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From the hydroclimatic disaster to the forced (re)construction : Case study of the Akatani watershed in Japan †

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Abstract: In 5th–6th July 2017 (J17), an unusual train of rainfalls induced a concentration of precipitations in Northern Kyūshū, Japan, reaching 516 mm for 24 h in Asakura City, a first in its history since the beginning of observation in 1976. It triggered unprecedented hydro-meteorological hazards (landslides, debris-flows, and floods) in forested mountainous areas, such as in Akatani watershed where the estimated discharge reached 520 m^3/s at its outflow. It induced numerous deaths, structural damages, destruction of river channels and deposition of sediment in flood plains. If smaller-scale hazards have usually driven authorities to build protection systems in the watershed, the J17 crisis has called for a full remodeling of it, interrupting waterways, reshaping slope shapes and structures. Considering the means deployed by the central government for this reconstruction, the J17 event has triggered a full "re-construction" of rivers, modifying the hydrosystem's functioning at the watershed scale. Thus, our objective is to show that after the relative stability of Akatani watershed's hydrosystem over 75 y, the exceptionality of J17 crisis forced to rethink the watershed's organization, using this event as the reference for post-disaster reconstruction. The research relies on field surveys in 2019 and 2022, interviews of officials, and GIS analysis based on historical aerial-photograph interpretation and geospatial data. It revealed that (a) the geometry of post-disaster channels has been completely redesigned to match a new referential; (b) sediment control structures were multiplied to restructure slopes, breaking the slope angles in sub-watersheds. The Akatani watershed case then illustrates the full range of structural measures developed by Japanese engineering to reduce the hydrological risk.

Keywords: Post-disaster reconstruction; River System Sabo; Akatani watershed

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1. Introduction

In 5th–6th of July 2017 (J17), an unstable atmospheric condition caused an unusual train of rainfalls which triggered a set of hydro-meteorological hazards in Fukuoka and Ōita prefectures, Kyūshū island (Figure 1) [1]. The region registered an unusual amount of daily rainfall, reaching 516 mm in 24 h in Asakura city [1]. Between 1977 and 2017, precipitation rates have already exceeded 600 mm on a monthly scale on 9 occasions [2].

However, J17 precipitation rate is exceptional with an estimated occurrence probability higher than 1/200 [3], leading to thousands of landslides in the mountainous areas of sub-watersheds on the right bank of Chikugo River (CH) [1].

Landslides were accompanied by debris flows and river floods, stroking mountainous villages and cities located in CH's floodplain. It resulted in several structural damages and death loss: damages were evaluated at 224,070 M of yens with 3,067 dwellings impacted, 41 victims, including 22 of them in the Akatani (AK) watershed (Figure 1) [4]. The amount of dragged sediment in the watershed reached 2.9 M m^3, floods inundated 106 ha, and 258 houses were affected by the disaster [3]. During J17 crisis, the four rivers of AK watershed (AK; OT: Otoishi; OY: Oyama; OG: Ogouchi) (Figure 1) were damaged, especially rivers AK and OT. We divide them into sections for calculations (Figure 1).

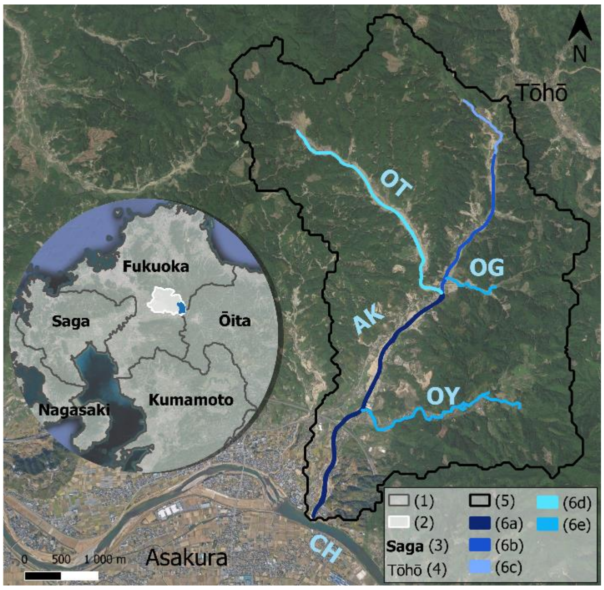

Figure 1. Location of AK watershed (approximately 20 km^2). (1) prefecture boundaries; (2) Asakura boundaries; (3) prefecture name; (4) city name; (5) AK watershed; (6a) AK downstream; (6b) AK middle stream; (6c) AK upstream; (6d) OT stream; (6e) other rivers.

