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Ministry of Infrastructure, Port Services and Transport

Hurricane Tomas Emergency Recovery Project

Hydraulic assessment for flood risk assessment in Soufrière, Fond St Jacques and Dennery

Report # 3: River and Drainage options report

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Acronyms and abbreviations

DRM	Disaster Risk Management
GOSL	Government Of Saint Lucia
PCU - MF	Project Coordination Unit – Ministry of Finance
MIPS&T	Ministry of Infrastructure, Port Services and Transportation
NRDU	National Reconstruction and Development Unit
IPCC	Intergovernmental Panel on Climate Change

Chapter 1. Introduction

1.1 Context and objectives of this report

The vulnerability of Saint Lucia's population and economy, to natural disasters related to water phenomena has become an important national issue.

In October 2010, the Hurricane Tomas impacted Saint Lucia. An important rainfall, in quantity (533 mm) and duration (24 hours), accompanied this hurricane. Due to Saint Lucia's topography and land occupation, numerous flooding and landslide were deplored. To support the Saint Lucia's recovery and reconstruction effort the government of the island received a Credit from the World Bank.

The extreme rainfall associated to the Hurricane Tomas also altered the river-courses and accumulated sediment in the channels due to significant number of landslides and important run-off. Theses sediments now increase the flooding risk, in particular on specific risk areas: the watershed communities of Dennery, Soufriere and Fond St-Jacques.

The objectives of the assignments are to provide the implementation of flood management measures in 3 watershed areas (of the Dennery, Soufriere and Fond St-Jacques communities):

- Carry out flood risk assessment
- Identify and quantify appropriate cost effective remedial measures to reduce flood hazard.

The project is divided in 6 phases:

- Phase 1 : Site characterization, flood hazard and vulnerability analysis
- Phase 2 : Drainage designs standards and flood risk mapping
- Phase 3 : River and drainage and mitigation measures
- Phase 4 : Preliminary designs
- Phase 5 : flood mitigation measures
- Phase 6 : Flood risk design and flood management training

This report describes the phase 3 analysis. It contains for each community:

- The identification and comparison of feasible options for river and drainage rehabilitation works.
- The map and identification of existing critical infrastructure necessary to be rehabilitated or reconstructed, and vulnerable infrastructures that should be protected and strengthened.
- Costing and prioritizing of various types of mitigation measures (works and non structural measures).

Figure 1 : Location Map : Dennery, Fond Saint Jacques and Soufrière

1.2 Principles of flash flood risk management

Saint Lucia and especially the three communities studied in this assessment are vulnerable for flash floods, caused by heavy rainfalls and/or landslides.

Flash flood risk management can include structural and non-structural measures. A common strategy to cope with floods has been to construct civil works such as floodwalls, transversal protection works, embankments, conduits, and reservoirs to protect the environment up to an acceptable risk threshold.

Structural measures tend to consider mainly the hydrological and hydraulic implications of flooding, which are generally solved by choosing the alternative that maximises the expected net benefit. In addition, such measures can have a substantial impact on the riverine environment and ecology. Furthermore, while structural solutions contribute to flood reduction and protection, they also have hidden 'piggy-back' liabilities associated with them, such as the issue of their long-term value, the false sense of security they may provide, their possible environmental impact, and costs related to their operation and maintenance.

In contrast, **non-structural measures** offer a variety of possibilities, ranging from land use planning and construction and structure management codes, through soil management and acquisition policies, insurance, and perception and awareness, to public information actions, emergency systems, and post catastrophe recovery, all of which contribute towards the mitigation of flood-related problems. The advantage of non-structural measures is that, generally, they are sustainable and less expensive. Non-structural measures are often the most effective in managing flash floods. However, they can only be efficient with the participation of a responsive population and an organized institutional network.

A combination of structural and non-structural measures can be the best. This report is giving both types of measures for each of the three studied communities.

Chapter 2. Structural measures

2.1 Dimensioning data

In this chapter, all data are taken from **report #1 and #2**, especially:

- Topographical survey
- Hydrological analysis and flow calculations for 1 in 10, 50, 100 years flood event and Tomas event
- Hydraulic actual conditions (velocity and heights of water for 1 in 10, 50, 100 years flood event and Tomas event

FOCUS ON CLIMATE CHANGE RAIN CONDITIONS:

Climate change scenarios have been studied by IPCC (Intergovernmental Panel on Climate Change). The Fifth Assessment Report provides a clear and up to date view of the current state of scientific knowledge relevant to climate change.

Figure 2 : IPCC fifth report

This report is a large scale study (world scale). It concludes to the raise of temperature, the raise of sea levels, the raise of number of extreme rainfall events.

The next figure shows that for all the scenarios studies by IPCC, average precipitation is going to decrease in the West Indies. But there is no projection for rain intensity or duration.

Projected precipitation and temperature changes imply possible changes in floods, although overall there is *low confidence in projections of changes in fluvial floods*. Confidence is low due to limited evidence and because the causes of regional changes are complex.

There is *medium confidence* (based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions.

There is no data focuses in Saint Lucia or the West Indies.

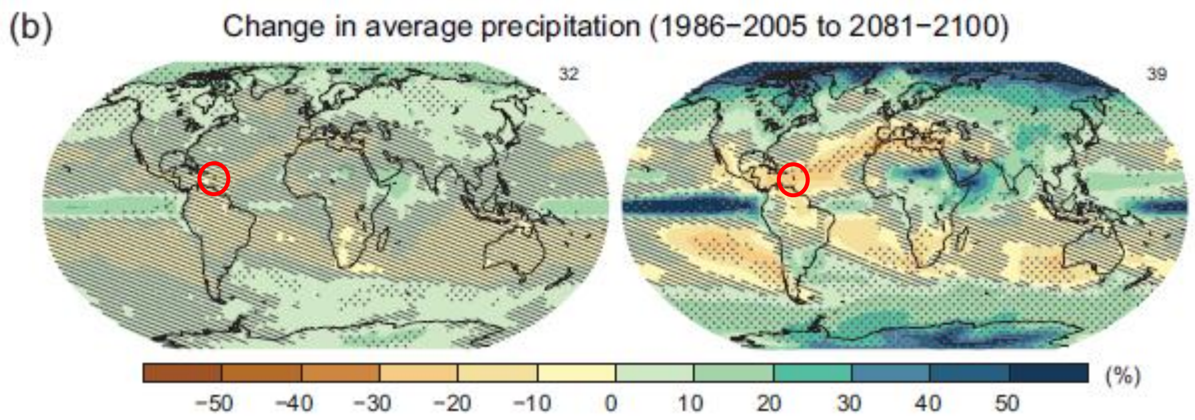


Figure 3 : IPCC conclusion for average precipitation – Red circle on the West Indies

Figure 4 : Existing local reports on climate change

According to Saint Lucia Hires Report **GCM Projections of Future Climate suggest:**

1. Temperature

- • The mean annual temperature is projected to increase by 0.5 to 2.1°C by the 2060s, and 1.0 to 3.6 degrees by the 2090s. The range of projections by the 2090s under any one emissions scenario is around 1- 2°C. The projected rate of warming is similar throughout the year, but a little more rapid in the colder seasons DJF and SON.
- All projections indicate substantial increases in the frequency of days and nights that are considered ‘hot’ in current climate.
- Annually, projections indicate that ‘hot’ days will occur on 28- 67% of days by the 2060s, and 37- 100% of days by the 2090s.
- Nights that are considered ‘hot’ for the annual climate of 1970- 99 are projected to occur on 28- 68% of nights by the 2060s and 37- 99% of nights by the 2090s. Nights that are hot for each season are projected to increase most rapidly in SON, occurring on 79- 100% of nights in every season by the 2090s.
- All projections indicate decreases in the frequency of days and nights that are considered ‘cold’ in current climate. These events do not occur at all by the 2060s in projections from most of the models.

2. Precipitation

- Projections of mean annual rainfall from different models in the ensemble are broadly consistent in indicating decreases in rainfall for Saint Lucia. Ensemble median values for all seasons are negative. Annual projections vary between -56% and +15% by the 2090s with ensemble median values of -10 to -22%.
- The proportion of total rainfall that falls in heavy events decreases in most model projections, changing by -26% to +6% by the 2090s.
- Maximum 1- and 5-day rainfalls tend to decrease in model projections, with 5-day maxima changing by -31 to +13mm by the 2090s.

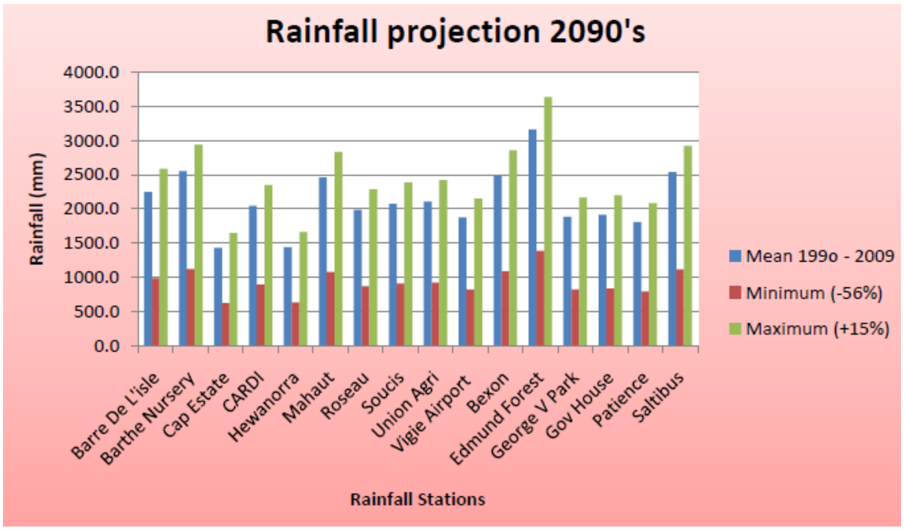


Figure 5 : rainfall projection in 2090’s in Saint Lucia

The climate projections suggest the following about the current and future climate of St. Lucia [CSG Climate Change Projections, 2009]:

- There is evidence to suggest that the climate of St. Lucia is changing.
- Minimum temperatures have increased at a rate of ~0.16° C per decade, and maximum temperatures at ~0.20° C per decade.
- There is no statistically significant trend in rainfall which shows considerable inter-annual variability.
- The warming trend is expected to continue. The country is projected to be warmer by up to 1.2° C by the 2030s, 2.1° C by the 2060s, and 3.6° C by the end of the century.
- The projected rate of warming is marginally more rapid for December, January, February (DJF) and September, October, November (SON).
- The frequency of very hot days and nights will increase, while very cool days and nights will decrease.
- There is a likelihood that the country will be drier (in the mean) by the end of the century.
- GCMs show a median decrease of up to 22% for annual rainfall, while the RCM suggests a decrease of up to 57%.
- Climate change will likely make the dry period early in the year and June-July drier.
- Hurricane intensity is likely to increase (as indicated by stronger peak winds and more rainfall) but not necessarily hurricane frequency.
- Caribbean sea levels are projected to rise by up to 0.24 m by mid century.
- Sea surface temperatures in the Caribbean are projected to warm, perhaps up to 2°C by the end of the century.

Refer to SNC Climate Chapter for more details

Two other local studies, done by **Meteo France in Martinique** (October 2013) **and Guyana** (April 2013) shows that rather the temperatures rise almost continuously for 50 years, **no significant tend is observed neither for average precipitations nor for extreme rainfall events.**

Following these studies, Martinique's and Guyana's authorities decided to keep actual precipitation data for future projects dimensioning.

Regarding heavy rains in Saint Lucia, as :

- the island is situated between Martinique and Guyana,

- and local Saint Lucia's report could not define a clear trend for intense precipitations,

we propose to use their conclusions for Saint Lucia's : no evolution of rainfall for extreme events in the future.

In conclusion the hydrological analysis in actual condition given in report#2 will be used for structural measures dimensioning hereafter.

2.2 In Dennery

2.2.1 Existing critical infrastructures in Dennery

In Dennery the critical infrastructures are described below and mapped in the next figure :

- **1/ The left Mole river dike (1)** : the dike was overflowed during Tomas and all the top structure of the dike is gone : the dike is not high enough to protect the city of Dennery (it overflows for 1-in-10 years flood event). Moreover, the **rip rap protections** of the dike are collapsing, making the structure more fragile. The whole dike needs to be rehabilitated, strengthened and extended.

- **2/ The Ravine Trou à l'Eau natural bends (2a)** are fragile, they need bank protection. The **downstream concrete channel (2b)** is too small (it overflows for 1-in-10 years flood event) and need to be enlarged.

- **3/ The concrete main central drain (3a)** is too small (it overflows for 1-in-10 years flood event) and need to be enlarged. Moreover its **oulet in the Mole river (3b)** is not well functioning and should be moved

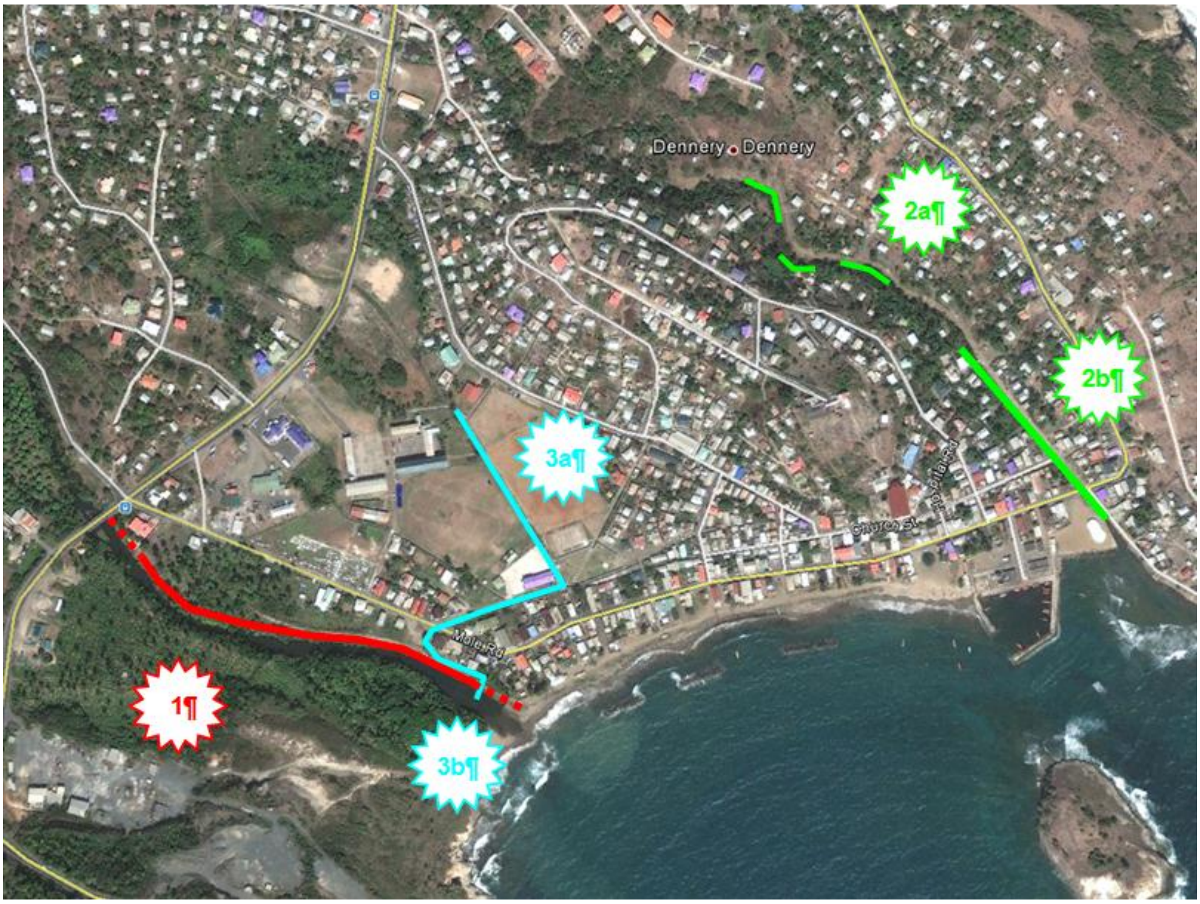


Figure 6 : Dennery critical infrastructures

2.2.2 Proposed structural measures in Dennery

To protect to town of Dennery against floods, we propose de following structural measures :

1/ Rehabilitation of the left dike along the Mole river, taking account of 2 different hypothesis of development on the right bank:

- Hypothesis 1 : enlarge the outlet is possible by the removal of the existing spur at the mouth of the river in order to enable flood expansion and drainage,
- Hypothesis 2 : take account of a project of hotel on the right bank wich will require to fill a part of the right bank and keep the spur. (We were asked to examine this hypothesis by Elizabeth Charles-Soomer- Unit Chief of the National Reconstruction and Development Unit).

2/ Re-calibration of the central drain combined (or not) with retention area (storm management pond) upstream to the East Coast Road, and creation of a new direct outlet to the sea,

3/ Bank protections in the bends of the ravine Trou à l'Eau,

4/ Re-calibration of the Ravine Trou à l'Eau between first overflow point and the outlet in the sea.

2.2.2.1 Rehabilitation of the left dike along the Mole river

The crest of the actual dike is irregular and has been lowered by last devastating floods. The actual riprap embankment protection are also collapsing into the river, fragilizing more and more the stability of the dike.

The proposed solution consists in rebuilding the left river dike between the East Coast Road bridge and the outlet into the sea.

In order to limit the hold on the ground in a private property, we propose the construction of a wall for a total length of 60 m downstream of the bridge (actual gabion baskets).

After the wall, we propose to rebuild an earth dike for the rest of the distance to the sea (410m), to replace the existing one which is collapsing.

The left embankment of the river will be protected with riprap along the whole works length.

The 2 existing outlets trough the dike will be removed.

