Dominica Geothermal
Development Company Limited
*Powering a New Generation...*

# DISASTER RISK and EMERGENCY MANAGEMENT (DREM) PLAN

Second Edition | December 2021

# FOREWORD

The Dominica Geothermal Development Company (DGDC) is focused on the sustainable development of Dominica's geothermal resources, starting with the delivery of a domestic plant in the near future. The delivery of this facility is critical to both the nation's renewable energy goals and its climate resilience strategy.

We need no reminders of our vulnerability to the forces of nature. We have been well schooled on how easy it is for a single natural hazard event to reverse progress on the most promising of initiatives. This Plan is intended to help mitigate the impact of these natural events on DGDC personnel and facilities, as well as on the communities in which we operate. This detailed strategy and plan aim to heighten awareness of the relevant issues, and provide instructions on steps to be taken in preparation for and response to natural hazard events. The emphasis is on prevention, mitigation and preparedness. These begin with design and construction to reduce our exposure and vulnerability and extend to how we operate. Response, recovery and rehabilitation are addressed in greater detail in other avenues.

We wish to commend and thank the staff of DGDC for developing this document. We also wish to express DGDC's gratitude to the agencies that worked alongside our staff and provided expert guidance throughout.

This plan will also continue to evolve to reflect best practices, and to reflect changes in social, operational and environmental factors.

The DGDC Board of Directors

## ACKNOWLEDGEMENT

The DGDC extends its gratitude to its international partners that have supported and guided the design of the first Disaster Risk and Emergency Management (DREM) Plan.

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Contributions were also provided by the Office of Disaster Management (ODM), Dominica Meteorological Service, UWI Seismic Research Centre, the Ministry of Communications & Works, University of Twente.

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- Fitzroy Pascal, Coordinator of ODM, Dominica
- Marshall Alexander, Senior Meteorological Officer, Dominica
- Richard Robertson and staff of UWI-SRC, Trinidad and Tobago
- Magnus Williams, Chief Engineer – Dominica Water & Sewerage Company Ltd, Dominica
- Cees van Westen, Associate Professor, University of Twente, The Netherlands
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# Acronyms and Abbreviations

| | |
|---|---|
| AFD | Agence Française de Développement |
| CIF | Caribbean Investment Facility of the EU |
| DGDC | Dominica Geothermal Development Company Ltd |
| DREMP | Disaster Risk and Emergency Management Plan |
| EOC | The Emergency Operations Centre of NEPO |
| EPC | Engineer, Procure and Construct |
| EU | European Union |
| NEPO | National Emergency Planning Organization |
| ODM | Office of Disaster Management |
| UWI-SRC | Seismic Research Centre of The University of the West Indies |

# INTRODUCTION

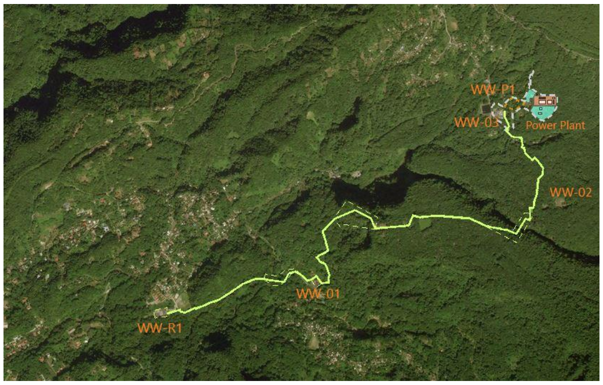
## 1. Purpose and Objectives

The very first geothermal power plant to be developed at Laudat in the Roseau Valley is regarded as a critical component of Dominica's future infrastructure development plans as well as country's sustainable development priorities. Dominica is a volcanic island situated in the common path of tropical cyclones and in a seismically active part of the planet. It has suffered devastating consequences of several hurricanes in the past, including the recent one, the hurricane Maria (Category 5+)[1] considered the worst in the history of Caribbean hurricanes. Dominica was the most affected country in the region hit by hurricane Maria on 28 September 2017. It, therefore, is essential that the plant be designed, built, operated and maintained in a manner consistent with the country's stated goal of becoming the world's first climate resilient nation. Appendix 6 provides a brief overview of the rationale for this Plan.

Towards this end, the Disaster Risk and Emergency Management (DREM) Plan is developed by the staff of Dominica Geothermal Development Company (DGDC) to ensure resilience of this critical infrastructure to **natural hazards.** The DREM Plan is aimed at fostering a heightened attention to safety and security issues among the employees of the Company and preparing them to ensure adequate preparedness and response to various scenarios if natural hazards such as ***floods, landslides, earthquakes, volcanic eruptions, and hurricanes*** impact the geothermal power plant. Hence, the ***purpose*** of the plan is to guide the resilience building efforts of the DGDC throughout the ***pre-construction, construction, and operation & maintenance*** phases.

This document (2nd edition – December 2021) is an update of the original edition (August 2019). It accounts for changes in the project design, specifically the adoption of a new injection strategy. A new reinjection well RV-I2 is to be drilled and WW-R1 and WW-01 will no longer be part of the project. The route of the reinjection pipeline has consequently changed, which is significantly shorter as illustrated in Figure 1. A new backup production well RV-P2 will also be drilled.

[1] To be classified as a hurricane, according to the Saffir–Simpson hurricane wind scale, a tropical cyclone must have one-minute maximum sustained winds of at least 74 mph (33 m/s; 64 kn; 119 km/h) (Category 1). The highest classification in the scale, Category 5, consists of storms with sustained winds exceeding 156 mph (70 m/s; 136 kn; 251 km/h). However, it is noticed that the sustained winds increasingly exceed the margins set in the Saffir-Simpson scale. The hurricane Maria in 2017 was classified as 5+.




Original Reinjection Pipeline Route


Revised Reinjection Pipeline Route

**Figure 1: Pipeline Routes - Comparison**

The ***overall objective*** of the plan is to *save lives, prevent injury to persons, minimize damage to Company's property, protect the environment and ensure rapid recovery from a disaster*. The ***specific objectives*** of the DREM Plan include:

a. To develop the awareness of the staff and other stakeholders of the various disaster risks from natural hazards that are likely to impact the geothermal powerplant.

b. To clearly define the roles and responsibilities of the DGDC's staff in the management of disaster risk. Appendix 1 provides an overview of the organogram of the DGDC.

c. To guide disaster mitigation, preparedness and emergency actions of DGDC staff and contractors at all phases of the project implementation: ***pre-construction, construction, and operation & maintenance*** phases.

The DREM Plan covers the geothermal power project sites, which include associated steam fields and reinjection line, whereby

- **WW-P1** and **WW-03** are the production wells;
- **RV-I2** will be the reinjection well, and
- the areas that will be used for routing the pipelines.

The areas where the **WW-01**, **WW-02** and **WW-R1** wells are located are also covered by the DREM Plan. These areas are not part of the revised project, i.e. they will not be further exploited, however, since they are the property of the DGDC and there are some assets available at the sites, they are therefore included in the DREM Plan. Additionally, a proposed production well **RV-P2** is covered by this Plan. See Figure 2b below.


**Figure 2a: Geothermal project location**


**Figure 2b: Project Area Details**

## 2. Limitations of the DREM Plan

While developing the DREM Plan Second Edition, due to time and resource constrains a number of limitations are encountered and must be taken into consideration:

a) The DREM Plan is limited to only natural hazards. Any other hazards are beyond the scope of this Plan.

b) The DREM Plan is concerned only by the risks to the geothermal power plant areas. No cascading effects were considered beyond the project area.

c) The DREM Plan is limited by the data that is currently available on hazards, exposure, and vulnerabilities. For example, although some hazard maps for Dominica have been produced, the extent to which they can be useful for hazard/risk analysis of the project site, is limited by the scale of those maps.

d) The current version of the DREM Plan is focused only on the pre-construction phase. The next iterations of the DREM Plan will cover construction and operational phases respectively.

## 3. Key concepts

***Emergency*** – is an out-of-the-ordinary situation that must be managed by urgent procedures in order to stop it escalating and thus having consequences that are more serious and damaging.

***Disaster*** - is an event that has a substantial negative impact on human lives and activities and on the built or natural environment.

***Crisis*** – is a sudden, intrusive interruption of normal conditions with potentially adverse consequences.

# APPROACH AND METHODOLOGY

## 1. Approach to DREM Plan

The approach used in developing the DREM Plan is based on understanding disaster risk as the interaction between **hazard** and the characteristics that make people and places **exposed** and **vulnerable**. The theory behind this approach is further explained in Appendix 4: Understanding Disaster Risk.

The approach employed for the DREM Plan is, therefore,

(a) to identify those natural hazards that are likely to impact the geothermal power plant site.

(b) to examine the extent of exposure and vulnerability of the plant site to each natural hazard at the pre-construction phase.

(c) to determine the worse-case scenarios caused by the combination of the natural hazard and exposure/vulnerability of each of the seven areas of the geothermal power project.

(d) consider each scenario as a unique risk and identify the likelihood and impact rate of each scenario, hence, the risk severity. Detailed description of impact is critical in order to guide adequate prevention, preparedness, and response and recovery measures. Applying precautionary principle, the focus of the risk assessment is based on the worst-case scenarios.

(e) design the response measures to address high risk scenarios. When disaster risks are identified, the DREM Plan provides recommendations on disaster preparedness and disaster mitigation actions.

This approach is visualized in Table 2: Disaster Risk Profile.

## 2. Methodology for Disaster Risk Assessment

The combination of hazard maps and the geolocation of the geothermal power plant is used to help determine the level of exposure of the geothermal power plant site to a particular hazard. With the guidance of a subject matter expert, the vulnerabilities of the installation are assessed. On this basis the extent of risk is evaluated, and recommendations are provided as appropriate.

Hazard analysis is largely outsourced as it requires scientific analysis and must be based on a highly reliable source. Various experts and scientific/research institutions are contacted. They are asked to categorize hazard for each of the seven location areas according to the following scale: ***high***, ***moderate***, ***low***.

Exposure and vulnerability analysis and impact description for the preconstruction phase is carried out using the DGDC's in-house expertise and with the help of Seureca team. The findings for the exposure and vulnerabilities too are categorized for each of the location areas according to the following scale: ***high***, ***moderate***, ***low***.

Conclusions about disaster risk level for each of the location areas are presented both as a colour code and as a rating:

***High:*** extensive damage to property and injury to people or serious disruption of the operations (red)
***Moderate:*** damage to properties and human injuries (yellow)
***Low:*** minor or no impact to assets and people (green)

# HAZARD PROFILE

This section provides an overview of the hazard profile of the geothermal power plant site during the pre-construction phase. See Appendix 8: Scientific References for more details.

**Earthquake:** the geothermal power plant site is located in the moderate/high seismic activity zone. The expected magnitude varies from average 2.5M to peaks of 5M. Experts conclude that the seismic hazard probability in all seven areas of the geothermal power plant are moderate to high. It is recognized that because geothermal operations will be conducted in areas that are also tectonically active, it will be difficult to distinguish between any geothermal-induced and naturally occurring events.

**Volcanic activity:** the geothermal power plant is to be built in a region that has perhaps the densest collection of volcanic centres in the Caribbean region. Nevertheless, for the pre-construction phase, there are sufficient reasons to conclude that the probability of volcanic activities is low. It is, however, important to distinguish between volcanic activities of Morne Micotrin and Phreatic explosion in Wotten Waven area. It is also important to mention the likelihood of phreatic eruption or phreatic explosion in Wotten Waven area. This type of eruption is related to the sudden, violent boiling of shallow heated aquifers related to the geothermal system. There is no direct relation with a volcano. Several phreatic explosions have been experienced in the past in the Wotten Waven area.