Aftermath natural disasters, the Japanese government usually sets up reconstruction plans. If precedent events have usually driven the regional and local authorities to build protection systems in AK watershed, the amplitude of J17 disaster has called for a full remodeling of it, interrupting waterways, reshaping slope shapes and structures, implying central government and about 30 building and public works companies over 5 y. Our research aims to explain how after the relative period of stability, the exceptionality of the J17 crisis forced to rethink of the watershed's organization, leading to the use of a new referential for post-disaster reconstruction plans.

We will show that (i) between 1947 and 2017, AK watershed organization was stable despite hydro-meteorological hazards registered for the period; (ii) J17 crisis represents a low-frequency, high-magnitude (LFHM) phenomenon, which caused severe damages in the watershed and forced to develop a large-scale post-disaster reconstruction with a new referential; (iii) reconstruction policies induced by this crisis based on structural measures such as erosion control dams (ECD) or channel enlargement reflect the engineering response of the Japanese government after an hydroclimatic disaster.

To verify our hypothesis, we will rely on (i) work fields and 3 interviews done in 2019 and 2022, (ii) digitalization of floods and mass movement in the AK watershed supported by data from the Geospatial Information Authority of Japan (GSI), (iii) diachronic analysis of river-channel width and sinuosity between 1947 and 2022, and (iv) evolution of pre- and post-disaster number of ECD.

2. Materials and methods

To highlight the J17 disaster's impacts and follow reconstruction policies, we based the methodology on a diachronic analysis of multi-sources imagery from 1947 to 2022 (Figure 2). To show the relative stability of AK watershed before 2017 and the disequilibrium J17 crisis caused, we analyzed the watershed's evolution over 75 y by comparing (i) river sinuosity index, (ii) channel width, and (iii) construction of erosion control structures (ECS). Those comparisons were done with manually georeferenced aerial photographs (AP) for 1947 and 2009 [5], 2017 AP [6] and 2022 satellite images (Figure 2). AP mainly cover AK watershed area, with a focus on valley bottoms. Due to the physiography of the area, we used polynomial 2 function for the georeferencing. We accepted a margin error of 1 to 2 pixels for each georeferenced AP. We used 2017 and 2022 images to georeference 2009 AP. Due to the similarity of land use, we georeferenced 1947 AP with the help of 1980's AP [6]. Margin errors are most important for 1947, due to the bad quality of photos.

