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Résumé de l'article

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Eight criteria can be considered to analyse the links between the stakeholders and their environment, and assess their relevance as DWM planners: geographic scale, time scale, resources, responsibilities, planning tools, coordination capacities, disaster, and waste. According to the existing literature, it seems that a comprehensive DWM plan is more detailed, centralises all the information and enables systematic waste treatments. However, in practice, the study shows that it is difficult to find an adequate stakeholder to develop such a plan and enhance the participation and collaboration of other stakeholders on this subject.

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LOCAL PLANNING RESPONSIBILITIES FOR DISASTER WASTE MANAGEMENT (DWM): BUILDING KNOWLEDGE FROM STORM ALEX IN THE SOUTH REGION OF FRANCE

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Abstract: As natural disasters increase, the stakes around disaster waste management (DWM) are rising and planning becomes necessary. Yet, planning for DWM faces many obstacles, in particular regarding the lack of clear responsibilities. Who should be mandated to plan for DWM? What benefits and downsides does each potential planner offer? Is a centralised DWM planning process more effective than several? This article aims at answering these questions and assessing the assets and weaknesses of potential DWM planners, by looking into the case study of DWM after storm Alex in the Roya Valley (South France).

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Keywords: Disaster waste – disaster waste management planning – disaster planning – planning responsibilities – regional public actions

INTRODUCTION

Climate change and urbanisation are raising new environmental issues, such as air or water pollution, increase in disaster frequency and intensity, pressure on natural resources or high quantity of waste. This creates new stakes: lack of concern and knowledge, high uncertainty, need for transdisciplinary approaches, etc.

Among these environmental issues, disaster waste management (DWM) is still not well known. Disaster waste generally refers to waste generated directly by disasters, which can include: vegetative debris; sediment; household or industrial hazardous waste (pesticides, oils, etc.); construction and demolition (C&D) debris from damaged buildings and infrastructure (such as roads, pipe networks and other services); vehicles and vessels; recyclables (plastics, metals, etc.); electronic and white goods; human and animal corpses, etc. (Brown et al., 2011). However, it also includes waste generated post-disaster for emergency management: waste from evacuation shelters (Asari et al., 2013), excessive unwanted donations, healthcare waste, and emergency relief food packaging (Brown et al., 2011). Finally, "normal" waste (household waste, healthcare waste, etc.) that needs to be managed after a disaster is disaster waste (CEREMA, 2019).

Disaster waste can slow down the recovery process by obstructing the emergency services response or the resumption of technical networks (water, roads, communication, electricity…). They also threaten human health by propagating vector-borne diseases through organic waste or standing water pools. Poor management can lead to high environmental impacts: spreading of hazardous substances, law recyclability rate, high carbon footprint, etc. (Lauritzen, 1998). On top of that, the abnormally high quantity of waste – for instance six years of peace-time production for hurricane Katrina in Alabama, Mississippi and Louisiana in 2005 (Luther, 2008)– or damages to waste treatment infrastructures are likely to overwhelm the waste treatment network for a long period. The United States Federal Emergency Management Agency (FEMA) estimated that disaster waste management accounts for around a third of the total cost of disaster recovery (FEMA, 2007).

Thus, literature and authorities recognise the need to plan for DWM (Brown & Milke, 2009). DWM case studies emphasise planning as a means to improve reaction in times of disaster (Faleschini et al., 2017; Gabrielli et al., 2018; Karunasena et al., 2009; Poudel et al., 2018; Sakai et al., 2019; Sasao, 2016). Despite this, few territories have disaster waste plans or guidelines. Furthermore, few papers are investigating DWM planning. Asari et al. (2013) identify existing guidelines and share their experiences to help implement strategies for disaster waste separation and treatment. Brown (Brown, 2012b; Brown & Milke, 2016, 2009) realised a series of fieldwork in New Zealand and studied several large disasters to determine elements to consider when developing a plan. Malaysian researchers worked on the implementation of DWM plans in disaster management in their country (Yusof et al., 2016; Zawawi et al., 2015, 2018). There is a large panel of works on decision-support tools for implementing DWM strategies: quantification methods (Beraud et al., 2012; Chen et al., 2007; Poudel et al., 2018; Tabata et al., 2016), tools to identify temporary storage site or facilitate logistic (Lorca et al., 2017; Onan et al., 2015; Ruas & Lhomme, 2019), environmental and economic analysis methods for DWM strategies (Amato et al., 2019; Tabata et al., 2017; Wakabayashi et al., 2017). Yet, their operational use, in particular for planning purposes, is rare.

The only systematic studies of DWM plans are Crowley's. She studied the effectiveness and efficiency of DWM plans in the United-State, showing that post-disaster, counties with a plan had a better recycling rate, faster clean-up and more facilities to access the federal funds (Crowley, 2017). She also studied the coherence between the different DWM planning scales (from federal guides to local plans) (Crowley & Flachsbart, 2018).

The main difficulty faced by DWM is that it is transversal and multidisciplinary, at the cross of disaster, risk, waste and urban planning. It implies various scales and various places of the territory – waste treatment infrastructures can be far from disaster localisation. Then, several actors, often not used to working together, are concerned and responsibilities are generally unclear (Brown et al., 2011). Most stakeholders consider they are not responsible for DWM planning and are passing the parcel in-between each other. This problem is recurrent in planning in general (not only for DWM): the multiple planning authorities in urban areas can lead to overlapping functions, unclear roles, and responsibilities not fully discharged (Wapwera & Egbu, 2013).

