 2017).

> Barra de Sahy used to have the best carnival in the region. It was considered a safe place for surfing. I used to rent out my rooms months ahead every year from Christmas to Carnival. I haven't rented out one room the last two years and I am living on my savings. There are a lot of us like that, with shops or restaurants or bars which no longer open, and that affects the whole economy of the town.
>
> *Owner of guest-house, Barra de Sahy (on the coast south of the mouth of the Rio Doce)*

The inhabitants of Bento Rodrigues (and some of the residents of Paracatu de Baixo) have been forced to leave their settlement and live in the town of Mariana. That means a complete change in their mode of life, including separation from their neighbours and even other members of the family.

Well-established daily routines have had to be abandoned. Instead time is taken up with meetings and grappling with uncertainty about the future. This leads to tensions among affected people trying to make decisions in a terrain of uncertainty and insecurity.

K CONCLUSIONS

The catastrophic failure of the Fundão tailings dam in Minas Gerais (Brazil) on 5th November 2015 spilled 45 million cubic metres of mining waste into 637 km of the Rio Doce and its tributaries.

This is the largest area of a river basin ever affected by a tailings dam collapse: the only comparable tailings dam collapses are in Mexico in 2014 (420 km of contamination by copper residues) and of the El Porco Dam in Bolivia in 1996 (that affected 300 km of a river basin) and nine other tailings dam failures that affected 100 to 200 km of river. It is also the largest spillage from a tailings dam, the next largest spillage being 32 million cubic metres at Tubu in the Philippines in 1992 (Carmo et al, 2017, page 5) (CSP2 Database of Tailings Dam Failures).

There are two different scales of tailings dam failures. The first concerns dam failures (usually of a smaller-scale) where there is a passive dispersion of waste into the environment and tailings are transported alongside the natural sediment load of a river with little disruption of natural systems. The second concerns dam failures of a larger scale, in which the input of waste material leads to an active transformation of the whole fluvial system. The movement of large quantities of waste at a high velocity causes a transformation of the landscape and remobilisation of other elements; the dramatic increase in sediment supply leads to significant changes in the morphology of river basins. It is not just mining waste that is brought into the wider environment by a dam failure of this kind but other elements mobilised as it moves through the wider environment. These larger scale failures are likely to become more common as tailings dams increase in size (Hatje et al, 2017).

The failure of the Fundão tailings dam is an example of a larger-scale failure leading to an active transformation of the river basin and the ocean near the river mouth. The slurry input promoted an active transformation of the fluvial system, causing readily observable erosion and degradation along its flow and intense floodplain deposition in several areas. The area in which the Fundão Dam is located

has been the site of gold and iron ore mining for more than three centuries, and the rock strata associated with iron and gold deposits is rich in toxic elements such as arsenic, manganese and mercury. Higher than normal levels of these elements can be expected in the soils as historic mining activity is likely to have led to their movement into the environment. There are 2 million people living along the Rio Doce discharging waste into septic tanks or untreated directly into the river. These wastes are likely to have been remobilised by the movement of large quantities of waste at a high velocity after the dam collapse (Hatje et al, 2017). Thus, although the waste itself may be inert, it may have made available nutrients and heavy metals. The isolation and identification of all the pollutants present in the soils and water can be difficult, and large and systematic studies are required to monitor all the affected areas. Some studies indicate a potential for effects on human health (Segura et al, 2016).

The effects of the tidal wave of mining waste were devastating in the areas just downstream of the dam, but there were (and still are) significant impacts all along the 600 km of river from the District of Mariana to the mouth of the Rio Doce, and in the maritime region around the mouth of the river. It created serious environmental issues throughout the river system. There were a number of immediate and extreme effects with the arrival of the mud and immediately afterwards, but also chronic long-term and on-going effects that could put at risk the ecosystem.

In some places, mining waste has been deposited on land beside the river. The mining waste in the river has had an effect on the water, which in turn has had an effect on water-supply, agriculture, fishing and tourism, and thus on household livelihoods, social life and health in different ways along the river and on the nearby Atlantic Ocean coast. The process of containing and removing sediment clean-up creates, in turn, other issues. Many people who depended on the river for their livelihood, (in fishing, farming or tourism) consider that the river is dead.

There is sediment in the water from the dam to the ocean, and on the river banks in some areas. Communities in the Rio Doce basin have historically developed around access to water (Zhouri et al. 2017) so a sudden change in the quality of water has multiple impacts. The event of 5th November 2015 has changed the character of the river basin.