**Landslide:** the available mass movements susceptibility map classifies landslides into four categories: low, moderate, high, and historical landslides. The geothermal project is located in a zone with low landslide susceptibility.

**Hurricane:** the project area, like the rest of the island, is located in the common path of tropical cyclones. Historical information on impacts of this natural hazard is well-documented, so that even without reference to scientific data, the recent history of extreme wind events like Hurricane David (1979) and Hurricane Maria (2017) category 5 and 5+ respectively, as well as the frequent occurrence of less intense hurricanes and tropical storms, supports the conclusion of high wind hazard probability. It should be noted, however, that in the absence of scientific data, the level of uncertainty is significantly high.

**Flood:** the level of flood exposure of the project area was established by reference to historical data and the use of a flood hazard map. The extreme level of flooding experienced during Tropical Storm Erika (2015) and Hurricane Maria was indicative of the worst-case scenario. It points to relatively low flood susceptibility for most of the project area. Further detailed study is required to substantiate this conclusion.

# DISASTER RISK PROFILE: SCENARIOS

During the pre-construction phase only few assets are available at the geothermal power project sites and extended areas of interest, the list and the condition of which are presented in Table 1.

**Table 1: Condition of Assets per area**

| Area | Description of Assets | Condition of Assets |
|---|---|---|
| Production Well site (WW-P1 & WW-03) | Two well heads, flow line, flash tank, weir box, sump, one diesel powered sump pump. | • Wellhead valves serviced in June 2019. Rehabilitation work carried out on flow line in June 2019.<br>• Wellhead, flash tank and weir box are all in fair to good condition. Some early signs of corrosion were observed at the wellhead. These, upon close examination, were found to be minor.<br>• The sump pump was fitted with some replacement parts in July/August 2019 and is now in prime working condition. |
| Power Plant site | No assets available | |
| Reinjection Pipeline route | No assets available | |
| Reinjection Well site (RV-I2) | No assets available | |
| Production Well site (RV-P2) | No assets available | |
| Former Reinjection Well site (WW-R1) | One well head, sump | Wellhead valves serviced in June 2019. Wellhead is in fair to good condition. Some early signs of corrosion were observed at the wellhead. These, upon close examination, were found to be minor and are being addressed. |
| Exploratory Well site (WW-01) | One well head, sump | Wellhead valves serviced in June 2019. Wellhead is in fair to good condition. Some early signs of corrosion were observed at the wellhead. These, upon close examination, were found to be minor and are being addressed. |
| Exploratory Well site (WW-02) | One well head, sump | Wellhead valves serviced in June 2019. At that time there was severe corrosion of the |

| | | |
|---|---|---|
| | | flange bolts securing the wing valve. DGDC is currently working on a solution to this issue. Wellhead is in fair to good condition. Some early signs of corrosion were observed at the wellhead. These, upon close examination, were found to be minor and are being addressed. |

The exposure and vulnerability analyses are further considered while developing worse-case scenarios that are realistically possible for the geothermal power plant. Appendix 5 explains the approach employed for scenario development.

Table 2 below illustrates the disaster risk profile of the geothermal power plant site in its pre-construction phase. The risk levels are assigned a numerical score and are colour coded based on a combination of impact and likelihood of the site to the related hazard: **green** depicts a **low** level of risk, **yellow** for **moderate** level, and red for **high** risk.

Emerging from the risk level analysis, those risks indicated in red, meaning high likelihood and high impact are analyzed in terms of:

a) What to do to prevent this scenario from happening, and if this is not possible
b) What to do to prepare DGDC to respond to such a scenario in the most effective way.

## Table 2: Disaster Risk Profile: Phase I. PRE-CONSTRUCTION

| Item # | Type of Hazard | Location of Asset | Hazard Probability | Exposure and Vulnerability | Expected Events | Worst-case Scenario Impact Description | Likelihood of Worse-case Scenario | Impact of Worse-case Scenario | Risk ** Level |
|---|---|---|---|---|---|---|---|---|---|
| 1 | **Hurricane** (category 5+) | Steamfield and Production Wells (WW-P1 and WW-03) | HIGH | LOW | Impact by flying debris (trees, roofs, …) | Scenario: H1<br>Wellhead rupture: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | Low | High | Low/3 |
| | | Power Plant* | HIGH | n/a | | | | | |
| | | Reinjection Pipeline* | HIGH | n/a | | | | | |
| | | Reinjection Well (RV-I2)* | HIGH | n/a | | | | | |
| | | Production Well (RV-P2)* | HIGH | n/a | | | | | |
| | | Former Reinjection Well (WW-R1) | HIGH | LOW | Impact by flying debris (trees, roofs, …) | Scenario: H4<br>Wellhead rupture: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | Low | High | Low/3 |
| | | Test Well (WW-01) | HIGH | LOW | Impact by flying debris (trees, roofs, …) | Scenario: H5<br>Wellhead rupture: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | Low | High | Low/3 |
| | | Test Well WW-02 | HIGH | LOW | Impact by flying debris (trees, | Scenario: H6<br>Wellhead rupture: Gas and steam emission in | Low | High | Low/3 |

| Item # | Type of Hazard | Location of Asset | Hazard Probability | Exposure and Vulnerability | Expected Events | Worst-case Scenario Impact Description | Likelihood of Worse-case Scenario | Impact of Worse-case Scenario | Risk ** Level |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | roofs, …) | atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | | | |
| 2 | **Earthquake** (magnitude 5.0) | Steamfield and Production Wells (WW-P1 and WW-03) | MODERATE | LOW | Ground displacement | Scenario: E1<br>Production casing rupture: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Power Plant* | MODERATE | n/a | | | | | |
| | | Reinjection Pipeline* | MODERATE | n/a | | | | | |
| | | Reinjection Well (RV-I2)* | MODERATE | n/a | | | | | |
| | | Production Well (RV-P2)* | MODERATE | n/a | | | | | |
| | | Former Reinjection Well (WW-R1) | MODERATE | LOW | Ground displacement | Scenario: E4<br>Production casing rupture: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Test Well (WW-01) | MODERATE | LOW | Ground displacement | Scenario: E5<br>Production casing rupture: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Test Well WW-02 | MODERATE | LOW | Ground displacement | Scenario: E6<br>Production casing rupture: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |

| Item # | Type of Hazard | Location of Asset | Hazard Probability | Exposure and Vulnerability | Expected Events | Worst-case Scenario Impact Description | Likelihood of Worse-case Scenario | Impact of Worse-case Scenario | Risk ** Level |
|---|---|---|---|---|---|---|---|---|---|
| 3 (a) | **Volcanic Activity of Morne Micotrin** | Steamfield and Production Wells (WW-P1 and WW-03) | LOW | LOW | Ash fall, rock fall, pyroclastic flow, lahar | Scenario: V1.1 Wellhead rupture, wellhead burying: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Power Plant* | LOW | n/a | | | | | |
| | | Reinjection Pipeline* | LOW | n/a | | | | | |
| | | Reinjection Well (RV-I2)* | LOW | n/a | | | | | |
| | | Production Well (RV-P2)* | LOW | n/a | | | | | |
| | | Former Reinjection Well (WW-R1) | LOW | LOW | Ash fall, rock fall, pyroclastic flow, lahar | Scenario: V1.4 Wellhead rupture, wellhead burying: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Test Well (WW-01) | LOW | LOW | Ash fall, rock fall, pyroclastic flow, lahar | Scenario: V1.5 Wellhead rupture, wellhead burying: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Test Well WW-02 | LOW | LOW | Ash fall, rock fall, pyroclastic flow, lahar | Scenario: V1.6 Wellhead rupture, wellhead burying: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | | | | | | | | |

| Item # | Type of Hazard | Location of Asset | Hazard Probability | Exposure and Vulnerability | Expected Events | Worst-case Scenario Impact Description | Likelihood of Worse-case Scenario | Impact of Worse-case Scenario | Risk ** Level |
|---|---|---|---|---|---|---|---|---|---|
| 3 (b) | **Phreatic Volcanic Activity** | Steamfield and Production Wells (WW-P1 and WW-03) | LOW | LOW | Steam and gas emission, ash emission | Scenario: V2.1<br>Ash fall: Troubles for exploitation | **Low** | **Low** | **Low/1** |
| | | Power Plant* | LOW | n/a | | | | | |
| | | Reinjection Pipeline* | LOW | n/a | | | | | |
| | | Reinjection Well (RV-I2)* | LOW | n/a | | | | | |
| | | Production Well (RV-P2)* | LOW | n/a | | | | | |
| | | Former Reinjection Well (WW-R1) | LOW | LOW | Steam and gas emission, ash emission | Scenario: V2.4<br>Ash fall, wellhead burying: Troubles for exploitation or abandonment of exploitation | **Low** | **Low** | **Low/1** |
| | | Test Well (WW-01) | LOW | LOW | Steam and gas emission, ash emission | Scenario: V2.5<br>Wellhead rupture, production casing rupture: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Test Well WW-02 | LOW | LOW | Steam and gas emission, ash emission | Scenario: V2.4<br>Ash fall | **Low** | **High** | **Low/3** |
| 4 | **Landslide** | Steamfield and Production Wells (WW-P1 and WW-03) | LOW | LOW | Rock fall, mudflow and debris flow, scarp | Scenario: L1<br>Wellhead rupture, production casing rupture, wellhead burying: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Power Plant* | LOW | n/a | | | | | |
| | | Reinjection | LOW | n/a | | | | | |

| Item # | Type of Hazard | Location of Asset | Hazard Probability | Exposure and Vulnerability | Expected Events | Worst-case Scenario Impact Description | Likelihood of Worse-case Scenario | Impact of Worse-case Scenario | Risk ** Level |
|---|---|---|---|---|---|---|---|---|---|
| | | Pipeline* | | | | | | | |
| | | Reinjection Well (RV-I2)* | LOW | n/a | | | | | |
| | | Production Well (RV-P2)* | LOW | n/a | | | | | |
| | | Former Reinjection Well (WW-R1) | LOW | LOW | Rock fall, mudflow and debris flow, scarp | Scenario: L4<br>Wellhead rupture, production casing rupture, wellhead burying: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Test Well (WW-01) | MODERATE | LOW | Rock fall, mudflow and debris flow, scarp | Scenario: L5<br>Wellhead rupture, production casing rupture, wellhead burying: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| | | Test Well WW-02 | LOW | LOW | Rock fall, mudflow and debris flow, scarp | Scenario: L6<br>Wellhead rupture, production casing rupture, wellhead burying: Gas and steam emission in atmosphere, brine discharge and river pollution, soil erosion and landslide by flood, high level of noise | **Low** | **High** | **Low/3** |
| 5 | **Flood** | Steamfield and Production Wells (WW-P1 and WW-03) | MODERATE | LOW | Rupture of the hydro-electric pipeline running between the Fresh Water Lake and Laudat | Scenario: F1<br>Well pad covered by mudflow deposits, Well pad erosion, wellhead cellar full of water: No significant or slight troubles for exploitation (corrosion, damaged gauges) | **Low** | **Low** | **Low /1** |

| Item # | Type of Hazard | Location of Asset | Hazard Probability | Exposure and Vulnerability | Expected Events | Worst-case Scenario Impact Description | Likelihood of Worse-case Scenario | Impact of Worse-case Scenario | Risk ** Level |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Hydro Power Plant | | | | |
| | | Power Plant* | MODERATE | n/a | | | | | |
| | | Reinjection Pipeline* | MODERATE | n/a | | | | | |
| | | Reinjection Well (RV-I2)* | MODERATE | n/a | | | | | |
| | | Production Well (RV-P2)* | MODERATE | n/a | | | | | |
| | | Former Reinjection Well (WW-R1) | LOW | LOW | Sustained heavy rainfall and compromised drainage in the area above the site | Scenario: F4<br>Well pad covered by mudflow deposits, Well pad erosion, wellhead cellar full of water: No significant or slight troubles for exploitation (corrosion, damaged gauges) | **Low** | **Low** | **Low /1** |
| | | Test Well (WW-01) | LOW | LOW | Sustained heavy rainfall and compromised drainage in the area above the site | Scenario: F5<br>Well pad covered by mudflow deposits, Well pad erosion, wellhead cellar full of water: No significant or slight troubles for exploitation (corrosion, damaged gauges) | **Low** | **Low** | **Low /1** |
| | | Test Well WW-02 | LOW | LOW | Sustained heavy rainfall and compromised drainage in the area above the site | Scenario: F6<br>Well pad covered by mudflow deposits, Well pad erosion, wellhead cellar full of water: No significant or slight troubles for exploitation (corrosion, damaged gauges) | **Low** | **Low** | **Low /1** |

**Notes:**

* Asset not yet realized.

