Adaptation to Flood Risk on Reunion Island (France): A Historical Perspective from Mapping and Photographic Evidence

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1 - INTRODUCTION

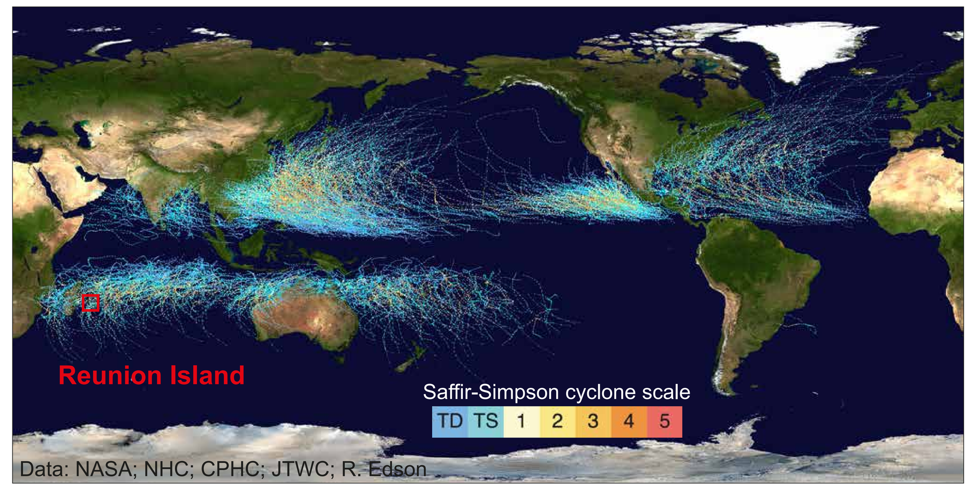


Fig. 1 - Tropical cyclone tracks between 1985 and 2005

BACKGROUND

Located in the southwest Indian Ocean (**Fig. 1**), "La Réunion" (in French) is a volcanic island spanning 2,520 km2. Formed by an asthenospheric hot spot approximately 2.5 to 3 million years ago, the island has experienced significant flood risks since its early settlement in the mid-17th century (**Fig. 2**). The population has increased from just 12 inhabitants in 1646 to 881,348 in 2022, making Reunion Island the most populous French overseas region (**Fig. 3**). The population growth trajectory reveals distinct phases: minimal growth in the initial decades of settlement, a gradual increase during the coffee boom, a notable surge between 1820 and 1870, followed by demographic stagnation due to crises until the 1920s, and an unprecedented population explosion from the mid-20th century onwards.