The proposed works are localized in the next figure :

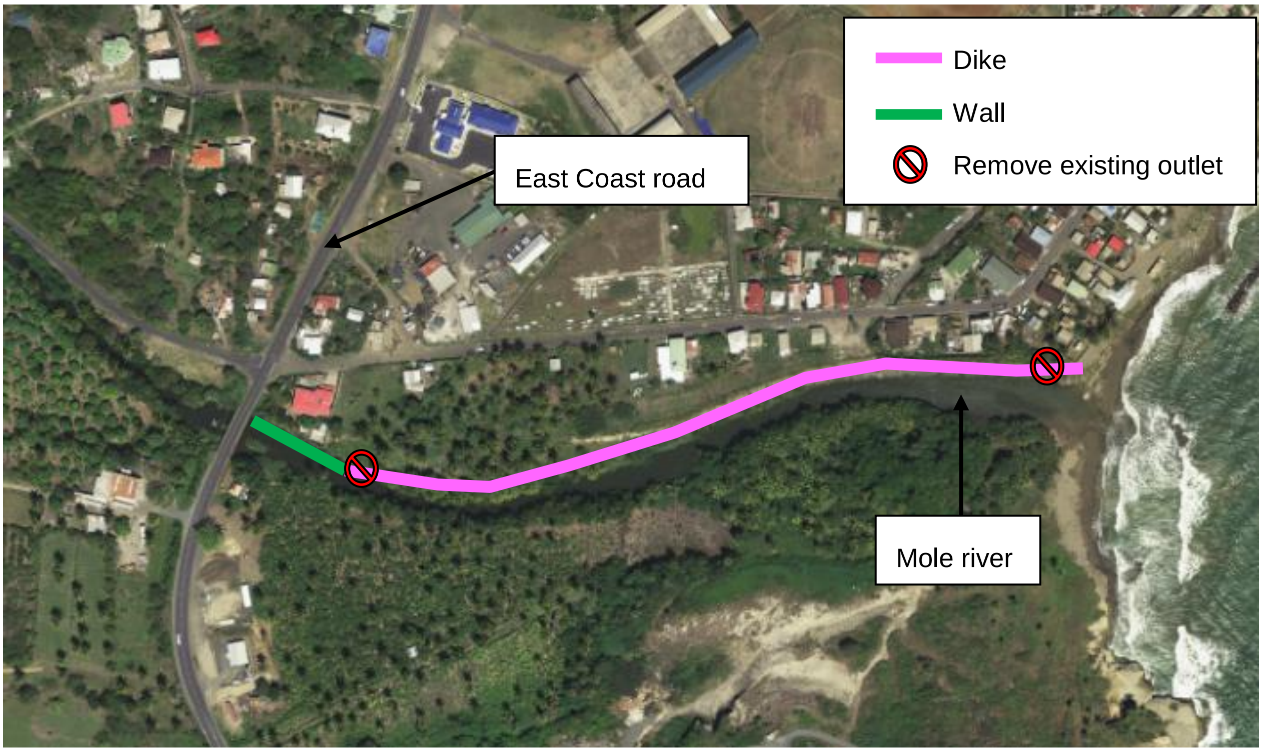


Figure 7 : Mole River rehabilitation of the wall and the dike in Dennery

Figure 8 : localization of proposed works along the Mole river in Dennery

The corresponding standard profiles are the followings :

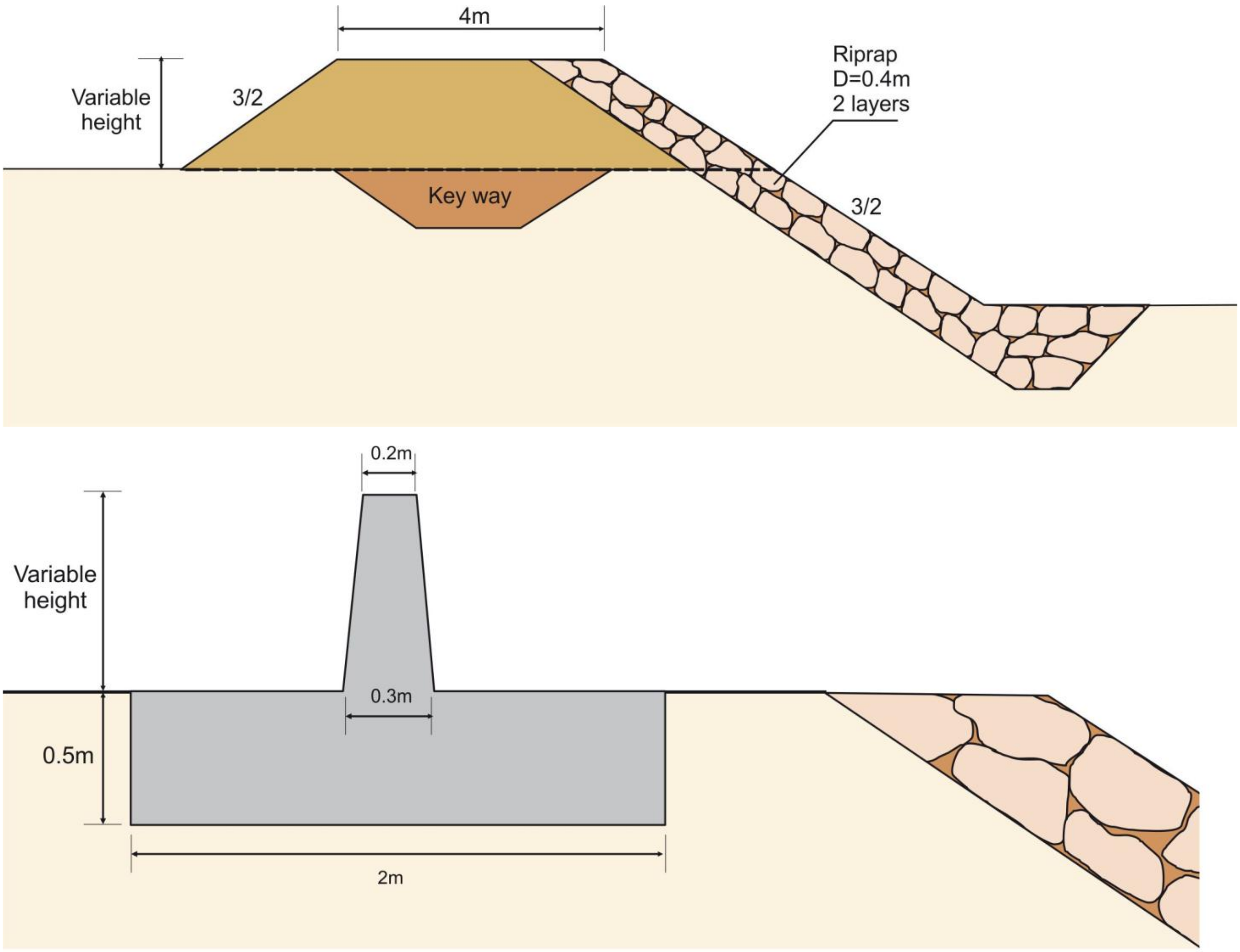


Figure 9 : Standard profiles of the proposed works along the Mole River in Dennery

The crest elevation of the dike and wall are set to the maximum water levels corresponding to various return periods (in order to provide a large scale of proposed solutions to be chosen by the client), increased by 0.50m of safety margin.

Three level of protection are proposed :

- 1-in-50-year flood event,
- 1-in-100-year flood event
- Tomas flood event

For each proposed hypothesis, the longitudinal profiles are given in the next figures :

- Hypothesis 1 : enlarge the outlet -> removal of the spur,
- Hypothesis 2 : taking account of the project of hotel on the right bank -> fill the right bank.

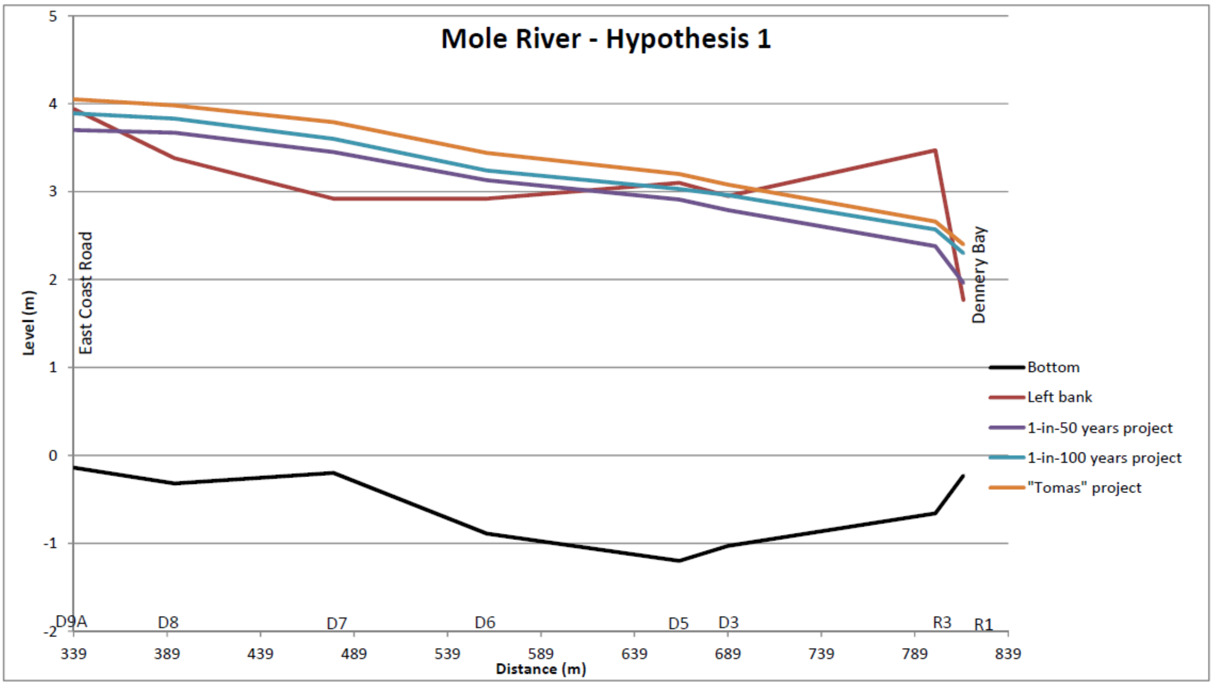


Figure 10 : longitudinal profiles – Hypothesis 1

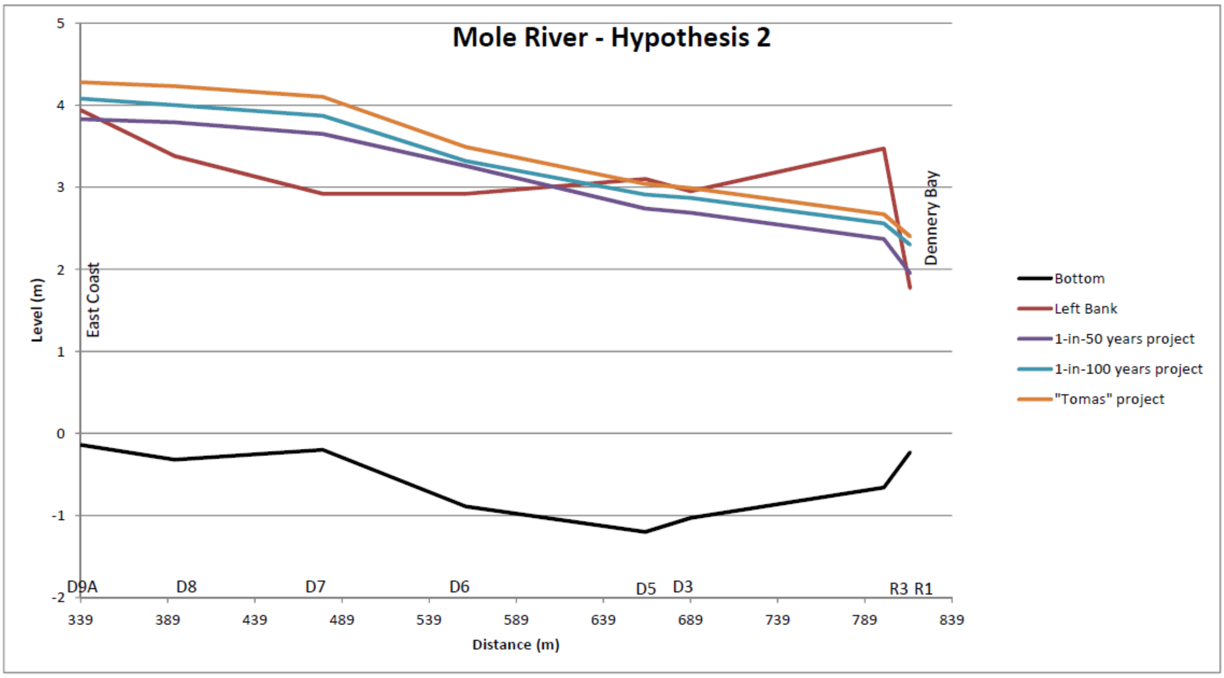


Figure 11 : Longitudinal profiles – Hypothesis 2

2.2.2.2 Re-calibration of the central drain combined (or not) with retention area (storm management pond) upstream to the East Coast Road, and creation of a new direct outlet to the sea,

Two different solutions are proposed hereafter :

- Solution 1 : recalibration of the central drain between East Coast Road and Church Street, and creation of a new outlet between Church Street and the sea.
- Solution 2 : same as solution 1 with creation of a storm management pond (retention area) upstream of the East Coast Road.

2.1.2.2.1 Solution 1

Solution 1 consists of recalibration of the central drain between East Coast Road and Church Street, and creation of a new outlet between Church Street and the sea. To complete this solution, we propose also to reverse the flow direction (reverse the slope of the drains) of the concrete channel along the Mole road and the actual outlet of the central drain.

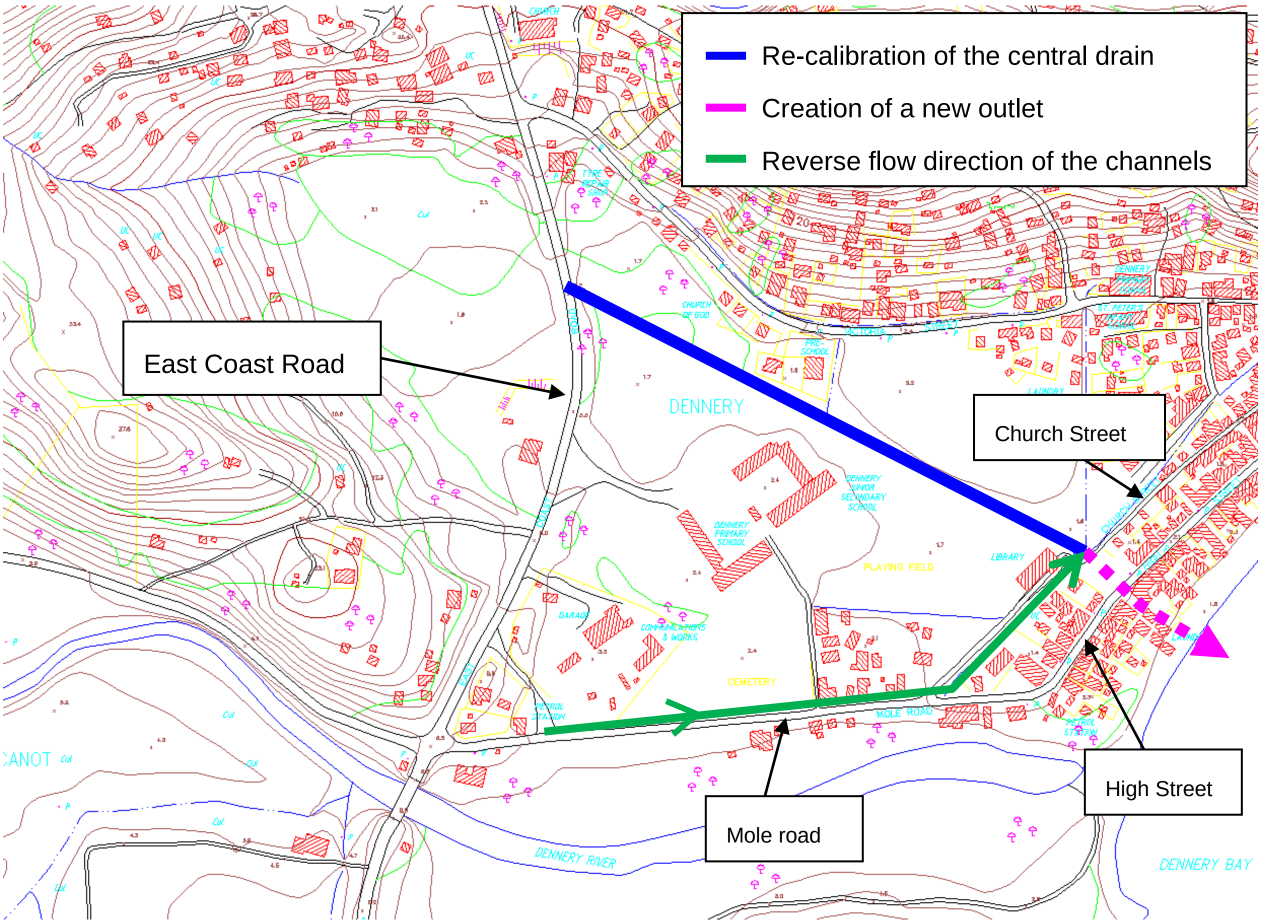


Figure 12 : Solution 1 : localization of the proposed works

The solution consists of creating a new reinforced concrete channel.

The crest elevation of the channel are set to the maximum water levels corresponding to various flood return periods (in order to provide a large scale of proposed solutions to be chosen by the client), increased by 0.50m of safety margin.

For all tested flood, the width of the channel is set at 3 meters.

All the existing drainage channels which have their outlet in the central drain will be equipped with non-return valves.

The corresponding standard cross-section is given hereunder:

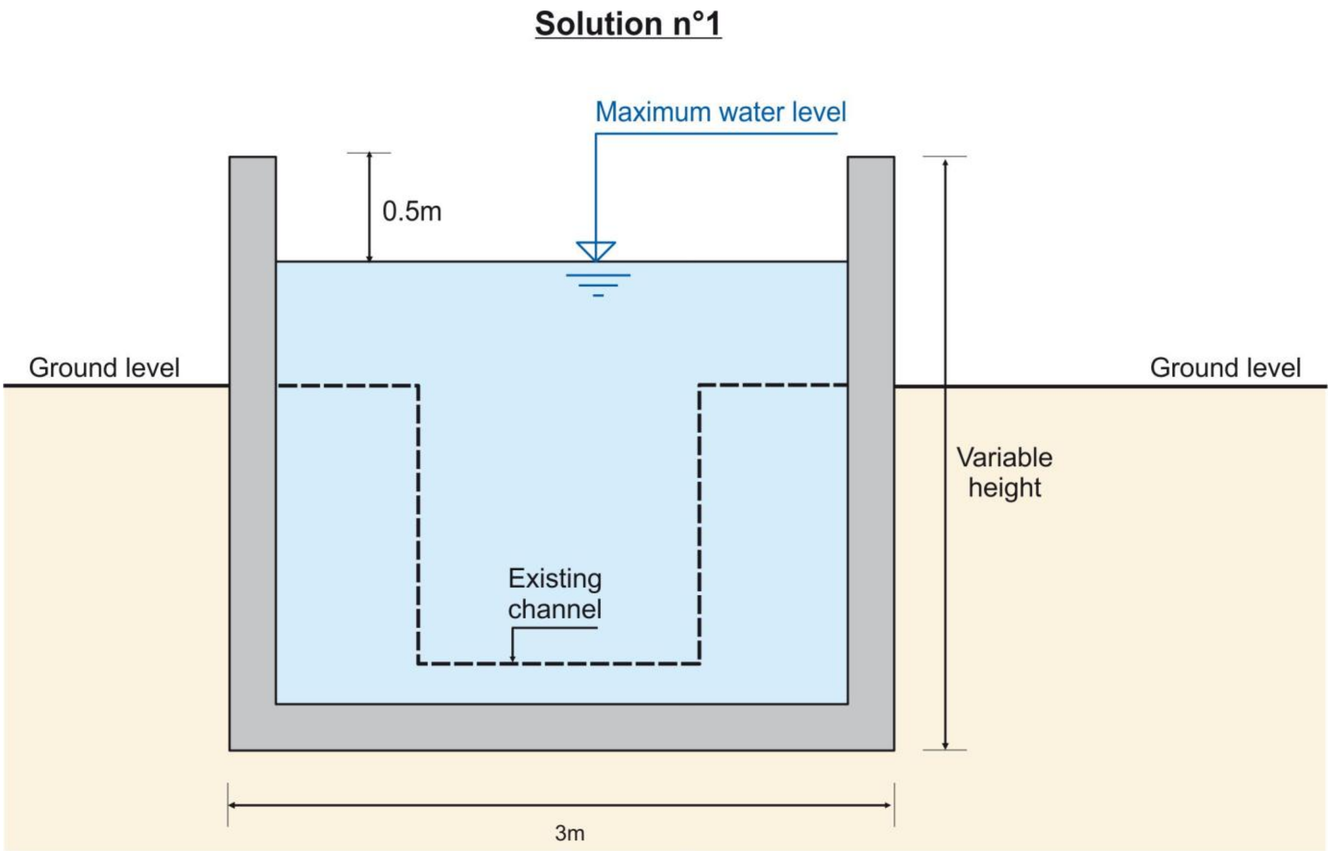
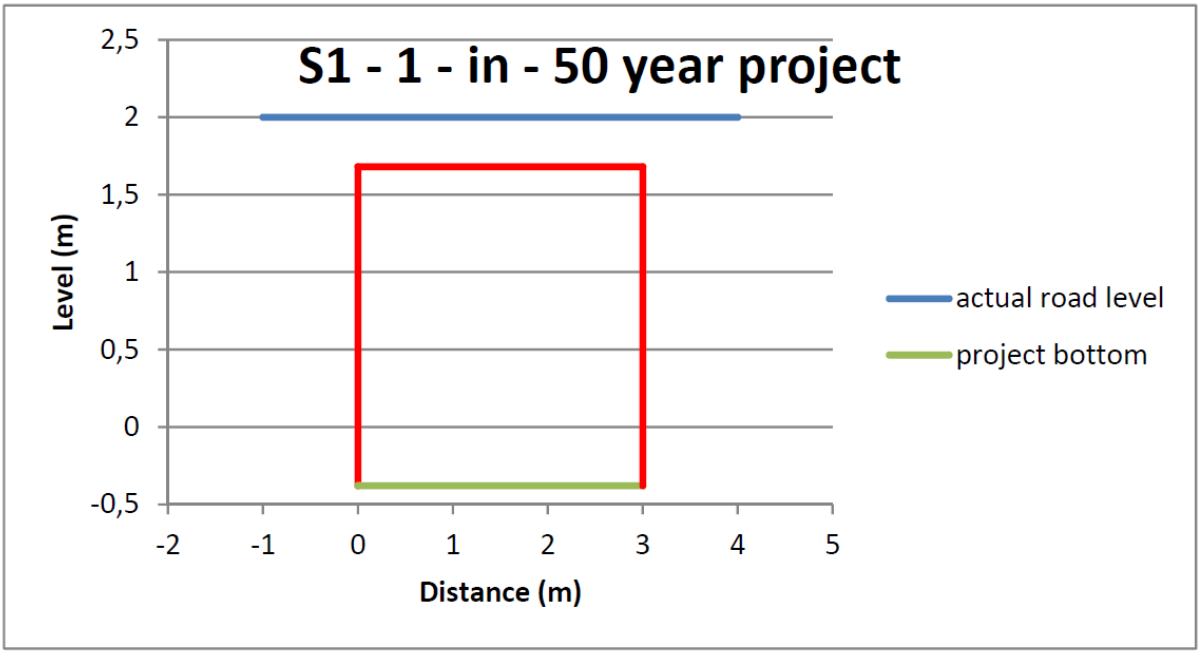


Figure 13 : Solution 1: standard cross-section for the re-calibration of the central drain

The creation of a new outlet into the sea requires the crossing of 2 streets : Church Street and High Street. These crossing will be realized with reinforced concrete rectangular hydraulic structures.

The size of the new hydraulic structures for Church and High streets are given hereafter :



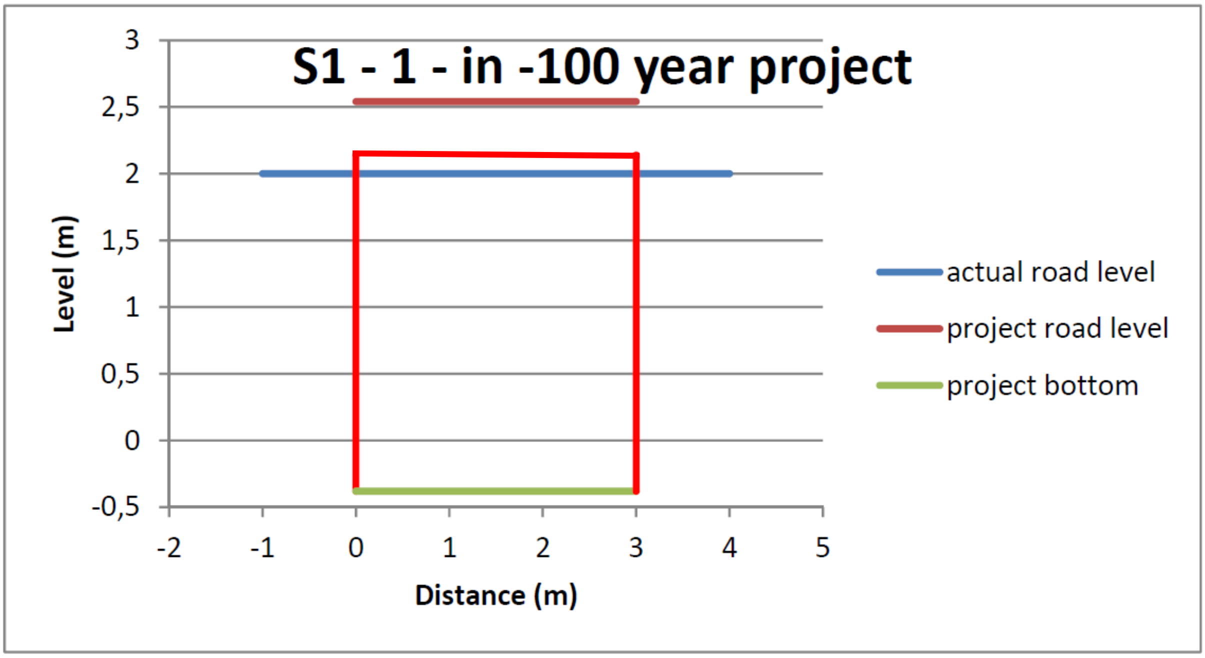
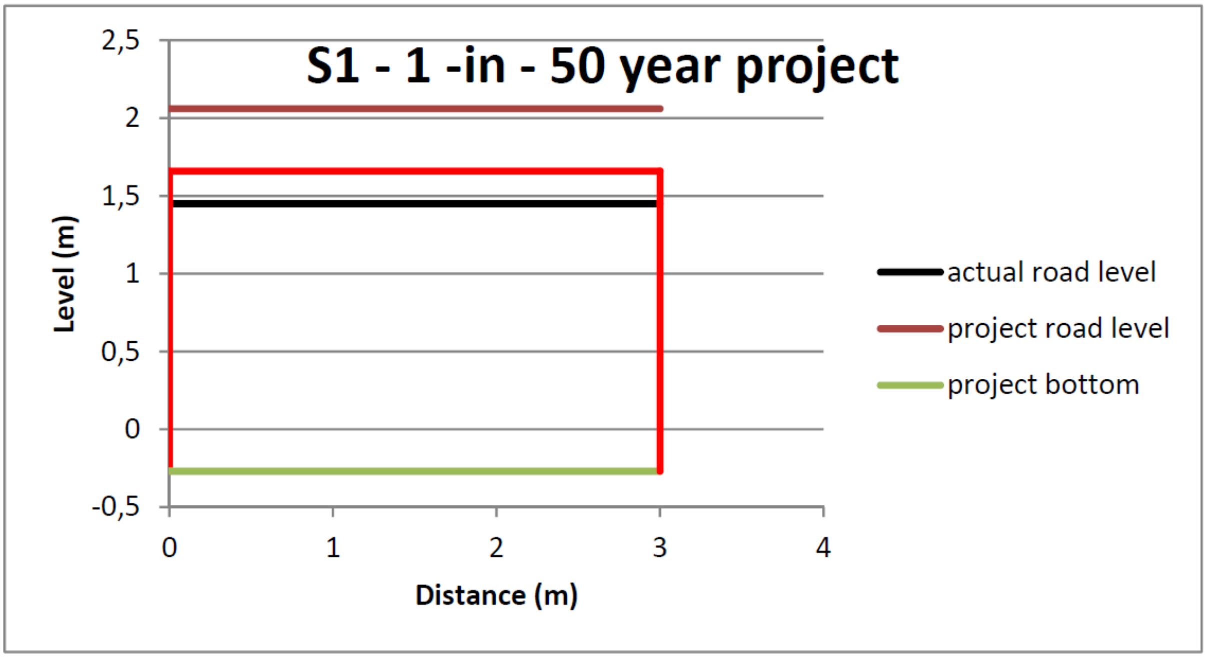


Figure 14 : Standard cross section of hydraulic structures under High Street– Sol 1

The level of High street should be raised (0.5m higher) for 100 year flood calibration.



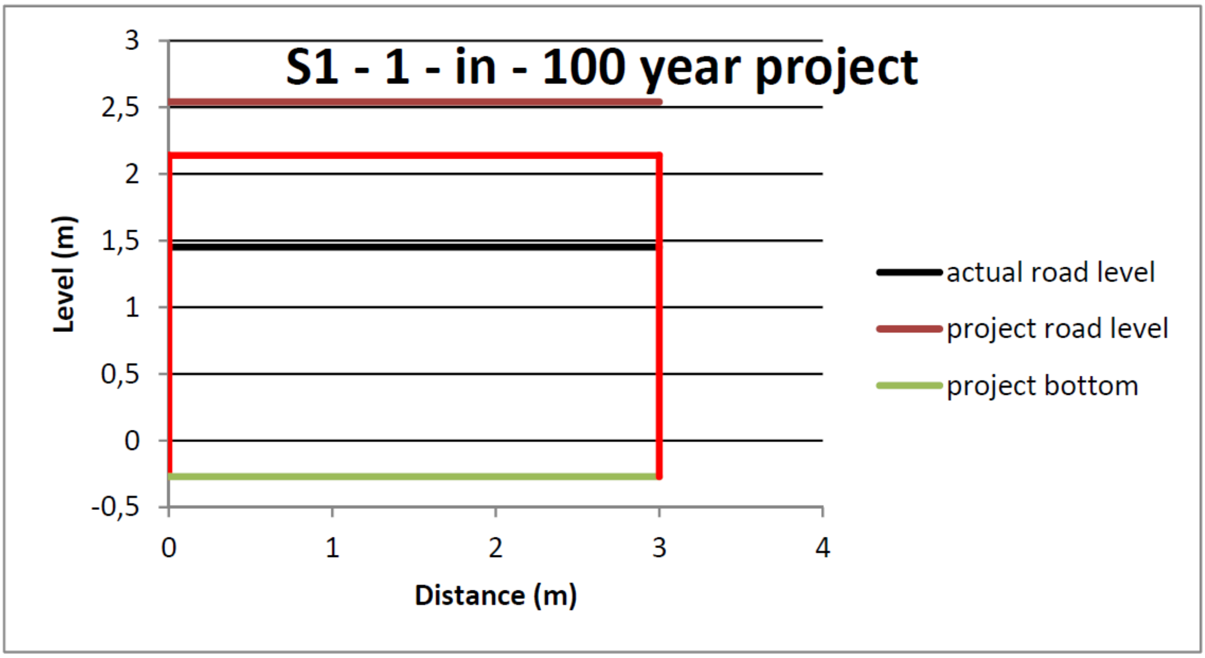


Figure 15 : Standard cross section of hydraulic structures under Church Street– Sol 1

The level of Church street should be raised :

- 0.6m higher for 50 year flood calibration.
- 1.1m higher for 100 year flood calibration.

The corresponding longitudinal profile of the new concrete channel is given hereafter.

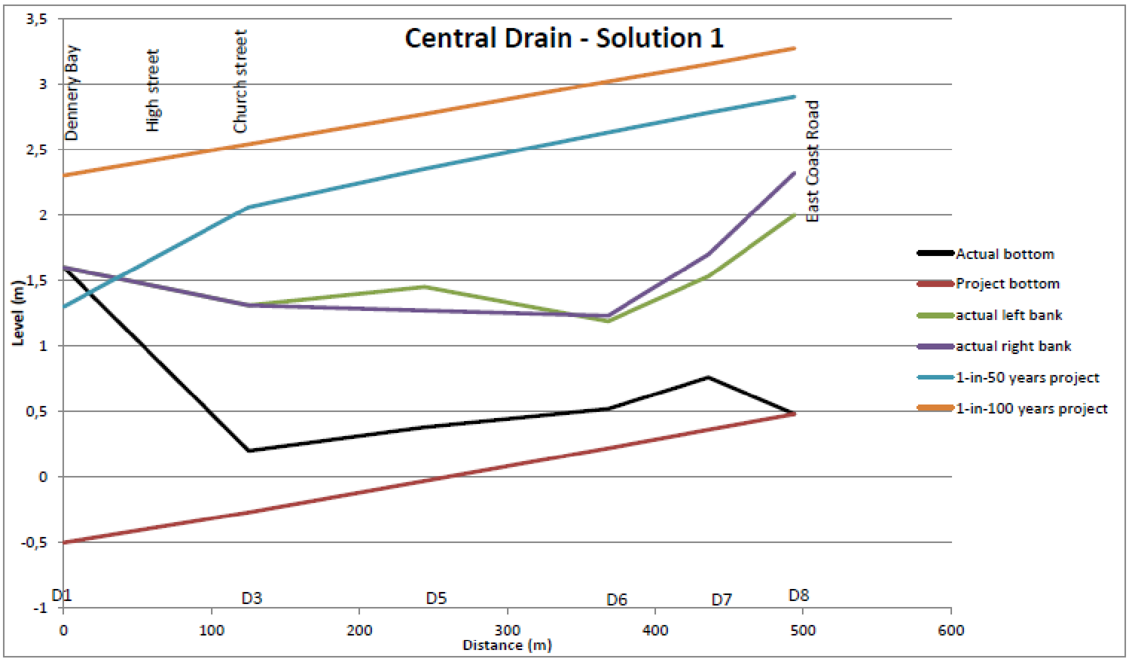


Figure 16 : Solution 1 : longitudinal profile of the re-calibration and creation of a new outlet into the sea

To reverse the flow direction (reverse the slope of the drains) of the concrete channel along the Mole road and the actual outlet of the central drain (the green channel of the *Figure 12 : Solution 1 : localization of the proposed works*), we propose to adjust the slope as given in red on the following figure. This has to be done in order to remove their existing outlets into the Mole river. All the runoff of the Mole road neighborhood will be collected by this new drain and evacuated in direction of the new outlet created.

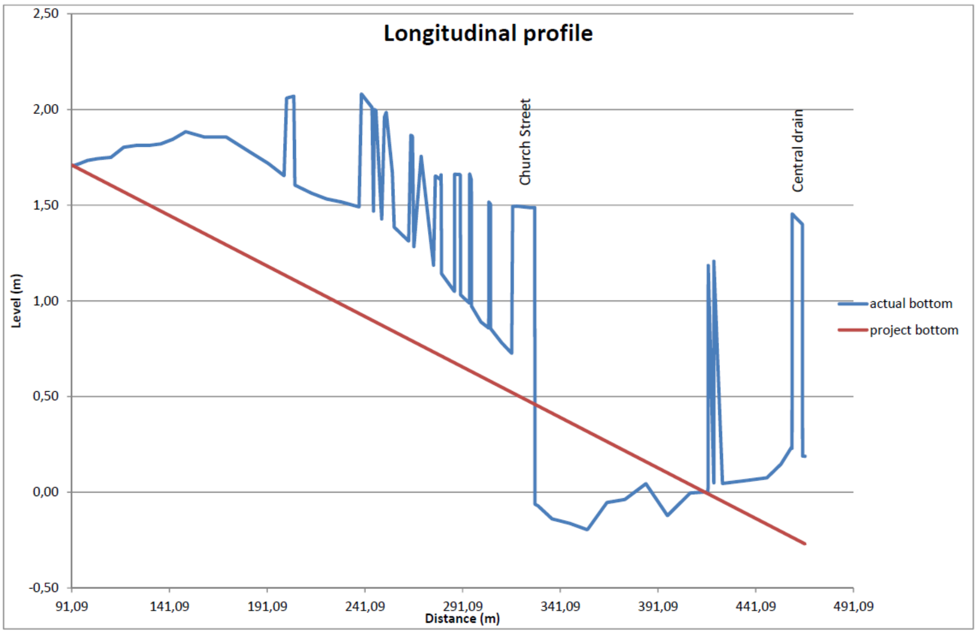


Figure 17 : Longitudinal profile of the Mole road channel

2.1.2.2.2 Solution 2

The solution 2 consists in creation of a storm management pond upstream of the East Coast Road (dig the ground where a former wetland had been filled), in order to control the release of water downstream and then reduce the size of the concrete channel through the city.

In the light of the calculated volume, which is quite small comparing to the available room, it is possible to store the whole runoff volume upstream of the East Coast Road.

The corresponding volume (V), for each return period, to store is (without outlet) :

V50 = 6 300 m3

V100 = 7 300 m3

Vtomas 73 000 m3

Tomas runoff volume is very important because of the long duration of the rain phenomenon.

The available area for the storm management pond is approximately 10 000 m²

The corresponding depth (H), for each return period is :

H50 = 0.63 m

H100 = 0.73 m

Htomas = 7.3 m (!!!)

This shows that it is impossible to store the entire volume of a long raining event like Tomas. We propose to add an outlet under the East Coast Road to release downstream through the city (into the central drain) a controlled flow.

With a **maximum flow release of 1 m3/s**, the storm management pond would have the following characteristics:

V50 = 4 200 m3

V100 = 5 100 m3

Vtomas 7 800 m3

The corresponding depth (H), for each return period is :

H50 = 0.42 m

H100 = 0.51 m

Htomas = 0.78 m

For all these solutions, the East Coast Road has to be reinforced and create a spillway to pass high floods (if the outlet fails for example).

The downstream flow through the city will be evacuated by a reinforced concrete channel of 2 meters wide. All the other works are the same as the solution 1 ones.