Although DWM literature is paying increasing attention to the content of DWM plans, no attention has been given to where DWM planning responsibilities should lie. Therefore, this article aims at providing knowledge on the matter and helping to develop proper DWM policies. It looks into the following questions: which actor can efficiently plan for DWM? What benefits and downsides does each potential planner offer? What are the obstacles to setting a DWM planning process?

The study proposes criteria to assess the relevance of each stakeholder that could develop a DWM plan. The framework is used in a case study of DWM in the South region of France, which was severely impacted by Storm Alex in October 2020, and where the regional waste authorities are willing to spread DWM preparedness. The fieldwork enables a systematic identification of the stakeholders involved in DWM and the selection of potential DWM planners, using the framework to question their advantages and limitations.

ANALYTICAL FRAMEWORK

Background

Several issues regarding disaster planning emerge in the literature: environmental and social impacts, community participation, stakeholder collaboration, legal framework, experience sharing, operational actions and strategic planning, planning for uncertainty, etc. These issues are raised by multiple disaster management activities (risk mitigation and prevention, emergency preparedness, research and rescue activities, temporary shelter management, reconstruction and territory recovery, feedback, experience sharing, teaching, etc.).

These activities are operated by a large panel of stakeholders, from emergency operators to environmental managers. Thus, responsibilities for disaster management need to be documented to avoid potential conflicts or a misuse of resources (Rouhanizadeh & Kermanshachi, 2020). As governments are responsible for general safety, the primary responsibility goes to government agencies (Raikes et al., 2019). Local governments are responsible for implementing mitigation and safety measures through planning and zoning (Neuvel & van den Brink, 2010; Somers & Svara, 2009) as well as assessing risk and ensuring resource availability for response and recovery phases (Henstra, 2010). Non-governmental stakeholders and organizations (Henstra, 2010), research institutions and private companies – such as building companies (Chang et al., 2011) – can have important roles depending on their former competencies. This proliferation of activities and actors creates increased organisational complexity, as well as unclear and overlapping responsibilities that often lead to a liability release.

Stakeholders also evolve at different geographic (and administrative) scales. Generally, disaster management is decentralized and involved a multi-level network of stakeholders (Raikes et al., 2019). It enables a fast reaction at the local level; and regional and state levels provide technical, human, material and financial support. Higher levels, i.e. state and federal governments and agencies, should establish mitigation policies but local communities have to implement these policies to adopt mitigation strategies (Pearce, 2003).

If on paper, the responsibility per geographic scale seems quite clear, in reality, this geographical imbrication brings complexity and can increase the liability release. When each scale should intervene? How do they coordinate? Who responds to who?

Other than the problems of coordination brought by the lack of clear responsibilities, tensions are created by the competing goals of each actor. In particular, there are often tensions between the speed of recovery, the cost of recovery and environmental impacts (Brown et al., 2021). Many stakeholders want a fast recovery to relaunch economic life. Yet a hasty reconstruction can increase poverty and inequity, because of poor resource allocation (Finucane et al., 2020). Hasty reconstruction planning also leads to hard constructions such as giant seawalls or city relocation in rural or coastal areas that unnecessarily create great environmental damages and maintenance burdens for future generations (Murakami et al., 2014). Resource exploitation must not increase the environmental, economic and social burden of the disaster-stricken area (Chang et al., 2011). Therefore, one central challenge in disaster recovery is to address short-term needs quickly while considering long-term reconstruction and development to avoid worsening the vulnerability of the community (Finucane et al., 2020).

Moreover, each actor can have competing interests between disaster planning and its other activities. Assuring the planning process requires important resources (material, human, technical, and financial). This creates a competition for scarce resources with other needs that appear more urgent (Henstra, 2010). Somers and Svara (2009) emphasize the lack of resources and staffing for emergency preparedness functions in local governments, linked sometime to the declining economic circumstances that reduce the fiscal capacity of the government. Berke et al. (2014) go along, saying that local governments with a population of less than 10,000 are unlikely to develop planning for recovery. On top of that, the demand for public participation increases the planning costs as assuring real participation requires important resources (Dovers, 1998). Often, there is also a lack of technical expertise (Neuvel & van den Brink, 2010).

Because of the diversity of stakeholders involved in disaster management (at different geographical levels, from different sectors, from elected officials, public agencies, NGOs or private companies, etc.), their competing interests and the need to optimise resources, disaster management planning requires strong coordination. To be efficient, planning should enhance collaboration between all stakeholders as well as community participation (Finucane et al., 2020). Some stakeholders may be in a better position for leading this coordination thanks to a formal leadership position which legitimates actions, coercive power enabling to deliver penalties, or reward capacity toward those who participate in the process (Somers & Svara, 2009).

Furthermore, each of these stakeholders has different planning tools available. Disaster planning activities can be divided into pre-disaster and post-disaster activities (Pearce, 2003). Risk mitigation plans such as strategic and operational land-use plans or environmental conservation programs aim at reducing risk exposure by influencing the physical characteristics of a territory. Preparedness plans identify the possible hazards and their impacts (Brown et al., 2021), specify operational procedures and provide guidance for emergency response coordination (Neuvel & van den Brink, 2010). Pre-disaster planning activities include training and disaster simulation exercises (Henstra, 2010), as well as developing disaster scenarios (Brown et al., 2021) to accelerate actors' actions in times of crisis.

