

# MADEIRA ISLANDS (PORTUGAL). FUNCHAL WATERFRONT. AFTER A CATASTROPHE THE OPPORTUNITY FOR RECUPERATION AND MODERNISATION.

by



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### KEY WORDS:

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### MOTS-CLES:

Île de Madeira (Portugal), résilience aux catastrophes, ouvrages maritimes, correction de rivières, récupération urbaine

### 1. INTRODUCTION

Madeira Islands is a Portuguese archipelago located in the North Atlantic Ocean, west of Morocco and just less than 400 kilometres north of the Canary Islands. The archipelago consists of the main island, Madeira, Porto Santo and the uninhabited Desert and Savage Islands. The group forms an autonomous region of Portugal and it is an outermost region of the European Union.

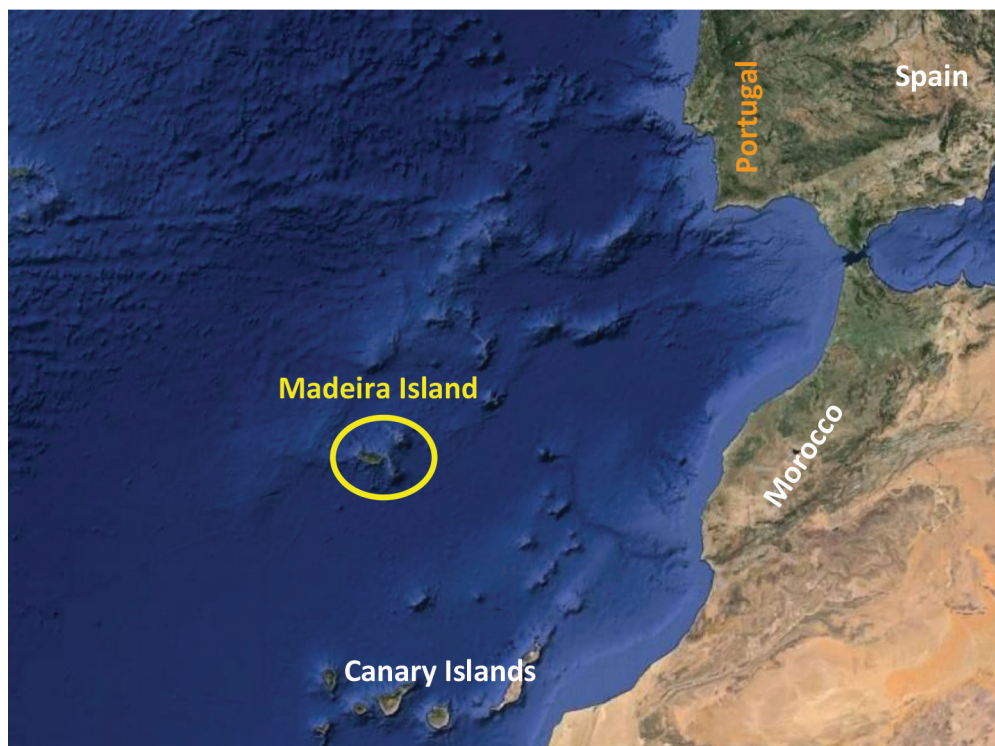


Figure 1: Madeira Island location

Funchal is the largest city, the municipal seat and the capital of this archipelago. It is located inside a natural amphitheatre-shaped valley, with gentle slopes beginning at the coast rising up to 1,200 metres. These natural conditions provided a natural shelter for early settlers. Its harbour is located in a bay close to the city front.

Funchal has three main rivers carrying the mountain run-off water through the urban area back to the sea and into the port basin. They are called the São João, Santa Luzia and João Gomes rivers.

On Saturday February 20, 2010 the city of Funchal and other towns and villages on the South Coast were seriously affected after a long period of strong winds and heavy rain. The total precipitation, including the previous days, caused landslides and floods. Trees were brought down and rocks carried away by the floodwaters blocking existing roads. The rivers couldn't cope and overflowed, causing a flash flood down the mountain side damaging the city centre of Funchal with rocks, mud and debris, as well as water. Some bridges and roads were washed away and cars were swept away. A total of 49 people lost their lives on the island on that day.