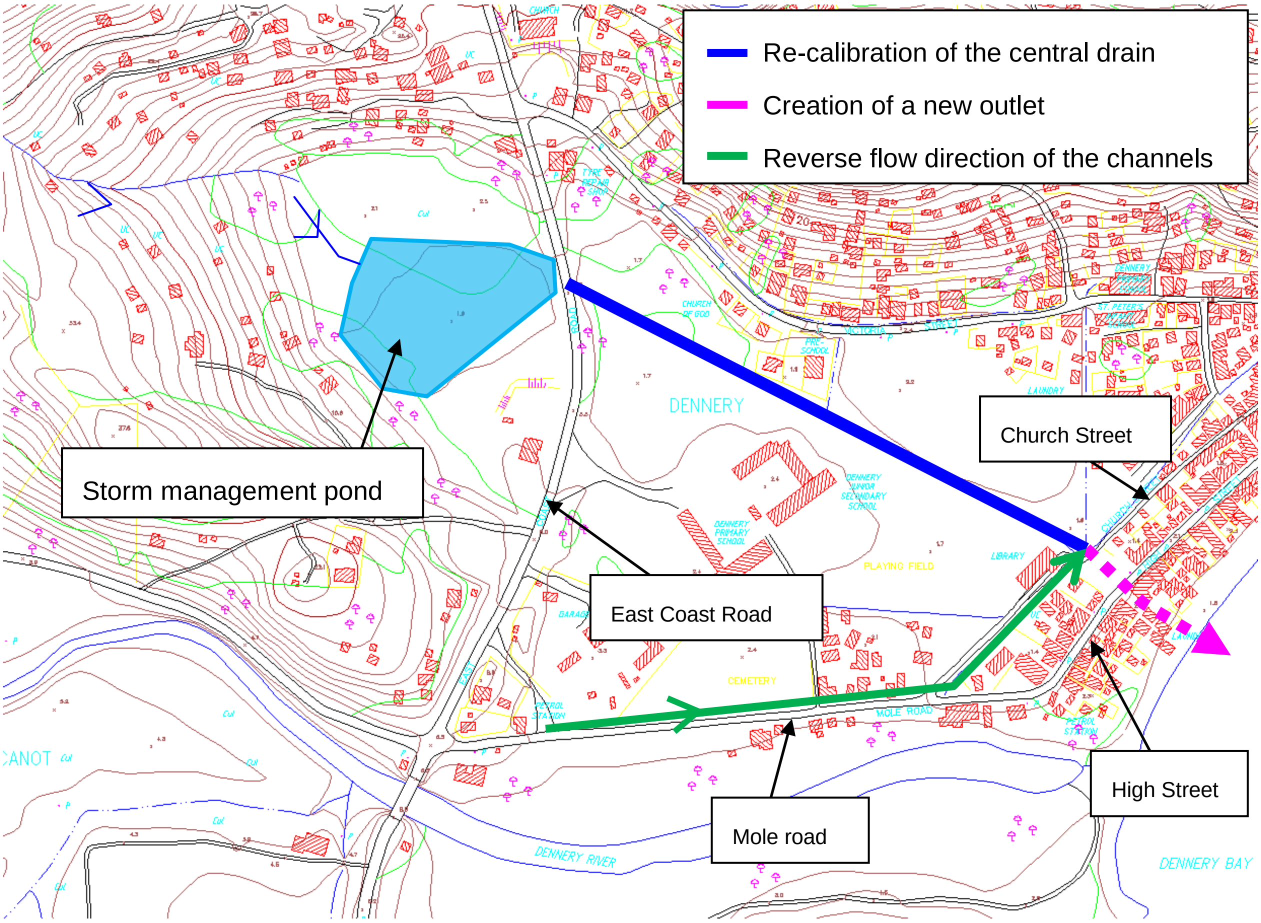


Figure 18 : Solution 2 : localization of the proposed works

The corresponding longitudinal profiles are the following :

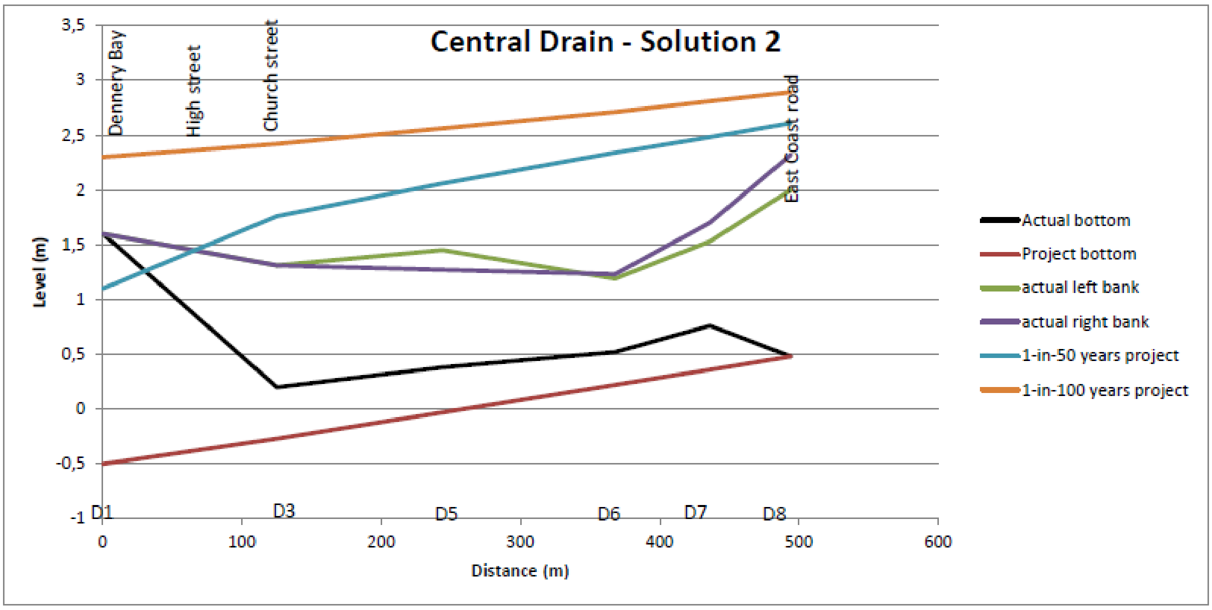


Figure 19 : Solution 2 : Longitudinal profile of re-calibration of the central drain

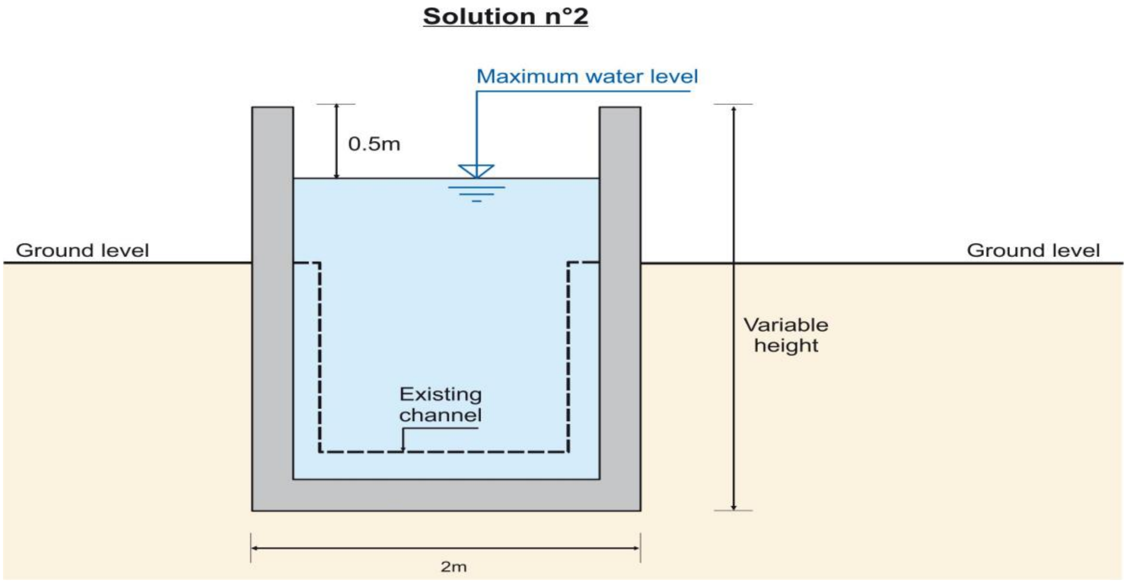


Figure 20 : Solution 2 : standard cross-section for the re-calibration of the central drain

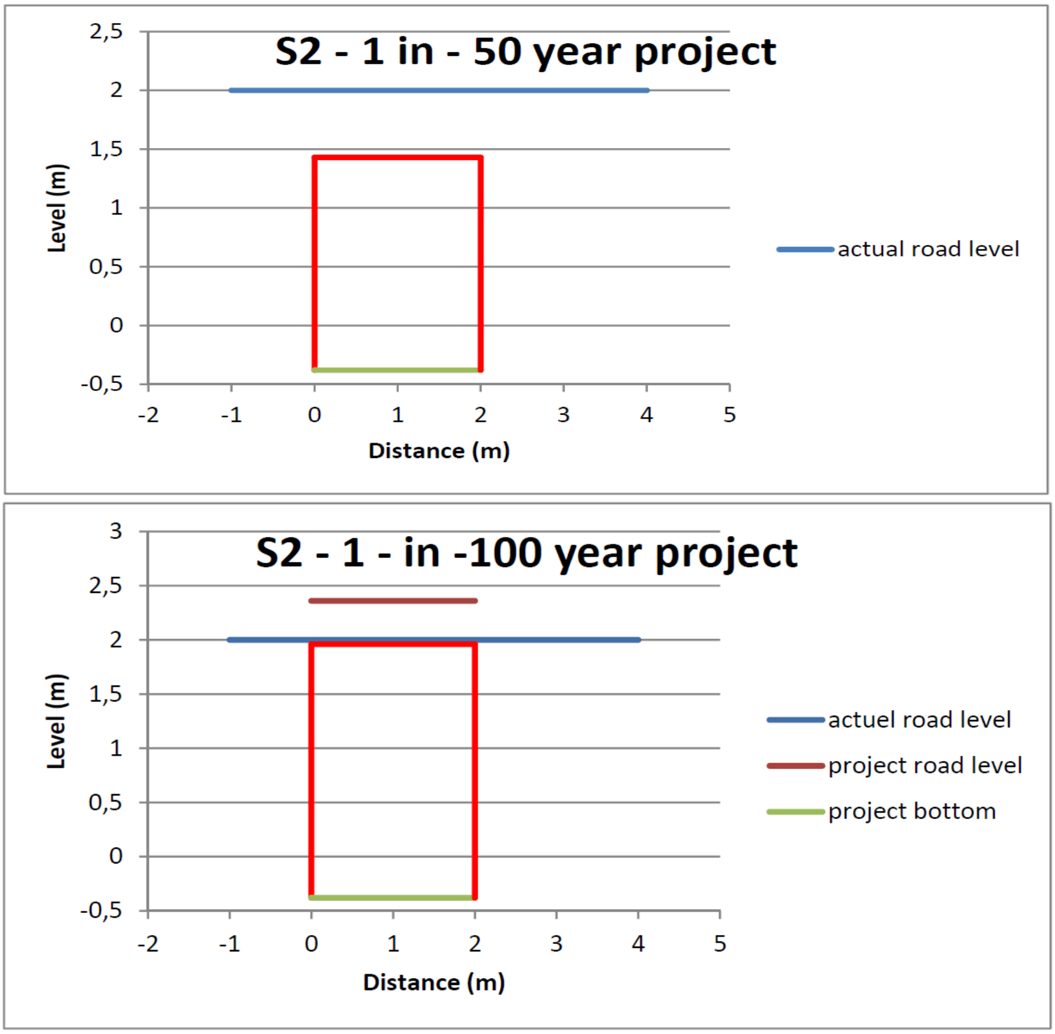
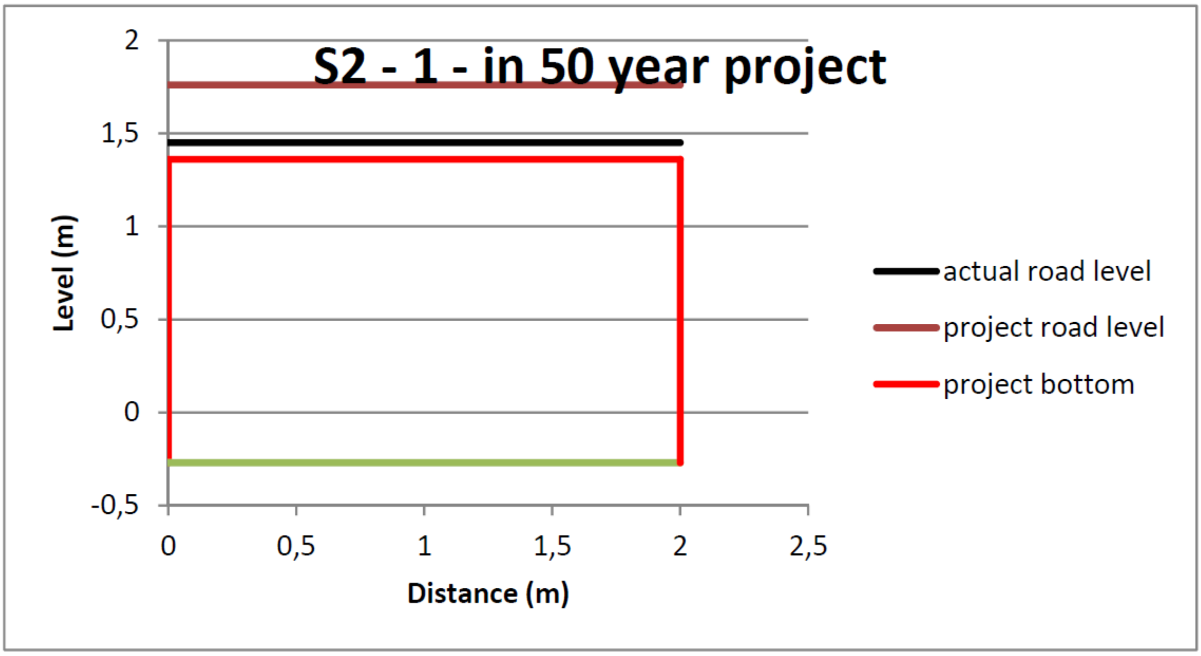


Figure 21 : Cross sections of the hydraulic structures under High Street



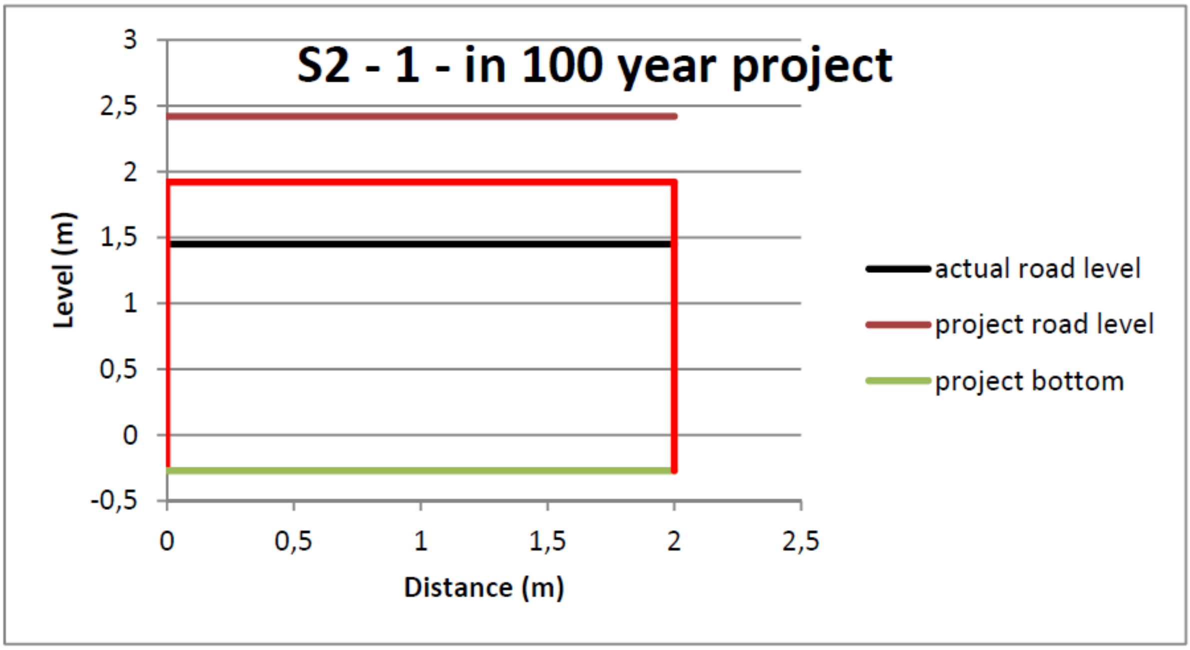


Figure 22 : Cross sections of the hydraulic structures under Church Street

The level of Church street should be raised :

- 0.3m higher for 50 year flood calibration.
- 0.8m higher for 100 year flood calibration

2.2.2.3 Ravine Trou à Eau structural measures

The localization of the proposed works on the ravine Trou à l'Eau is given hereunder:

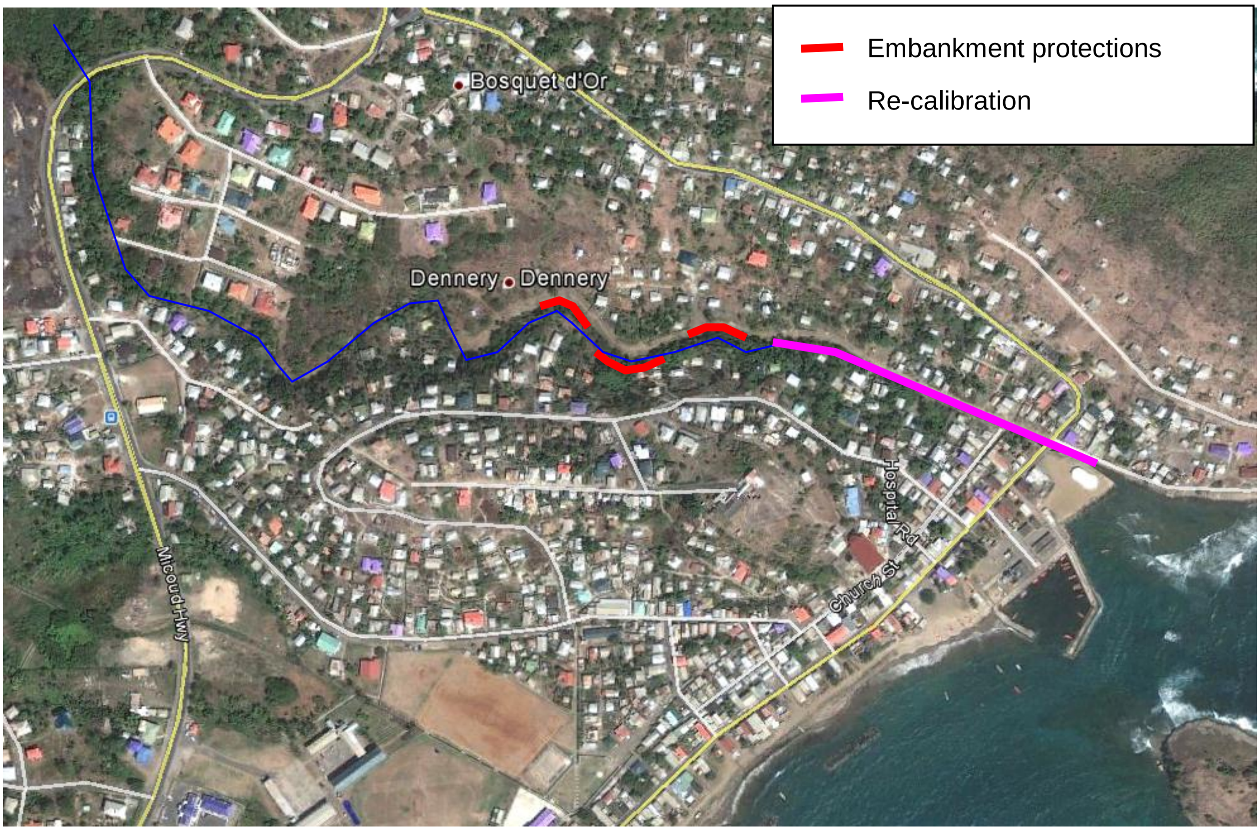


Figure 23 : Localization of the proposed structural measures on ravine Trou à l'Eau