Post-disaster, recovery and reconstruction plans enable a long-term vision which is essential (Labadie, 2008), especially in case of a large-scale disaster. The main difficulty for these plans is that they need to respond to emergencies while respecting the existing planning system (Murakami et al., 2014). Other instruments are available: legal and financial incentives, information sharing to raise public awareness (Finucane et al., 2020), regulations such as building codes or land-use planning laws (Raikes et al., 2019), environmental licences or private law arrangements (Neuvel & van den Brink, 2010). Each planning tools have different short-term and long-term implications and can improve or prevent efficient disaster management.

DWM planners framework

To assess the DWM potential planner's relevance, we propose a framework to synthesise the information one needs to know. The literature review above shows the interest to look into six criteria (time scale, geographic scale, resources, planning tools, responsibilities, and coordination capacities) when defining planning responsibilities. Two criteria specific to DWM planning (disaster, waste) need to be added. This section introduces the criteria and justifies their utility for investigating DWM potential planners' advantages and challenges.

1. **Geographic scale**: *the territory, the geographic or administrative scale in which the potential planner evolves.* The geographical scale is particularly relevant for urban and technical networks such as electricity, water and, in our case, waste. The extent of the waste network will likely differ from the extent of the disaster. On the one hand, it can enable to absorb the important quantities of disaster waste generated; yet, if a structural installation is damaged, the effects of the disaster can spread outside the impacted zone (Beraud et al., 2013). Moreover, some disasters, such as tsunamis or floods, can create significant movements of waste, sending waste outside the disaster-stricken area, and outside the national boundaries, undermining waste ownership legislation (Brown, 2012a). Thus, if the disaster impacts propagate along the waste network, stakeholders from further territories will be involved.
2. **Time scale**: *the moment in the disaster management cycle in which the stakeholder intervenes*. Tensions between short-term emergencies and long-term environmental impacts are very noticeable for DWM. The debris cleaning of the roads is crucial in the emergency response as debris prevents access to emergency aid teams (Berktaş et al., 2016) and slows down reconstruction activities (Brown et al., 2011). However, fast debris removal prevents reuse and recycling by increasing the mixing of waste (Brown & Milke, 2016). Temporary storage sites can avoid this inadequate segregation as well as illegal dumping but the location is often not decided quick enough, increasing the treatment time (Tabata et al., 2017). The priorities of the actors will differ regarding the time scale they operate.
3. **Resources**: *financial, technical or institutional resources available.* DWM literature identifies the lack of resources as an obstacle to DWM planning (Asari et al., 2013; Brown et al., 2011; Karunasena et al., 2009). Stakeholders with more resources will be more likely to support a strong and efficient DWM planning process.
4. **Responsibilities**: *the former responsibilities of the stakeholder.* Emergency managers are more likely to have an overall view of the articulation between DWM and other emergency needs but might ignore the environmental impacts of waste management, contrary to waste actors. The former responsibilities of potential DWM planners orient their planning strategies.
5. **Coordination capacities**: *the possibility for the planner to coordinate the plan and enhance collaboration between stakeholders.* The question of coordination is highly significant here as DWM is not the core task of disaster management. Coordination between waste and disaster stakeholders is difficult because they are not used to working together. The capacity to strengthen these links during the planning process would be an asset.

Table 1. Types of DWM planning documents.

Type of documents	Uses and limits
Pre-disaster documents	
DWM guidelines	Help actors prepare for DWM or respond in case of a disaster. General guidelines, not specific to the territory, with no legal obligations.
Laws	Legally binding obligations. Very general.
DWM specific plans; DWM appendix or section in waste prevention and management plans; DWM appendix, section or scattered elements in disaster management plans	Territory-specific plans. More or less detailed. Can be legally binding.
Contracts between stakeholders	Specify the contracting terms post-disaster.
Post-disaster documents	
Emergency action plans	Assess the situation and organise the response.
Recovery plans	Plan the long-term reconstruction and recovery.
Decrees or ordinances	Adapt laws when inappropriate.

6. **Planning tools**: *the planning tools already available*. An international inventory of 45 DWM planning documents (written in the last 25 years at local, regional and national scales) shows that planning tools for DWM are multiple. Table 1 summarises the type of tools available. Each tool offers different assets or drawbacks, depending on its format, its bearer, its targets, etc. Available planning tools have to be considered, as DWM may need to be integrated into existing processes.
7. **Disaster**. Emergency managers generally have an "all-hazard" approach when planning for disaster, with some hazard-specific appendices or plans to cover the unique characteristics of different types of events (Somers & Svara, 2009). However, mitigation planning can be more hazard-specific, for instance, flood-risk policies (White & Richards, 2007). Furthermore, common disasters, experienced frequently, "simple" and "predictable" can be planned more easily, in a more traditional way, than infrequent extreme events with unpredictable impacts (Brown et al., 2021). The DWM planners may then differ considering the characteristics of the event.
8. **Waste**. There are multiple type of disaster waste (see the list in the introduction). Each type of waste involved different stakeholders: construction contractors for C&D debris, forest managers for vegetative debris, city councils for household goods, etc.

The three first criteria are, to some extent, "scalable". We will discuss the advantages and downsides regarding the scale with the case study. Responsibilities, coordination capacities and planning tools are centred on the stakeholder and closely interlinked. They are likely to depend on the other criteria. Finally, disaster and waste are criteria specific to our goal and our case study. As different disasters will create different wastes (earthquakes create a large amount of construction debris with few movements, hurricanes generate mostly construction and vegetative debris but also consumer goods that are likely to be wet, etc.), those two criteria may interact together.