Figure 2: Main rivers crossing Funchal city



Figure 3: Landslides at Madeira Island (February 20, 2010)



Figure 4: The rivers overflowed at city centre (February 20, 2010)



Figure 5: Floods in the city centre (February 20, 2010)



Figure 6: Floodwaters blocking the river's course and roads (February 20, 2010)



Figure 7: Rocks carried by the floodwaters and blocking roads (February 20, 2010)

After the catastrophe, a particular urgency was given to rocks, mud and debris removal carried by the floodwaters and to the cleaning of the affected urban area, including the de-cluttering of the river beds. For logistic reasons all these materials were deposited on the city nearshore front, in the area immediately to the East of the old City Pier.

So, as a result of this action, an embankment was build, with an area more than 25,000 m<sup>2</sup> and a volume on the order of 150,000 to 200,000 m<sup>3</sup>, in the front of the city centre, between the old City Pier and the mouth of the Santa Luzia and João Gomes rivers, a total length of 350 m and a width of about 60 to 70 m, which is approximately at an elevation of the littoral avenue.

After the re-establishment of the city normal activity the Autonomous Regional Government of Madeira decided to implement a set of projects having the following objectives:

- The hydrologic study of the main rivers crossing the city and the regularisation and correction of the rivers cross sections and of the river mouth configurations. The creation of a jointed mouth of the Santa Luzia and João Gomes rivers was decided.
- The design of the rivers margins retaining and guiding structures at the final section of each of the three rivers.
- Definition of an urban design solution for the central area of the city, including the use of the created landfill and its surrounding areas, bear-

ing in mind the solutions proposed for final sections of the rivers.

- The alteration of the road network affected by the regularisation and correction of final sections of the rivers, including the design of the new bridges in the central area of the city.
- The design for the affected technical networks and urban infrastructures replacement.
- The design of the marginal city front maritime protection solutions.

## 2. THE REGULARISATION AND CORRECTION OF THE FINAL SECTIONS OF THE RIVERS

Accounting for good practices in situations of this type, it was considered that the beds of the rivers must be dimensioned in such a way as to contain, without overflow, the flow with a return period of 100 years.

In reality, the widening of the river cross sections was not possible by the proximity of the existing downtown buildings on both sides of the rivers. The deepening was theoretically possible, but it would involve the regularisation of the entire length of the rivers and the change of the entire bed along the urban area traversed by them and probably even more upstream.

On the other hand, the efficiency of the deepening in the terminal area is limited by the level of the sea that tends to control the flow downstream. To solve the problem of the reduction of flow capacity on final sections of Santa Luzia and

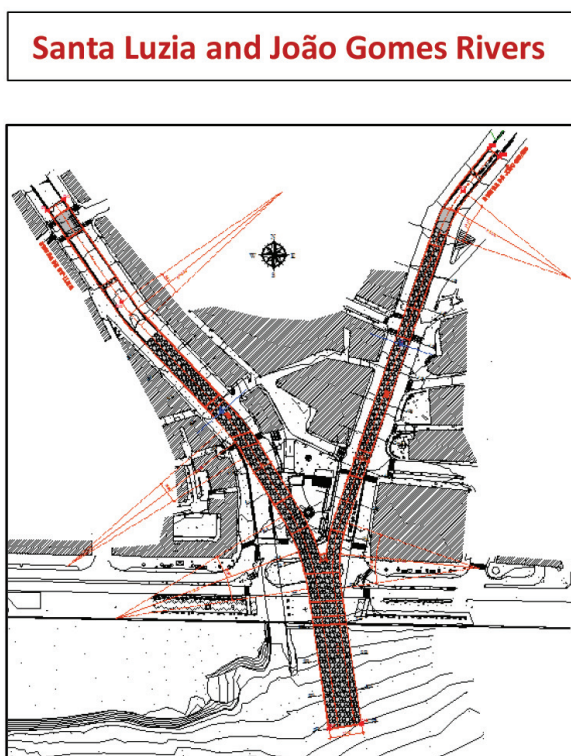


Figure 8: Regularisation and correction of final sections of the Santa Luzia and João Gomes Rivers

João Gomes rivers, a solution was adopted to ensure that on these sections, during a centenary flow, the runoff takes place without overflows. This solution implied:

- The elimination or, at least, the increase of the radius of the channels bends.
- Ensuring that, despite the reduction of slope

in the final sections, this will not cause the loss of the transport capacity of the solid material coming from upstream and its consequent deposition.