The river bends protections will be ensured by riprap on the embankments, on a combined length of 150m. The standard cross section is given hereunder :

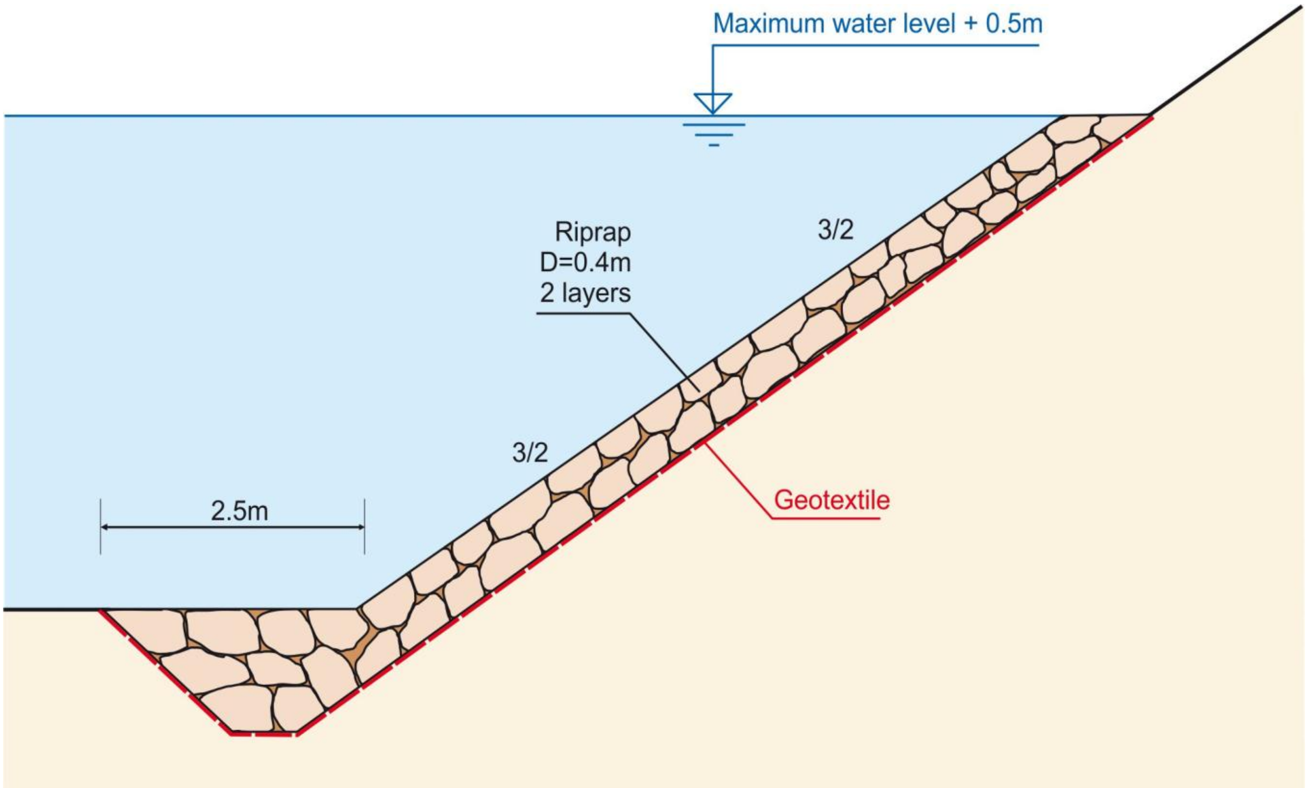


Figure 24 : Standard profile of the rip rap embankment protections along the ravine Trou à l'Eau.

The downstream part of the ravine (where water starts to overflow) will be re-calibrated over a line of 305m. Two solutions have been examined for various flood return-periods:

- Solution 1 : consists in creating a new channel, widening the existing one on the right bank gardens (private properties),
- Solution 2 : keep the existing channel and create a wall 2 meters away from the actual left bank (this will reduce the actual dirt road right-of-way), and a wall on the right bank to raise it. With this solution the private properties on the right bank are not modified.

2.2.2.3.1 Solution 1

The corresponding standard cross section is:

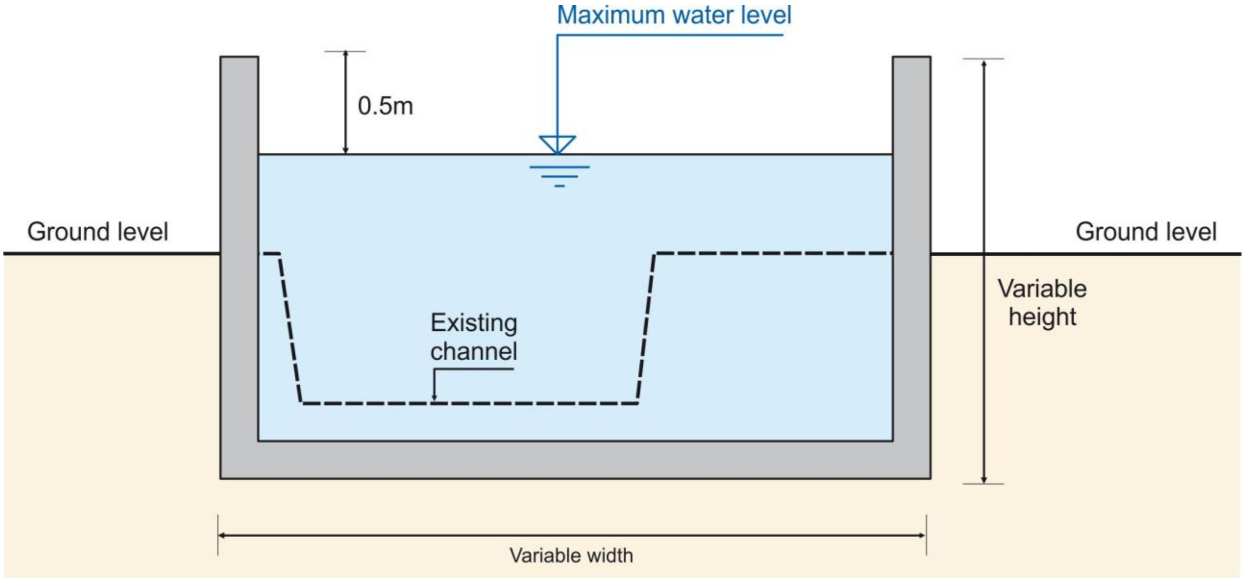


Figure 25 : Solution 1 – standard cross section

The channel width is:

- 4 m for 1-in-50-year flood period,
- 5 m for 1-in-100-year flood period,
- 6 m for Tomas flood

The crest elevation of the walls are set to the maximum water levels corresponding to various flood return periods (in order to provide a large scale of proposed solutions to be chosen by the client), increased by 0.50m of safety margin.

All the existing drainage channels which have their outlet in the re-calibrated part of the ravine Trou à l'Eau will be equipped with non-return valves.

The corresponding longitudinal profiles are given on the following figure.

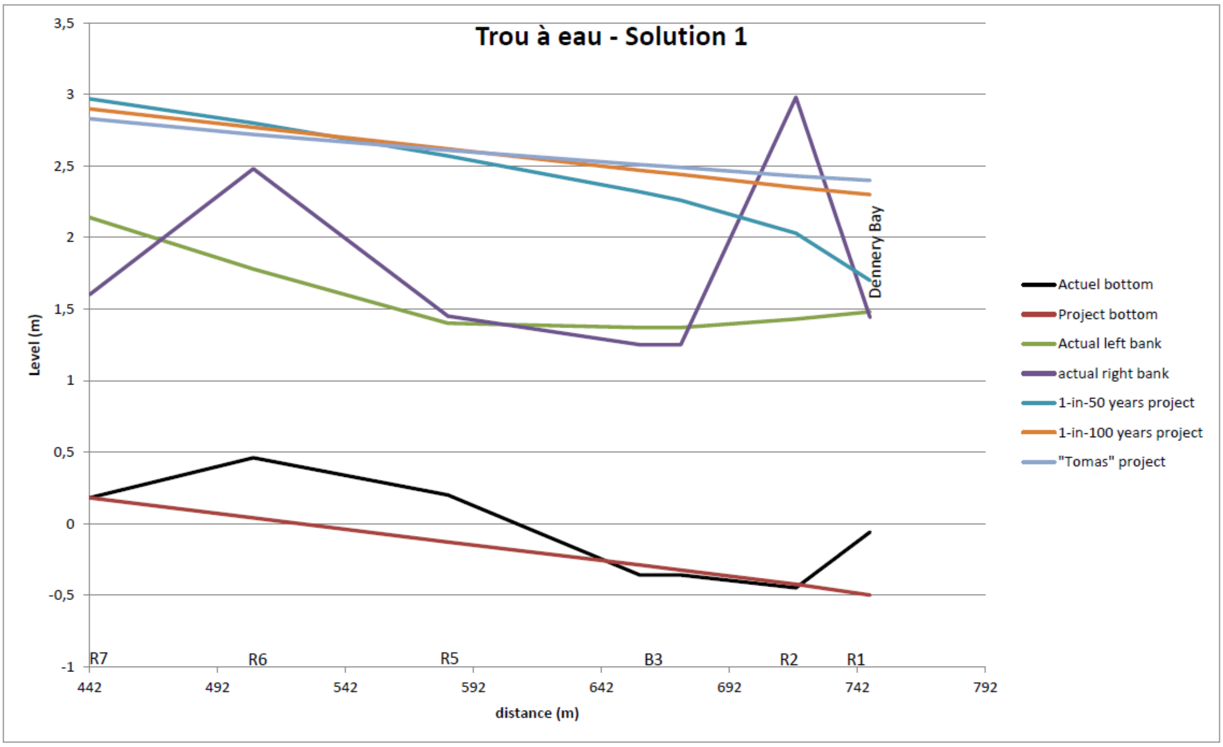
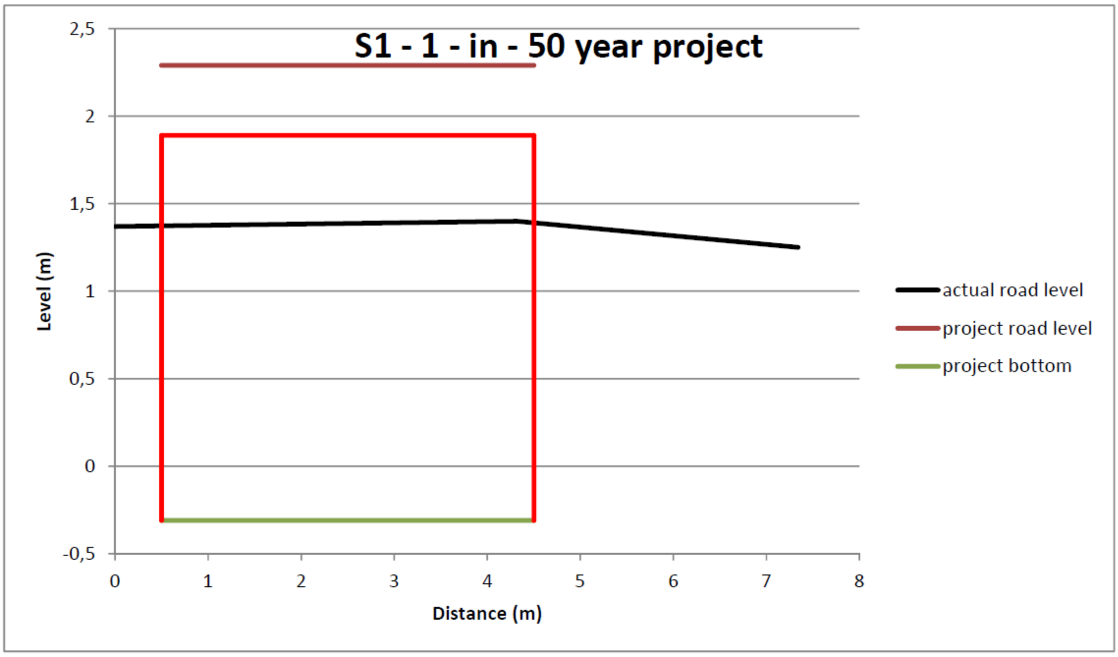
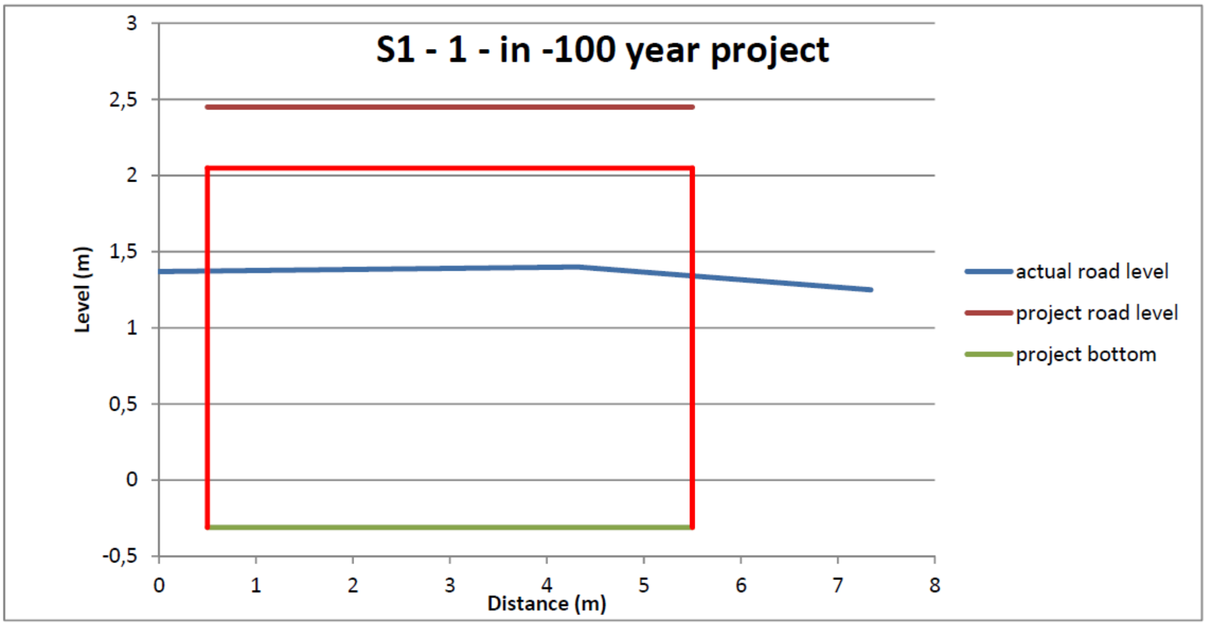


Figure 26 : Solution 1 – Longitudinal profiles

Moreover, the **hydraulic structure of High Street** on the ravine should also be re calibrated.

The new size of the bridge opening are given hereunder, for various return periods





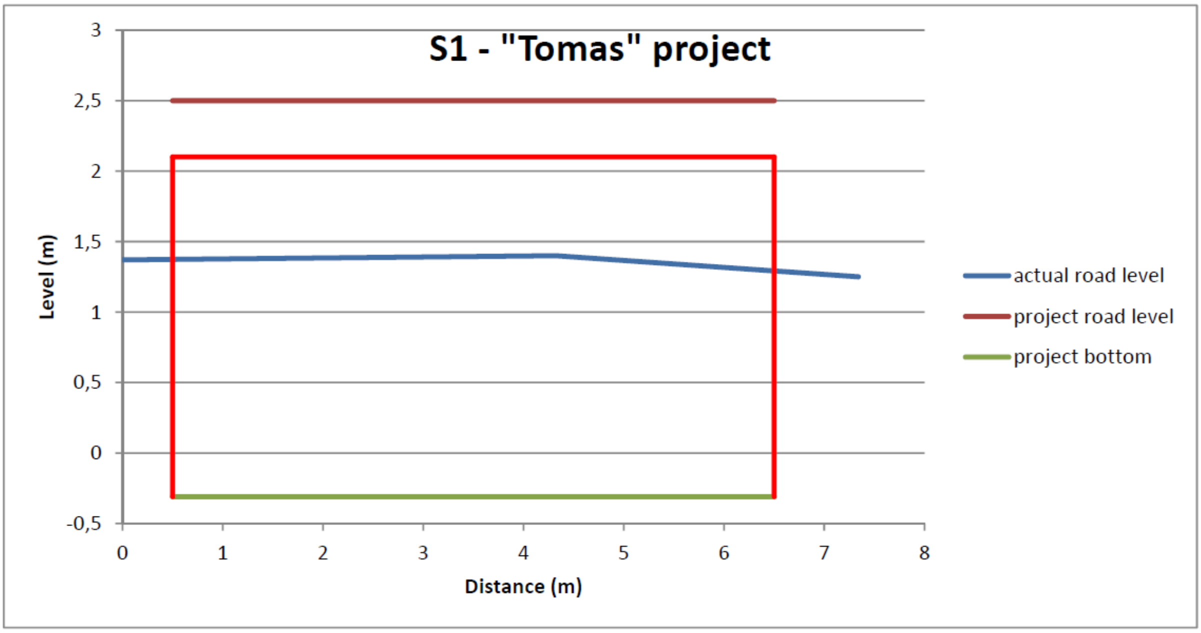


Figure 27 : re calibration of the High Street bridge on the ravine Trou à l'Eau

2.2.2.3.2 Solution 2

The corresponding standard cross section is:

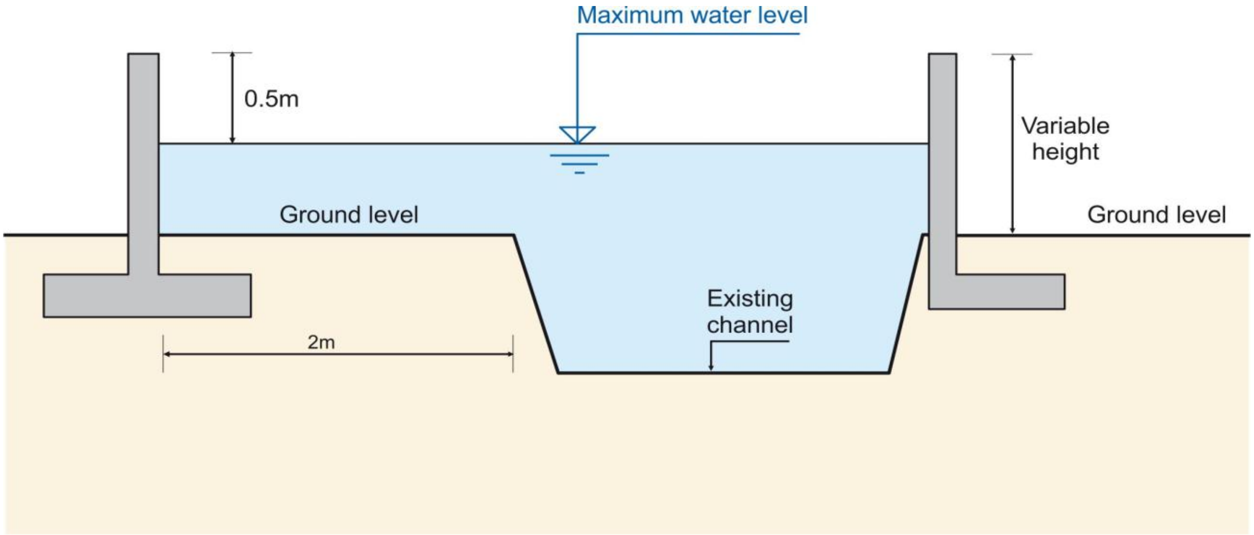


Figure 28 : Solution 2 – standard cross section

The crest elevation of the walls are set to the maximum water levels corresponding to various flood return periods (in order to provide a large scale of proposed solutions to be chosen by the client), increased by 0.50m of safety margin.