Hypothesis

The analysis of the DWM planning documents inventoried shows that comprehensive DWM plans, including all types of waste and disaster, are more detailed than elements scattered in several plans. They introduced more systematic waste treatment strategies. They balance some emergency and long-term needs, whether crisis management or environmental actors drive the plan. However, except for Japanese plans, most of them are not territory specific. We also do not know if their implementation is efficient: is the planning process easily developed? Can it be generalized quick enough to respond to the fast increase in disasters? Are all stakeholders involved in the process? Is the plan regularly update and practice? Does it enable efficient post-disaster waste management? These questions are not addressed in DWM literature, where most articles on planning focus on the elements that should be considered in a DWM plan, a priori comprehensive. Therefore, the present study will discuss the hypothesis that one single comprehensive DWM plan should be developed, by questioning if one single stakeholder can efficiently build and drive this plan.

METHODOLOGY

Case study: DWM after storm Alex in the Roya Valley

Legal framework for DWM in France

Responsibilities for DWM are still unclear in France. In peacetime, responsible for operational household waste management are the municipalities or the Public Establishments for Intercommunal Co-operation (EPCI)[1] (article L.2224-13 of the General Local Authorities Code). Municipalities are responsible for crisis management and public hygiene (article L.2212-2 of the General Local Authorities Code). The prefecture, the state representative at the departmental level, is in charge of emergency planning and management (coordination of public means and civil security) if the municipality is overloaded.

Moreover, since 2016, Regions have to implement a section on disaster waste in their Regional Plan for Waste Prevention and Management (PRPGD). Article R.541-16-II of the Environment Code stipulates that *the plan must identify collection and treatment infrastructures for the management of waste produced in "exceptional circumstances"*[2]*, especially pandemics and natural disasters. The details regarding collection organisation are coordinated with the civil security dispositions, in particular the ones taken by municipalities and their groupings.*

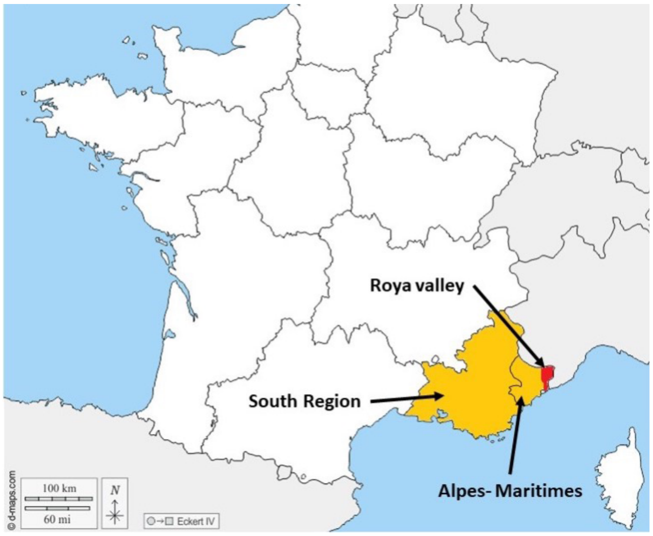
Disaster waste is considered "normal" waste. Therefore, it responds to the national waste laws, in particular the Environment Code. The Environment Code specifies waste producers' and waste holders' responsibilities, among which are: source separation, separate collection and respect for waste treatment hierarchy. Post-disaster, the municipality is waste producer and holder (CEREMA, 2019).

A special norm has been created for *"temporary storage site for waste generated from accidental marine or river pollutions, or natural disasters"* in the nomenclature for industrial installations classified for environmental protection. These installations are controlled by the environmental state representative.

1 Groups of municipalities that carry out common development projects.

2 French law does not mention "disaster waste" but "waste produced under exceptional circumstances" – with no clear definition.

Figure 1. Localisation of the case study. Background: d-maps.com



DWM in the Roya Valley after storm Alex

On the second and third of October 2020, storm Alex hit the Roya, the Vésubie and the Tinée valleys in the Alpes-Maritimes (South of France). The violence of the event – with exceptional rainfall, heavy flash floods and associated landslides – caused 18 casualties (ten deaths and eight missing persons) and around one billion euros of damages[3], with 420 habitations and around 60 bridges and tunnels impacted, 100 km of road and 200 km of destroyed networks.

In the Roya Valley (see figure 1 for localisation), building damages generated large amounts of waste. 35 km of roads, 12 bridges and the tunnel to Italy were destroyed. The railways were heavily affected. The villages at the top of the valley were inaccessible for several months. The river, difficult to access for debris removal, moved much waste (sediment, construction debris, vegetative debris, car wrecks, household goods, etc). Some waste was carried across the border, creating tensions between waste producers, in France, and holders, in Italy.

The disruption to the road network hindered waste collection. Waste was transported by alternative means such as helicopters, trains or jeeps.