- Providing the rivers capacity to transport the solid material to an area where the seabed is already sufficiently deep, avoiding the channels plugging by the transported solid material.

**Santa Luzia and João Gomes Rivers**

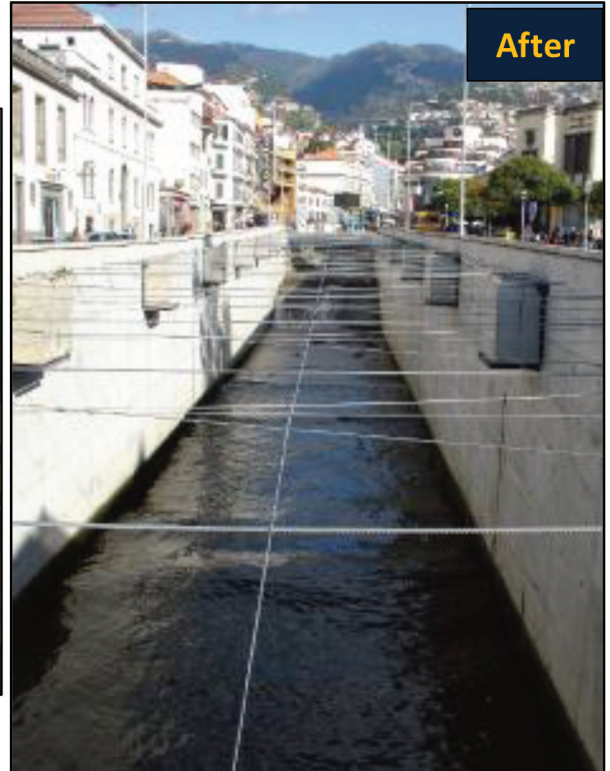


Figure 9: Regularisation and correction of final sections of the Santa Luzia and João Gomes Rivers