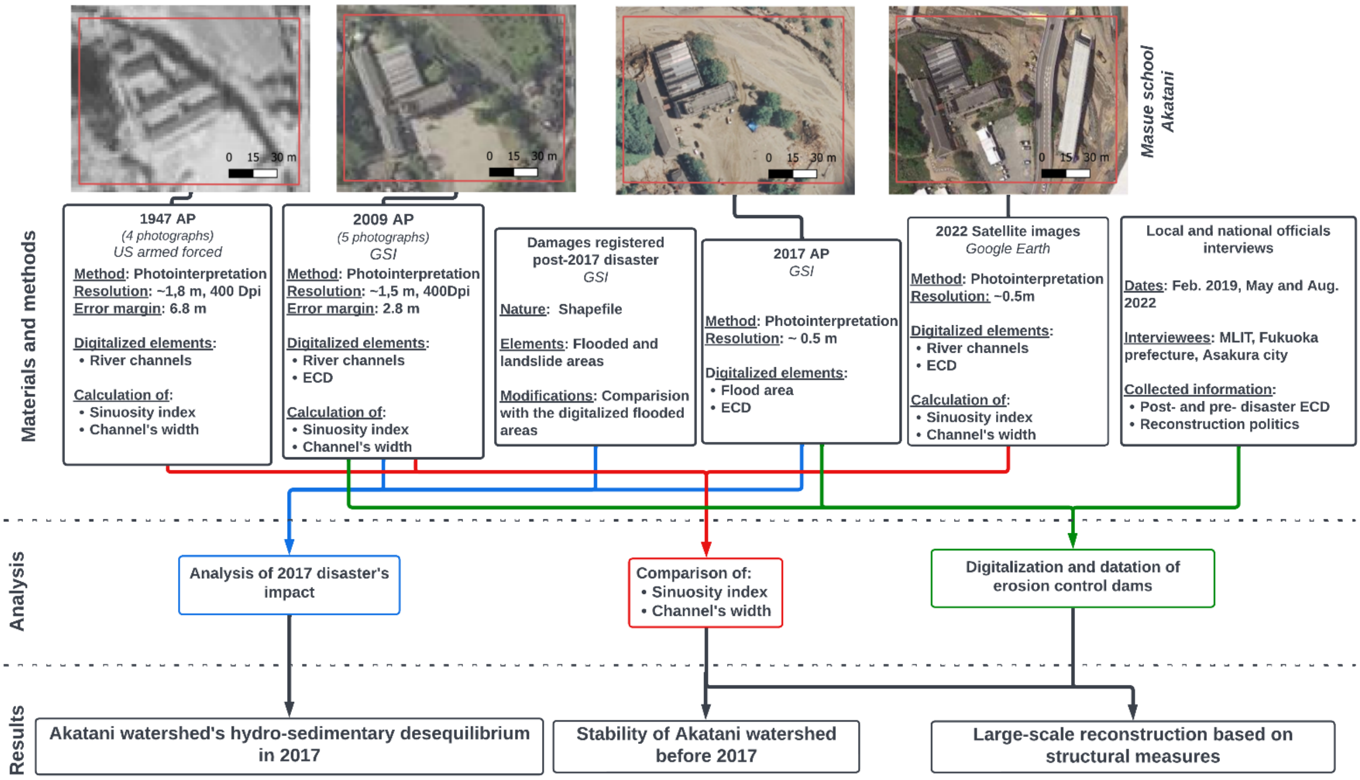

Figure 2. Diagram of the used methods and materials.

With 1947, 2009, 2017, and 2022 resources, we digitalized river channels and erosion dams (Figure 2). Because of the chosen method, error may occur in the digitalization process. To calculate the margin error of the digitalized elements, we used two disconnected channels visible in 2022's images (Figure 3). Every 15 m, we calculated and merged the difference between pre-disaster and disconnected channels for each bank (Figure 3). Errors may be due to the vegetation along rivers, limits of photointerpretation or mismatch during georeferencing process. To identify rivers modification, we calculated their width and sinuosity index at 3 periods (Figure 2). Following thresholds characterise sinuosity indexes: <1.05: straight; 1.05-1.3: sinuous; 1.3-1.5: moderate meandering; >1.5: meandering form [7]. For their width, we calculated their mean length from a bank to another with transects every 100 m.

In addition, we acknowledge damages in the watershed and follow its restoration through three field surveys done in February 2019, May, and August 2022. Three interviews with national and local officials involved in the reconstruction process completed our observations by collecting data related to ECS (Figure 2). Within those structures, we inventoried two categories of ECD: (i) sabo dams, constructed by the Ministry of Land, Infrastructures, Transport and Tourism (MLIT) and prefectures; (ii) chisan dams, managed by the Ministry of Agriculture, Forestry and Fisheries (MAFF). For lacking data dams, the comparison of 2009, 2017 and 2022 images helped to define approximately their construction date and classify them as pre- or post-disaster constructions.

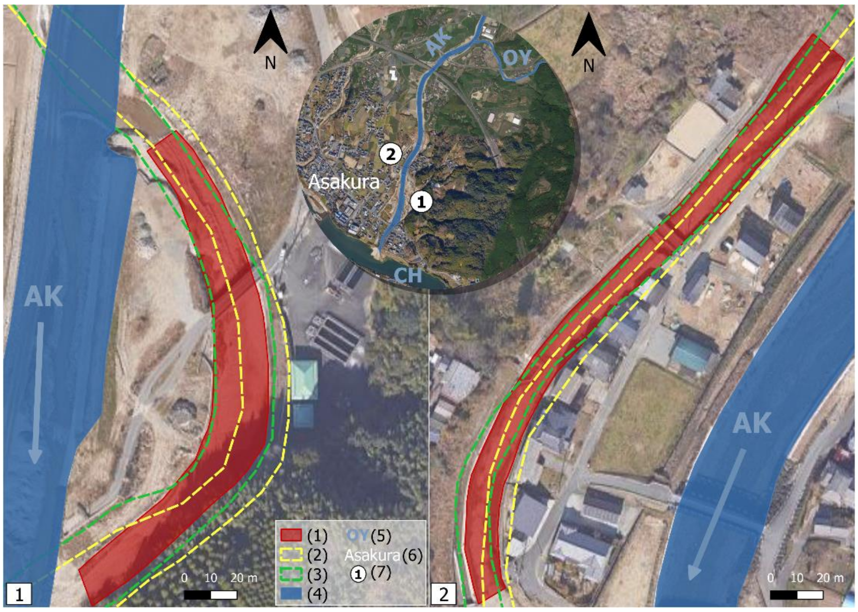

Figure 3. Example of remaining channels used to calculate margin errors. (1) disconnected channel; (2) 1947 channel; (3) 2009 channel; (4) 2022 channel; (5) hydronym; (6) city name; (7) channel location