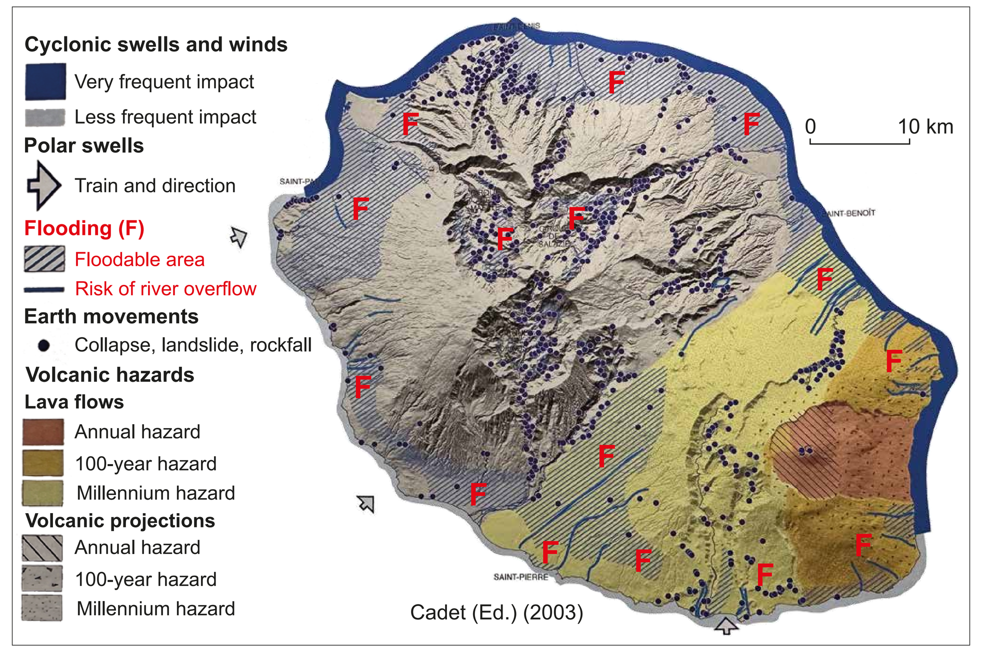


Fig. 2 - The flooding as a major risk in Reunion Island

Concurrently, La Réunion is frequently affected by cyclones, which contribute to severe and often catastrophic flash floods. Since the 17th century, the island has recorded 162 storms or cyclones that have caused damage (**Fig. 3**). The 18th century alone witnessed 53 cyclone events, making it the most affected period, compared to 44 events in the 19th century and 43 in the 20th century.

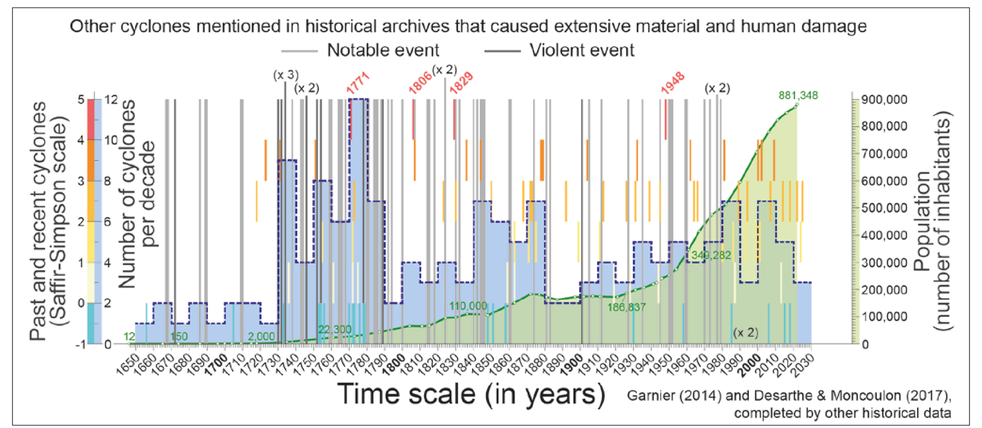


Fig. 3 - The cyclones in the hydroclimatic history of the Reunion Island

WORKING HYPOTHESIS AND RESEARCH OBJECTIVES

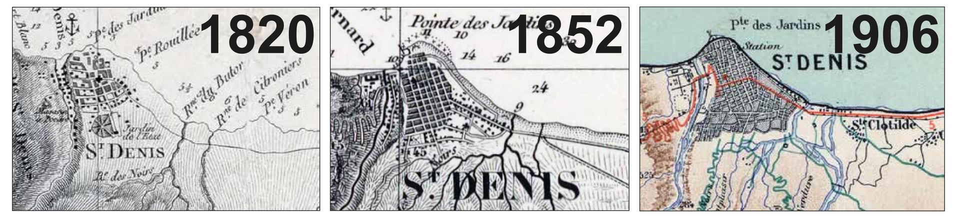
The significant hydroclimatic constraints of Reunion Island have influenced settlement patterns, leading populations to adapt to these challenges from the early stages of colonization. Today, the island is divided into six territories recognized as flood-risk areas (TRI). Understanding the historical context of the flood risk is essential for developing effective management and adaptation strategies. However, the physical characteristics of the environment alone cannot fully account for why thousands of residents continue to inhabit these flood-prone areas. This study aims to trace the evolution of settlement patterns on the island and to identify the key factors (physical, societal) influencing habitation in flood-risk zones.

2 - METHODS

To investigate the evolution of flood risk, we conducted a diachronic analysis of iconographic documents, including maps and photographs.

