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**DOI**
10.1016/j.ifacol.2022.07.644

**Publication date**
2022

**Document Version**
Final published version

**Published in**
IFAC-PapersOnline

**Citation (APA)**
Van Der Hucht, L. E., & Van Nooijen, R. (2022). Designing a sustainable water management strategy including disaster management. *IFAC-PapersOnline*, *55*(5), 84-89. https://doi.org/10.1016/j.ifacol.2022.07.644

Available online at www.sciencedirect.com

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IFAC PapersOnLine 55-5 (2022) 84–89

# Designing a sustainable water management strategy including disaster management

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**Abstract:**
This paper presents preliminary results on the application of a water management approach that includes the principles of Build Back Better (BBB) and explicitly considers the performance of a water system during the different phases of the disaster management cycle. As a case study, a small touristic island was taken that is faced with drinking water shortages due to recurring disasters (tropical storms, hurricanes, and storm surges). While water management already provides some criteria for sustainability and resilience, BBB provides an additional context to determine criteria for system performance in the different phases of the disaster cycle. Once these criteria have been established for a specific case, different solution strategies can then be analysed for a given set of scenarios through a multi-criteria analysis (MCA).



*Keywords:* Build Back Better, Disaster cycle, Multi-criteria analysis, Water management, Disaster management.

## 1. INTRODUCTION

In 2019, hurricane Dorian hit the small island of Grand Bahama. To analyze the reconstruction that took place afterwards, a group of researchers and students of the Technical university of Delft and the University of the Bahamas used the vision of Build Back Better (BBB). The multidisciplinary workgroup proposed a strategy that reduced the risk posed by similar future hurricanes (van der Hucht et al., 2021; van de Ven et al., 2021). Based on the data collected by this work-group and the exposure of the lack of integration of water management and BBB, this paper further explores the possible connection between these two topics. The island of Grand Bahama will serve as a case study. Preliminary results for one component of the system are used to illustrate how inclusion of the disaster cycle in the evaluation, as suggested by BBB, may change the way solutions are scored.

Hurricane Dorian impacted the island of Grand Bahama much more than other recent hurricanes and had a serious impact on the water availability on the island. In the light of the increasing economic activity on the island as well as rising sea level and more frequent storms, rebuilding the damaged water structures as they were was determined to be insufficient. The problems arising from climate change, combined with extreme repeating natural cataclysms, are big and complex. Consequently, there is much room for improvement. Small or medium sized islands are an ideal setting for the investigation of the interaction between society and the environment due to their clear boundary. The goal of this paper is to present preliminary results on the translation of concepts from BBB and disaster management into a form that can be used in water management.

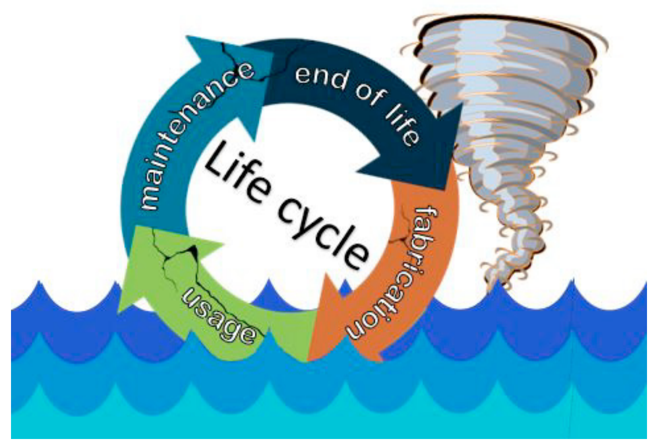



Fig. 1. Illustration of the impact of the disturbance due to disaster on a life cycle

## 2. WATER MANAGEMENT PERSPECTIVE

Water systems provide important services to the population; they ensure there is sufficient water of sufficient quality for a wide variety of applications (drinking, bathing, watering crops, etc.). Water systems are normally designed for a service life of 50 year to 100 years, sometimes even longer. Disasters cause disturbances or outright destruction of these systems, making it more difficult to design a durable water system. For instance, on the Island of Grand Bahama water systems may be disrupted or de-