** Color codes for Risk: ***high (red), moderate (yellow), and low (green).***

**IMPORTANT:** The Disaster Risk Profile will be updated during each major review of the Plan, prior to the construction and maintenance phases. Additional updates might be envisaged as necessary and feasible during each next phase.

The analysis of disaster risk profile of the geothermal power plant suggests that there are no major disaster risks (i.e. risks with severity of 9 or red) to expect during the pre-construction phase, i.e. till the end of 2019. However, introducing time dimension in risk analysis suggests considering DGDC's capacities to cope with any emergency situation should it occur. ***Time is the major multiplier for the DGDC***. Even if the initial impact of the identified worse-case scenario is not significant, over time if there are no capacities to address the situation, the consequences might have serious further implications for the DGDC, the geothermal power plant, environment, and the communities nearby. Table 3 explains the time range to be considered for the response to an emergency situation in each of the 5+1 geothermal power plant areas.

**Table 3: Time consideration in risk analysis**

| *Worst case scenario considered* | *Natural hazards involved* | *Impacts of worst case scenario* | *Indicative time to repair / to mitigate risk* |
|---|---|---|---|
| Wellhead rupture | Hurricanes<br>Earthquakes<br>Volcanic activity Micotrin<br>Phreatic explosion in Wotten Waven<br>Landslides | Gas and steam emission in atmosphere,<br>brine discharge and river pollution,<br>soil erosion and landslide by flood,<br>high level of noise | A few weeks to a few months |
| Production casing rupture | Earthquakes<br>Phreatic explosion in Wotten Waven<br>Landslides | Gas and steam emission in atmosphere,<br>brine discharge and river pollution,<br>soil erosion and landslide by flood,<br>high level of noise | A few months to one year |
| Wellhead burying | Volcanic eruption Micotrin<br>Phreatic explosion in Wotten Waven<br>Landslides | Troubles for exploitation or abandonment of exploitation | A few weeks to a few years depending on the duration of the eruption |
| Ash fall | Volcanic eruption Micotrin<br>Phreatic explosion in Wotten Waven area | Troubles for exploitation | A few weeks to a few years depending on the duration of the eruption |

| ***Worst case scenario considered*** | ***Natural hazards involved*** | ***Impacts of worst case scenario*** | ***Indicative time to repair / to mitigate risk*** |
|---|---|---|---|
| Well pad covered by mudflow deposits | Landslides<br>Flood | Troubles for exploitation | A few days or a few weeks depending on the extent of damage |
| Well pad erosion | Landslides<br>Flood | Troubles for exploitation | A few days or a few weeks depending on the extent of damage |
| Wellhead cellar full of water | Flood | No significant or slight troubles for exploitation (corrosion, damaged gauges) | A few days or a few weeks depending on the extent of damage |

# DISASTER PREVENTION and MITIGATION MEASURES

## Conclusion

During the pre-construction phase, it is obvious that the main risks are related to the wells. While the priority attention is on worst case scenarios, during the pre-construction phase ***all the risks from natural hazards to the geothermal power plant are low***. Nevertheless, it is important to acknowledging that time is the major multiplier and that if the DGDC's capacities are not in place, any damage caused by natural hazards may have large implications on DGDC assets and on the natural and human environments. ***Therefore,*** *the focus of the prevention and mitigation measures for the pre-construction phase is to build* ***prevention and mitigation capacities*** *of the DGDC to ensure resilience of the geothermal power plant over time.* The critical capacities of the DGDC includes those geared towards (a) prevention of the worst-case scenarios, (b) management of emergency and crisis situation, (c) capacity building of the DGDC personnel, (d) revision of the DREM Plan, and (e) capacities to monitor the realization of the DREM Plan.

Several measures are proposed and can be further detailed by the DGDC team as deemed necessary. While the measures below are designed for the pre-construction phase, the realization of some of them might take longer time and cross over the construction phase. In that case, those activities must be further informed by the risk assessment(s) organized during the construction phase.

## Recommendations

**A. Measures to prevent the occurrence of worst-case scenarios**

- Ensure regular visual survey to detect any problem or any weakness on wellhead.
- Regular maintenance of wellheads. A well-maintained wellhead will be more resistant to damages caused by natural hazard and also by corrosion.
- Monitoring of surface manifestations in Wotten Waven area to detect precursory signs of phreatic explosion (specific to well WW-01).
- Have a stock of spare parts of main components of wellhead (for instance, main valves, side valves) to be able to replace defective (or broken) components. This is particularly critical given that Dominica is an island and transportation of necessary spare parts might take weeks if not months. The need for such a stock might be obviated if the WW-P1 and WW-03 master valves are replaced.

- Mainstream disaster risk thinking into the design and the location of future equipment to reduce the likelihood and/or the impact of natural hazards.
- Ensure seasonal hazard forecasts and scenario planning to anticipate the occurrence of hurricanes and heavy rains which are the main trigger for landslides, rock falls and floods.

**B. Measures to manage emergency and crisis situations**

- Prepare procedures of technical intervention in case of emergency (emergency response plan)
- Have in Dominica equipment and products for controlling fluid discharge at wellhead (for example: pump, barite, water reserve nearby);
- Prepare a list of local contractors likely to be mobilized in case of emergency (for instance: welding, piping, pumping, crane, diesel supply, civil work);
- Prepare a list of foreign experts on geothermal wells who can be requested in case of emergency to provide help.

**C. Measures to build capacities of the DGDC personnel**

- Training with international consultants to learn, to develop, and to practise emergency response plan (in Dominica or in foreign country);
- Regular checking and update of the emergency response plan, of the stock of spare parts, of the list of contractors and experts, of the equipment for controlling discharge at wellhead.

**D. Measures regarding revision of the DREM Plan**

- Expand the focus of the DREM Plan during its next iteration to go beyond natural hazards and to consider cascading effects including those on the environment and the nearby communities.
- If considered feasible, organize monitoring of seismic activities at locations in and around the project area and discuss findings with the UWI-SRC on need basis. In addition it will also provide useful data on baseline micro-seismicity in the project area.
- Recalibrate the impact criteria and indicators for the construction and operational phases.

**E. Monitoring of the DREM Plan Realization**

The DGDC emergency response team will set up a system to monitor and verify that the actions of the EPC and O&M contractors are in conformity with the requirements of the

DREM Plan during the construction and operational phases of the project. The monitoring plan is to be developed prior to the construction phase.

# DISASTER PREPAREDNESS and EMERGENCY MEASURES

This section provides an overview of the existing and planned measures to increase ***preparedness capacities*** of the DGDC to face various disaster risks. The current version of the Plan is focused on pre-construction phase and therefore, the measures that are feasible and necessary for this phase of the project. In the meantime, the proposed measures have more universal nature and will add value for the construction and operation phases. This section will be further updated as deemed necessary for the construction and operation phases respectively.

The focus of disaster preparedness at all phases is on ***(1)*** emergency equipment and facilities, ***(2)*** emergency notification procedures and communication system, ***(3)*** community awareness raising and communication, ***(4)*** responsibilities of the team members, and ***(5)*** evacuation and assembly points.

## 1. Emergency Equipment and Facilities

As of December 2021, the emergency equipment available under the ownership of DGDC and those required for the effective disaster risk management include the following:

**Table 4: Emergency Equipment available and required during pre-construction phase**

| Currently available | Required |
|---|---|
| five (5) self-contained breathing apparatus kits | five (5) |
| Three (3) emergency escape breathing apparatus kits | three (3) |
| one (1) Automated External Defibrillator (AED) unit | One (1) |

## 2. Emergency Notification Procedures and Communication Systems

DGDC has set up a roster for 'Duty Officer on-call' such that at each point of time one person is available to respond to emergency calls round the clock. There is a dedicated emergency mobile telephone retained by the Duty Officer: **767 235 2222 is displayed on <u>all</u> DGDC signage in and around the work sites.**

When an emergency call is received, it is the responsibility of the Duty Officer to decide who to contact next:

(a) In case of significant emergency situation (i.e. *direct threat to the functioning of the geothermal power plant, direct threat to the life and well-being of the staff, threat to the neighbouring communities and environment*), Duty Officer contacts immediately the national fire-fighting services at **911 or 448 2888**, after which contacts next-in-line within the DGDC.

(b) In all other cases, the Duty Officer records the calls in the Record Log (see Appendix 7) and acts upon as necessary: provides response to enquiries, follows-up on calls to clarify the situation and provides feedback to the caller, provide daily update to the next-in-line authority (see Appendix 8). When deemed necessary, the Duty Officer might contact the next-in-line authority for additional guidance.

Note: the organogram displayed in Appendix 1 shows the reporting relationships for the normal functioning of the company, not involving disaster/emergency management.

## 3. Community awareness raising and communication

Awareness raising of the local communities and continuous communication with them related to seismic activity merit particular mention. At the time of preparing the 1st Edition of this Plan, a series of earth tremors were being experienced around the south of Dominica where the project is located. Although these earthquakes are not in any way related to the project, there is the perception among part of the population that they are. Therefore, as a response measure, there is need to educate and inform the public so as to raise their awareness and dispel this myth.

In April 2021, with the assistance of experts from UWI-SRC, DGDC installed a network comprising four seismic stations to gather baseline data on micro-seismicity around the project area. The stations are located at Laudat village, Fresh Water Lake, WW-02 compound (near the old aerial tram) and WW-R1 compound in Trafalgar.

## 4. Responsibilities of DGDC's Team Members

Each permanent and temporary (e.g. consultant) staff member within the DGDC has delegated authority with regards to disaster preparedness, mitigation and risk management.

***Management*** has overall responsibility to produce, make available and update this DREM Plan and to ensure that staff at all levels are familiar with its contents and have clear understanding of their own responsibilities under the Plan. They must provide staff with the necessary training in disaster risk management, as appropriate.

The line of authority within the DGDC in the context of disaster risk management during the preconstruction phase is as follows:

> The Managing Director has overall responsibility. He maintains contact with the general public and news media on matters pertaining to emergencies, working in collaboration with the Project Support Engineer-Electrical, who serves as Health & Safety and Emergency Response Coordinator, on matters of disaster risk management. The two are assisted by the Project Support Engineer-Mechanical, the Community Liaison Officer and the Site and Office Attendant. This arrangement will likely be modified at the start of the construction phase of the project, and then again for the operation phase.