All the existing drainage channels which have their outlet in the re-calibrated part of the ravine Trou à l'Eau will be equipped with non-return valves

The corresponding longitudinal profiles are given on the following figure.

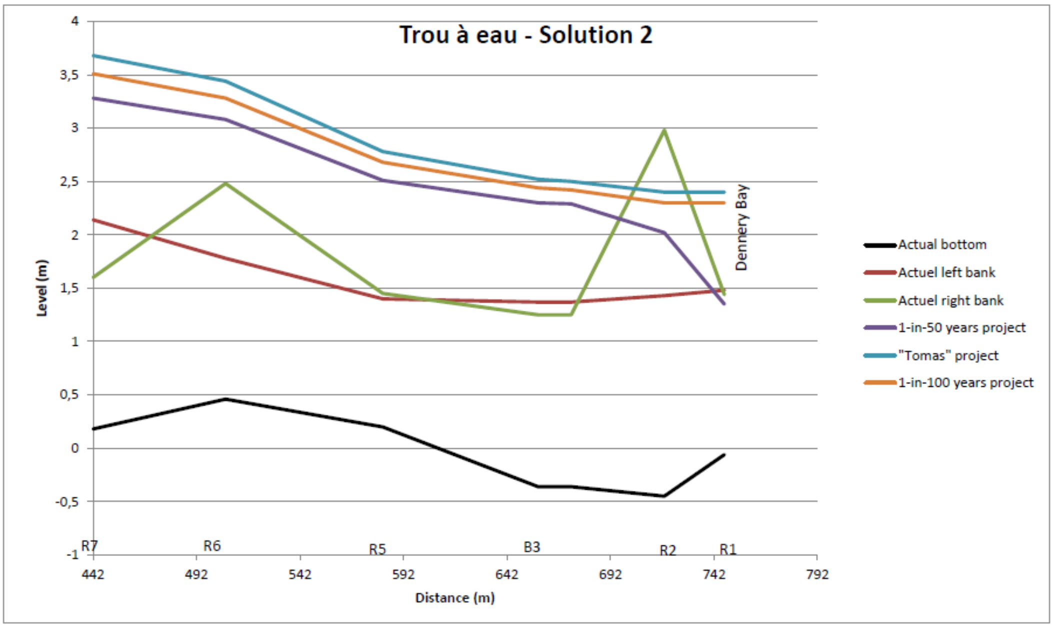


Figure 29 : Solution 2 – Longitudinal profiles

2.3 In Soufriere

2.3.1 Existing critical infrastructures in Soufriere

In Soufriere the critical infrastructures are described below and mapped in the next figure :

- **1/ The Soufriere river natural bends (1a)** are fragile, they need bank protection. The **center town artificial channel (1b)** between the 2 bridges is too small (it overflows for 1-in-10 years flood event) and need to be enlarged.

- **2/ The "Ruby" tributary channel (2a)** is too small to evacuate the 10 years flood event and need to be enlarge. Moreover a **more direct outlet (2b)** into the Soufriere river need to be found.

Figure 30 : Soufriere critical infrastructures

2.3.2 Proposed structural measures in Soufriere

To protect to town of Soufriere against floods, we propose de following structural measures :

1/ damming the Soufriere river between the 2 bridges, on left and right banks,

2/ Embankents protections of the river bends upstream,

3/ Re-calibration of the « Ruby » stream and creation of a new direct outlet into the Soufriere river

2.3.2.1 Damming the Soufriere river

The damming of the Soufriere river in town have to be done between the downstream bridge (Bridge street) and the upstream bridge (Fond Saint Jacques road - Fond Cacao), on a combined length of 900 m.

The localization of these works are given hereunder:

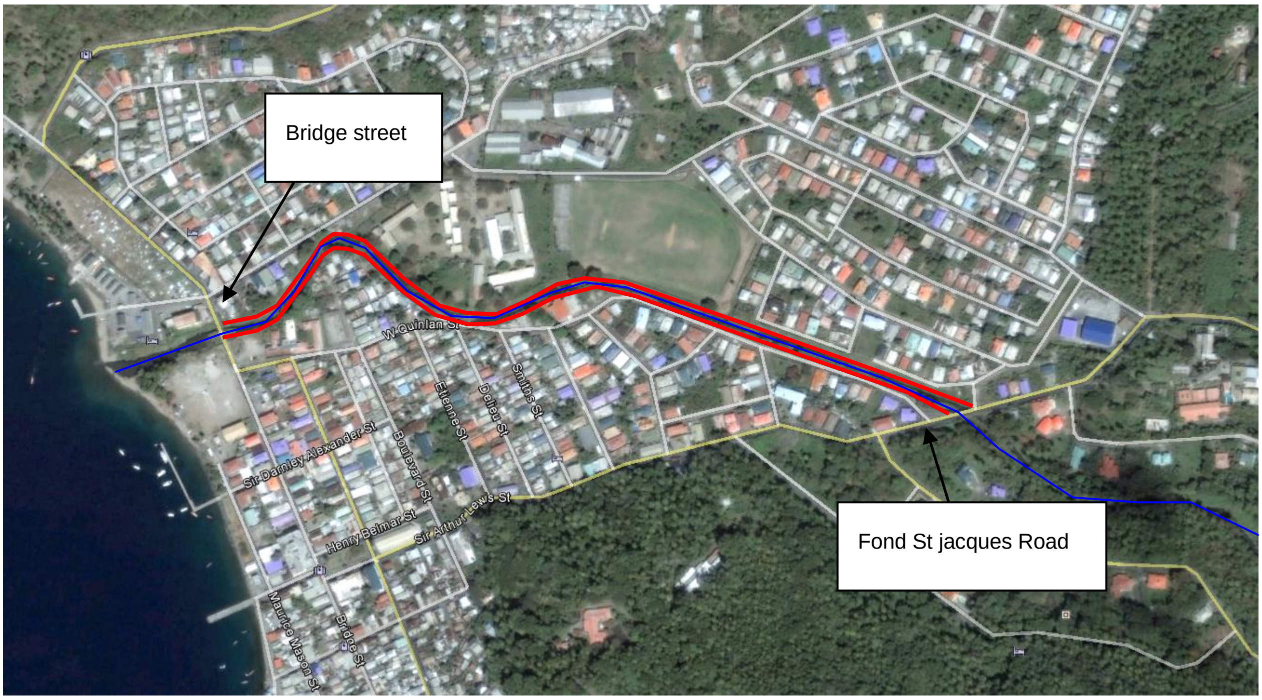


Figure 31 : Damming works localization in Soufriere

There is no available room to widen the cross section of the river in town. This is why the proposed solution is to carry out the construction of reinforced concrete walls on each bank to raise them.

All the existing drainage channels or tributaries which have their outlet in the dammed part of the Soufriere river will be equipped with non-return valves

A foundation survey should be done beforehand along the interior facings of existing stone walls. After this geotechnical expertise, reinforcements, consolidation or rehabilitation works (for example repointing the stone walls) should be necessary to carry out.

The standard cross section of the proposed solution is given hereunder :

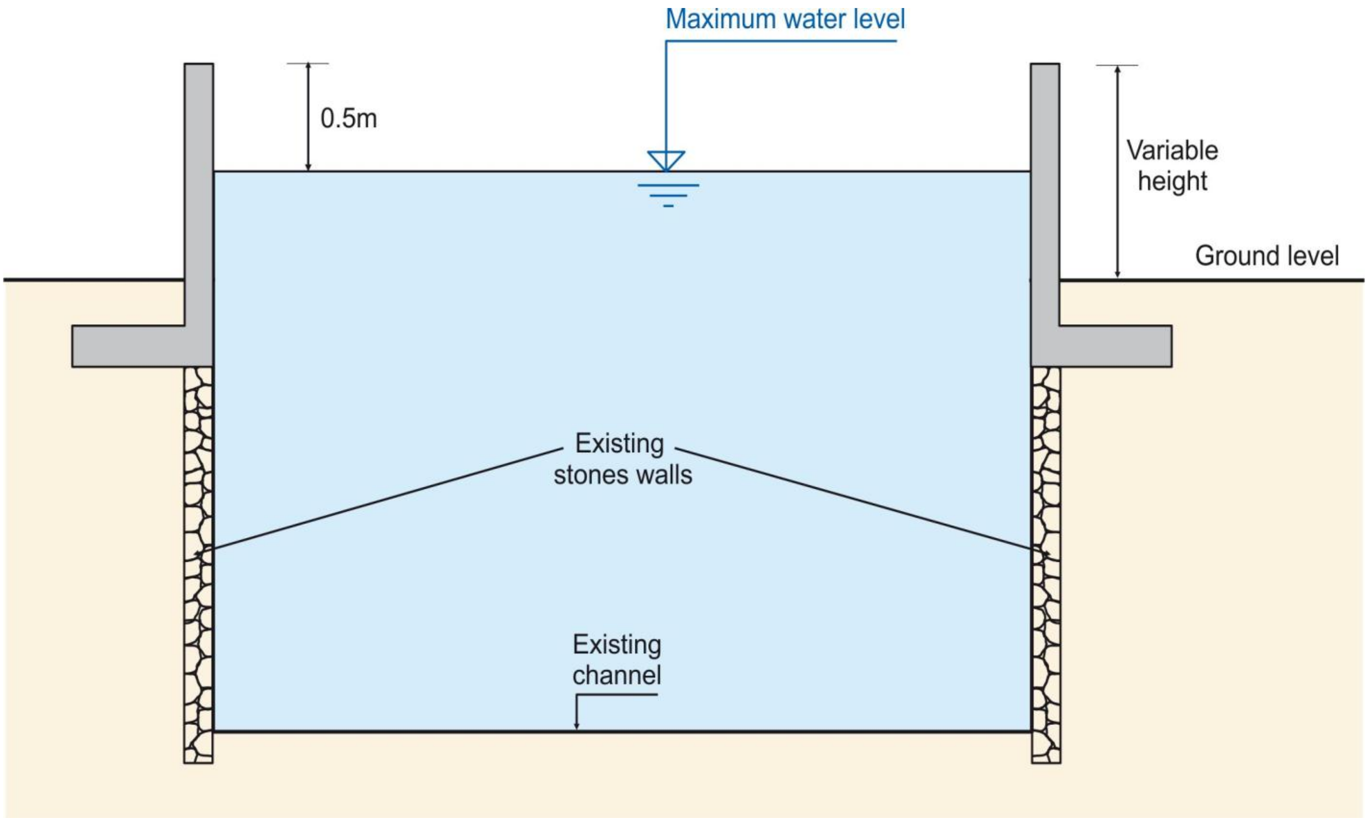


Figure 32 : standard cross section for the damming of the Soufriere river

The crest elevation of the walls are set to the maximum water levels corresponding to various flood return periods (in order to provide a large scale of proposed solutions to be chosen by the client), increased by 0.50 m of safety margin.

However, for Tomas flood event sizing, there will not be a safety margin in order to limit the height of the walls (and let them been accepted by the riverside residents).

The following figures shows the longitudinal profiles of the proposed works for the 3 tested floods :

- 1-in-50-year return period event and 0.50m of safety margin,
- 1-in-100-year return period event and 0.50m of safety margin,,
- Tomas event without safety margin

0

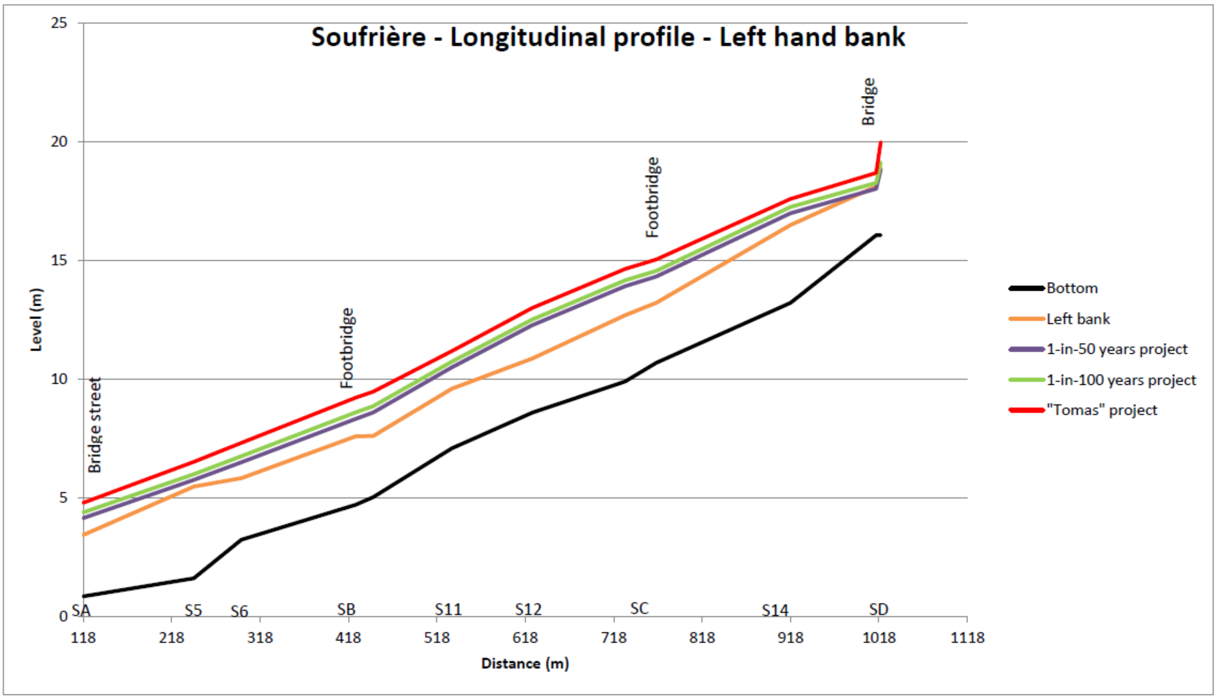


Figure 33 : Longitudinal profile of the left bank wall

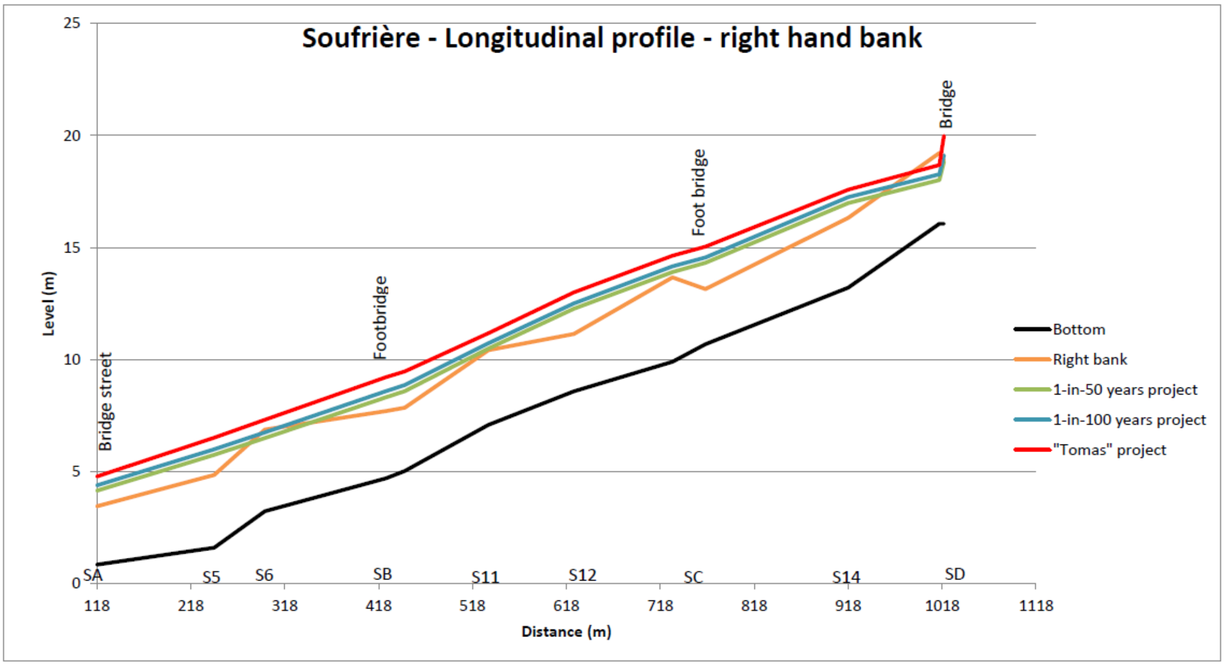


Figure 34 : Longitudinal profile of the right bank wall

The following table shows the height of the walls (from the ground level) in different cross section of the river, for the 3 tested floods. The corresponding localization of the cross section is given in the newt figure.

	1 -in- 50 years project		1 - in - 100 years project		"Tomas" project	
Profile	h RG (m)	h RD (m)	h RG (m)	h RD (m)	h RG (m)	h RD (m)
SA	0,71	0,69	0,95	0,93	1,35	1,33
S5	0,28	0,9	0,52	1,14	1,04	1,66
S6	0,67	0	0,93	0	1,49	0,44
SB	0,74	0,62	1,01	0,89	1,63	1,51
S10	0,99	0,74	1,26	1,01	1,87	1,62
S11	0,9	0,07	1,14	0,31	1,59	0,76
S12	1,41	1,13	1,65	1,37	2,14	1,86
S13	1,22	0,24	1,47	0,49	1,95	0,97
SC	1,11	1,17	1,35	1,41	1,83	1,89
S14	0,5	0,66	0,76	0,92	1,1	1,26
S15	0	0	0,15	0	0,57	0
SD	0	0	0,24	0,24	1,1	1,1

Table 1 : Heights of the damming walls along the Soufriere river

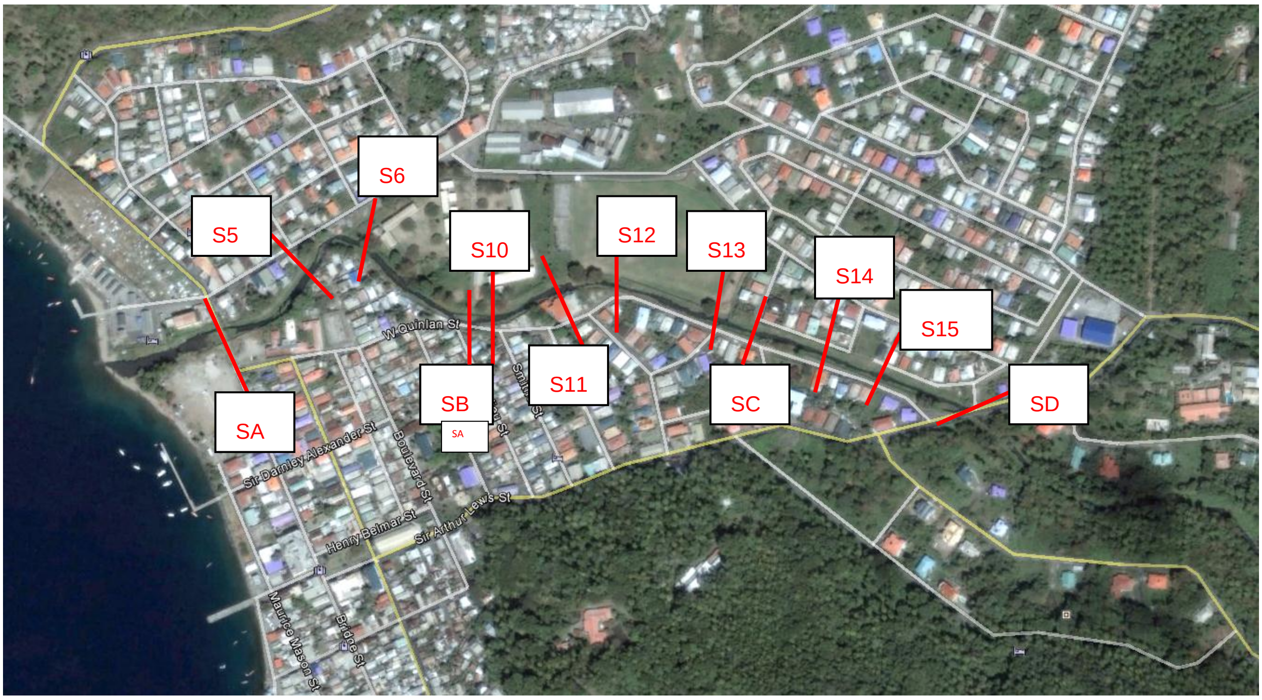


Figure 35 : Cross sections localization

2.3.2.2 Bends embankements protections

The bends which need to to be protected are given on the newt figure

Figure 36 : Embankment protections localization

The banks protections are ensured by rip rap placed on the embankments. The corresponding standard cross section is given on the following figure.