MAPS

We examined a comprehensive collection of historical maps spanning from 1653 to 2025. While maps from the 17th and 18th centuries were analyzed, they were deemed unsuitable for habitat quantification due to their lack of precision and completeness. For more accurate assessments, we focused on maps from 1820, 1852, 1906, 1950, and 2023 (**Fig. 4**), and quantified the number of buildings across various geomorphological units, including "planèzes" (volcanic plateaus), slopes, floodplains, and coastal plains (**Fig. 5**).



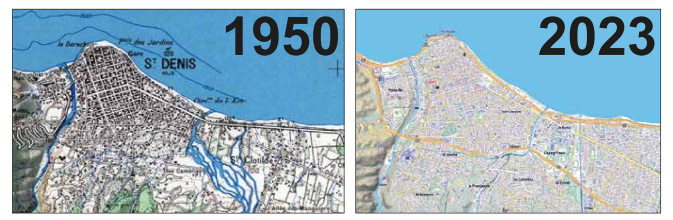


Fig. 4 - Habitat quantification by geomorphological unit using historical maps

Throughout the period from 1820 to 2023, we identified a total of 463,300 buildings. This data was processed using QGIS software, enabling us to visualize and analyze the spatial distribution of these habitats. By employing the above geomorphological classification, we aim to pinpoint at-risk areas where housing development is occurring. The "planèzes" are particularly susceptible to flooding due to overflow from small rivers and rainwater runoff. Although slopes, including alluvial terraces, offer some protection against flooding, but slopes are vulnerable to landslides whereas alluvial terraces can be eroded by active-channel-widening. The floodplain poses the highest flood risk, while the coastal plain exposes residents to the threats of marine submersion and erosion.

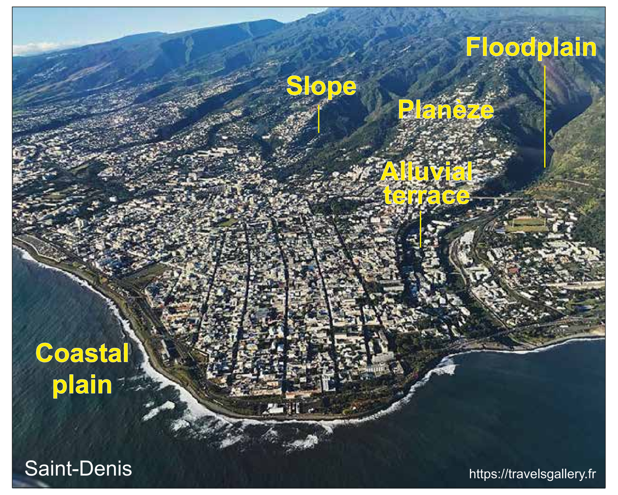


Fig. 5 - Habitat quantification by geomorphological unit

PHOTOGRAPHS

We examined a series of postcards from the late 19th to early 20th centuries, available at the Archives Départementales in Saint-Denis. We selected approximately fifty postcards based on specific criteria: the relationship between habitats and rivers, the need for a compre-hensive spatial perspective, and the represen-tation of diverse watersheds across the island. Field missions conducted in 2024 (February-March and June) and 2025 (March) allowed us to replicate the photographs at the same locations as depicted on the ancient postcards, facilitating a direct comparison of changes in land use and hydro-morphological structures (**Fig. 6**).

Fig. 6 - Diachronic habitat analysis based on photographic comparison of the same site