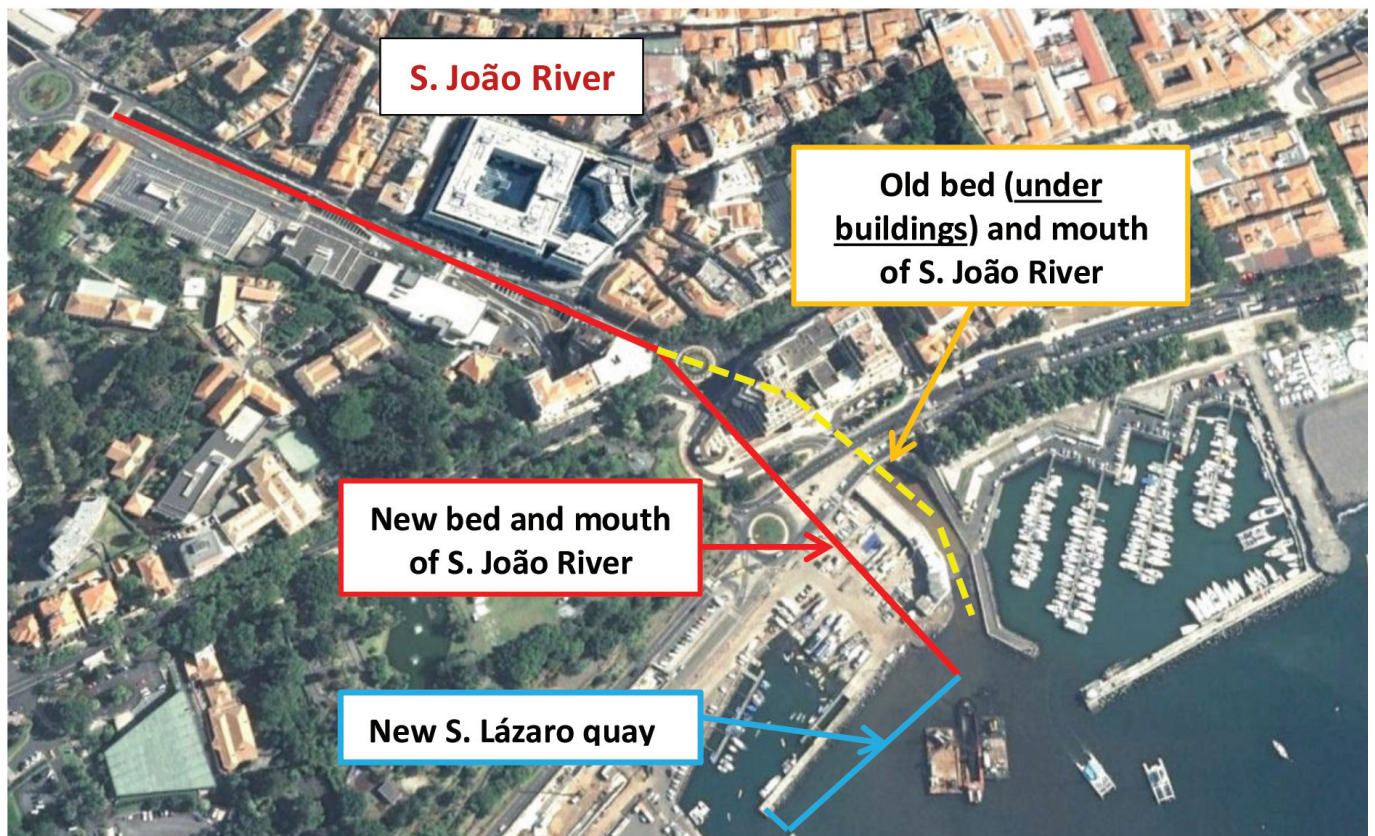


Figure 10: Regularisation and correction of final section of the S. João River

In the case of the terminal sections of Santa Luzia and João Gomes rivers the adopted solution was to join the two rivers and creating a single mouth which has been extended into the sea up to about 75 m from de sea front. The single terminal section of the two rivers was deepened and in order to reduce the roughness and to ensure the transport capacity of the solid flow rate, the channels bottom was covered with concrete.

### 3. THE VALORISATION OF THE LANDFILL AREA

After the catastrophe, particular urgency was given to the removal of the rocks, mud and debris carried by the floodwaters. Due to logistic reasons, all these materials were deposited on the city near-shore front, in the area immediately to the East of the old City Pier.



Figure 11: Regularisation and correction of final section of the S. João River



Figure 12: Landfill created after February 2010

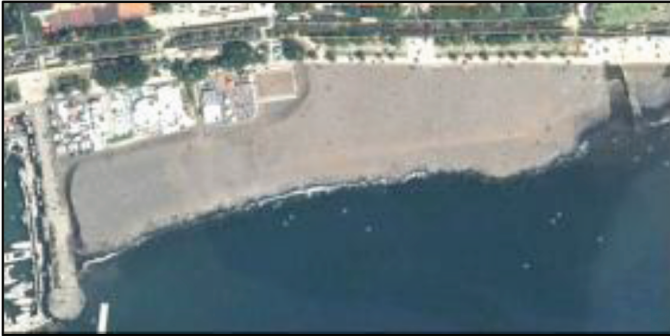


Figure 13: Landfill created after February 2010

The created embankment had an area of more than 25,000 m<sup>2</sup> and a volume on the order of 150,000 to 200,000 m<sup>3</sup>, with a total length of 350 m and a width of about 60 to 70 m. The embankment crown elevation was approximately the same as that of the littoral avenue.

After the total removal of the rocks, mud and debris from the city centre the question was what to do with this landfill.

Two possibilities were considered:

- Remove the landfill, being necessary to transport the materials up to a deposit on land or to launch it on the sea; or
- Take advantage of this landfill, being necessary the construction of containment and protection structures.

Given that the landfill had an economic value and its removal would have major economic and environmental costs, it was decided its exploita-

tion as a mean for the urban development of the city's sea front.

Since this landfill was subject to direct action of maritime agitation, with the consequent risk of silting of the harbour basin, it was necessary to study the technical solutions for its containment and protection.

The simplest solution would be to build a seawall protected with a heavy concrete armour slope (tetrapods or modified cubes), but this type of solution does not constituted any asset landscape and wouldn't have any port functionality.

Thus, it was decided to build a vertical protection that can be used as a quay.