3. Results

The evolution of AK watershed over 75 y and the role of the J17 crisis into the modification of watershed's organization can be described in 3 stages: (i) the J17 hydroclimatic event represents a complete disruption of the hydrosystem's functioning; (ii) the organization of AK watershed remains relatively stable before 2017. After J17 event, the watershed is subject to a complete restructuration of the river channel; (iii) and a huge number of ECD construction.

3.1. From 1947, the hydroclimatic event of 2017 completely disrupted the area

Heavy rainfalls concentrated in a short period of time such as J17 event are rare in AK watershed [2]. Kyūshū Regional Management Service Association (KRMSA) registered all significant disasters such as hydroclimatic-related ones since 679 for Fukuoka prefecture. Very few registered events explicitly imply AK watershed: one in 1921 and J17 one [8]. It shows that hydro-meteorological hazards rarely trigger high-magnitude disasters in the watershed, strengthening the singularity of J17 disaster. At this time, AK watershed registered significant damages in 2017. In the mountains, landslides and debris flows were triggered in several sub-basins, carrying driftwood (Figure 4) [9]. Downstream, river floods inundated valley bottoms, carrying sediments from the upper slope erosion. In addition to the death loss, those hazards damaged building and transportation systems in AK watershed [10].

Regarding the magnitude and the repercussions of the event, the restoration works were considered necessary to (i) rehabilitate damaged structures and protection systems, and (ii) protect inhabitants living in mountainous areas and downstream from future high-magnitude hazards. As the J17 event showed the limits of previous protection systems for LFHM crisis, the government undertook post-reconstruction plans based on rainfall rates with an occurrence probability of 1/50 [3], leading to the complete remodeling of river channels and the development of erosion protection systems in the watershed.

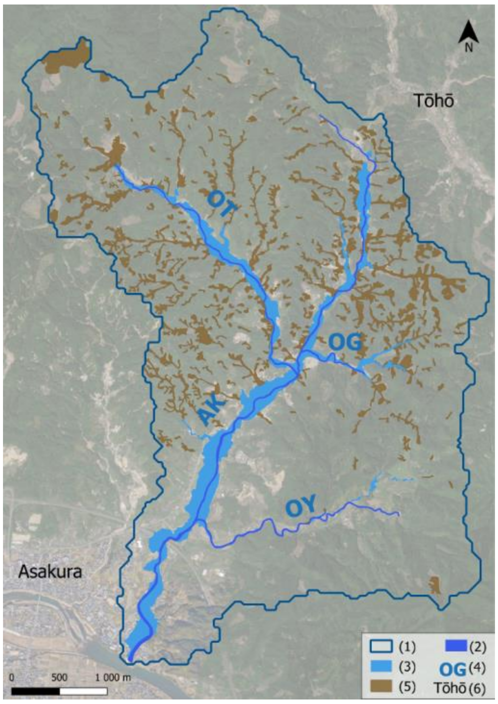

Figure 4. Spatial coverage of hydroclimatic hazards after the heavy rainfall of the J17 event. (1) AK watershed area; (2) 2009 channel; (3) 2017 flood; (4) hydronym; (5) landslide area; (6) city name.

3.2. A reconstruction of the geometry of the channel after 2017

After J17, river channels were redesigned to "increase the reliability of flood control" by widening and straightening rivers [11], increasing AK bankfull discharge from $50 m^3/s$ to $330 m^3/s$ at CH's confluence [3]. This evolution is detailed in Table 1 for each section presented in Figure 1.

From 1947 to 2022, channel's mean width globally increased (Table 1). AK downstream, middle stream and OT's width respectively increased by 142.9%, 75.4% and 136%. AK upstream is relatively stable over 75 y. Between 1947 and 2009, channel's width sightly varies, decreasing in some cases (AK middle stream and OT). We can assume that those variations fall within the margin of error.