Recovery of the Rio Doce will be a large-scale and long-term undertaking, the dimensions of which are only now being realised. A structured scientific study of the impacts is only just beginning. There are areas where deposited waste has still not been stabilised. Removal of waste from the reservoir of the Candonga Dam is constrained by the difficulty in finding sites to deposit it. River turbidity has declined since emergency erosion control measures have been implemented in upper reaches of the river but it is unclear whether they will significantly decline further in the short-term. There are no published plans for the fine sediment that has been deposited in the river bed, for example in the lower river, and it will be challenging to find ways of removing it. There is still a large mass of waste material in the river channel that will release contaminants to the environment (Bastos, 2017). This implies that the character of the river has been changed, and native species of fish may have difficulty in returning. A wide variety of people have had their livelihoods affected, and re-establishing livelihoods will be challenging. What is being planned for recovery of the environment, or finding alternative livelihoods for those affected, is not very clear, at least to those who have been affected.

The active transformation of the river system and the multi-dimensional impacts of the dam collapse were not contemplated in the Environmental Impact Assessments (EIAs) carried out before construction of the dam, which limited themselves to impacts in the immediate vicinity of the dam and considered neither the possibility of the collapse of the dam, nor the chances of large-scale tailings overflow (Santos and Milanez, 2017).

Tailings dams of ever-increasing size are being constructed, in Brazil and elsewhere: three are being planned in the same region of Brazil that will be three times the size of the Fundão Dam, and are in the river basin of the Rio das Velhas that provides the city of Belo Horizonte with its water supply. Technology improvements in mining and concentration processes have allowed the economic excavation of lower grade deposits, but this poses greater challenges for the management of mine waste and waste water (Bowker and Chambers, 2015). Tailings dams of ever-increasing size will mean that spillages and dam collapses will have impact on the environment and downstream communities of the scale of the Fundão Dam collapse, with a transformation of the landscape and remobilisation of other waste elements in the soils and water. EIAs need to take this into account, as do decisions about whether or not to permit tailings dams. Higher tailings dams containing increased volumes of waste have a higher risk profile. The increased size increases the stresses in the dam (as well as the consequences of a catastrophic failure). More rapid filling of a dam can mean higher pore pressure, greater risk of static liquefaction, greater risk of construction errors and less time for observation and checking (Robertson, 2011). There is a risk in future of unfundable damages from catastrophic failure at the super-sized tailings dams that are being constructed, and this will damage investors, communities and natural resources (Bowker and Chambers, 2016).

The International Council on Mining and Metals (ICMM) carried out a review of tailings management after the collapse of the Fundão tailings dam and produced a Position Statement in December 2016 (ICMM, 2016) about preventing catastrophic failure of tailings storage facilities. This focuses on governance of tailings dams, though in practice this Position Statement is limited to matters of internal governance by the mining industry (management) while there is no mention of external governance (outside regulation).

Studies from outside the mining industry, on the other hand, identify the fragile state of State regulation of tailings dams as a contributory factor in this case and consider internal management as being a necessary, but not sufficient, condition for preventing catastrophic failure of tailings dams. A regulatory capacity is needed to ensure that there are no deviations from best available technological practices. Serious risk reduction requires significant changes, namely identifying and developing best available technologies and practices and development of the capacity for effective regulation (Santos and Milanez, 2017; Bowker and Chambers, 2016).

In their 2016 study of the Root Causes of Tailings Dam Overtopping, Lindsay Newland Bowker and David M. Chambers state: "All over the world new mines and new dams are approved within regulatory and legal structures that do not hold miners to best available technology and best applicable practices. Until this changes, it is clear that the industry will not consistently choose best available technology and best applicable practices unless required to do so." This would require clear standards in law, and regulatory capacity to ensure that they were followed. This is the opposite of what has happened recently in Brazil, where the Temer government has made approval of mining projects more flexible. Such regulation should not permit mining projects unless they have a clearly identified means for managing the resulting tailings waste with the best available technology and practices. It should also ensure that deviation from best available technology and practice should not be permitted at any time in the life-cycle of a tailings dam, and that early warning signs of heightened risk be recognised and oversight strengthened at those time, particularly when prices are falling and there is a risk of increased throughput and tailings production (Bowker and Chambers, 2016). This should include a serious review of the risks of upstream tailings dams, which are widely used but create environmental and social risks, and the oversight and monitoring of such structures (Carmo et al, 2017, pages 1 and 8).