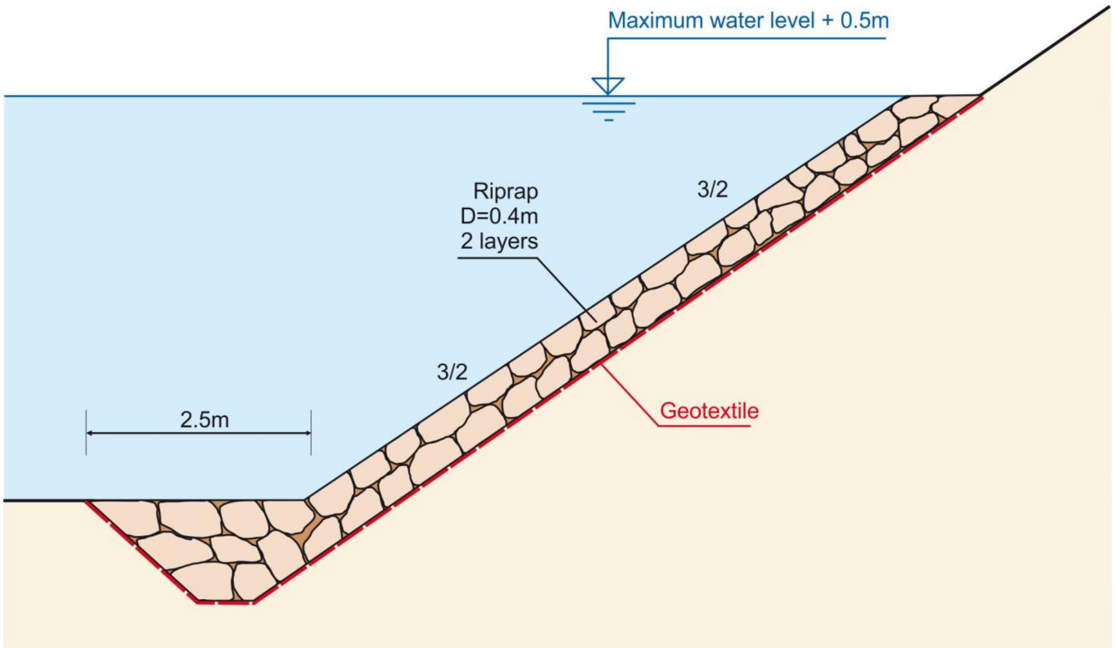
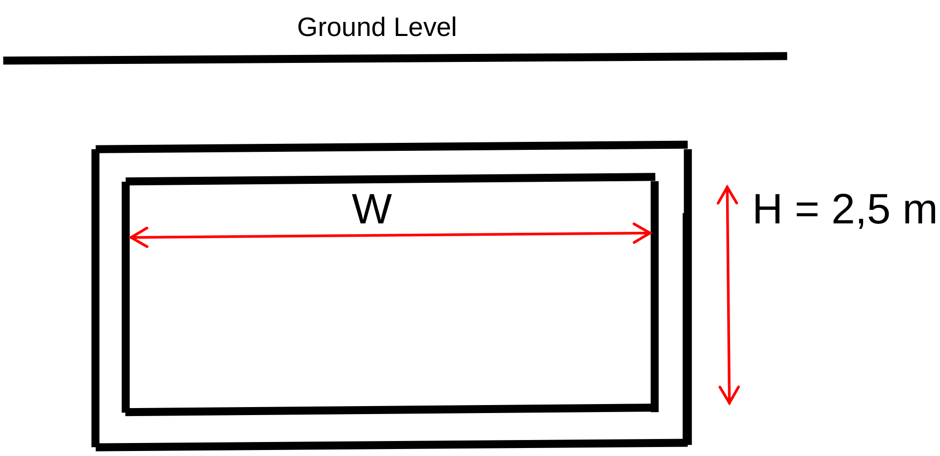


Figure 37 : Standard cross section of the embankments protections of the Soufriere river

2.3.2.3 Re-calibration of the « Ruby » stream and creation of a new direct outlet into the Soufriere river

Arriving in the urban area of Soufriere, the « Ruby » stream will have to be resized in order to reduce flood risk. The proposed channel will be a reinforced concrete open channel. A new outlet would be constructed directly into the Soufriere river ; its last part would be covered.

Covered section and road crossing culvert :



- 1 – in – 10 year project : W = 4,5 m
- 1 – in – 50 year project : W = 6,5 m
- 1 – in – 100 year project : W = 7,1 m
- Tomas" project : W = 7,3 m

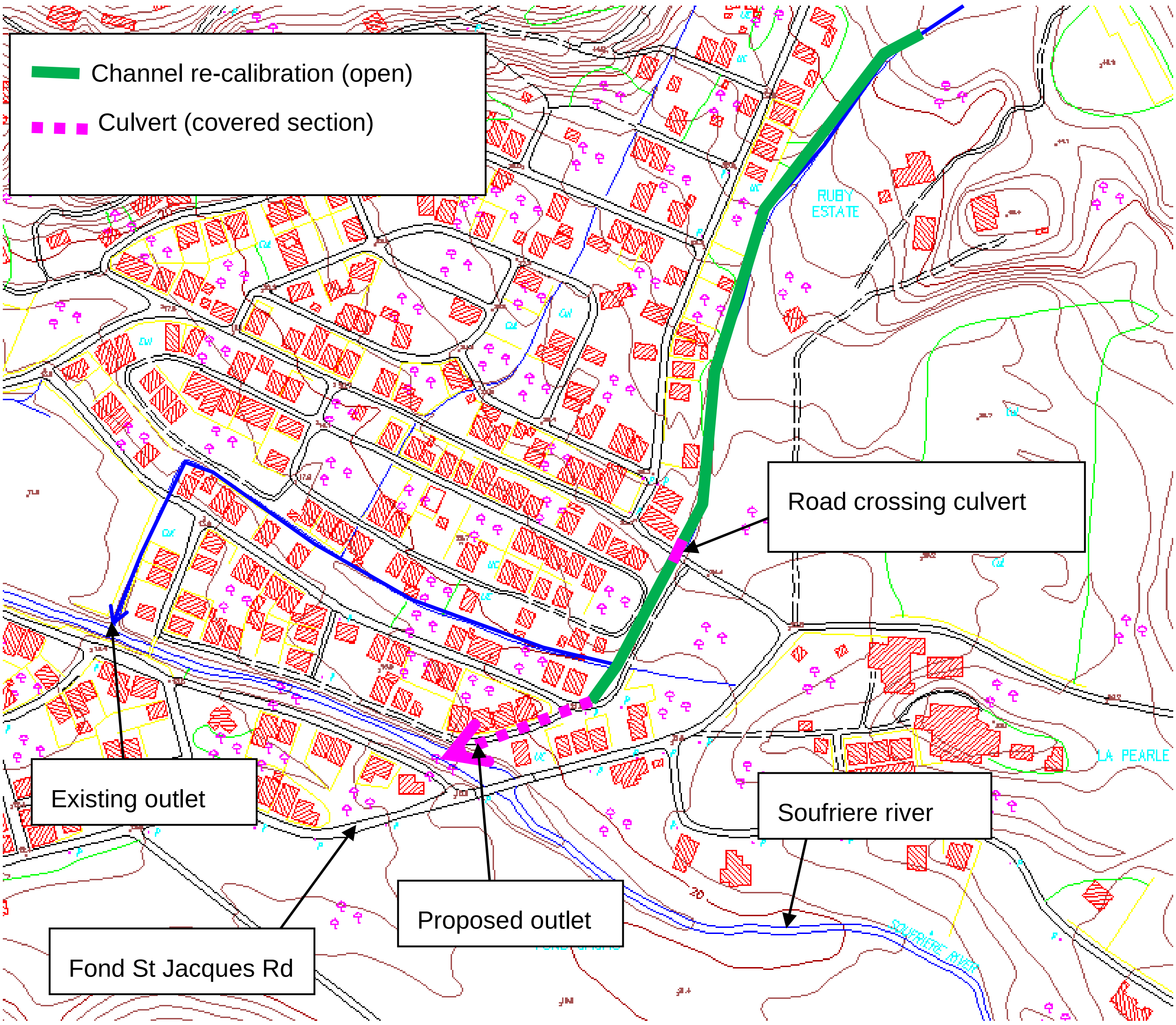


Figure 38 : « Ruby » stream new course

In order to limit the water velocity to 5 m/s in the channel, the natural of the stream has to be reduced with 1.5m high falls.

With this modified slope (reduced to 0,006 mpm) and the maximum flows to evacuate, for a 2.5m high channel (taking account of a safety margin of 0.5m above maximum water levels) the width would be : :

- 4,5 m for 1-in-10-year return period event
- 6,5 m for 1-in-50-year return period event
- 7,1 m for Tomas event,
- 7,3 m for 1-in-100-year return period event.

The standard cross section and longitudinal profile of the Ruby channel are given in the next figures.

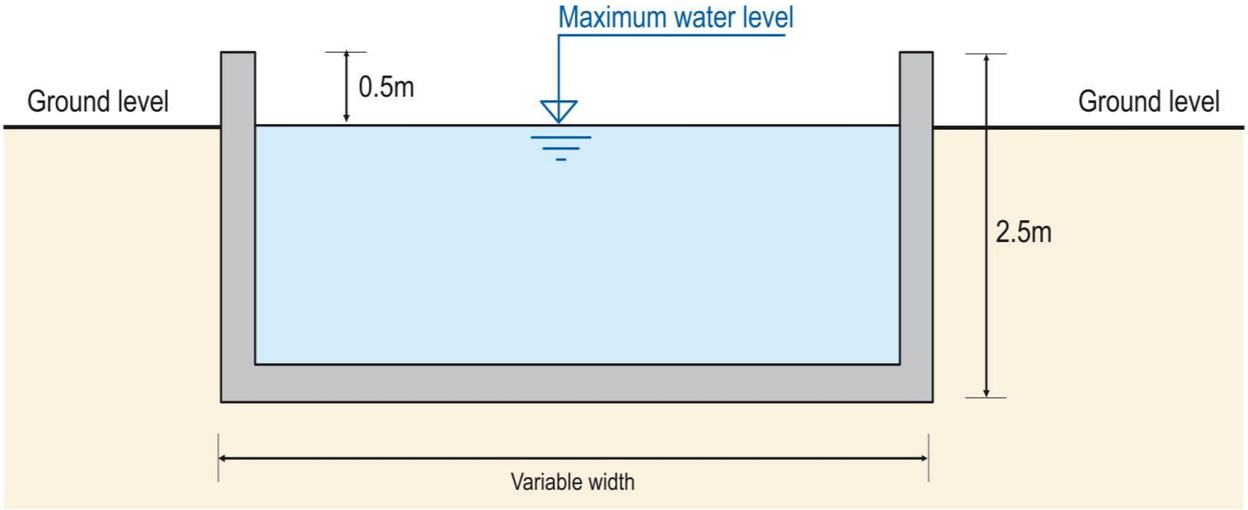


Figure 39 : Standard cross section of the Ruby channel

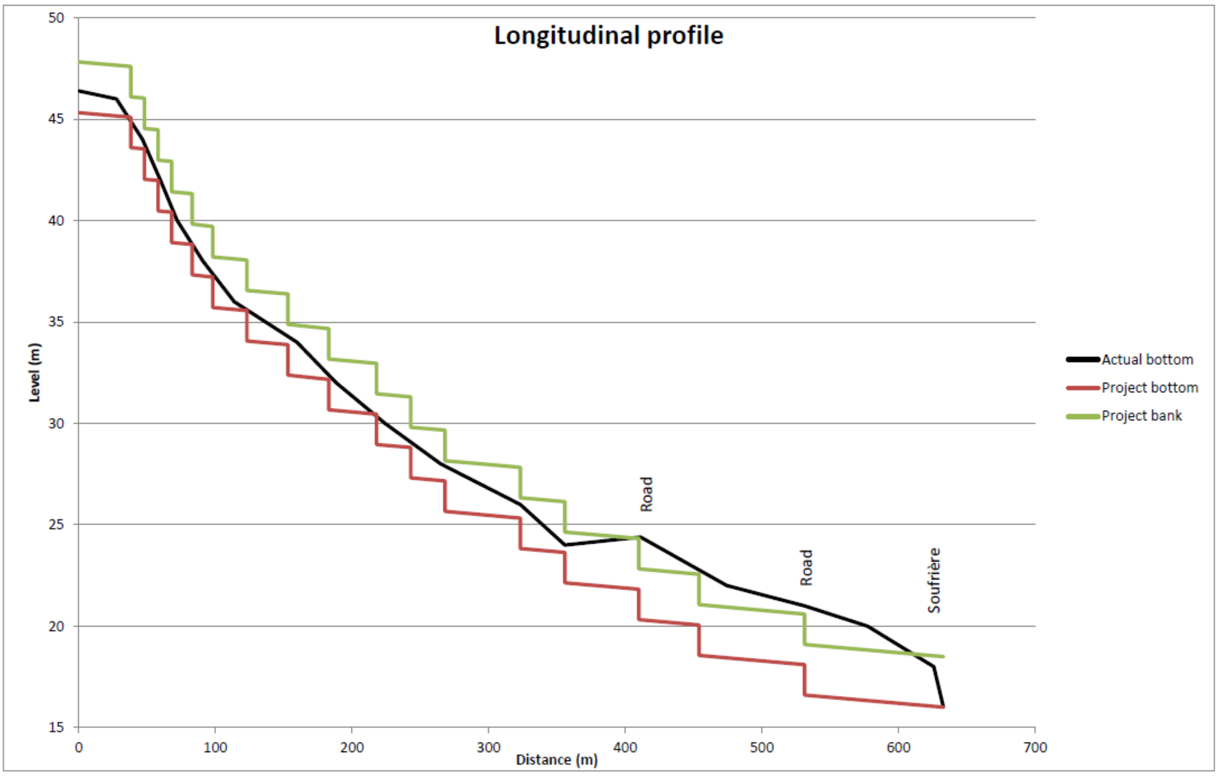


Figure 40 : Longitudinal profile of the Ruby channel

2.4 In Fond Saint Jacques

2.4.1 Existing critical infrastructures in Fond Saint Jacques

In Fond Saint Jacques the critical infrastructures are described below and mapped in the next figure :

- **1/ The streams natural bends and banks (1)** are fragile, they need protections
- **2/ Two bridges** (1a and 1b) are not well dimensioned (overflowed for 1-in-10 year flood event)

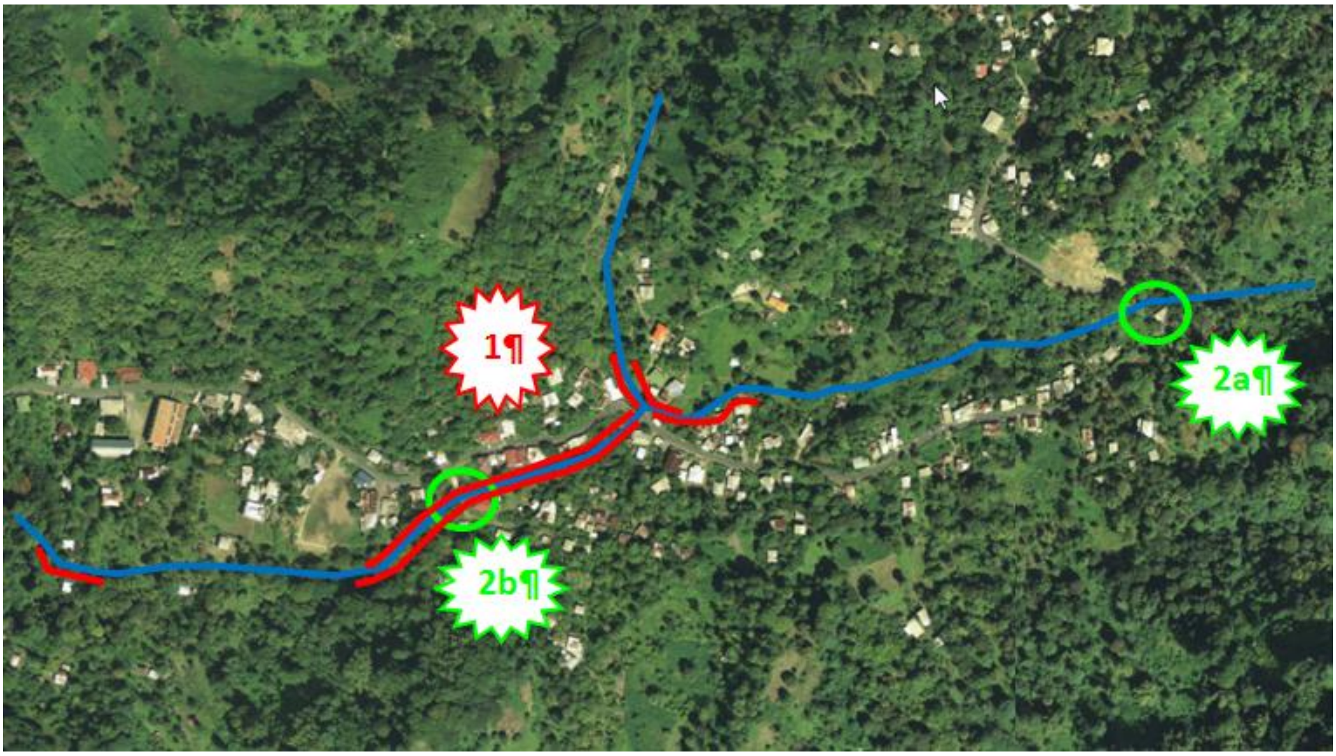


Figure 41 : Fond Saint Jacques critical infrastructures

2.4.2 Note about the debris flow modeling

As said before, the Fond Saint Jacques particularity is debris flow caused by upstream landslides. Those debris flows can't be modeled : as it is not possible to determine the amount of cubic meters of debris that could collapse during a rainfall event, there is **NO EXISTING LANDSLIDES DEBRIS FLOW HYDRAULIC MODEL.**

During our field survey, we have seen that a lot of landslides might occur again (lot of very steep and non-vetetalized slopes in the upper catchment).