Table 2. Stakeholders interviewed

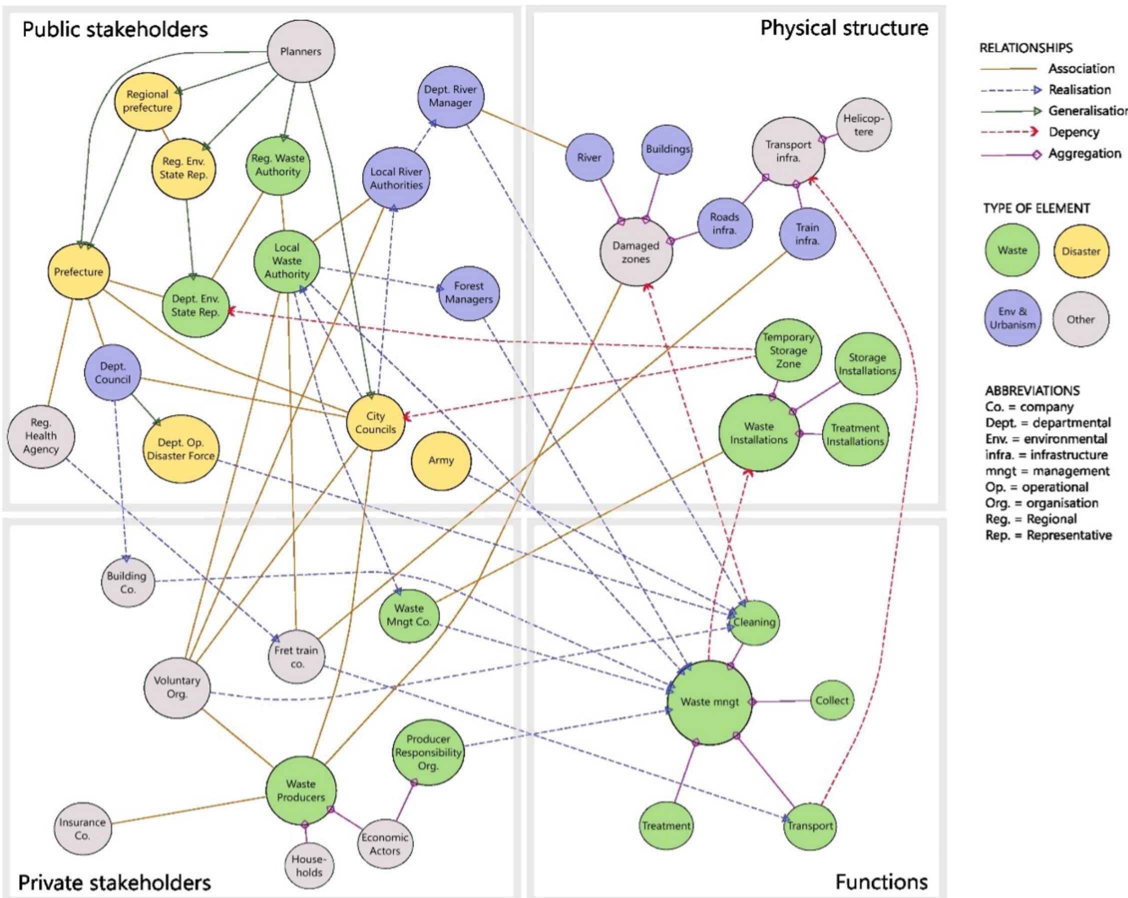
Structure	Level	Position
Interviewees for regional DWM planning activities		
Regional waste authorities	Region	Head of the waste team
Dracénie Agglomeration	Inter-municipality	Head of communication and protocol Head of the waste management team
Local waste authorities (Est-Var)	Inter-municipality	Sustainable development manager
Departmental environmental state representative (Alpes-Maritimes)	Department	Head of the Departmental Unity
Regional environmental state representative	Region	Waste infrastructures manager
Producer Responsibility Organisation for electric and electronic equipment waste	Inter-region	Regional collection manager for South-Est and Corsica
Private waste management company 1	Region	Communication and Development manager
French Geological Survey public office	Region	Waste engineer
Interviewees for post-storm Alex DWM in the Roya valley		
Regional Waste Authorities – departmental delegation	Department	Local representative
Fret train company	Inter-region	Head of the fret
Private waste management company 2	Region	Head of the urban sanitation service
Departmental Direction for Territories and Sea (for the Prefecture)	Department	Housing damage assessment manager
Departmental Direction for Territories and Sea (for the Prefecture)	Department	Feedback coordination manager
Alpes Maritimes Department Council	Department	Head of the reconstruction mission
Departmental Operational Disaster Force	Department	Est territory manager
Local river manager	Department	River engineer
Forest manager	Department	Head of the wood service
Mercantour National parc	Department	Vice-director
Local waste authorities (Roya valley)	Inter-municipality	Head of the waste service
Local river authorities (Roya valley)	Inter-municipality	River and flood engineer
Municipality (Breil-sur-Roya)	Municipality	Urbanism deputy, Emergency deputy
Municipality (Tende)	Municipality	Mayor
Municipality (La Brigue)	Municipality	Head of the technical services

Table 3. Documents used for the case study

Stakeholder	Documents	Date
Ministry of Environment	Storm Alex Feedbacks: learnings and proposal for a resilient reconstruction	Oct. 2021
Regional waste authorities	Regional Waste Prevention and Management Plan	Jun. 2019
Producer Responsibility Organisation for electric and electronic equipment waste	Natural disaster process	2021
Prefecture	Storm Alex Feedbacks: operational part	Dec. 2021
Prefecture	Storm Alex Feedbacks: technical networks	May 2021
Departmental Operational Disaster Force	Storm Alex Feedbacks: west littoral territory	2021
Mercantour National Parc	Storm Alex: roles and needs	Jan. 2022
Local waste authorities	Roya valley: household waste management after storm Alex	Jan. 2022
Local waste authorities	Annual report 2020	Jul. 2021
City councils	Municipal Safety Plans	2016

3 Report from the 2021/09/29 Council of Ministers. https://www.gouvernement.fr/conseil-des-ministres/2021-09-29

Figure 2. UML class diagram of stakeholders involved in DWM in the Roya Valley.