REFERENCES

Bastos, 2017. Alex Cardoso Bastos. "UFES apresenta em Brasília resultados de pesquisa sobre o desastre de Mariana" ("UFES presents in Brasilia results of the research about the Mariana disaster") Universidade Federal Espírito Santo press release of summary of research, 22nd June 2017.

Brasil de Fato, 2016. "Marcas da lama" ("Marks of the mud"). Special edition of Brasil de Fato, October/November 2016. https://www.brasildefato.com.br/marcas-da-lama/

Bowker and Chambers, 2015. Lindsay Newland Bowker and David M. Chambers. "The Risk, public liability and economics of tailings storage facilities." Center for Science in Public Participation.

Bowker and Chambers, 2016. Lindsay Newland Bowker and David M. Chambers. "Root Causes of Tailings Dam Overtopping: The Economics of Risk& Consequence." Protections 2016 - 2nd International Seminar on Dam Protection Against Overtopping. Ft. Collins, Colorado, USA, 7-9 September 2016. ISBN: 978-1-1889143-27-9.

Campos, M.B. 2016. Presentation to the Seminário Segurança de Barragens (Seminar on Safety of Dams), Brasília, 9th November 2016. Câmara Técnica de Gestão de Rejeitos e Segurança Ambiental (Technical Office of Waste Management and Environmental Safety).

Carmo F.F. et al, 2017. Fundão tailings dam failure: the environment tragedy of the largest technological disaster of Brazilian mining in global context. Perspect Ecol Conserv. (2017). http://dx.doi.org/10.1016/j.pecon.2017.06.002

CdH/UFMG, 2017. Clínica de Direitos Humanos da Universidade Federal de Minas Gerais (CdH/UFMG). "Direito das populações afetadas pelo rompimento da barragem de Fundão: Povo Krenak." ("Rights of populations affected by the collapse of the Fundão Dam: Krenak people.") UFMG and Greenpeace, March 2017.

CSP2 Database of Tailings Dam Failures. Center for Science in Public Participation database on Tailings Dam Failures 1915 - 2017. http://www.csp2.org/tsf-failures-1915-2017

EMBRAPA, 2015. EMBRAPA press release, 17th December 2015. "Tragédia em Mariana: produção agropecuária em áreas atingidas está comprometida". Empresa Brasileira de Pesquisa Agropecuária. https://www.embrapa.br/busca-de-noticias/-/noticia/8410974/tragedia-em-mariana-producao-agropecuaria-em-areas-atingidas-esta-comprometida. ("Tragedy in Mariana: farming production in affected areas is prejudiced." Brazilian Company of Farming Research.)

GIAIA. Grupo Independente para Avaliação do Impacto Ambiental. "Relatórios do GIAIA e material de suporte" (GIAIA reports and supporting material".) http://giaia.eco.br/materialdesuporte/

Globo, 2016. "Ano de lama: ciência ainda não sabe dizer qual o impacto ambiental." ("A year of mud: science cannot yet tell us what is the environmental impact"). Globo, 5th November 2016.

http://g1.globo.com/espirito-santo/desastre-ambiental-no-rio-doce/noticia/2016/11/ano-de-lama-ciencia-ainda-nao-sabe-dizer-qual-o-impacto-ambiental.html

Globo, 2017. "Samarco não cumpre prazo para limpeza da Usina de Candonga, diz Ibama." (SAMARCO has not met the deadline for cleaning out the Candonga hydro-electric plant says IBAMA"). Globo, 16th February 2017. http://g1.globo.com/minas-gerais/desastre-ambiental-em-mariana/noticia/samarco-nao-cumpre-prazo-para-limpeza-da-usina-de-candonga-diz-ibama.ghtml

Hatje V. et al. "The environmental impacts of one of the largest tailing dam failures worldwide." In Nature/Scientific Reports. 7: 10706 Published online 06 September 2017. DOI:10.1038/s41598-017-11143-x

IBAMA maps of plume at the mouth of the Rio Doce. "Mapas de monitoramento da pluma na foz do Rio Doce" http://www.ibama.gov.br/informes/rompimento-da-barragem-de-fundao#mapasdemonitoramentodaplumanafozdoriodoce. Available through the webpage of IBAMA "Rompimento da Barragem de Fundão: Documentos relacionados ao desastre da Samarco em Mariana/MG" http://www.ibama.gov.br/informes/rompimento-da-barragem-de-fundao

ICMM, 2016. International Council on Mining and Metals. "Position statement on preventing catastrophic failure of tailings storage facilities." London, December 2016.