3 - RESULTS

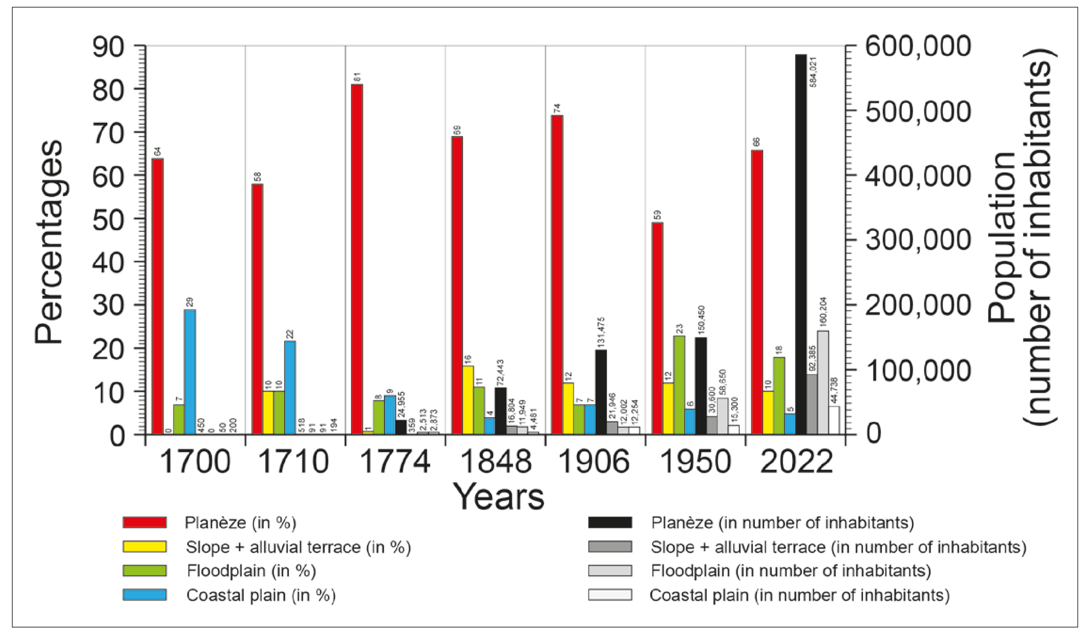


Fig. 7 - Quantification of habitat and population in geomorphological units from 1700 to 2022

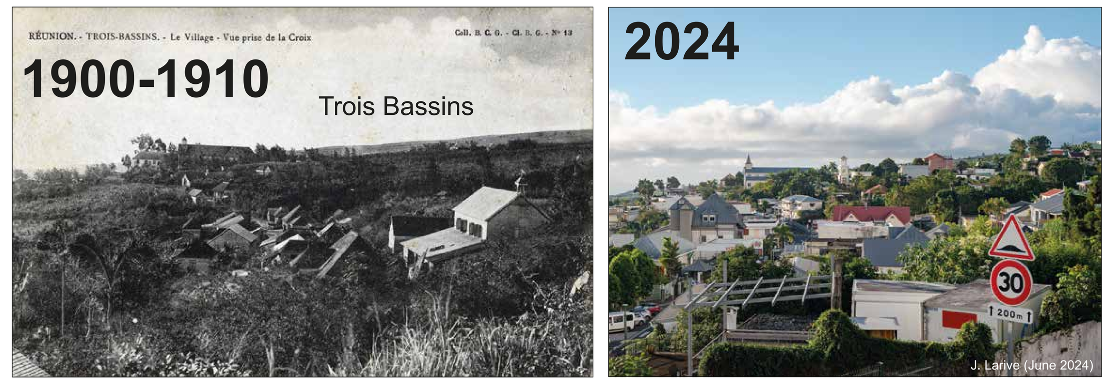


Fig. 8 - Densification of housing on the "planèzes"

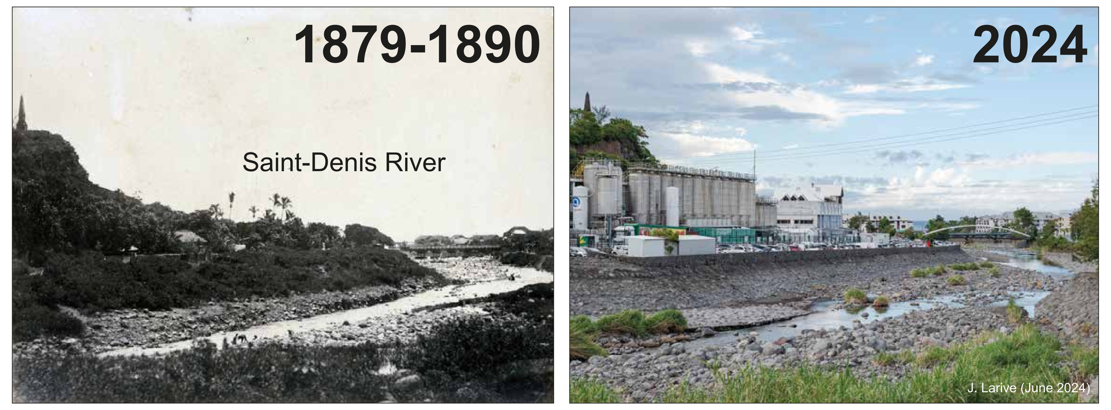


Fig. 9 - Urban development on the margins of active channels protected from flooding by dikes