***Staff members*** must familiarize themselves with the instructions and procedures outlined in the Plan. They must also perform the specific roles and responsibilities assigned to each of them under the Plan, including the participation in training exercises required under the Plan. The following roles apply to the pre-construction, construction and O&M phases of the project. They will be revised in due course and amended, as necessary.

- Duty Officer – receives calls from the public on the emergency phone number and provides adequate response. He/she keeps a note of the nature of each call and submits these notes to his/her supervisor at the end of his/her rostered cycle. Appendix 2 provides an overview of the Duty Officer on-call roster for the current period of the pre-construction phase. The roster will be extended to the end of the said phase, at which time it will be reviewed and amended as necessary.
- Media contact person – is the only one authorized to give information on the business of DGDC and the emergency situation or disaster risk to the media and the public. The media contact person must liaise with project team leaders to verify facts and should first seek clearance for his/her supervisor before releasing any item of information for public consumption. For the time being Ms Lyn John-Fontenelle, Safeguards and Administrative Manager is performing this role.
- Site Attendant – has a critical role to play in the early detection of any potential direct threats to the site. He/she must inform the Duty Officer immediately of any such threat. Mr Garry Shillingford is currently employed in this position.
- Contractors have an obligation to conform to the general requirements of the Plan and be conversant of its contents, specifically as relates to the responsibilities set out in their contracts. More specific roles and responsibilities of each contractor will be discussed and contractually agreed in due time, i.e. during the construction and operation phases.

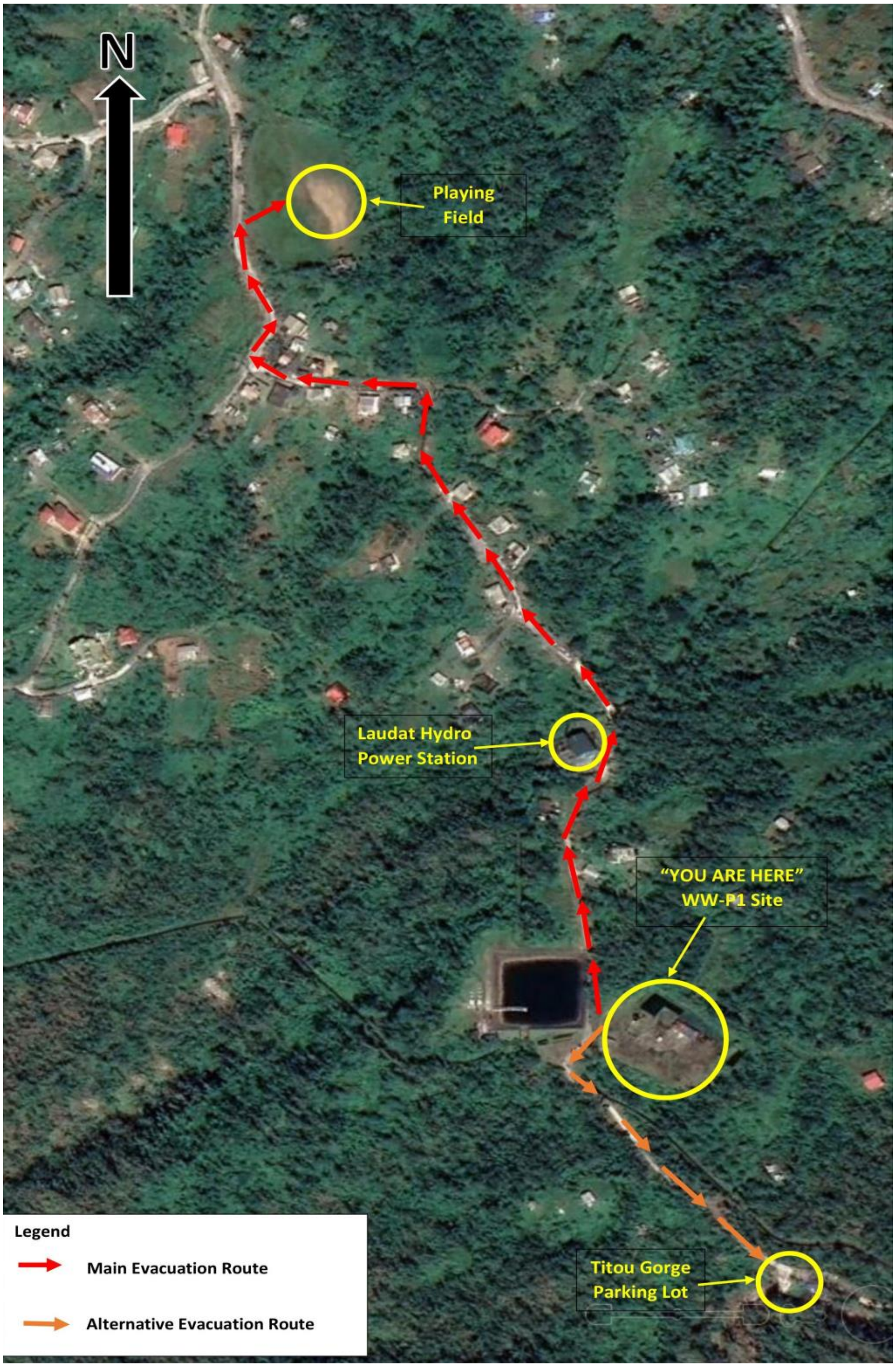
## 5. Evacuation and Assembly Points

The Plan indicates the designated ***main and alternative areas*** as assembly points. These assembly points might change from phase to phase and therefore, the current version of the Plan indicates the main and alternative assembly points for the DGDC's staff and contractors during the pre-construction phase only.

During the pre-construction phase of the project, the designated **main** assembly point (safe briefing area) for the DGDC team including staff, consultants, contractors, suppliers and other visitors to the Roseau Valley generation facilities, in case of an emergency is the **Village Playing Field at Laudat**. If in the event of a major gas release, the main assembly point happens to be downwind of the facilities, an **alternate** assembly point – the parking lot at the Titou Gorge/ Aerial Tram junction, which is in the opposite direction from the worksite, should be used instead. The alternate assembly point should only be used when specifically instructed to do so by the DGDC management.

Both main and alternative areas are public spaces and therefore, there are no ownership issues to address. Figure 3 provides geolocation of the main and alternative evacuation points.

**Figure 3: Main and Alternative Evacuation Points**



At the transition of each phase of the project the assembly points will be re-evaluated and, if necessary, revised as appropriate. The designation of assembly points for the construction and operational phases will be stated in subsequent revisions of this Plan.

A wind sock is to be installed in a prominent position at each of the principal sites of the generation facility to enable those present to have visible indication of the wind direction during an evacuation. During the pre-construction phase only one wind sock is required (at WW-P1). However, for the other two phases wind socks must be prominently installed at the power plant site and at each well location.

A flow diagram showing the evacuation procedure as well as the main and alternate assembly points shall be prominently displayed at all sites along with the emergency number.

When directed to leave the premises, personnel must move quickly but do not run; exit the compound in an orderly manner taking only personal belongings which are handy in work areas but must not go to other parts of the premises to collect them; proceed to the main assembly point (or alternate) as instructed.

## 6. Training and Regular Drills

All DGDC staff at the facility and staff of contractors carrying out work on behalf of DGDC shall be trained on the emergency response measures set out in this Plan. The training requirements are as follows:

- Basic first aid and CPR certification
- Training in emergency management
- The use of personal protective equipment, including self-contained breathing apparatus (SCBA)
- The proper use of fire extinguishers
- Emergency Response simulation exercises
- Technical diagnosis in emergency situation to assess accurately the failure and to prepare the right response

In order to ensure that staff are familiar with the evacuation procedures outlined in the Plan, regular training and drills will be conducted, at least every six months in accordance with the approved schedule shown in Table 5.

**Table 5: Programme of Training for DGDC Staff**

| Training | Date Last Performed | Next Scheduled Date | Person Responsible | Repeat Frequency |
|---|---|---|---|---|
| Basic First Aid | 1-Feb-2021 | February 2023 | Rawlins Bruney | Every two years |
| CPR | 2-Feb-2021 | February 2022 | Rawlins Bruney | Annually |
| Crisis Management | N/A | N/A | Rawlins Bruney | (needs driven) |
| Use of Self-contained Breathing Apparatus (SCBA) | 27-May-2019 | March 2022 | Rawlins Bruney | Every six months |
| Operation of fire extinguishers | N/A | 26-Jan-2022 | Rawlins Bruney | Annually |
| Emergency Response drill | 11-Jul-2019 | TBD | Rawlins Bruney | Every six months |
| Disaster Risk Management | 9-Jul-2019 | N/A | Rawlins Bruney | (needs driven) |
| Operational Health & Safety | 16-Jul-2019 | Q1 2022 | Rawlins Bruney | Every two years or immediately after an accident involving the breaking of a rule from the content of the training. |

Both the procedure and schedule will be reviewed and modified as necessary.
In addition, the emergency procedures must be included in the induction training for all new staff of DGDC and contractors to the sites.

For the avoidance of doubt, it should be pointed out that the training and drills set out in Table 5 pertain to DGDC staff only. Contractors will be required to conduct their own training programme in accordance with their obligations under the contract, and as approved by DGDC. Generally, every contractor is expected to assist DGDC proactively to instill a strong safety culture for all site activities.

# REVIEW AND UPDATES OF THE DREM PLAN

While the DREM Plan is deemed as a living document that will be edited on a regular basis, the current prefatory version of the document is focused predominantly on setting the ***framework*** for the analysis and testing it for the pre-construction phase.

The document will be reviewed and updated on *a quarterly basis during the pre-construction and construction phases.*

During the construction phase it is intended to complement and be used in conjunction with the relevant section[2] of the *DGDC Occupational Health and Safety Manual*.

During the operational phase it is recommended to maintain annual review cycle.