Data collection

The case study is based on the examination of the existing DWM planning actions in the region and fieldwork of one month in the Roya Valley, a year and a half after Storm Alex, to realise DWM feedback. 21 semi-structured interviews were conducted. The analysis was completed with official documents provided by the interviewees. Table 2 lists the stakeholders interviewed, and table 3 the documents used. Generic stakeholders' names were given to facilitate comprehension outside France and knowledge transfer.

Selection of the potential DWM planners

To select potential DWM planners, the study identifies stakeholders involved in DWM, i.e.: 1) in DMW planning activities at the regional scale, and 2) in DWM in the Roya valley after storm Alex. Actors were identified from interview to interview, starting with four "obvious" stakeholders: the regional waste authorities, the prefecture, the local waste managers and the city councils.

Most stakeholders are either waste or natural risk/emergency stakeholders. Some are outside these two fields (e.g. Regional Health Agency, train company…). They have not been considered potential DWM planners as their responsibilities are not directly linked.

Emergency management is primarily a public responsibility: although private entities could prepare by planning for their continuity of operations, it is not their responsibility to develop comprehensive DWM plans. Therefore, private actors have not been considered potential planners either. All other stakeholders are considered potential DWM planners.

The data collected (interviews and documents) are used to assess the assets and weaknesses of each potential DWM planner through the framework introduced above.

RESULTS AND DISCUSSION

Identification of stakeholders involved in DWM in the Roya Valley

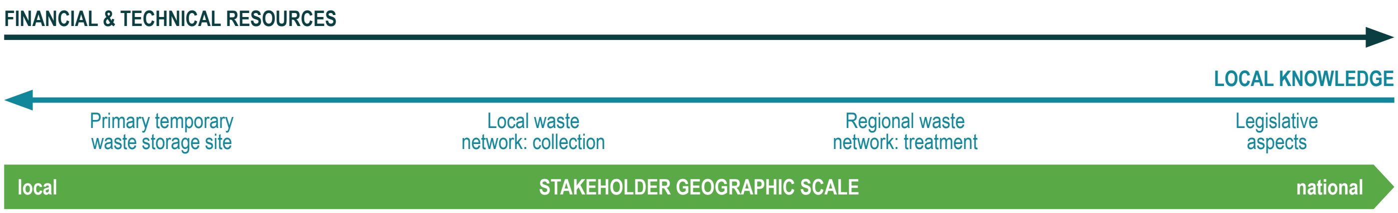
Figure 2 maps the stakeholders identified and their links. Two actors had previous DWM planning activities but did not intervene after the storm:

1. The regional waste authorities had the legal obligation to integrate a DWM part into the regional waste plan. The DWM part is very light and does not comply with the obligation of identifying collection and treatment infrastructures for DWM. However, it acknowledges that further work is necessary and suggests the creation of a working group.
2. The regional environmental state representative, to whom the regional prefecture asked in 2017 to identify temporary waste storage sites in case of accidental marine pollution. Yet, the list was not made public or shared because it would imply lands to be tied up (and therefore require compensation).

The other stakeholders intervened at some point after storm Alex, for DWM or crisis management.

We see that the main link between disaster and waste stakeholders is the environmental state representative, who heavily works on natural disasters at the regional level and is responsible for controlling waste management installations at the departmental level. Another one is between the city councils and the local waste authority, as the first ones are responsible for local crisis management and delegate waste management to the second. These links could be a starting point for a DWM planning process.

Figure 3. Evolution of resources and knowledge with the geographic scale



DWM planners framework

The section below discusses the results following the criteria proposed above. The framework enables to analyse the links between stakeholders and their environment.

Geographic scale

Resources and knowledge evolve with the geographic scale of the stakeholder. Actors with competencies at larger scales are likely to have more resources, in particular for the technical support needed for DWM planning. However, they will lack local knowledge, about urbanism, local stakes and stakeholders, and the waste network. Figure 3 summarizes these evolutions.

DWM planning is likely to depend on the size or the localization of the disaster. Storm Alex DWM did not involve regional waste authorities and environment state representative as no structural regional waste treatment installations was impacted. They both stated that they would have been more concerned if, for instance, the departmental incinerator was affected.

Time scale

The case study emphasizes the tension between short-term emergencies and long-term environmental impacts. For instance, to hasten debris cleaning after the disaster, no segregation was done, making recycling impossible. Most municipal solid waste was incinerated. This confirms the interest in looking at the time scale on which potential DWM planners are situated (and, above all, for future planners to consider this tension carefully).

Moreover, none of the DWM planning documents analysed had a long-term vision of the resiliency of the waste network to natural disasters. It may be difficult for emergency planners to deal with this.

Resources

As mentioned above, mobilizing the human and technical resources to develop but also implement and update a DWM plan has a financial cost. However, even though a lack of financial resources hinders planning, particularly for small municipalities such as the one in the Roya valley (less than 2000 inhabitants), the lack of interest in DWM seems a bigger barrier. In France, ultramarine territories were the first to work on DWM, as they are more prone to natural disasters. Likewise, the Dracénie Agglomeration (in the neighbouring department), which has resources comparable to those of the Roya valley, is proactive in DWM planning since a major flood in 2010.

On the contrary, the prefecture, which mobilised significant resources after Storm Alex, set an important feedback process. Yet, DWM was not included, as the prefecture did not perceive it as a problem and has few links with the local waste authorities. Similarly, the departmental council is strengthening its operational disaster force, but has not yet formed it to DWM issues.