THE GENERAL EVOLUTION OF HABITAT

Between 1700 and 2022 (**Fig. 7**), significant trends in habitat evolution emerged:
- "Planèzes": This geomorphological unit has consistently been the preferred location for settlement, with occupancy percentages remaining relatively stable over the period, ranging from 58% to 81%. In absolute numbers, the population on the "planèzes" has increased dramatically, growing from 450 inhabitants in 1700 to 584,021 in 2022.
- Slopes, including alluvial terraces: They have always constituted no more than 16% of the island's habitat. However, in absolute terms, the population increased from 91 in 1700 to 92,385 in 2022, reflecting a 3-fold increase from 1950 to 2022.
- Floodlains: Occupancy of the floodplains has risen from 7-11% in earlier years to 23% in 1950 and 18% today. This growth is even more pronounced in absolute terms, with the population living on these flood-prone lands expanding to 160,204 individuals in the present day, compared to fewer than 59,000 in 1950 and earlier.
- Coastal plains, which is different from the 'coastal fringe' of the territorial division, have experienced a steady decline in habitat, decreasing from 29% in 1700 to just 5% in 2022. However, in absolute terms, the population has reached an all-time high, with 44,738 inhabitants in 2022.
- Highlands: The number of residents in the highlands (defined as land at altitudes exceeding 400 m) has evolved from 23% occupancy in 1906 to 39% in 1950, but has decreased to 28% by 2022.

INCREASINGLY DENSELY POPULATED "PLANÈZES"

The densification of housing on the "planèzes", alongside the significant rise in population, has heightened the risk of urban runoff, and flooding particularly in relation to small rivers. In the municipality of Trois Bassins, the number of buildings on the "planèzes" is projected to be two to three times greater in 2024 than it was in 1900-1910 (**Fig. 8**).

THE SAFETY UTOPIA OF URBAN RIVER DIKES

The origins of diking projects in Reunion Island can be traced back to the second half of the 18th century; however, it was during the 1970s and 1980s that significant efforts were made to construct dikes designed to prevent river overflow into urban areas, such as Saint-Denis, Le Port, and Saint-Paul. These initiatives were largely influenced by the legislative framework of risk zoning (PER) and were propelled by the impacts of Cyclone Hyacinthe (Duvoisin, 1994). Despite their construction and subsequent elevation over time, dikes cannot guarantee complete protection against breaches, fostering a sort of utopian sense of security against flooding, bank erosion, and avulsion (Lorion, 2006; **Fig. 9**).

INADEQUATE ASSESSMENT OF LONG-TERM RIVER DYNAMICS

The failure to account for the lateral variability of active channels when siting habitats has been consistently demonstrated throughout history:
- The 'Lazaret n°2' case exemplifies the ill-considered placement of a structure within the active channel of the Grande Chaloupe River in 1860 (**Fig. 10**). Its foundations rested precariously on the ancient pebbles of the riverbed. Ultimately, the river destroyed the building on February 28, 2025, as the active channel widened during Cyclone Garance.
- On March 4, 1913, a cyclone significantly widened the Saint-Denis active channel, causing a breach in the dike that was meant to safeguard the lower quarters of the city situated on the margins of the active channel (**Fig. 11**). An almost identical reconstruction of the dike allowed for urban development in this area, ignoring the historical 'freedom space' of the active channel, and subsequently placing residents at high risk of flooding in future events.
- More recently, on February 28, 2025, Cyclone Garance caused substantial widening of the rivers in western Reunion Island, particularly between Saint-Denis and Saint-Gilles.