In order to provide the required depth for cruise ships up to 270 m long berthing (-8.00 m ZH of nominal quay depth) the waterfront structure was designed being detached from the existing landfill.



Figure 14: Perspective of the new quay

Due to the maritime agitation that can occur from the sector S-SE, although it has a relatively low frequency, this quay will only be fully operational when, in the future, the main breakwater of the Funchal harbour is extended.

Thus, to minimise the effects of wave reflection on the new structure in the operation of the harbour, and in particular the quays located in the inner side of the main breakwater, it was adopted a solution consisting of prefabricated concrete caissons of different width, in order to promote the dissipation of the wave energy; the outer walls of the caissons in the inner chambers are perforated and the adjacent cells are empty. This solution was

tested in physical model and its results were quite favourable regarding the possible repercussions for the port operation (this quay is under construction, which will be finished in April 2015).

With this solution comprising a vertical protection of the landfill, which can be used as a quay, it was created a new dock for mega-yachts and maritime tourism and leisure activities vessels operating in the harbour of Funchal.

The platform of the landfill has been transformed into a pleasant garden that valued the touristic and environmental quality of the city's urban sea front.



Figure 15: Perspective of the new quay and the inner dock  
(Source: Courtesy of the Autonomous Government of Madeira)





Figure 16: The inner dock and the garden  
(Source: Courtesy of the Autonomous Government of Madeira)

#### 4. THE WATERFRONT PROTECTION OF THE EAST SIDE OF FUNCHAL

In addition to the interventions described previously, it was decided to study a solution to protect the waterfront of the east side of the city.

Overtopping at this part of the city's seafront was frequent during S-SW storm waves. Also, this seafront was significantly degraded not only due to the action of the sea as well as due to the existence of remains of several interventions on the old protection interventions.



Figure 17: Waterfront of the east side of Funchal before intervention

On the other hand, it was important to find a place to deposit the products resulting from the excavation works for the rivers terminal sections regularisation.

The simplest technical solution would be to build a seawall protected with a heavy concrete armour slope (tetrapods or modified cubes), with a crest high and wide enough to prevent the waves overtopping. However, this type of solution would have a significant negative impact on the landscape character given its location in the waterfront of the urban zone of the city.

Thus, an innovative solution was studied based on the establishment of an artificial diffraction beach

to induce the dissipation of incident wave energy.

Once in Madeira Island there are no natural sandy beaches and the containment protection works of this structure should have a crest sufficiently low so as not to constitute a visual barrier, it would not be possible to provide the sand filling of the beach.

Thus, it was decided to fill the top surface beach with small and a medium pebble, the beach substrate was modelled with the referred products of excavation.

This artificial beach was protected by an oblique groin in the west side and a detached breakwater in the centre and east side.



Figure 18: Waterfront protection of the east side of Funchal. Aerial view (Source: Courtesy of the Autonomous Government of Madeira)



Figure 19: Waterfront protection of the east side of Funchal



Figure 20 : Effect of the waterfront protection of the east side of Funchal under a storm (October 2014)

## 5. TECHNICAL REFERENCES

The project, started in July 2010, was awarded to Joint Venture of the Portuguese consultants WW, Consultores de Hidráulica e Obras Marítimas, S.A./ NORVIA PRIMA – Engenharia e Arquitectura, S.A. by de two entities responsible for overall development of the interventions, which are:

- Autonomous Regional Government of Madeira/ Regional Administration of Public Equipment (all interventions all interventions except the new quay for the protection of the landfill)
- APRAM – Port Authority of the Autonomous Region of Madeira, S.A (new quay for the protection of the landfill)

The main responsibilities of the project were as follows:

- General coordination: WW, S.A./NORVIA PRIMA, S.A.
- Hydraulic studies (correction of the final sections of the rivers): CENOR, S.A.
- Urban design: PROAP, Lda
- Inland structures (rivers margins retaining structures and bridges): WW, S.A./NORVIA PRIMA, S.A.
- Maritime engineering and structures: WW, S.A.
- Road and technical infrastructures networks: NORVIA PRIMA, S.A.