Table 1. Evolution of AK and OT channels mean width (in m).

	AK downstream	AK middle stream	AK upstream	OT
1947	11.31	7.32	5.82	5.34
2009	13.03	6.56	5.87	5.18
2022	27.47	12.84	5.24	12.60

In 1947, with a sinuosity index exceeding 1.05, channels were sinuous (Table 2). AK downstream is the one with the highest sinuosity index (1.11), which may be due to its location in lowlands, while other sections are in mountainous area with narrow valley bottoms. In 2009, 3 of them remained sinuous (Table 2). The upstream part of the AK channel is the only one considered straight with a sinuosity index inferior to 1.05. The highest indexes are for the downstream of the AK (1.10) and OT (1.07) channels. In 2022, a real shift in their sinuosity occurs with all rates below 1.05. From 1.10 to 1.03, AK downstream sinuosity index decreased the most (Table 2). Figure 5 illustrates this straightening process in AK downstream and OT. While river's paths were mainly similar in 1947 and 2009, 2022 channels show an abrupt change.

Table 2. Evolution of sinuosity index for the rivers AK and OT.

	AK downstream	AK middle stream	AK upstream	OT
1947	1.11	1.07	1.07	1.07
2009	1.10	1.05	1.04	1.07
2022	1.03	1.02	1.04	1.02

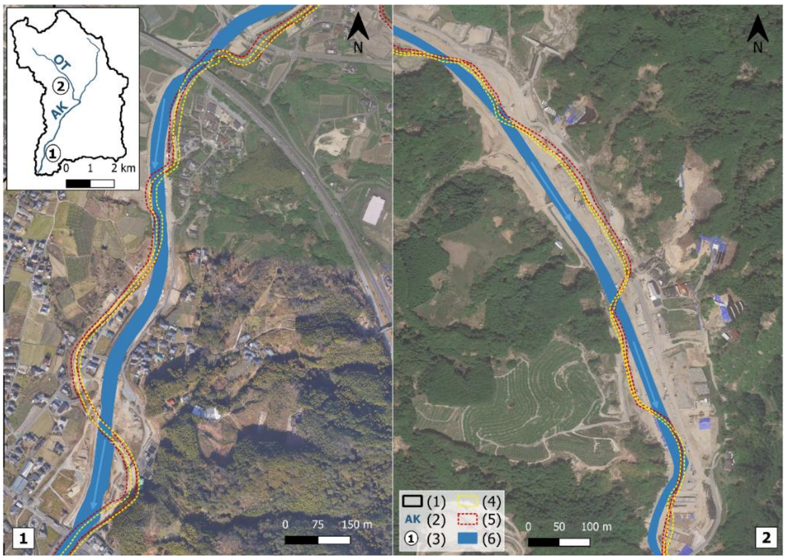

Figure 5. Close-up of sinuosity index evolution. (1) AK watershed; (2) hydronym; (3) close-up location; (4) 1947 channel; (5) 2009 channel; (6) 2022 channel.

Calculating channel width and sinuosity evolutions allowed us to appreciate shifts induced by post-disaster reconstruction plans. By comparing 1947 and 2009, AK watershed geometry was globally stable for 75 y. The disruption induced by J17 crisis then forced the government to restore rivers. Instead of reconstructing identically, they decide to enlarge and straighten channels to cope with rainfall rates with a probability of occurrence of 1/50 [3]. In addition to the modification of river's geometry, the government multiplicated the number of erosion protection structures to limit sediment-related disasters in the area.

3.3. The multiplication of ECS since 2017

In addition to remodeling valley bottoms, the government added ECS. Erosion control were valorised by governmental actors in the process of AK watershed reconstruction. Before 2017, 33 dams were located (Figure 6). Among them 27 were managed by the MAFF and only 6 of them by the prefecture. After 2017, the central government planned the construction of 30 new sabo dams and the MAFF constructed 15 more chisan dams (Figure 6). In total, we inventoried 78 ECD in the watershed in 2022. Between 2017 and 2022, the number of sabo dams was then multiplied by 5.

ECD are located in mountainous areas, and 92% of them were constructed in AK or OT watersheds. New constructions are closer to valley bottoms than the pre-disaster ones (Figure 6). In the OT river, many sabo dams are at the outflow of mountainous sub-watersheds [12]. Here, two main types of sabo dams were constructed: (i) closed-type dams, storing sediments, and (ii) slit dams, which catch large-scale debris and allow flow to circulate (Figure 7).