Justiça Global, 2016. "Vale de Lama: Relatório de inspecção em Mariana após o rompimento da barrage de rejeitos de Fundão." ("Valley of Mud: inspection report of Mariana District after the burst of the Fundão tailings dam"). Rio de Janeiro. Justiça Global, 2016.

Kiernan 2016. Paul Kiernan. "Mining waste dams grow in size and in risks" Wall Street Journal. Monday, April 4th 2016

Leitão, 2017. Rebeca Borges M. A. Leitão. "Financialization and human rights abuses provoked by business: the case of Samarco disaster in Brazil." Dissertation for Erasmus Mundus Master's Programme in Human Rights Policy and Practice, Spring 2017.

Leonardo et al, 2017. Leonardo, F; Izoton, J; Valim, H; Creado, E; Trigueiro, A; Silva, B; Silva, B; Duarte, L; Santana, N. "Rompimento da barrage de Fundão (SAMARCO/VALE/BHP-Billiton) e os efeitos do desastre na foz do Rio Doce, distritos de Regência e Povoação, Linhares (ES). Relatório de pesquisa." (Collapse of the Fundão Dam and effects on the disaster at the mouth of the Rio Doce, districts of Regência e Povoação. Research report.") GEPPEDES and Greenpeace, 2017.

Minas Gerais, 2016. Governo do Estado de Minas Gerais - Secretaria de Estado de Desenvolvimento Regional, Politica Urbana e Gestão Metropolitana. (Government of the State of Minas Gerais - Secretary of State for Regional Development, Urban Policy and Metropolitan Management). "Relatório: Avaliação dos efeitos e desdobramentos do rompimento da Barragem de Fundão em Mariana-MG" ("Report: Evaluation of the effects and impacts of the collapse of the Fundão Dam in Mariana - Minas Gerais"). Belo Horizone, February 2016.

Piresi et al, 2003. "Potencial poluidor de resíduo sólido da Samarco Mineração: estudo de caso da barragem de Germano" ("Pollution potential of the solid waste of Samarco Mineração: case study of the Germano dam"). José Maurício Machado Pires; Jorge Carvalho de Lena; Carlos Cardoso Machado; Reginaldo Sérgio Pereira. Revista "Árvore" vol.27 no.3 Viçosa May/June 2003. On-line version ISSN 1806-9088. http://dx.doi.org/10.1590/S0100-67622003000300017

RENOVA - PRAI, 2017. Fundação RENOVA. "Atualização do Plano de Recuperação Ambiental Integrado - PRAI" ("Updating of the Integrated Plan for Environmental Recovery"). RENOVA, March 2017.

RENOVA - 2017. Fundação RENOVA. "Plano de Manejo de Rejeito." ("Waste Management Plan"). Prepared by CH2M for Fundação RENOVA, April 2017.

Santos and Milanez, 2017. Rodrigo Salles Pereira dos Santos and Bruno Milanez. "A construção do desastre e a "privatização" da regulação mineral: reflexões sobre a tragédia do Vale do Rio Doce, Brasil. ("The construction of the disaster and the "privatization" of mining regulation: reflections on the tragedy of the Rio Doce Basin, Brazil") In Vibrant, Vol. 14, No. 2. http://www.vibrant.org.br/issues/lastest-issue-v-14-n-2-05-082017/

Segura F.R. et al, 2016. "Potential risks of the residue from Samarco's mine dam burst (Bento Rodrigues, Brazil)" Environmental Pollution, 2016

SOS Mata Atlântica, 2016. "Rio Doce - O retrato da qualidade da água" (Rio Doce - a portrait of water quality"). Technical report, November 2016.

Terra Arrasada, 2016. "Terra Arrasada: causas di maior desastre socioambiental da história do país". ("Scorched earth: causes of the worst socio-environmental disaster in the history of the country.") Revista Poli. Vol. VIII, no 43. January/February 2016. FIOCRUZ, Rio de Janeiro, Brazil.

Vormittag et al, 2017. Vormittag, Oliveira, Rodrigues and Gleriano. "Avaliação dos riscos em saúde da população afetada pelo desastre de Mariana" (Evaluation of the health risks f the population affected by the Mariana disaster".) Greenpeace Brazil. March 2017.