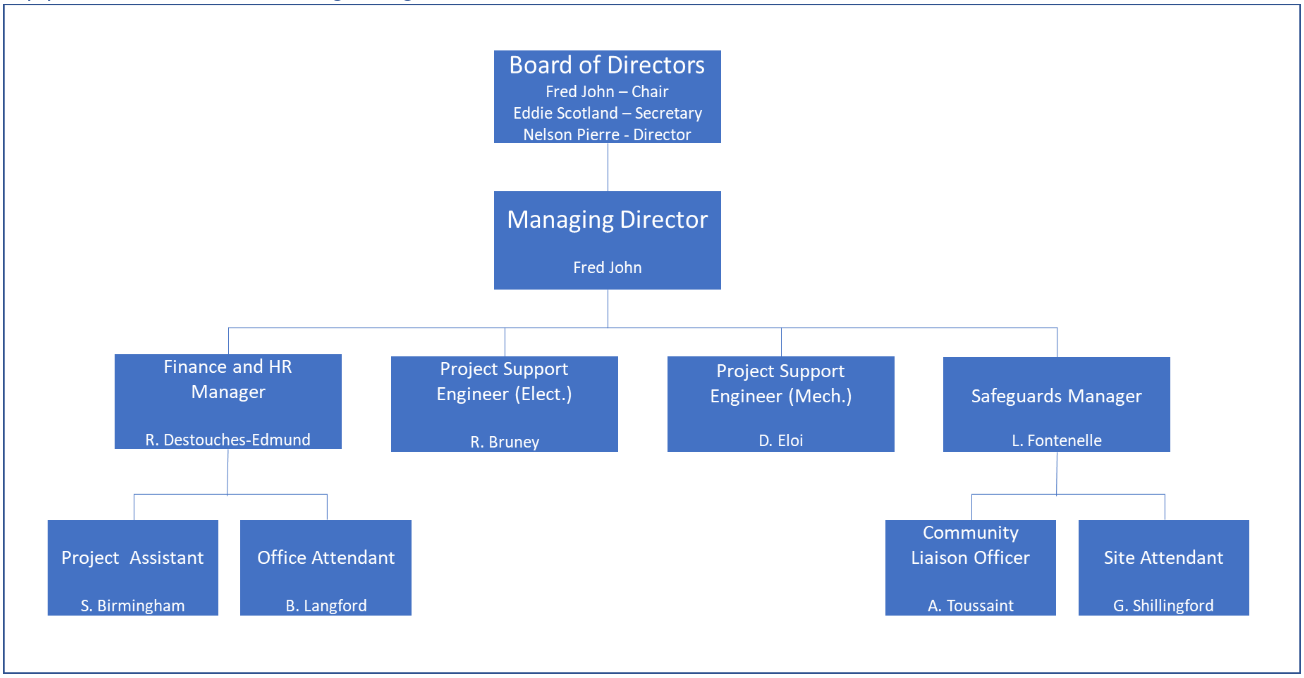
***The next review of the Plan is envisioned at the beginning of the construction Phase, in Q3 2022.***

***

[2] DGDC-OHS-038 Emergency Procedures.

# APPENDICES

## Appendix 1: DGDC's Organogram



## Appendix 2: Duty Officer on-call Roster

| December 2021 | wk48 | wk49 | wk50 | wk51 | wk52 |
|---|---|---|---|---|---|
| | 30-Nov | 07-Dec | 14-Dec | 21-Dec | 28-Dec |
| Allan | | | | | |
| Dalton | | | | | |
| Garry | | | | | |
| Lyn | | | | | |
| Rawlins | | | | | |
| Rita | | | | | |
| Shisha | | | | | |

| January 2022 | wk1 | wk2 | wk3 | wk4 |
|---|---|---|---|---|
| | 04-Jan | 11-Jan | 18-Jan | 25-Jan |
| Allan | | | | |
| Dalton | | | | |
| Garry | | | | |
| Lyn | | | | |
| Rawlins | | | | |
| Rita | | | | |
| Shisha | | | | |

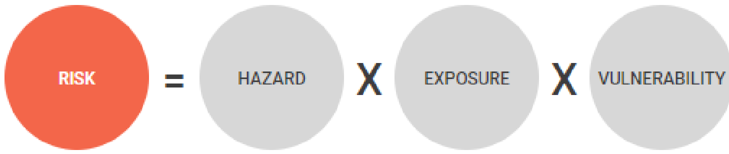
| February 2022 | wk5 | wk6 | wk7 | wk8 |
|---|---|---|---|---|
| | 01-Feb | 08-Feb | 15-Feb | 22-Feb |
| Allan | | | | |
| Dalton | | | | |
| Garry | | | | |
| Lyn | | | | |
| Rawlins | | | | |
| Rita | | | | |
| Shisha | | | | |

## Appendix 3: Contact Information for Subject Matter Experts

| | |
|---|---|
| Hurricane: | Dominica Meteorological Services<br>Senior Meteorological Officer<br>tel. 275 5461; email metoffice@cwdom.dm |
| Landslide: | Cees van Westen<br>Associate Professor<br>Natural Hazards and Risk Assessment<br>Department of Earth Systems Analysis<br>Faculty of Geo-Information Science and Earth Observation (ITC)<br>University of Twente<br>Email: c.j.vanwesten@utwente.nl<br>Tel: +31 534874263<br>Skype: cees.van.westen<br>Web: https://research.utwente.nl/en/persons/cj-van-westen |
| Earthquake: | Seismic Research Centre, UWI, Trinidad<br>tel. 868 662 4659; email uwiseismic@uwiseismic.com |
| Volcano: | Seismic Research Centre, UWI, Trinidad<br>tel. 868 662 4659; email uwiseismic@uwiseismic.com |
| Flood: | Office of Disaster Management<br>tel. 448 7777; email odm@dominica.gov.dm |

## Appendix 4: Understanding Disaster Risk

Disaster risk is a function of three interlinked components: hazard, exposure, and vulnerability as demonstrated in the exhibit below:




**Definitions used from UNDRR Terminology guide:**
https://www.unisdr.org/we/inform/terminology#letter-r

***Hazard*** is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.

***Exposure*** is the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

***Vulnerability*** is the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

The Plan is focused only on the risks posed by natural hazards to the geothermal power plant site. The secondary data analysis and consultations with subject matter experts suggest that the historical hazard profile of Dominica includes ***landslide***, ***hurricane***, ***flood***, ***volcanic eruption*** and ***earthquake***. Therefore, the hazard analysis for the geothermal power plant site is concerned with these five natural hazards. For the hazard analysis, the scale of ***highly likely, moderate, low, unlikely*** probability is used.

The exposure and vulnerability analyses are combined in this Plan.

(a) The *exposure analysis* is referred to the assets of the geothermal power plant and the people exposed to the hazard. The exposure analysis is divided into three parts: during the ***pre-construction phase***, during the ***construction phase***, and during the ***operation phase o***f the geothermal power plant.

(b) The *vulnerability analysis* instead is focused on the principal components of the geothermal power generation premises, namely the ***production wellpad (WW-P1)***,

***the power plant site,*** and ***three reinjection wells (WW-01, WW-R1, and WW-03)*** as well as the pipelines and other equipment that connect each of them. Wellpad WW-02, though not part of the generation facilities, is included in this Plan because it belongs to DGDC and as such it is the company's responsibility to maintain it in a safe condition.

The analysis of exposure, vulnerabilities, and eventually, the risk assessment is proposed to carry out for each phase: ***pre-construction phase, construction phase, and operation phase.*** This is explained by the fact that during each of these phases the exposure and vulnerability to the identified natural hazards is different. Hence, during the pre-construction phase, both the exposure and the vulnerabilities to all five hazards are minimal because only few assets are available on the geothermal power plant location. Understandably, during the construction phase the work will be initiated to build the power plant and more people and increasingly more valuable assets will be expected on the site. This will be addressed during the review of the Plan to reflect on the changes in the exposure and vulnerabilities during the construction phase. Similarly, during the operation phase another review of the Plan will be required and new update on the exposure and vulnerability analyses must take place.

The *disaster risk assessment* for the geothermal power plant is concerned with the ***likelihood*** of an event, i.e. a serious disruption of the functioning of the geothermal power plant caused by natural hazards, and the human, material, economic and environmental ***impact*** this event might have. The plausible set of events combined with their consequences is called ***scenario***. In developing scenarios, it is important to consider scenarios that are plausible or possible.

In developing a scenario, it is important to understand (a) the context, (b) the causes or triggers, (c) the event itself, (d) primary consequences, (e) secondary consequences. The proposed approach is concerned with the ***incident scenarios***: a scenario that evolves in a relative short period of time and with a clear major event which has direct negative consequences. An incident scenario can be described by a series of causes and hazards that precede a major event which has direct negative consequences.

For the phase of the geothermal power plant, the decision is made to measure impact across the following three criteria:

- Human life and health
- Economic value and the environment
- Society's functioning

### Table 6.1: Classification of likelihood

| High | Medium | Low |
|---|---|---|
| **Frequency** | | |
| 1 per less than 10 years | 1 per 10 to 100 years | 1 per 100 to 1000 years |

***** This guideline uses Annual Exceedance Probability (AEP), or the chance of the event occurring once in a year.

### Table 6.2: Impact criteria and indicators

| Impact Criteria | Indicators |
|---|---|
| Human life and health | 1.1 Number of fatalities (0 – 1 - or more than 1) |
| | 1.2 Number of severely injured/ill (0 – 1 - or more than 1) |
| | 1.3 Number of people who need to be evacuated (0 – 5 - or more than 5) |
| Economy and the environment | 2.1 Total economic impacts (0 – 1% - more than 1% of the annual budget of DGDC) |
| | a. impacts for nature and environment (no additional resources required for recovery from damage – major resources are required for recovery – pre-emergency condition has been lost but some degree of restoration is possible) |
| Society's functionality | a. Disruptions to everyday life (0 –up to 24 hours disruption – above 48 hours disruption) |
| | 3.2 Loss to cultural heritage (no damage to MTPNP* - minor damage to MTPNP – partial loss beyond recovery) |

*Morne Trois Pitons National Park

Important to note that the disaster risk evolves spatially and temporally in response to changes in one or more of its three components (hazard, exposure, and vulnerabilities), and to the inherent interactions between them— i.e., changes in one factor can influence the other factors.

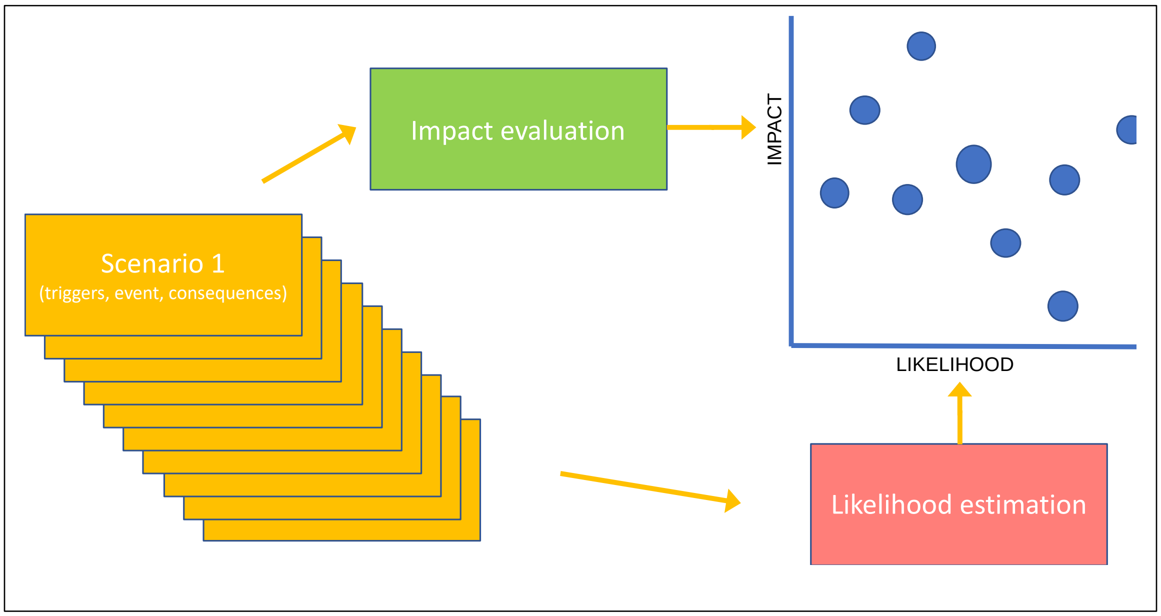
Possible scenarios for the geothermal power plans are identified using the following methods: historical data, literature review and modeling, expert knowledge.

The scenarios of various disruptive events could be addressed, however, the team working on this Plan has chosen to address the ***worst-case scenario***, i.e. *the most severe possible outcome that can reasonably be projected to occur in a given situation – all parameters are in worst position*.