The works, started in June 2012, were awarded to two Joint Ventures of the Portuguese contractors:

- ZAGOPE, S.A./AFA, S.A /TECNOVIA MADEIRA, S.A. (all interventions all interventions except the new quay for the protection of the landfill)
- SOMAGUE ENGENHARIA, S.A./ETERMAR, S.A. (new quay for the protection of the landfill)

All works were completed by November 2014, except those for the construction of the new quay for the protection of the landfill, planned to be ended by April 2015.

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## SUMMARY

Madeira Islands is a Portuguese archipelago located in the North Atlantic Ocean, west of Morocco and just less than 400 kilometres north of the Canary Islands. The main island of this archipelago is Madeira.

Funchal, the largest city and the capital of the archipelago, is located inside a natural amphitheatre-shaped valley, with gentle slopes starting at the coast rising up to 1,200 metres. These natural conditions provided a natural shelter for early settlers.

The Funchal harbour is located in a bay close to the city front. There are three main rivers carrying the mountain run-off water through the urban area back to the sea and into the port basin.

On Saturday February 20, 2010 the city of Funchal and other towns and villages on the South Coast were seriously affected after a long period of strong winds and heavy rain. The total precipitation, including the previous days, caused landslides and floods. The rivers couldn't cope and

overflowed, which caused a flash flood down the mountain side damaging the city centre of Funchal with rocks, mud and debris, as well as water. Some bridges and roads were washed away and cars were swept away. A total of 49 people lost their lives on the island on that day.

After the catastrophe, particular urgency was given to the removal of the rocks, mud and debris carried by the floodwaters. Due to logistic reasons, all these materials were deposited on the city nearshore front, creating an embankment with an area of more than 25,000 m<sup>2</sup> and a volume of 150,000 to 200,000 m<sup>3</sup>.

After the total removal of the rocks, mud and debris from the city centre the question was what to do with this landfill.

This article describes the interventions promoted by the Regional Government not only to solve the existing problems created as a result of the catastrophe, as well as in order to explore the created landfill and use it to urbanely improve this part of the city.

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## RÉSUMÉ

Les îles de Madère constituent un archipel portugais situé au nord de l'océan Atlantique à l'ouest du Maroc et un peu moins de 400 kilomètres au nord des îles Canaries.

Funchal, la ville la plus importante et la capitale de l'archipel, est située dans une vallée en forme d'amphithéâtre naturel avec des pentes douces depuis la côte jusqu'à 1200 m d'altitude. Ces conditions naturelles ont fourni un abri naturel pour les premiers occupants.

Le port de Funchal est situé dans une baie proche du front de mer urbain. Trois fleuves principaux évacuent l'eau de la montagne à travers la zone urbaine jusqu'à la mer ou au bassin portuaire.

Le samedi 20 février 2010 la ville de Funchal et les autres villes et villages de la côte sud ont été gravement touchés à la suite d'une longue période de forts vents et précipitations. Les précipitations cumulées y compris des jours précédents ont entraîné des mouvements de terrain et des inon-

dations. Les rivières n'ont pu évacuer la crue et ont débordé, avec une crue éclair en aval, du versant montagneux, endommageant la ville par des blocs rocheux, de la boue, des débris entraînés et par l'eau. Des ponts et des routes ont été emportés, comme les voitures. En tout 49 personnes ont perdu la vie ce jour dans l'île.

Après la catastrophe l'enlèvement des blocs, de la boue et des débris entraînés par les eaux ont été enlevés dans l'urgence pour des raisons logistiques tous ces matériaux ont été déposés dans la ville près du front de mer, créant un remblai d'une surface de plus de 25.000 m<sup>2</sup> et d'un volume de 150.000 à 200.000 m<sup>3</sup>.

À l'enlèvement du centre-ville des matériaux entraînés par la crue, s'est posée la question "que faire de ce remblai ?".

Cet article décrit les interventions promues par le gouvernement régional pour résoudre les problèmes existants du fait de la catastrophe mais aussi pour trouver une vocation au remblai créé et l'utiliser pour améliorer le fonctionnement urbain de cette partie de la ville.

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## ZUSAMMENFASSUNG

Die Insel Madeira ist ein portugiesischer Archipel im Nordatlantik, westlich von Marokko und knapp 400 km nördlich der Kanarischen Inseln gelegen. Die Hauptinsel dieses Archipels ist Madeira.