10.1016/j.ifacol.2022.07.644

stroyed on average every ∼ 8 years. This implies that the infrastructure has an unpredictable life cycle (Fig. 1). Due to the uncertainty in return period and magnitude of a disaster, it is impossible to pinpoint in detail what is required to manage the crises that will occur (Borell and Eriksson, 2013). A design that is disaster-proof is infeasible; a more realistic goal is to create a design that can 'bend' in a disaster and then bounce back ready to face the next event. Recover or 'bounce back' (Twigg, 2007) after an event can be illustrated with a design that has fragile components, for example, floating solar panels. These components should be temporarily removed before an event or be accepted as destroyed after an event. The infrastructure in which these fragile components were used would still be there and aid in the quick recovery of the system. Using the case study of Grand Bahama, this paper explores the translation process in the context of an increase of availability of the freshwater resources on a small touristic island coping with repeating hurricane risk.

## 3. BUILD BACK BETTER

BBB is a concept focused on effective long-term socioeconomic strategic implementation (Giovanni and Chelleri, 2019). It needs to be "better than before" (Matanle, 2013), affordable and realistic in long-term scenarios, and it needs to address previous vulnerabilities and long-term stresses. This is to prevent areas from remaining "ageing and shrinking" (Matanle, 2013). BBB has been mentioned in several guidelines (Mannakkara and Wilkinson, 2014) and in the Sendai Framework for Disaster Risk Reduction and is and should be an integral part of disaster management decision making (UNDRR, 2019).

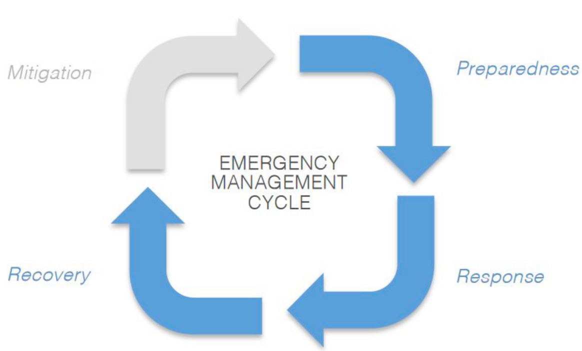



Fig. 2. Four-phase Disaster Cycle (Mergel, 2014)

### *3.1 Disaster cycle*

The four phases of the classical disaster cycle (Fig. 2) with their associated activities are: **preparedness** (actions that encourage and educate the public in anticipation of disaster events), **response** (actions that react to an ongoing disaster and provide the public notification, warning, evacuation, and situation reports), **recovery** (activities that continue beyond the emergency period to restore critical community functions and manage stabilization efforts, reestablishing normal operating capacity and returning to the standard operating procedure), **mitigation** (the implementation of strategies, technologies, and actions that will reduce the loss of lives and property in future disasters) see, for instance, Giovanni and Chelleri (2019) or Lettieri et al. (2009).

These four phases are commonly recognized in literature, dividing activities into three stages: **pre-disaster** (mitigation and preparedness), **disaster** (response) and **post-disaster** (recovery) (Lettieri et al., 2009). Giovanni and Chelleri (2019) state that 'Any disaster is considered as a divide, a discrete phenomenon separating time and places within a "before it" and "after" ... However, these two facets of our reality are mutually inclusive and interconnected'. They further state that BBB "emerges as a concept bridging the aforementioned two plans, of the past and for the future, introducing the necessity of improving recovery practices in line with longer-term sustainability objectives". Pelling (2012) states that each "reconstruction should dovetail into the next round of mitigation and preparedness work", so systems should learn from past events and connect with the other phases (Giovanni and Chelleri, 2019). For instance, during the mitigation phase, the recovery should already be incorporated.

## 4. MULTI CRITERIA ANALYSIS

Multi criteria analysis (MCA) is often used in water management (Hajkowicz and Collins, 2007; Hajkowicz and Higgins, 2008; Gutiérrez et al., 2016). It provides a systematic approach for ranking adaptation options against multiple decision criteria and can be used for problems with many alternative courses of action (Zarghami and Szidarovszky, 2011). Criteria can be weighted to reflect their importance relative to other criteria.