Fig. 11 - Breach in the Saint-Denis River dike, caused by the cyclone of March 4, 1913. Note that the area where the active channel was widened in 1913 has since been intensively built on

Fig. 12 - Habitat located in active channels, severely affected by flooding caused by cyclone Garance

In these valley bottoms, the historic right-of-way of the active channels was not taken into consideration by local residents, and a large number of houses were built along the active-channel axes as early as the 19th century, and especially from the 1950s onwards (**Fig. 12**). Given these circumstances, the flooding associated with Cyclone Garance, which contributed to the significant widening of riverbeds, resulted in extensive damage to many houses situated in the active channels, particularly in the upstream part of the rivers Saint-Denis (quarter 'La Colline'), Lataniers (La Possession), and Grande Chaloupe. Most of the observed damage pertains to informal housing, specifically dwellings constructed without proper planning permission.

Fig. 10 - Destruction of 'Lazaret n°2', a historic building over 150 years old, by the active-channel widening of the Grande Chaloupe River during cyclone Garance

4 - CONCLUSIONS

HISTORICAL CONTEXT OF CYCLONE-RELATED FLOODING IMPACT AND RESILIENCE

Historical data indicates that cyclones, while destructive, do not typically result in exceptional loss of life. However, there are pronounced racial and social disparities in mortality rates associated with these natural disasters. The damage inflicted by cyclones on housing is heavily influenced by the quality of construction, with distinctions between simple structures ("*paillotte*") and more durable homes ("*case*") playing a critical role (CAUE Réunion, 2006). More significant than the cyclones themselves are the secondary effects of flooding, which can lead to widespread destruction of crops and infrastructures, economic disruption, food insecurity, and health risks. Interestingly, small-scale crops cultivated by families have demonstrated greater resilience compared to more commercially speculative crops such as coffee and cloves. We align with Garnier's (2014) perspective that ancient societies did not passively endure the adverse effects of climate but actively sought to coexist with cyclonic waters and mitigate their dangers. In the early days of settlement, inhabitants sought refuge from flooding in nearby forests. By the 18th century, rudimentary yet effective warning systems had begun to be established at ports and churches. Following the cyclones of 1806 and 1807, which caused extensive damage to coffee and spice plantations, these enterprises were not reconstructed. Instead, sugar cane—a more resilient crop—was introduced, marking a significant shift in agricultural practices.

LIMITATIONS OF DIKING-SYSTEMS AND OBJECTIVES FOR FLOOD RISK ADAPTATION

The so-called safety achieved through diking systems in the floodplains during the 1970s and 1980s has revealed significant limitations (Lorion, 2013), as many river stretches remain high-risk flood areas today (**Fig. 13**). The expansion of settlements on the "planèzes" has exacerbated the risks associated with rainwater runoff and river overflow (**Fig. 14**). To effectively adapt to flooding risks on Reunion Island, it is essential to focus on reducing vulnerability.

Fig. 13 - Breach of the "Patates à Durand" River dike during cyclone Hyacinthe

Fig. 14 - Very high vulnerability to river flooding, bank erosion and rainwater runoff on "planèzes"

This process begins with the definition of the "*espace de bon fonctionnement des rivières*" (space for the proper functioning of rivers), an approach aimed at identifying areas where housing should not be constructed due to their location within historically active channels (Malavoi et al., 1998). This framework is intended to provide a clearer understanding than the existing PPRI (Flood risk prevention plan) zoning, highlighting sectors where housing has encroached into zones of high risk (**Fig. 15**). The urgency of reducing vulnerability in valley bottoms and "planèzes" is under-scored by recent IPCC (2023) predictions, which indicate that while the frequency of cyclones may not increase, their intensity is likely to rise, thereby heightening the potential impact on Reunion Island.