Funchal, die größte Stadt und die Hauptstadt des Archipels, befindet sich in einem Amphitheaterartig geformten Tal mit sanften Hügeln, die an der Küste beginnen und bis zu einer Höhe von 1.200 m ansteigen. Diese Geländebedingungen boten den ersten Siedlern einen natürlichen Schutz.

Der Hafen liegt in einer Bucht nahe der Stadt. Es gibt drei große Flüsse, die das Regenwasser aus den Bergen durch das Stadtgebiet zurück ins Meer und in das Hafenbecken abführen.

Am Samstag, den 20. Februar 2010, waren die Stadt Funchal sowie andere Städte und Dörfer an der Südküste nach einer langen Periode starken Winds und heftigen Regens stark betroffen. Die Gesamtmenge der Niederschläge, einschließlich der von den Vortagen, verursachte Erdbeben und Überschwemmungen. Die Flüsse konnten die Wassermassen nicht bewältigen und traten über die

Ufer, brachten eine Sturzflut aus den Bergen mit und verursachten im Stadtzentrum von Funchal Schäden durch Felsen, Schlamm und Geröll sowie Wasser. Einige Brücken und Straßen wurden weggespült und Fahrzeuge wurden mitgerissen. Insgesamt 49 Menschen verloren an diesem Tag ihr Leben.

Nach der Katastrophe war es vordringlich, von den Fluten mitgebrachte Felsen, Schlamm und Geröll zu entfernen. Aus logistischen Gründen wurde dieses Material in der Stadt nahe der Küste deponiert, wodurch eine Schutthalde mit einer Fläche von mehr als 25.000 m<sup>2</sup> und einem Volumen von 150.000 bis 200.000 m<sup>3</sup> entstand.

Nachdem Felsen, Schlamm und Geröll aus der Stadt entfernt wurden, stellte sich die Frage, was mit dieser Deponie geschehen sollte.

Der Artikel beschreibt die von der regionalen Regierung vorgeschlagenen Maßnahmen, nicht nur, um das bestehende Problem als Ergebnis der Katastrophe zu lösen, sondern auch, um das deponierte Material zu untersuchen und festzustellen, ob es geeignet ist, diesen Teil der Stadt städtebaulich zu verbessern.

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## RESÚMEN

Madeira es un archipiélago portugués situado en el Atlántico Norte, al oeste de Marruecos y a menos de 400 kilómetros al Norte de las Islas Canarias. La isla principal del archipiélago es la isla de Madeira. Funchal, la ciudad de mayor tamaño y capital del archipiélago, está situado en un valle con forma natural de anfiteatro, con suaves pendientes que nacen en la costa y se elevan hasta una altura de 1.200 metros. Estas condiciones otorgaron un abrigo natural para los primeros habitantes de la isla. Su puerto se ubica en una bahía junto al frente de la ciudad. Existen tres ríos principales que llevan el agua desde las montañas hasta el mar, atravesando áreas urbanas, desembocando en la dársena del puerto.

El sábado 20 de febrero de 2010, la ciudad de Funchal y otras poblaciones situadas en la costa Sur se vieron severamente afectadas por episodios de fuertes vientos y lluvia. Las precipitaciones de esa jornada, unidas a las acaecidas en días anteriores, provocaron deslizamientos de tierra e inundaciones. Los ríos superaron su máximo caudal admisible y se desbordaron, inundando el

centro de la ciudad de Funchal con piedras, barro y escombros, además de agua. Algunos puentes y carreteras resultaron dañados y los coches desplazados. Un total de 49 personas perdieron la vida ese día en la isla.

Después de la catástrofe, se dio prioridad a la retirada de piedras, barro y escombros arrastrados por la riada. Por razones logísticas, todos estos materiales se depositaron cerca de la zona costera, generando un terraplén con un volumen de 150.000-200.000 m<sup>3</sup>, ocupando una superficie de más de 25.000 m<sup>2</sup>.

Después de que las piedras, barro y escombros se hubiesen retirado completamente de la ciudad, la pregunta que se planteó fue qué hacer con todo ese material.

Este artículo describe las actuaciones llevadas a cabo por el Gobierno Regional, tanto para resolver los problemas generados por la catástrofe, como para dotar de un uso productivo a todos los materiales depositados, ayudando con ello a mejorar la parte de la ciudad que resultó afectada.