By adding criteria that correspond to the concepts from BBB and the needs of disaster management, MCA can provide a framework that includes these aspects in the evaluation process of water management solutions. The criteria should assure that the solution is sustainable under normal operation and serves the needs of the population during a disaster.

The criteria grouped under "Water management" correspond to normal operation and are based on a model used in the software package ACV4e (Catel et al., 2018), which uses Life Cycle Assessment (LCA). ACV4e considers effects of construction, consumption of resources and emissions during operation, and various end of life impacts. ACV4e also adds pathogens, but this is outside of the scope of this paper.

The term "Infrastructure" represents the "hardware" of the system. To integrate BBB and water management it is necessary to judge the infrastructure not only based on normal operation "Water management", but also under "Disaster management". "Emissions" refers to operational impacts; it includes effects of resource use such as electricity and waste streams. "Maintenance" groups impacts related to replacement parts and periodic repairs. "End of life" includes the reuse, redistribution and recycling. In this paper only "Infrastructure" will be used as a criterion under "Water management". The others will be addressed in future research.

Criteria for Disaster management are based on the disaster cycle and include the connection between stages and the four phases: preparedness, mitigation, recovery and response.

This paper does not consider monetary analyses alone. All cost-benefit studies entail elements which are identified as relevant impacts, but which are not (or cannot be) valued. In some circumstances, impact without a clear monetary value may be regarded as relatively minor in the resulting report. The choice might still be heavily impacted by the monetary results, and the non-monetary values may not be regarded as sufficiently important to change this ordering. But sometimes, where the difference between alternatives implied by monetary valuations is small, they may tip the balance. For each traditional criterion, three sub-criteria can be defined corresponding to the three sustainability indicators: effectiveness, robustness, and flexibility, where **effectiveness** (E) indicates that objectives for people, planet and profit are achieved as much as possible; **robustness** (R) means that it is effective now and in the future and preferably independent of future conditions; **flexibility** (F) indicates that there is room to adapt to future conditions (Haasnoot et al., 2009; van der Kley and Reijerkerk, 2009; Offermans et al., 2009). In this paper, a water management strategy is considered sustainable if the design is effective, robust and flexible.

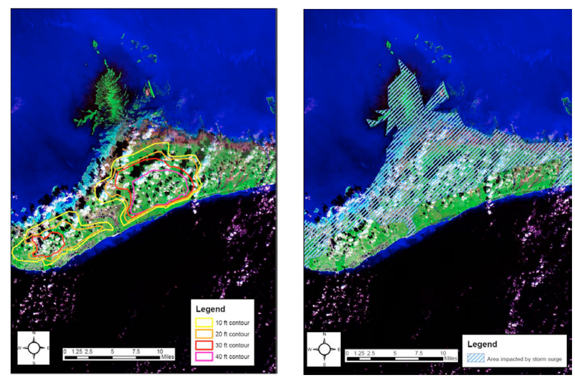
## 5. CASE STUDY

Grand Bahama is the largest island in the archipelago of the Commonwealth of The Bahamas. The hazards which threaten this island are twofold. On average once every eight years this island is struck by a hurricane or tropical storm. The rise of the average sea level has led to intrusion of salt water into the fresh water reservoirs of the island, leading to a freshwater shortage. Due to global warming, the number of hurricanes as well as the severity of the salt intrusion have increased significantly in the past two decades. This is causing severe strain on the rehabilitation capabilities of its citizens. Both hazards threaten the underground fresh water basins, due to hurricane made storm surges and sea level rise decreasing the available groundwater storage (Fig. 3). The purpose of the study is to explore the evaluation of water management solutions on both sustainability and compliance to BBB.