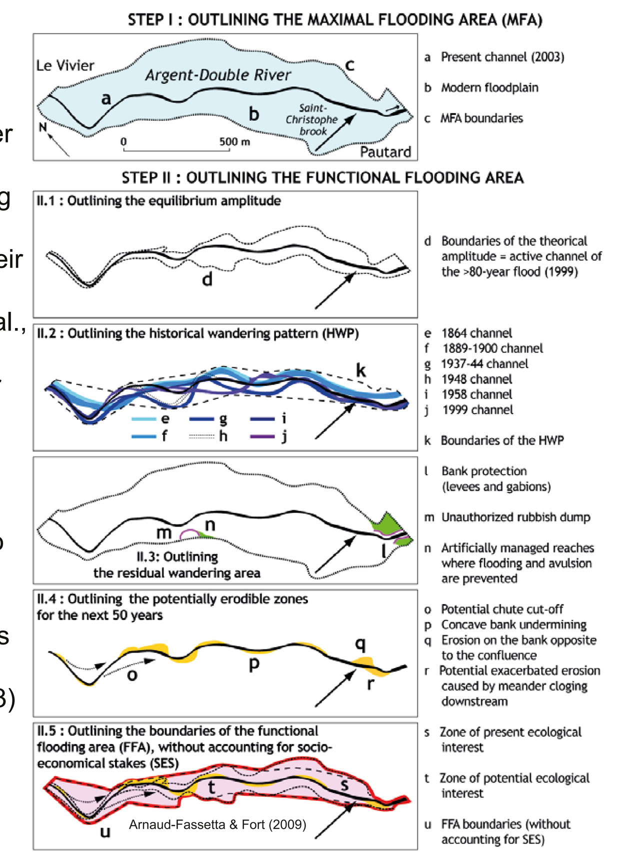


Fig. 15 - The reduction of vulnerability involves the application of the concept of the rivers' functional space

Poster presentation date and venue

Poster presented on April 28, 2025, during session HS7.5 - Hydro-Meteorological Extremes and Hazards: Vulnerability, Risk, Impacts, and Mitigation at the **EGU (European Geosciences Union)** General Assembly 2025 in Vienna (Austria), under identification number EGU25-6246. The work was carried out as part of the LABEX DYNAMITE project "*The Waters of Reunion Island in the Context of Climate Change: Balancing Societal Perceptions and Scientific Certainties (or Uncertainties)*", under the supervision of G. Arnaud-Fassetta.

References

Arnaud-Fassetta G., Fort M. (2009) The integration of space of good functionment in fluvial geomorphology, as a tool for mitigating flood risk. Application to the left-bank tributaries of the Aude River, Mediterranean France. In Gumiero B., Rinaldi M., Fokkens B. (Eds.) *IVth ECRR International Conference on River Restoration 2008.* Centro Italiano per la Riqualificazione Fluviale, 313-322. **Cadet F. (Ed.) (2003)** *Atlas de La Réunion*. Université de la Réunion/Institut national de la statistique et des études économiques, Saint-Denis (La Réunion), 143 p. **CAUE Réunion (2006)** *350 ans d'architecture à l'île de La Réunion*. CAUE Réunion, Saint-Denis, 207 p. **Desarthe J., Moncoulon D. (2017)** Quatre siècles de cyclones tropicaux dans les départements français d'outre-mer. *La Météorologie*, 99, 52-58. **Duvoisin J. (1994)** La Réunion « L'endiguement des grandes ravines sur leur cône de déjection ». In *Crues et inondations*. 23e journées de l'hydraulique. Congrès de la Société Hydrotechnique de France, Nîmes (France), 14-15-16 septembre 1994. Tome 2, 413-419. **Garnier E. (2014)** Cyclones et sociétés dans les Mascareignes XVII[e]-XVIII[e] siècle. *Revue historique de l'océan Indien*, 11, 229-247. **IPCC (2023)** *Climate Change 2023: Synthesis Report*. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (Eds.)]. IPCC, Geneva, Switzerland, 35-115. **Lorion D. (2006)** Endiguements et risques d'inondation en milieu tropical. L'exemple de l'île de la Réunion. *Norois*, 201, 45-66. **Lorion D. (2013)** From a utopia of security to the integrated management of drainage basins: The example of Reunion Island (France). In Arnaud-Fassetta G., Masson E., Reynard E. (Eds.) *European continental hydrosystems under changing water policy*. Friedrich Pfeil Verlag, München, 87-98. **Malavoi J.-P., Bravard J.-P., Piégay H., Heroin E., Ramez P. (1998)** *Détermination de l'espace de liberté des cours d'eau*. SDAGE Rhône Méditerranée Corse, Guide technique, 2, 42 p.