Responsibilities

If one centralized plan was to be developed (see hypothesis), we could assume that the prefecture, as a lead emergency manager and planner, should include DWM in its planning activities. Yet, during storm Alex management, the prefecture was unable to find the technical resources they needed for DWM. The prefecture asked the environmental state representative to coordinate DWM, who said it did not have the necessary knowledge for this, and that the local waste authorities, responsible for waste collection, should provide this function. However, local waste authorities were already overwhelmed and refused to handle waste they were not responsible for, such as medical waste. They are neither in charge of C&D waste, which accounts for a significant part of the waste generated.

A second hypothesis is that regional waste authorities should comprehensively plan for DWM as they are the only ones with a specific mandate on this. Yet, despite their legal responsibilities, they are not an operational actor, and none of the interviewees involved in the management of storm Alex acknowledge them as relevant DWM planners. However, interviewees thought regional waste authorities add a role to play in facilitating experience sharing and helping them to prepare for this kind of disaster. DWM planning goals may then differ depending on planners' former responsibilities.

Finally, the study excluded private companies as emergency management is a public responsibility (Henstra, 2010). However, in France, the "polluter pays" principle is becoming more and more central, through the extended producer responsibility organisations. Many of these organizations have extended collection obligations to waste from natural disasters (CEREMA, 2019). Their legal obligations may increase in a near future.

Planning tools

Due to the already numerous existing planning tools and their laborious articulation, it may be more efficient to integrate DWM elements into existing tools, to avoid increasing the organisational complexity. Moreover, a proper planning process is particularly time constraining: France was late on European obligations to plan for waste management so regional waste plans were built quickly, and regional waste authorities focused on issues perceived as more urgent than DWM. It may then be faster (and less resource-consuming) to modify existing plans to include DWM than to start a comprehensive plan from scratch.

Yet, this may require training or guidelines to enable each stakeholder to understand all the issues at stake.

Coordination capacities

All interviewees pointed out the lack of coordination around DWM after Storm Alex. Three problems, in particular, were mentioned. First is the lack of reverse logistics. It was deployed for trains but not for helicopters. This increased the environmental impact of DWM, and there was a shortage of helicopters in the region. Second, city councils chose temporary waste storage sites that were not accessible for waste collection trucks. Finally, coordination between volunteers participating in cleaning activities and local waste and river authorities was very difficult. For instance, although river managers recognised that they could not cope without solidary actions, volunteers generally stored waste on the riverside, inaccessible for collection trucks, and did not segregate waste.

Table 4. Elements to consider when planning for DWM. Summary and examples from the literature

General elements suggested to consider when planning for DWM		
1. Identification of stakeholders and their responsibilities; 2. Qualification and quantification of disaster waste; 3. Management options: collection, transportation, segregation, temporary storage sites, treatment; 4. Preventive actions; 5. Communication.		
Issues for DWM in Malaysia (Zawawi et al., 2018)	**Suggested Pre-incident Debris Management Plan Outline (EPA, 2019)**	**Anticipation actions for DWM (CEREMA, 2014)**
Phase 1: Set up the structural of coordination Combination with the disaster management government sector + private sector + volunteer. Phase 2: Waste classification & waste assessment Estimating the amount of waste & classification of waste. Phase 3: Collection & transportation of waste Process of collecting waste, estimation of time, transportation factor and quantity of manpower Phase 4: Handling of waste Recycling, disposal & landfill method Phase 5: Reporting & documentation Preparation and submission of completed reports - current issues and reference on the lesson learnt from developed countries	I. Plan Overview 1. Scope 2. Planning assumptions 3. List of officials who should be notified in the case of an incident and contact information 4. Roles and responsibilities for waste management activities 5. Regulatory requirements 6. Documentation of plan development process 7. Record of plan approvals, reviews, and updates to include any changes made II. Materials and Debris Streams III. Debris Quantities IV. Waste Characterization Sampling and Analysis V. Debris Management Strategies/Options	1. Identification of crisis situations 2. Qualification of post-disaster waste 3. Estimating the quantity of post-disaster waste 4. Prevention actions 5. Organisation and operation of temporary waste storage sites 6. Communication 7. Waste management actors

All these aspects could be thought pre-disaster but require important collaboration between stakeholders. If a single comprehensive DWM plan was to be developed, the planner should have coordination capacities to reunite (or at least consult) all these stakeholders during the planning process. It should also foresee debris movements to collaborate with neighbouring territories and avoid conflicts like the disagreement between the French and Italian sides of the Roya.

Furthermore, memory saving is difficult in public institutions: city councils are re-elected every five years, and public servants often move every three years. Without any particular attention and structures, feedback is forgotten.

Disaster

Some stakeholders intervene only in specific types of disasters. It is the case for river managers, who have no reason to develop a comprehensive DWM plan that would include, for instance, earthquake waste. Similarly, forest managers were only a secondary stakeholder after storm Alex, whereas they are actively involved in cases of windy events such as 1999 cyclones in Europe or 2017 hurricanes Irma and Maria in the French Antilles.

Waste

Being legally responsible for one type of waste impediments stakeholders to implement a comprehensive DWM plan. On the contrary, some stakeholders cleaned all types of waste but without segregating them (e.g. the army), which prevents specific treatment and recycling. Therefore, although a single stakeholder planning for all waste types would enable systematic management, it may be more efficient environmentally if stakeholders responsible for a specific type of waste take the lead on it.

Learnings about DWM planning elements

Table 4 illustrated the elements classically suggested for DWM planning.