To guide the disaster risk reduction, preparedness and disaster mitigation activities for the geothermal power plant, the expected impact in the worst-case scenario is described in detail. The risk then rated as ***HIGH/ damage to property and people (deep red), MODERATE/ damage to properties and human injuries (yellow), and LOW/ minor or no impact to assets and people (green).***

Disaster risks can be presented in the risk diagram as presented in the Figure 4.

**Figure 4: Process of developing disaster risk diagram**




***Mitigation***: The lessening or minimizing of the adverse impacts of a hazardous event.

***Preparedness***: he knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters.

Based on the results of the assessment, recommendations will be made regarding measures that must be taken in order to prevent or to mitigate the expected impacts. The focus of the prevention work will be on addressing exposure and vulnerabilities. The focus of mitigation work will be on addressing preparedness to respond and recover from a disastrous event.

***Critical infrastructure:*** The physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society.

***Disaster risk reduction*** is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development.

## Appendix 5: Approach to Scenario Development

### Scenario Analysis

The worst-case scenario situations that are possible for each natural hazard, as indicated by subject matter experts, are examined for each of the five areas of the geothermal power generation facility. The highest hazard probability – as indicated by the experts – is used. This exercise is conducted with initial focus on the pre-construction phase. The construction and operation phases will be considered in subsequent updates of this Plan.

### Likelihood and Impact

For the agreed worst-case scenario the likelihood is rated as ***low (1), moderate (2), and high (3)***. Also, the level of impact expected from such an event (or a combination of events), is rated similarly as ***low (1), moderate (2), and high (3)***, based on three dimensions of impact:

- Human life and health: (a) number of fatalities, (b) number of severely injured, (c) number of people who need to be evacuated.
- Economy and the environment: (a) *Total economic impacts* and (b) *impacts for nature and environment.*
- (disruption of) Society's functionality / *this one is not yet relevant during the pre-construction phase.*

### Risk Level Scores and Color Coding

The total risk level, which is the function of likelihood and impact [Risk level = Likelihood x Impact], is determined and recorded in accordance with the following scale and as illustrated by the matrix in Figure 5 below:

Low (green): scores 1-3
Moderate (yellow): scores 4-6
High (red): score 9

| *Impact* | | | |
|---|---|---|---|
| High | 3 | 6 | 9 |
| Medium | 2 | 4 | 6 |
| Low | 1 | 2 | 3 |
| | Low | Medium | High |
| | | | *Likelihood* |

**Figure 5. Risk Colour Matrix**

The results of the scenario analysis for the pre-construction phase are presented as the Framework for the DREM Plan on Table 2, in which there is a brief description of each scenario.

## Appendix 6: Rationale for DREM Plan

The resilience pathway of the Caribbean region outlined in the CARICOM's *Strategic Plan for the Caribbean Community 2015-2019: Positioning CARICOM* [3] implies building region's resilience to natural and technological hazards and thereby "*to reduce vulnerability to disaster risk and the effects of climate change and ensure effective management of the natural resources across Member States*".[4] However, for Dominica building disaster resilience is of utmost priority. Building disaster resilience and more specifically, climate resilience in Dominica is an existential question conditioning the future well-being and prosperity of the Nature Island.

Located within hurricane belt, this mountainous Caribbean island has suffered devastating consequences of several hurricanes in the past. The recent one, the hurricane Maria (Category 5+)[5] was the worse in the history of Caribbean hurricanes, while Dominica was the most affected country in the region. It hit the country on 28 September 2017.

The findings of the Post-Disaster Needs Assessment (PDNA) of hurricane Maria issued by the Government of Dominica and implemented by the WB in conjunction with the UN, ECCB, and CDB, and the EU revealed the scale of its devastating impact. Hence, the estimated damages reached $931million and losses $382million, with total recovery needs of almost $1.3billion, which amounts to 226% of its 2016 gross domestic product (GDP).[6]

As a volcano island, Dominica remains prone to volcanic eruptions – while all other Lesser Antilles islands have only one active volcano, Dominica has nine[7] and is considered '…*the most worrying of all the Caribbean volcanic areas*….' [8] – and continuous frequent seismic swarms and vigorous widespread geothermal activities. As a volcano island covered by rainforest, Dominica is also prone to large number of landslides and floods. A large-scale landslide inventory/study carried out by the University of Twente after hurricane Maria (also available at UNITAR UNOSAT), shows that the hurricane Maria has triggered in total of 9,960 landslides, which include 8,576 debris slides, 1,010 debris flows and 374 rock falls.[9] The hurricane was paired by heavy rain as a result of which almost all rivers flooded due to intensive precipitation.

[3] Strategic Plan for the Caribbean Community 2015-2019: Positioning CARICOM: https://caricom.org/STRATEGIC%20PLAN%202016_opt.pdf

[4] Ibid.

[5] To be classified as a hurricane, according to the Saffir–Simpson hurricane wind scale, a tropical cyclone must have one-minute maximum sustained winds of at least 74 mph (33 m/s; 64 kn; 119 km/h) (Category 1). The highest classification in the scale, Category 5, consists of storms with sustained winds exceeding 156 mph (70 m/s; 136 kn; 251 km/h). However, it is noticed that the sustained winds increasingly exceed the margins set in the Saffir-Simpson scale. The hurricane Maria in 2017 was classified as 5+.

[6] Post Disaster Needs Assessment Hurricane Maria, A Report of the Government of the Commonwealth of Dominica, September 2017

[7] http://caribbeanvolcanoes.com/dominica-geology/

[8] Ibid.

[9] https://www.unitar.org/unosat/maps/114

Dominica remains highly exposed to various disaster risks that are further exacerbated by changing climate. In the meantime, after the hurricane Maria, Dominica is left with sky-high recovery needs, heightened recognition of the importance of disaster management and resilience building, and a major commitment to build the first climate resilient nation in the world. For the purpose of the latter, the Government of the Commonwealth of Dominica together with its development partners created and launched the Climate Resilience Agency of Dominica (CREAD)[10] in 2018.

Contributing towards increased disaster resilience of the country and building upon its safety and security priorities, the management of the DGDC aims to ensure disaster resilience of the key critical infrastructure in the country, i.e. the first geothermal power plant of Dominica.

The ***Disaster Risk and Emergency Management Plan*** for DGDC has been developed with due consideration of natural hazards. The Plan will be supplemented with the Emergency Management procedure to be activated and comply in case of *force majeure* situation.

[10] http://news.gov.dm/index.php/news/4546-climate-resilience-execution-agency-of-dominica-launched

## Appendix 7: Emergency Call Register

To be documented and reported by the Duty Officer for emergency calls received during his/her rostered time on shift

REPORTED BY:________

DATE OF REPORT: __________

POSITION: _______

TIME OF REPORT: __________

DATE OF CALL: __________

INCIDENT TYPE: ___________

TIME OF CALL: __________

LOCATION: ____________

INCIDENT DESCRIPTION: ________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

NUMBER OF PEOPLE INJURED (M/F): _____________

CONTACTS OF THE CALLER: _____________

DAMAGE TO INFRASTRUCTURE:____________

DAMAGE TO ENVIRONMENT: ______________

DAMAGE TO COMMUNITIES: ______________

ACTIONS TAKEN BY DUTY OFFICER:
___________________________________________________________________________________

OTHER RELEVANT INFORMATION:
______________________________________

# Appendix 8: Scientific References

## Evaluation of landslide susceptibility for geothermal project area

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### Introduction

The Dominica Geothermal Development Company (DGDC) (www.geodominica.dm ) is a wholly-owned company of the government of Dominica with the mandate to construct the first geothermal power generating station on the island of Dominica in the eastern Caribbean. The project, funded by the World Bank and EU/AFD among others, is currently at the stage in which financing agreements have been signed and the tender documents are about to be advertised for the invitation of bids for the award of an Engineer, Procure and Construct (EPC) contract to build a 7 megawatt plant, along with its associated steam field and reinjection pipeline.

At this moment the DGDC is working on the development of a Disaster Preparedness, Mitigation and Risk Management Plan, focusing on natural hazards that are likely to impact the proposed power plant during three phases of development, viz: pre-construction, construction and operation & maintenance. As part of this exercise DGDC is looking to hold discussions with subject matter experts related to each of the hazards identified. ITC has been involved in the World Bank CHARIM project (www.charim.net ) and has carried out investigation on landslides in Dominica.

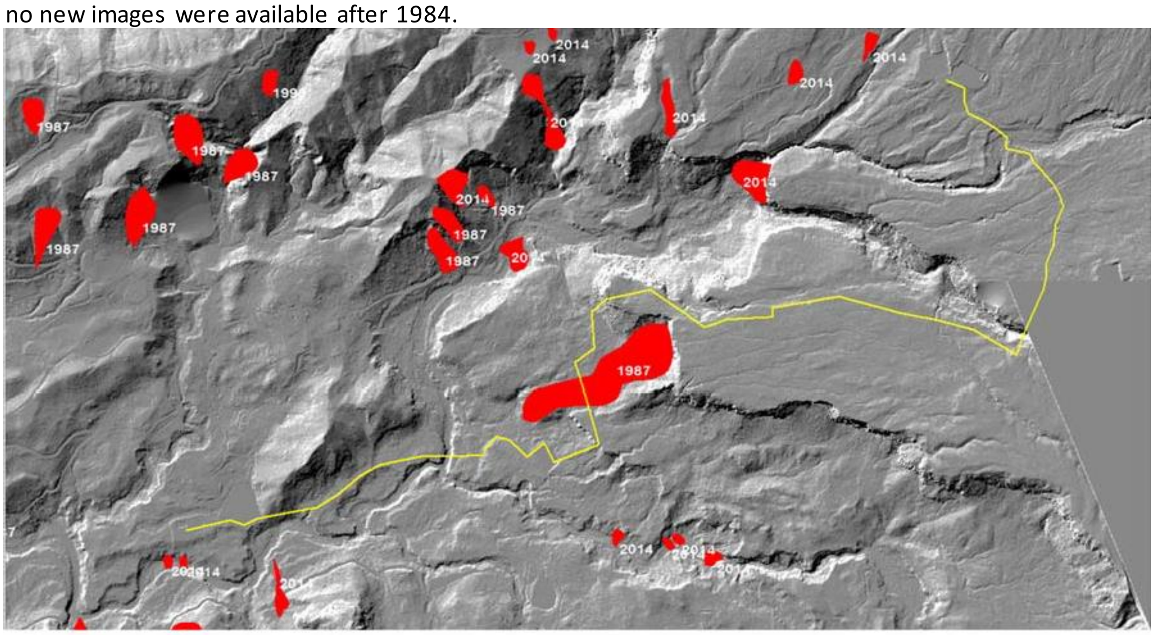
This document is aimed to support the discussion on the exposure of the plant to landslides, so as to help DGDC to determine the level of risk that exists. Figure 1 indicates the location of the project.