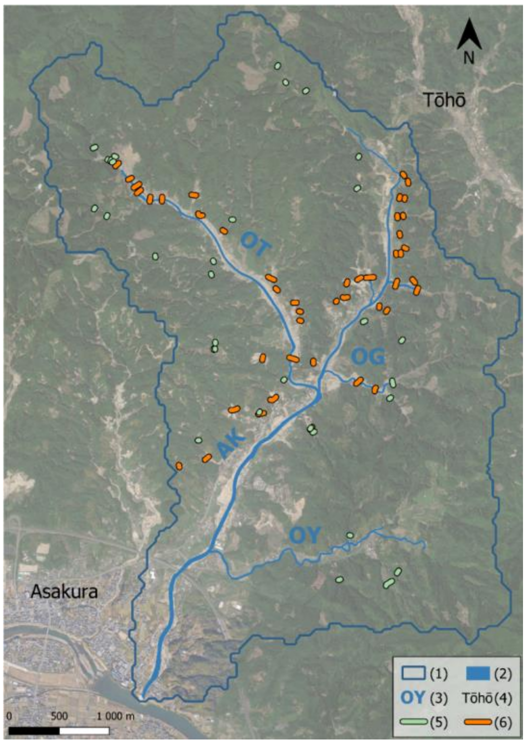

Figure 6. ECD constructed in AK watershed before and after 2017. (1) AK watershed area; (2) 2022 channels; (3) hydronym; (4) city name; (5) pre- 2017 dams; (6) post-2017 dams.

Figure 7. Illustration of the sabo dam constructed in the AK River. (a) closed-type sabo dam AK16, ©M. Dumont, 2022; (b) slit-dam type sabo dam OT15-6, ©V. Siccard, 2022.

Number of ECD increased in the AK watershed. While they were mainly located in forested area and constructed by the MAFF, sabo dams are now constructed outside of forested areas, sometimes in previously inhabited areas as the upstream part of OT. In AK middle stream, OT, and OG rivers, they structure water flow and reduce sediment transfer coming from torrential sub-watersheds. Between two dams, coffin streams replace pre-disaster channels. Thus, J17 disaster also modified the sediment transfer management of the watershed.

4. Discussion

The J17 disaster can be considered as a LFHM hydroclimatic event. The disruption induced a different equilibrium from the previously existing one. Right after the crisis, aerial images showed a new river equilibrium with partly destructed river channels and an evolution of river style from single channel to braided ones. However, because of the necessity of reconstruction of AK watershed, a new equilibrium was designed by the Japanese government. With the enlargement and the straightening of their channels, rivers are reaching a new balance between the pre- and post-disaster ones (Figure 8).

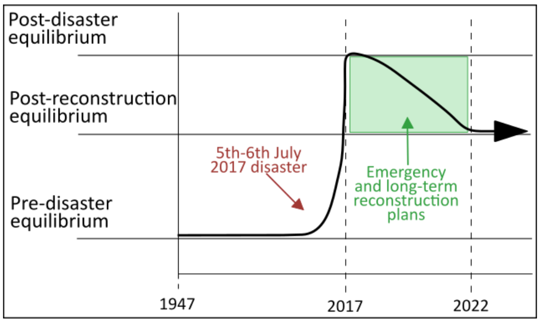

Figure 8. Dynamic of AK watershed's rivers. Adapted from Chorley and Kennedy (1971) [13].

5. Conclusions

After 75 y of stability, the J17 crisis disturbed AK watershed organization, which brutally reached a new equilibrium, causing structural damages and death loss. At this time, pre-disaster protection system and river channels could not handle the magnitude of triggered hazards. Aftermath the disaster, the watershed required a large-scale reconstruction plan. Based on a new referential (1/50 probability of occurrence rainfall), the Japanese government answered the need for reconstruction with a strong engineering response, implying a complete redesign of AK watershed with enlarged and straightened channels, and several erosion-control systems in mountainous areas. The new organization of the AK watershed illustrates the recurrent use of engineering methods in hydro-sedimentary-related hazards protection known as "River System Sabo". Japan, in its own way, responds to the current concerns of politicians and civil society, who wish to protect themselves from hydroclimatic hazards, an issue that goes beyond the question of territoriality and borders, with the ongoing climate change.

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