As stated in the introduction, studies on logistic modelling or quantification of disaster waste are becoming numerous. Disaster waste quantification is key in the planning process as it enables anticipating the size of temporary storage sites and the human and technical needs (Marchesini et al., 2020). However, none of the interviewees spontaneously mentioned the need for any logistic, quantification or decision-making tool. Most waste stakeholders doubted they could anticipate anything.

The identification of temporary storage sites was also a problem. The pre-existing list made by the environmental state representative only identified existing waste treatment installations that could temporarily be modified to store more or different types of waste. However, none of these installations could serve as a primary storage zone in the impacted zone. The mountainous field made the identification of such primary storage zones difficult. The selected zones did not comply with legal or technical requirements.

Most local stakeholders are not advanced enough in their DWM planning process to consider these questions. Raising awareness and improving the perception of DWM issues among local stakeholders and citizens should then become a short-term priority in DWM plans.

Finally, some stakeholders had to break the law (temporary storage zone and waste transportation did not respect the national norms, open burning was practised for cardboard, etc.). This prevents some stakeholders to act and slow down DWM. Special amendments should be made to facilitate DWM, such as the one for industrial temporary storage sites.

Replication of the results

Storm Alex is arguably small compared to major disasters like the 2004 tsunami, hurricane Katrina or the 2011 Tohoku earthquake. Nevertheless, it is very important on a national scale and is considered *"the most damaging event in mainland France since the Second World War"*. Considering this bias, Brown developed semi-quantitative indicators to *"allow for assessments to be made relative to the contextual situation".* This classification system enables transferring lessons learned from one event, and thus planning for future disasters (Brown, 2012a). Table 7 summarizes disaster and disaster waste impacts of the case study, using Brown's classification system.

Table 5. Disaster and disaster waste impact indicators (developed by Brown, 2012) for the case study. Disaster impacts indicators are given for the entire disaster-stricken area in France. Disaster waste indicators are given for the Roya valley only.

Indicators	Measure	Characteristics defined by Brown	Case study details
Disaster impacts indicators			
General disaster scale	Medium	Moderate level of damage, possible loss of lives. Regional resources required. Projected recovery time: 2-5 years.	National resources were required (army intervention) but recovery time will probably remain under 5 years.
Number of displaced persons	Medium	1-20% population displacement in affected area, with some or all intending on returning to the area.	1260 people transited through a reception facility or emergency shelter, i.e. around 10% of the population of the impacted municipalities. This figure goes up to 20% in the villages with the most difficult access.
Geographical extent	Medium - High	Medium: Regional area of the impact. High: difficult access to and from affected area.	The physical impact of the disaster was local but access was impossible.
Hazard duration	Low	One-off events with short-term effects, up to one week	One night flood.
Disruption to road network	High	Roading networks are disrupted for more than a month. Authorities require minimal traffic movement.	Villages at the top of the valley were inaccessible for several months, then possible traffic movement was low.
Disaster waste indicators			
Volume of waste	Low	Waste generated is equivalent to 1-2 years' worth of annual waste generation.	Calculation made only on waste collected by the local waste authorities
Human health hazard	Low – Medium (?)	Low: Hazard poses a weak, chronic threat. Medium: Hazard poses a minor acute or serious chronic threat.	Risk of pollution of the river, which serves as a drinking water source. Other sanitary risks (smell, moisture…) were quite low as the weather was cold.
Environmental health hazard	Low – Medium (?)	Low: Hazard poses a weak, chronic threat. Medium: Hazard poses a minor acute or serious chronic threat.	Risk of pollution of the river, which serves as a drinking water source.
Movement of waste	High	Significant waste transported across property boundaries	The river transported the waste up to the sea, passing by several municipalities, including in Italy.
Waste handling difficulties	High	Waste is difficult and dangerous to manage. Specialist skills and equipment are required.	Special equipment required: helicopters, boats, pick-up trucks, crushers, etc

Further works

This study opens the way to several questions. Works on the organisational DWM stakeholders' network are lacking. We identified all stakeholders involved in DWM activities in the Roya Valley but their connections could be investigated further. The opposition between routine planning VS planning for large-scale unpredictable events should be further investigated. Brown et al. (2021) for instance propose to use adaptive planning for DWM. Yet this kind of plan may be difficult to develop for waste planners who are not used to dealing with this kind of uncertainty. The question of DWM planning strategies based on the planner should be explored. Similarly, the benefits of a single central DWM plan or scattered elements in disaster or waste plans should be studied more systematically, to investigate how DWM plans could reduce the organisational vulnerability of a territory.

CONCLUSION

DWM planning responsibilities is unclear. The article proposed a framework to assess the assets and weaknesses of each potential DWM planner. Eight criteria must be considered: three "scalable" criteria (geographic scale, time scale, resources), three stakeholder-centred criteria (responsibilities, planning tools, coordination capacities), and two criteria specific to DWM (disaster, waste). The study opens questions on the benefits of a centralised comprehensive DWM plan VS scattered plans developed by several actors. According to the existing literature, it seems that a comprehensive DWM plan is more detailed, centralises all the information and enables systematic waste treatments. However, in practice, the study shows that it is difficult to find an adequate stakeholder to develop such a plan and enhance the participation and collaboration of other stakeholders on this subject. It may then be more efficient if each stakeholder involved developed its own DWM prevention and action plan. An analysis of the links between stakeholders and their environment, synthesised through the eight criteria mentioned above, could enable to start inclusive and adaptive DWM planning processes.

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