Zhouri et al. 2017. Andréa Zhouri; Raquel Oliveira; Marcos Zucarelli; Max Vasconcelos. "O desastre da mineração no Rio Doce, Brasil: entre a gestão da crise e a política das afetações" ("The Rio Doce Mining Disaster in Brazil: between policies of reparation and the politics of affectations.") In Vibrant, Vol. 14, No. 2. http://www.vibrant.org.br/issues/lastest-issue-v-14-n-2-05-082017/

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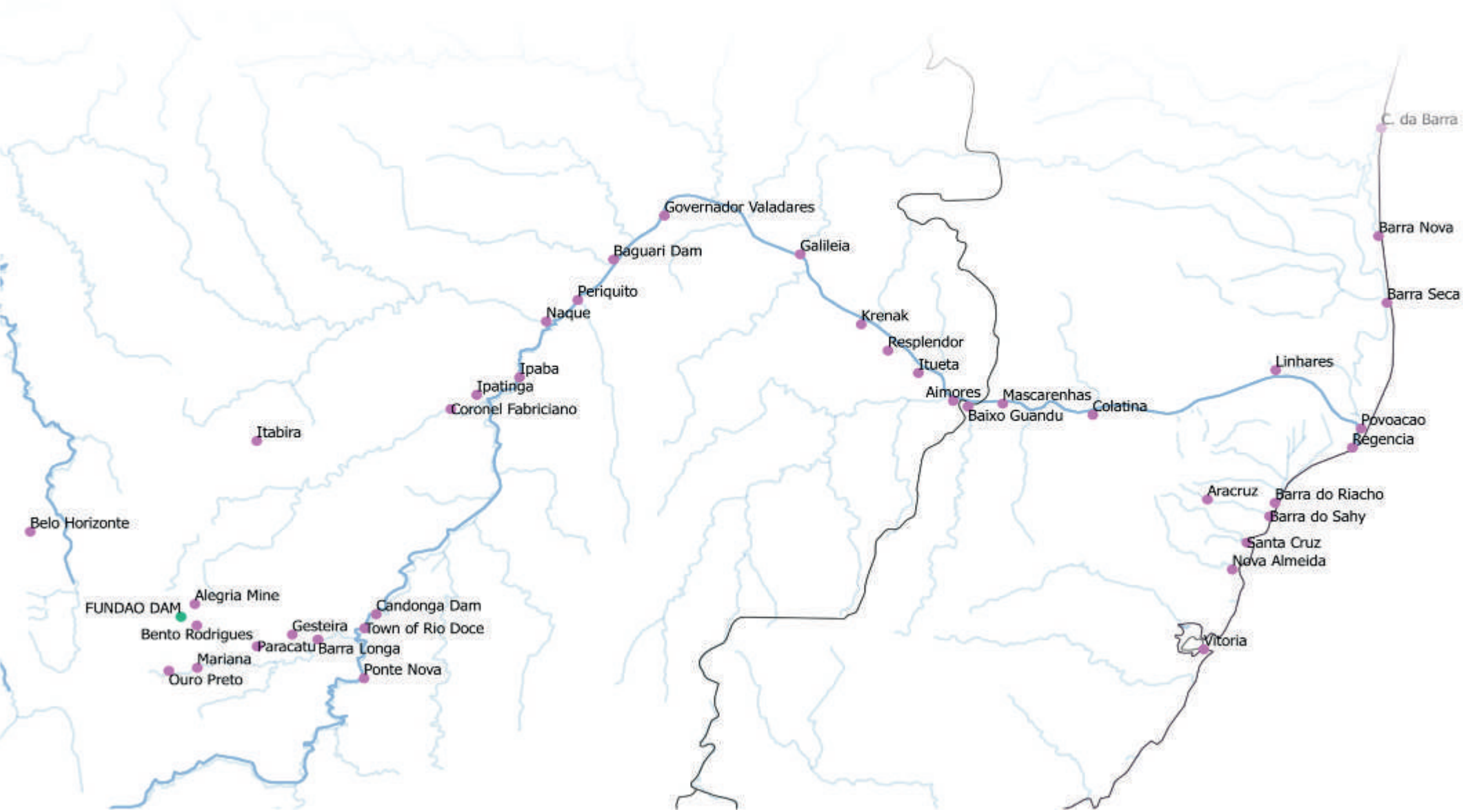

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london mining network

225-229 Seven Sisters Road,
London N4 2DA.

Tel: +44 (0)7903 851695
Email: contact@londonminingnetwork.org
Web www.londonminingnetwork.org
Twitter: @londonmining
Facebook: London Mining Network
Registered charity number: 1159778

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