*Figure 1: Location of the proposed geothermal project*

## Historical landslides

We have evaluated the occurrence of historical landslides in the area that might be of influence to the project. This is based on our previous work. The landslide report for Dominica can be downloaded here:
http://www.charim.net/sites/default/files/handbook/maps/DOMINICA/Landslide_susceptbility_report_Dominica.pdf

The first map on which landslides related to a triggering event are indicated is from a study related to the impact of Hurricane David in 1979. This very devastating hurricane could be seen as the worst case scenario for Dominica, given the reported casualties and damage. However, the map doesn't indicate actual landslide location, but merely the stretches of road that have to be repaired because of landslides. A full overview of the landslides caused by this category 4 event (which is considered to have a return period around 125 years) is not known. Walsh (1982) reported that small rotational failures triggered by Hurricanes David and Frederic were only noted on cultivated slopes. The baseline study for landslides in Dominica is the work carried out by Jerome DeGraff from the US Forest Service for the OAS in 1987. He carried out detailed image interpretation of landslides using detailed stereoscopic image interpretation of 1:20,000 scale black and white aerial photographs, which were taken in 1984, so five years after the occurrence of Hurricane David, which was very destructive in Dominica. DeGraff revisited the area several years later in 1990 to check the quality of the earlier landslide zonation, and he mapped the landslide that occurred in the years 1987-1990 (DeGraff, 1990). In this period two hurricanes produced significant rainfall amount (1987 Emily, 1988 Gilbert, and 1989 Hugo) and also a number of tropical storms and other rainfall events occurred. He only used field verification to map the new landslides, as no new images were available after 1984.




1987 Historical landslide with year in which it occurred
1987 and 1990 are based on two inventories made by J. deGraff based on airphoto interpretation.
2014 is an inventory made by C.J. van Westen based on high resolution satellite images.

*Figure 2: Historical landslide inventory before hurricane Maria in 2017*

As part of the CHARIM project we carried out a detailed landslide inventory that complements the earlier ones, and that portrays the current situation, incorporating also the older landslide inventories into a single new and comprehensive analysis. We obtained through the EU FP7 Copernicus project INCREO (http://www.increo-fp7.eu/) the possibility to order very high resolution satellite images (Pleiades images, with 0.5 m spatial resolution for panchromatic and 2 m multi-spectral) for Dominica. The high resolution images from 2014 covered different parts of the island, and also had sometimes serious cloud coverage which didn't allow us to map the entire island. Therefore we decided to carry out an extensive interpretation of landslides using different sets of satellite images, and also using historical imagery from Google Earth Pro.

We also carried out an evaluation of the landslides caused by Tropical Storm Erika in 2015. However, in this part of the island this event did not cause major landslides.

## Landslides during hurricane Maria

The largest triggering event that caused many landslides, debris flows and flashflood was hurricane Maria. Hurricane Maria which hit Dominica on September 18 2017, is regarded as the most destructive natural disaster that has affected Dominica in the last decades.
A large scale landslide inventory was carried out by a team from the University of Twente, use of 5 scenes of Pléiades satellite imageries with resolution of 0.5m, which were obtained in September 23 and October 5 after the hurricane, made available through UNITAR-UNOSAT. Apart from these also a series of Digital Globe Images were used that were collected for the Google Crisis Response through a KML layer. The images were visually interpreted by image interpretation experts, and landslides were mapped as polygons, separating scarp, transport and accumulation areas, and classifying the landslides in types. Unfortunately, due to cloud coverage in all available images.
Figure 3 shows the inventory of landslide and debrisflows/flashfloods for the study area. We also mapped the areas affected by flashflood and or debrisflows along the river channels by mapping unvegetated areas and accumulations of debris. From the image interpretation it was not possible to differentiate whether these were caused by flashflood, hyperconcentrated floods or debrisflows.

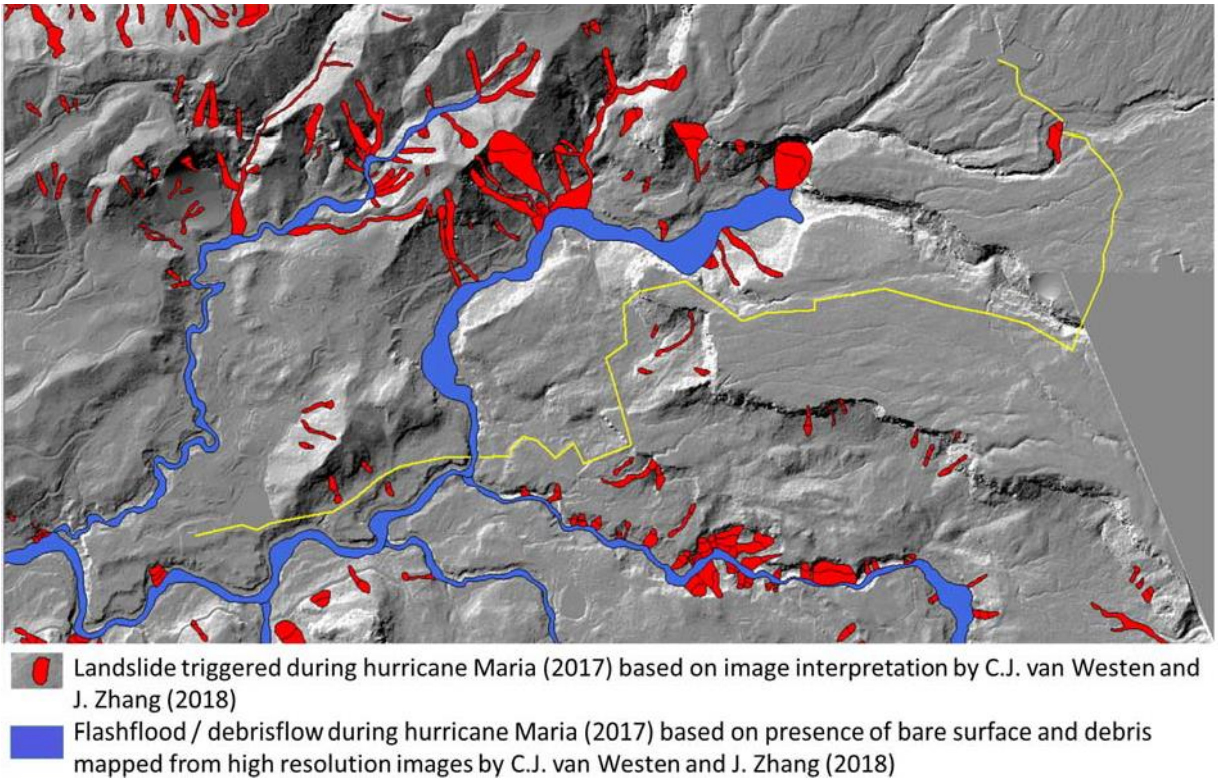



*Figure 3: Landslides and flashflood/debris flows triggered by hurricane Maria*

## Landslide susceptibility map

Based on the historical landslides and on causal factor maps , including the new LIDAR-based digital elevation model that was made available through the World Bank recently, we carried out an update of the landslide susceptibility evaluation for the project area. The evaluation was done based on the landslide susceptibility map which was produced within the CHARIM project and which can be downloaded here:
http://www.charim.net/sites/default/files/handbook/maps/DOMINICA/Dominica%20Landslide%20susceptibility%20Map.pdf
The map was updated after Tropical storm Erika. However, due to the occurrence of Hurricane Maria , the number of landslides in Dominica increased enormously. Although the landslide locations generally fitted well with the landslide susceptibility zones, it is important to generate an updated landslide susceptibility map. We are currently in a process with the World Bank to come to a new contract to update the landslide susceptibility map for Dominica. But the map is currently still not available. The availability of the high resolution Digital Elevation Model from the LIDAR data will certainly improve the quality of the landslide susceptibility map. Other factor maps, such as soil types and soil depth, and geology are currently also considered for updating.
We used the hillshading maps of the Digital Surface Model (containing also building and vegetation) and the Digital Terrain Model (bare surface model) to make an updated landslide susceptibility map for the project area. In the east part we were constrained by the absence of DTM data, as the LIDAR data is not available for the central mountainous part of Dominica, due to persistent cloud cover. We interpreted the terrain and subdivided it into four classes: historical landslides, high, moderate and low susceptibility (Table 1).

*Table 1: Mass movement susceptibility classes*

| Class | Explanation |
|---|---|
| Low | This class generally is landslide free, although under special circumstances it may be possible that a landslide might occur in this zone, but the density and frequency will be very low. |
| Moderate | This class has some probability that landslides might occur, although not very frequent and not with a high density. |
| High | This class has conditions related to slope conditions and soil materials that mass movements might be expected during future triggering events. Many of these areas experienced landslides in the past decades. |
| Historical landslide | Historical landslide / debris flow / flashflood activity. This area has experienced the impact of a mass movement before, and is therefore considered to be dangerous, unless mitigation measures are carried out. |

We have made a mass movement susceptibility map, and not a mass movement hazard map. This means that we didn't indicate the expected frequency of mass movements, nor the expected size or magnitude. This requires more detailed studies, and more detailed historical data on landslide occurrences and rainfall records, than that are now available for Dominica. However, we are also working on physically based multi-hazard modelling approach for Dominica where we can model the expected areas of instability and flooding based on given rainfall scenarios. This would be part of the upcoming World Bank funded project for updating the landslide susceptibility map for Dominica.

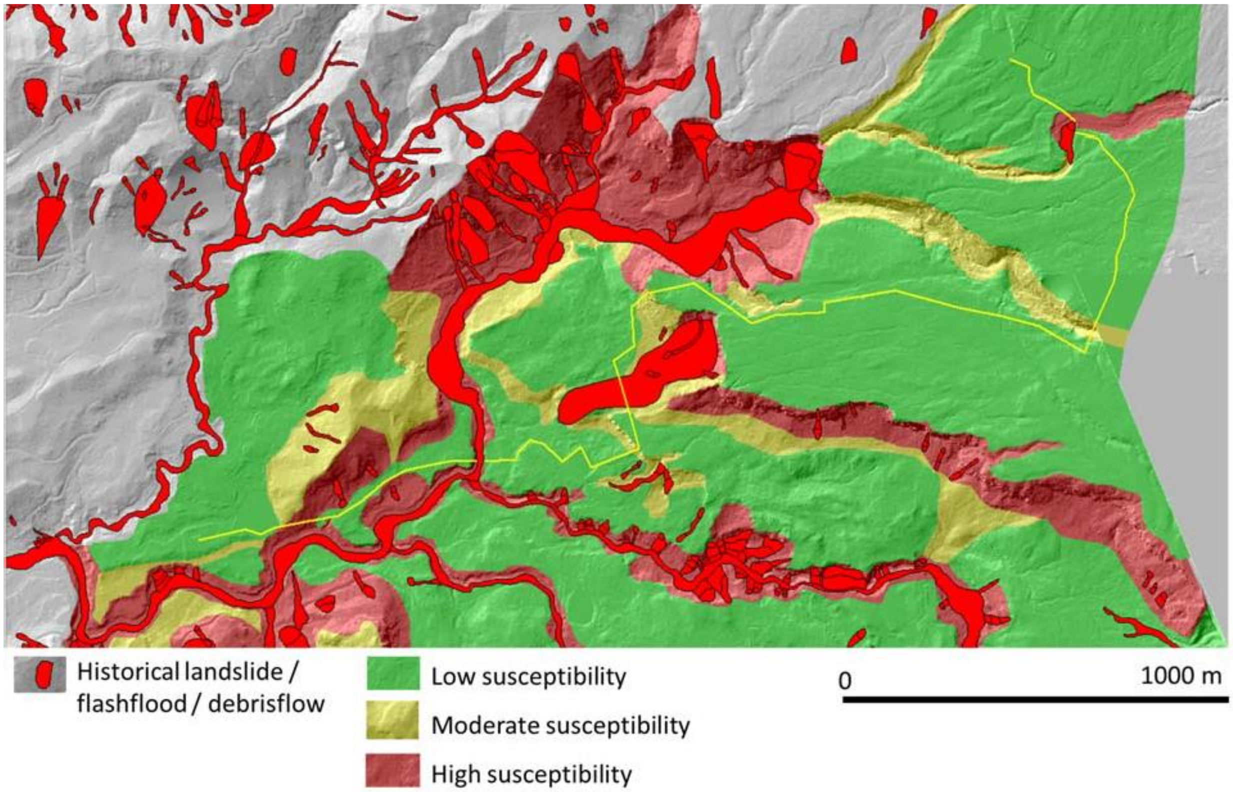



*Figure 4: Landslide and flashflood susceptibility map for the project area.*

## Areas of specific interest

Based on the landslide susceptibility assessment we have outlined a number of points where the geothermal project might be exposed to landslides. These are summarized in the table 2.