### *5.1 Alternatives and Scenarios*

Three alternatives for drinking water production were considered for the Grand Bahama case study . All alternatives could be used for the production of drinking water on a small or medium tropical island and have seen commercial use in the last 10 years. The first is the use of reverse osmosis. This technique is already widely used on islands in the Commonwealth of The Bahamas without a fresh groundwater basin, see Fig. 4. Therefore this alternative could be taken as a baseline in future research. The second is a combination of desalination and floating solar panels. This alternative has fragile elements, as seen in Fig. 5 and will help explore the possibilities of bouncing back if parts of the system are destroyed during a disaster, accepting damage but having a quick and easy fix at hand. These aspects were the reason to select this alternative for analysis in this paper. The third alternative will be an area protected by a levee, with no room for bending and a possible risk of breaking. This levee will protect the fresh groundwater from storm surge damage. There is a heavy focus on the mitigation phase for this alternative. The design for the levee is shown in Fig. 6.

To test the impact of different events on the alternative solutions, two scenarios will be used. Scenario 1 with a storm similar to a tropical storm in impact and frequency of occurrence. Tropical storm is the category below the impact and frequency of a category one hurricane Andrews (2007). In Scenario 2 the island is hit by a storm similar to Dorian, a category 5 hurricane that hit the island in 2019. The difference in impact between the two storm scenarios should be reflected by the scores on the criteria related to Disaster management for the two scenarios.




(a) Thickness of the fresh-groundwater lens

(b) Extent of storm surge impacting well-fields Hurricane Jeanne in 2004

Fig. 3. Impact of storm surge on the freshwater lens in Grand Bahama (GBUC, 2008)

Fig. 4. Alternative 1: reverse osmosis. Prime Minister the Rt. Hon. Hubert drinking reverse osmosis water in 2011 (Eleuthera, the Commonwealth of The Bahamas)

## 6. EVALUATING THE ALTERNATIVES WITH DISASTER IN MIND

This section will explore the reasoning behind the preliminary values assigned to criteria in the MCA. The goal is the translation of concepts from BBB and disaster management into a form that can be used in water management.

Table 1 shows partial scoring results for the MCA, concentrating on the energy component of alternative 2 for this paper. Alternative 2 is a combination with desalination techniques that converts salt sea water in fresh-drinking water a process that need electricity and floating solar

Fig. 5. Alternative 2: fragile components of floating solar panels for desalination


Fig. 6. Alternative 3: collective protection of population and freshwater source by adding levees to the existing landscape (20 feet contours) to create a protected zone

panels that produce electricity that can be used for desalination. This paper will focus on the energy component of this alternative to provide a streamlined example of the effects of also evaluating on criteria related to the disaster cycle.

### *6.1 Criteria for Water management*

The infrastructure of the energy component of alternative 2 consists of the floating components with solar panels and the connection with the land. It is effective and has an added bonus of projecting a green energy image that is beneficial for tourism. The energy component of alternative 2 is not robust due to it being dependent on calm water. However, the score is neutral because of the case study location. Outside hurricane season, calm water is readily available along the south coast of the island thanks to the deep water on that side, see Fig. 5. Flexibility is positive due to the floating components being easily transported, implemented and added to. The score is not ++ due to the necessary connection with the land.

### *6.2 Criteria for Disaster management*

The energy component of alternative 2 has fragile elements, which allows exploration of the possibilities of bouncing back if parts of the system are destroyed during a disaster, accepting damage but having a quick and easy fix at hand.

*Disaster criteria scenario 1* During a relatively low impact tropical storm of scenario 1, it will be possible to "bend" with the disaster circumstances and store the fragile components, making it possible quickly reestablish normal production. Bouncing back without needing to replace infrastructure or other elements. Preparedness for all sustainability indicators (E,R,F) are negative. Before a storm, the solar panels of alternative 2 still need to be stored. To be able to store the components technical skill and time are needed, both of these can be unreliable in a pre-disaster situation. Mitigation is neutral for all sustainability indicators. For the basic infrastructure of the energy component of alternative 2 the only added mitigation measure is storage space that can cope with scenario 1.