*Table 2: Area of specific threat to mass movements and floods*

| Location | Specific interest |
|---|---|
| A | Crossing of a Titou Gorge, where there was a landslide triggering by hurricane Maria. This site might experience a landslide of small size in future, and slope should be properly stabilized. |
| B | Here the pipeline crosses a major landslide that occurred most probably during hurricane David in 1979 and was mapped by DeGraff in 1987. Since then there were no major reactivations (although some minor events occurred during hurricane Maria). The location has the potential that it may be affected by another landslide in a future event. The recommendation is to deviate the pipeline a bit to avoid this area, |
| C | Crossing of a stream that had active flashflood/debris flow in hurricane Maria, and where there are many landslides in the upper section, thus carrying substantial volumes of sediments and tree debris during a flash flood event. Care should be taken to cross the channel high enough to avoid impact by future events. |

| | |
|---|---|
| D | The pipelines passes above an old landslide that was probably caused by river undercutting. The landslide could be old, and wasn't active in the period 1987 to 2018. But based on the topography it is a clear old landslides, and if reactivated might retrogressively affect the pipeline. Also minor landslide activity from the upslope part can be expected. |
| E | Pipeline crosses a section with a steep slope that is undercut by a stream, which had flashflood / debris flow activity during hurricane Maria. Further undercutting might destabilize this slope. |

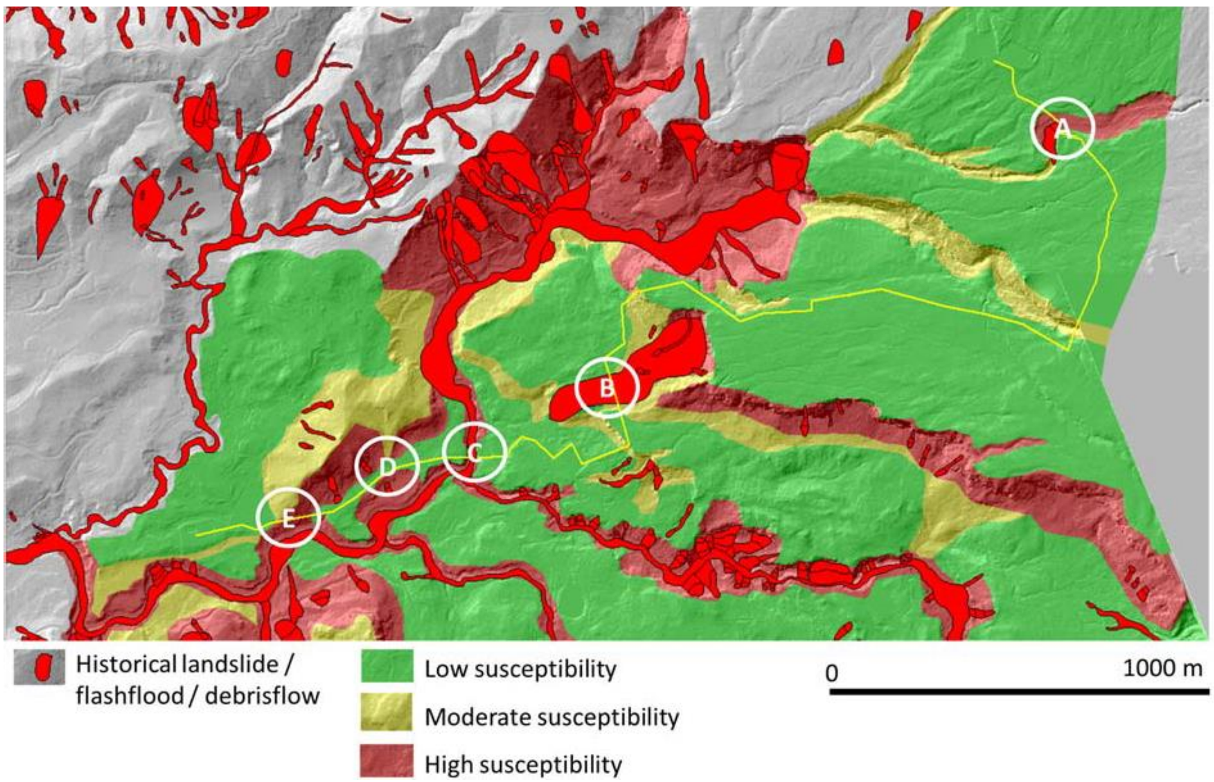



*Figure 5: Location of areas with specific attention to threats of mass movements*.

## Conclusions

Although the geothermal plant is located in a zone with low landslide susceptibility, the route of the reinjection pipeline runs through some dangerous locations with respect to landslides and flashfloods. Five locations have been identified, which may have to be further studied. Large volumes of sediments and tree trunks can be expected when a major triggering event occurs.

I agree with the statement given in the DGDC Post Hurricane Maria Report: Steeper hillside vegetation has been badly damaged which could lead to further erosion and slips (see DGDC Post Hurricane Maria Report, Figure 16). Major landslides evident which could destabilise further in time should another storm event occur. We are planning to study the recovering of vegetation in relation with instability with one of our MSc students this year.

## Considerations for volcanic and seismic hazard to geothermal plan in Dominica

**RESPONSE TO DOMINICA GEOTHERMAL DEVELOPMENT COMPANY LTD RE: EARTHQUAKE AND VOLCANIC ACTIVITY AND HAZARDS IN DOMINICA.**

### Background

The Commonwealth of Dominica is in the process of Disaster Preparedness, Mitigation and Management Plan for a proposed geothermal power generating facility in the Roseau Valley in Dominica. Given our mandate[1], the UWI-SRC was contacted by Mr Rawlins Bruney, of the Dominica Geothermal Development Company Ltd, in May 2019, requesting our assistance in this process with regard to seismic and volcanic hazards. Following several telephone conversations, email exchanges and a teleconference, it was agreed that we would provide a brief outline on existing hazard maps by Tuesday 28 May 2019. Furthermore, we indicated our intention to provide additional advice with respect to the ongoing monitoring and assessment of hazards and risks associated with the geothermal operation. This document is our assessment. Copies of some relevant papers and hazard may be found here: https://drive.google.com/open?id=1dYp1yEO2D1a5RYVYaA8Z1nWQ3U8kqgRH

### Seismic & Volcanic Activity & Hazard

The latest and most comprehensive study of volcanic activity in Dominica may be found in the Dominica chapter of the Volcanic Hazard Atlas (Lindsay 2005). Additional research has been done since then by other workers, the most significant with respect to having hazard implications are the publications of Smith et al (2013) and Howe (2014a, 2014b, 2015).

The latest assessment of earthquake hazard for Dominica is the update of the probabilistic seismic hazard maps of the Eastern Caribbean (including Dominica), which was undertaken by the UWI-SRC in collaboration with the EUCENTRE, Pavia, Italy. The results of that work were published (Bozonni et al. 2011) and copies of the maps, along with associated documents, are available on the SRC website (see http://uwiseismic.com/seishaz.aspx).

### Recommendations

1. Site-specific study

The 2011 Eastern Caribbean seismic hazard maps (Bozonni et al. 2011) use two methodologies for the calculation of the Probabilistic Seismic Hazard: the standard

Cornell- McGuire approach based on the definition of appropriate seismogenic zones, and the zone- free approach developed by Woo (1996), which overcomes the ambiguities related with the definition of seismic sources. The seismic hazard study includes an analysis of regional historical seismicity, along with an assessment of the seismic potential of known seismogenic sources. The seismic hazard maps show contours of various intensity measures of ground shaking (peak ground acceleration and spectral acceleration at 0.2 and 1.0 second) that are associated with specified probability of exceedance for periods of engineering interest. The intensity measures are calculated for rock sites using grid nodes spaced 0.025 degrees (2.8 km) apart and computations were performed for four return periods (95, 475, 975 and 2475 years). There is ongoing debate as to whether the parameters used to define maximum magnitude in the hazard analysis (tectonic constraints and maximum historical observed magnitude) are sufficiently robust, particularly for critical infrastructure. Moreover, the International Building Code (code recommended/mandated by the civil authorities in Dominica) has revised the seismic coefficient for the design of critical infrastructure to cater for ground motions of return period of 5000 years

Based on these considerations and in light of the potential critical nature of the geothermal plant, in the context of Dominica, we recommend that a site specific study of the area be done. Such a study will produce important subsurface geological detail that play a key role in seismic motion at the surface. This insight, within the constraints of current understanding, should lead to a more appropriate earthquake resistant engineering design.

2. Ongoing monitoring

Earthquake activity, or seismicity, is generally caused by displacement along active faults in tectonically active zones (Kagel et al, 2007). An earthquake occurs when a rock mass ruptures and radiates seismic waves that produce ground vibration (i.e. shaking of the ground). Although it is generally a natural process, seismicity may be induced by human activity, including the development of geothermal fields. Small earthquakes often occur during the development of hydrocarbon and geothermal reservoirs, particularly when fluid, under pressure, is injected into a borehole, in what are variously called stimulations, hydraulic injections, hydro fracturing and, colloquially, “fracking” (Stewart, 2013). In these cases, the resulting seismicity is usually low-magnitude events, known as “micro- earthquakes”. Humans do not generally feel such earthquakes, which are of magnitudes less than 2 or 3. They are centred on the injection site and are not considered to be a hazard to the geothermal power plants, or the surrounding communities. Most would go unnoticed unless sensitive seismometers are located nearby. However, there was one well-known example of earthquakes of magnitude >3.0 induced during such geothermal exploitation in Basel, Switzerland (Bachmann et al. 2011).

A significant level of seismicity may be induced by geothermal plant operation due to perturbations in the effective stress caused by fluid injection and contraction of the geothermal reservoir (Fialko and Simons, 2000). Because geothermal operations are usually conducted in areas that are also tectonically active, it is often difficult to distinguish between geothermal-induced and naturally occurring events (Kagel et al., 2007). Given the potential for altering the seismic signature during geothermal development, it is important to carefully monitor seismic activity throughout the exercise. Induced microseismicity is often monitored using a microseismic network that is used as a tool to track the movement of the injection fluid and to determine the extent of the reservoir. The microseismicity data can, in conjunction with other data, be useful for identifying additional drilling targets within the reservoir (e.g. Richards et al, 1994; Rothert and Shapiro, 2003; Maxwell et al, 2010; Simiyu, 2011; Fang et al. 2018).

Based on the issues outlined above we propose that serious consideration be given to the establishment of a mechanism to effectively monitor the seismic activity in and around the planned geothermal facility. The SRC has presented a proposal in the past, to the Geothermal Project Management Unit, to undertake this work and can easily update and resubmit, if there is an expressed interest in pursuing this matter by the Company.

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The UWI Seismic Research Centre (UWI-SRC) is the regional institution responsible for surveillance of and fundamental research into volcanoes and earthquakes for the English-speaking territories of the Eastern Caribbean