The response is dependent on the availability of technical manpower. Making response score negative for effectiveness and neutral for robustness and flexibility. Recovery has a positive score, because, thanks to safe storage, it can be quickly put back into use. Due to the floating components, no clearance of debris needs to be done before installing. If people with the proper technical skills are available immediately after or during the disaster, the recovery after the disaster can be very efficient and quick.

For the connection between phases, the most important interaction is between mitigation and preparedness. If the basic storage infrastructure stays safe and available, then the preservation of the fragile components is secured. It is however very tempting to use empty warehouses for other purposes. The goal of the "connection between phases" criterion is to explore how the resources related to one phase might be lost or used during another phase. The connection between phases criteria scores positive on effectiveness. Robustness is neutral, because the knowledge of the use of the warehouse needs to be continuously reestablished and refreshed. The transfer of this knowledge is not a huge task, but can still be difficult to guarantee. The criterion flexibility for the connection between phases is positive because the only direct connection is between mitigation and preparedness. There is no direct connection between the other phases. The speed with which fresh drinking water will be available again after a disaster can be improved if it is kept in mind during other phases. This is done by making sure skilled manpower is available after the event.

*Disaster criteria scenario 2* In scenario 2, in which a hurricane with impacts similar to those of Dorian occurs, most components are likely to break. The storage space may be flooded, damaged by debris or exposed to the elements. This means that components will not be able to be safely stored and immediate production after the disaster will not be possible.

Preparedness is negative for all sustainability indicators. Before a storm the energy component of alternative 2 still needs to be stored, because it could be that the hurricane foes not pass directly over the island and the chance exists the components can be saved. To be able to store the components technical skills and time are needed, both of these can be unreliable in a pre-disaster situation. For this alternative it is assumed that the basic storage space is designed for saving the energy component of alternative 2 for a scenario 1 tropical storm and not a scenario 2 hurricane. This makes the mitigation measures the same, but for this scenario unreliable. Mitigation is again neutral, as in scenario 1. Response scores −− on all sustainability indicators, this is based on the assumption that the components are flooded, damaged and exposed to the elements. Other external measures need to be taken to ensure sufficient drinking water availability in the disaster area. Recovery after the disaster could be very quick if the components survive in the storage unit. For this scenario, it is assumed that they will not. This means that the parts need to be rebuild or replaced. For recovery this alternative scores −− for effectiveness, neutral for robustness and flexibility. The connection between phases criteria scores −−, due to the loss of all components needed for recovery.

Table 1. Partial scores for alternative 2.

| Scenario | Tropical storm | | | Dorian hurricane | | |
|---|---|---|---|---|---|---|
| Sustainability indicators | E | R | F | E | R | F |
| Criteria watermanagment: | | | | | | |
| Infrastructure | ++ | 0 | + | ++ | 0 | + |
| ... | | | | | | |
| ... | | | | | | |
| ... | | | | | | |
| Criteria disaster management: | | | | | | |
| Preparedness phase | − | − | − | − | − | − |
| Mitigation phase | 0 | 0 | 0 | 0 | 0 | 0 |
| Response phase | − | 0 | 0 | −− | −− | −− |
| Recovery phase | + | + | + | −− | −− | −− |
| Connection between phases | + | 0 | + | −− | −− | −− |

## 7. DISCUSSION

This paper describes a work in progress. The aim is to combine sustainable water management and the disaster cycle to be able to "design with disaster". The biggest obstacle is the clash between the different time frames of the criteria. The criteria of water management are evaluated over the entire lifetime of the design, while the disaster criteria consider the shorter time frame between disasters. In additions the different scope in certainty and detail of the two perspectives makes it challenging to combine them in one MCA.

The perspective of BBB is the search for an effective long-term socio-economic strategy. Such a search is location and time dependent, which means that the alternatives for a water system are to some degree case-study specific. The challenge is then to keep such a strategy generic enough that it would be possible to implement it on other islands.

The exploration of the different aspects in designing with disasters in a long-term cycle presents many research challenges. Future research will explore the sustainability indicators: effectiveness, robustness and flexibility forh other alternatives and scenarios in combination with disaster management.

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