What can only be said is that Tomas event, with his big landslides, can occur again.

The model done for report #2 was calibrated with the Tomas water/debris levels survey: we have artificially increased the peak discharges until the levels calculated by the model reaches the water/debris levels surveyed.

This is the only way to produce a good flood/debris exposure map in this community, based on Tomas event.

2.4.3 Proposed structural measures in Fond Saint Jacques

It is not possible to protect the community of Fond Saint Jacques against landslides and associated debris and mud flow with structural measures.

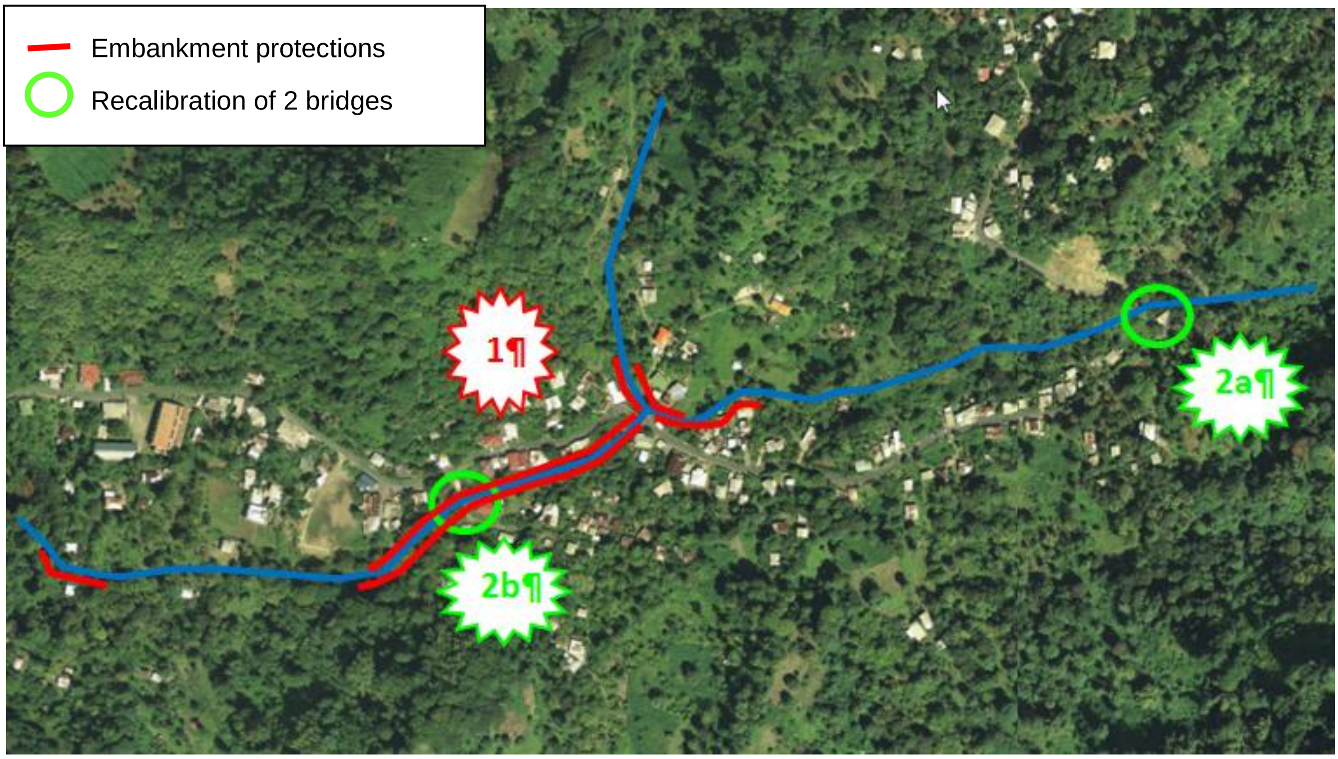
But we propose de following structural measures to reduce the risk :

1/ Embankments protections of the streams,

2/ Recalibration of 2 bridges (bridges 2a and 2b)

3/ Creation of 2 jam traps (3a and 3b)

The localization of the proposed works is given hereunder:



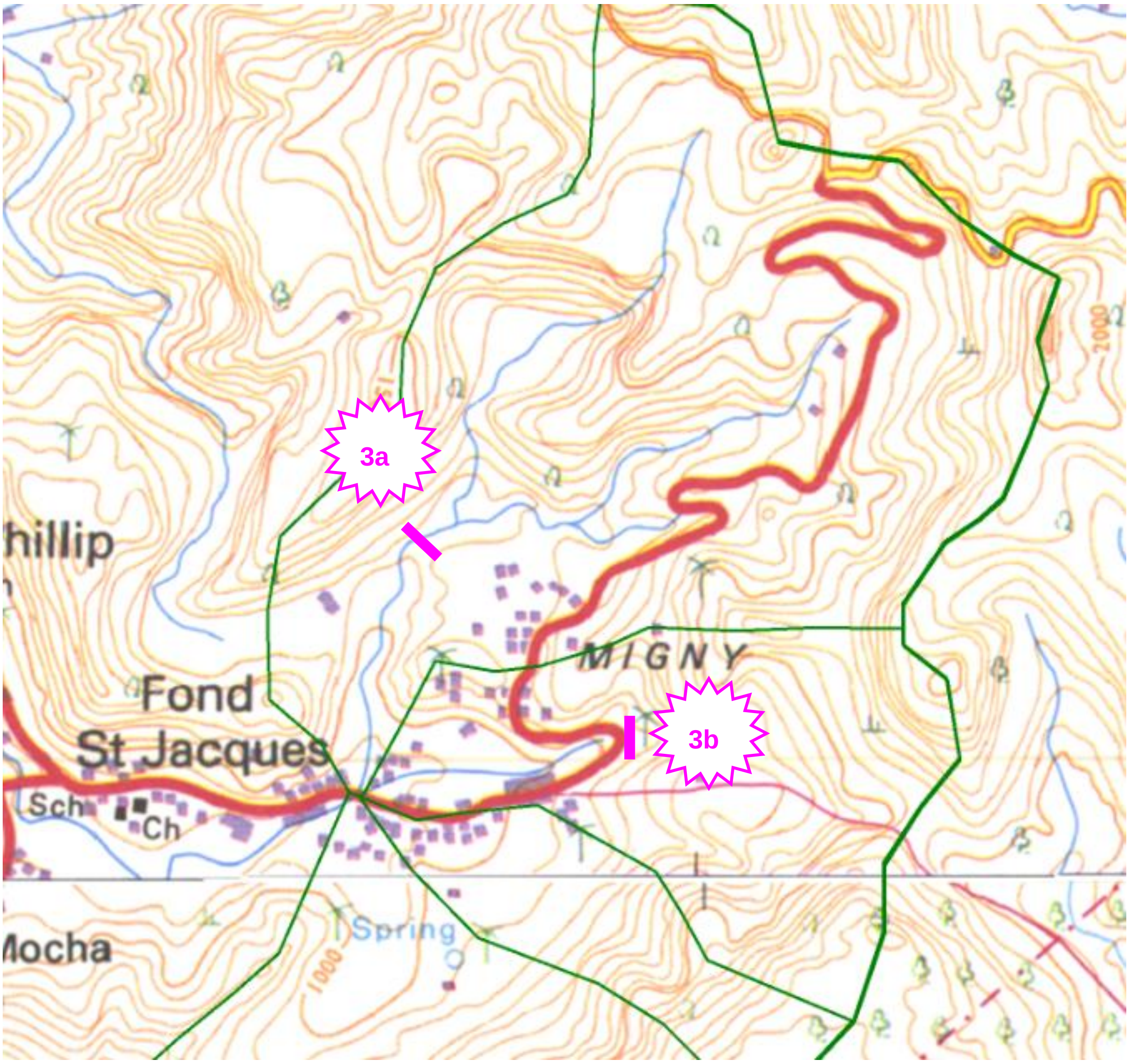


Figure 42 : Localization of structural measures in Fond St Jacques

2.4.3.1 Streams embankements protections

The banks protections are ensured by rip rap placed on the embankments. The corresponding standard cross section is given on the following figure.

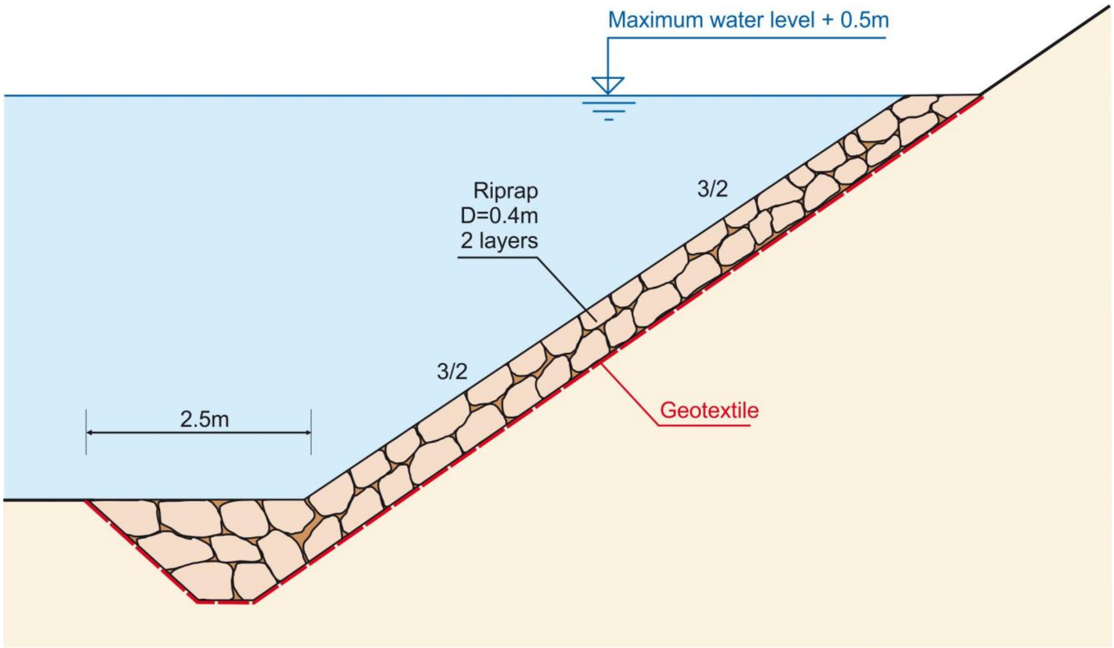


Figure 43 : Standard cross section of the embankments protections of the Fond Saint Jacques streams

2.4.3.2 Recalibration of 2 bridges

Bridge 2a on Migny road :

The actual culvert (1.7m wide x 2m high) is calibrated for 10 years return period.

In order to improve its hydraulic capacity the dimension of a new culvert should be :

- **For 50 year return period : 2.2m wide x 2m high)**
- **For 100 year return period : 2.5 wide x 2m high)**

Bridge 2b:

The actual bridge (7m wide x 1.3m high) is calibrated for 10 and 50 years return period (.

In order to improve its hydraulic capacity the dimension of a new culvert should be :

- **For 100 year return period : 7 m wide x 1.8 m high)**

2.4.3.3 Jam traps

The construction of a jam trap upstream of the streams of the community of Fond St Jacques is feasible and will be effective to protect the downstream inhabitants of the area.

It appears necessary to build a very massive structure in order to resist to a debris and mud flow caused by an upstream landslide.

An example of this kind of structure is given hereafter.

Figure 44 : view of a debris flow resisting jam trap

Chapter 3. Non-structural measures

Non-structural measures are particularly important for the island of Saint Lucia for several reasons:

- the high cost and short lifetime of structural measures
- lack of capacity to build and operate structural measures
- low involvement of local community, lack of feeling of ownership
- other environmental impacts of structural measures

Non-structural measures tend to be more sustainable because they include the active involvement of the community. National and regional policy should favour non-structural alternatives due to their low cost and reduced number environmental side effects, and implement structural measures only as a last resort.

Success in managing flood areas depends on selecting suitable measures based on flood characteristics, physical and morphological characteristics of flood areas, economic and social conditions, political and environmental conditioning, or flood-control works planning. Structural measures cannot reach these objectives if they are used alone; non-structural measures such as land use control and planning can be tools not only to reduce flood risk, but also to develop a sustainable approach to flood management. Risk reduction is one of the main goals in flash flood management.

It can be dealt with in two ways: prevention strategies and mitigation strategies.

Risk reduction	Prevention strategies	Watershed management
		Delimitation of flood areas and securing flood plains
		Implementation of flood area regulations
		Application of financial measures
	Mitigation strategies	Reduction of discharge through natural retention
		Forecasting and early warning
		Emergency action based on monitoring, warning, and response systems (MWRS)
		Public information and education

Table 2 : Non structural measures for risk reduction*(source : Colombo et al. 2002)*

3.1 Prevention strategies

3.1.1 Watershed management

Watershed management has both structural and non-structural components. Non-structural components can be important measures in reducing flash flood risk. Watershed management is a cross-cutting exercise closely related to socio-economy and development. Watershed management should consider a number of basic principles related to runoff and erosion including soil, topography, land cover and use, and farming practices.

The following measures in a watershed can significantly reduce the risk of flash floods (see figure below) :

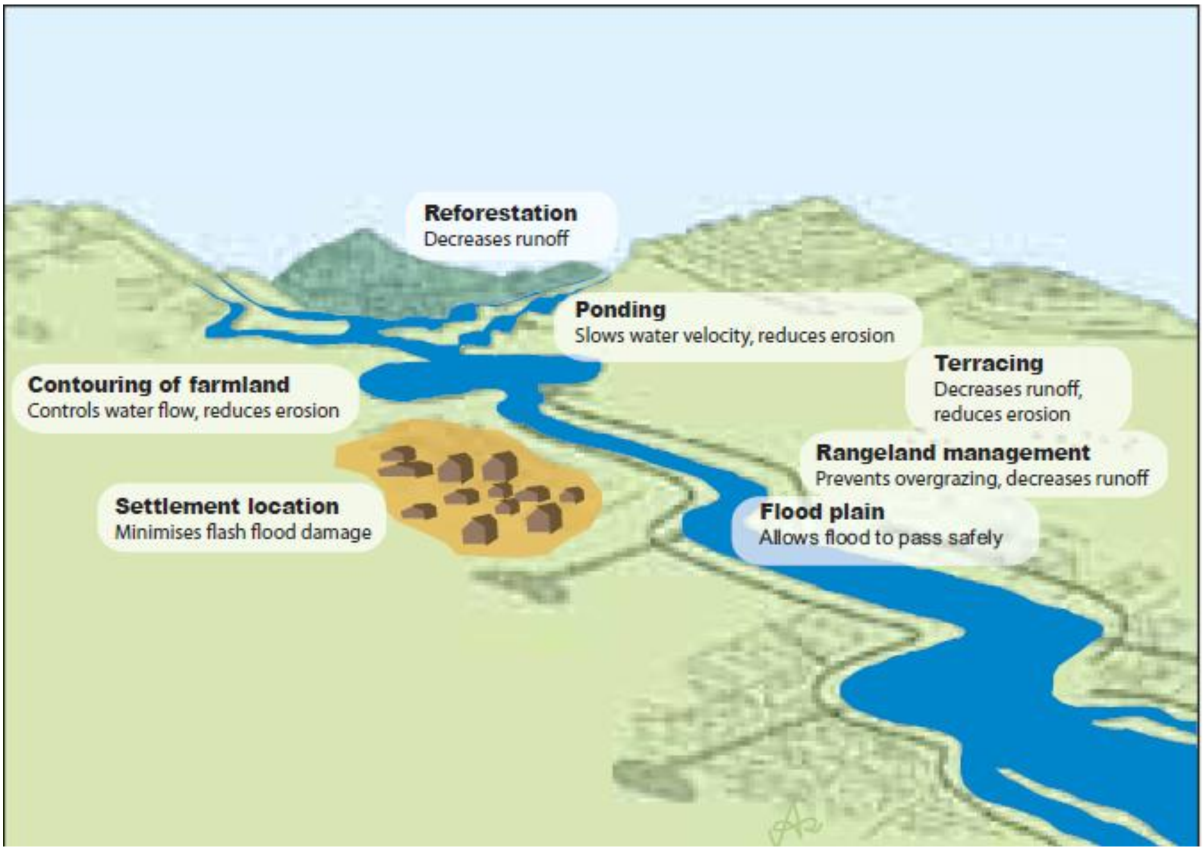


Figure 45 : some aspects of watershed management

3.1.1.1 Agricultural measures:

Agricultural activities should minimize the generation of runoff and sediment. Contouring and terracing of upland farms is a good measure to ensure this. Crops should be selected to ensure longer coverage, especially in rainy periods. Conversion into arable land should be avoided where slopes exceed 25%. Agricultural practices that increase organic matter in the soil should be favored.

Forestry:

Reforestation can be a good measure to decrease runoff. Tree species that do not prohibit undergrowth should be selected. Logging should be carried out during non-rainy seasons. Favor mixed, uneven aged, and autochthonous woods.

Rangeland management: Pasture renewal through fire must be avoided as this reduces soil organic matter.

For the three studied communities, we propose the following watershed management principles:

- **Steep slopes (>25%) : avoid the destruction of existing forest – reforestation if needed (especially on landslides)**
- **Promote agricultural practices in floodplains (bottom of the valleys)**
- **Control water on cultivated slopes in order to reduce soil erosion and landslide risk**
- **Avoid agricultural practice on landslides but reforestation**

3.1.1.2 Rivers maintenance plans:

In the three studied communities, lack of maintenance have been pointed out (see report#1 and #2) to be one of the causes of malfunctioning drainage et flood evacuation.

This is why it is important to adopt and follow a maintenance plan of the studied rivers :

- **Field inspections of river beds and banks at least twice a year (before and after hurricanes and heavy rains period) : overview of infrastructures stability (rip rap protections, bridges foundations …), state of the vegetation, state of cleanliness of the river channels …**
- **Mechanical or hand clearing of river banks in inhabited areas every often as needed**
- **Remove debris and rubbish every often as needed**
- **Mechanical clearing of the bottom of river beds (especially remove the sand from the mouth of the rivers: Mole River and Soufriere River) every often as needed**

The regularity of these maintenance activities is important and not easy to define. We propose to do it on a quarterly basis the first year and adapt the rhythm of the next years with this first year feedback.

3.1.1.3 Watershed management In Dennery:

See next figure

Most part of the watershed is composed of steep slopes and the forest has to be preserved in these areas.

We propose to **reforest 2 zones** where landslides have occurred during Tomas in the upper part of the Mole river catchment (delineated with the aerial photograph taken after Tomas).

A rivers maintenance plan should be done in Dennery :

- Along the Mole river, from the mouth to the bridge of the main road
- Along the ravine Trou à l'Eau, from the mouth to the bridge of the main road

More generally a maintenance plan should be set along all de concrete drainage culverts of the center of Dennery, to keep them clean and clear of obstruction.

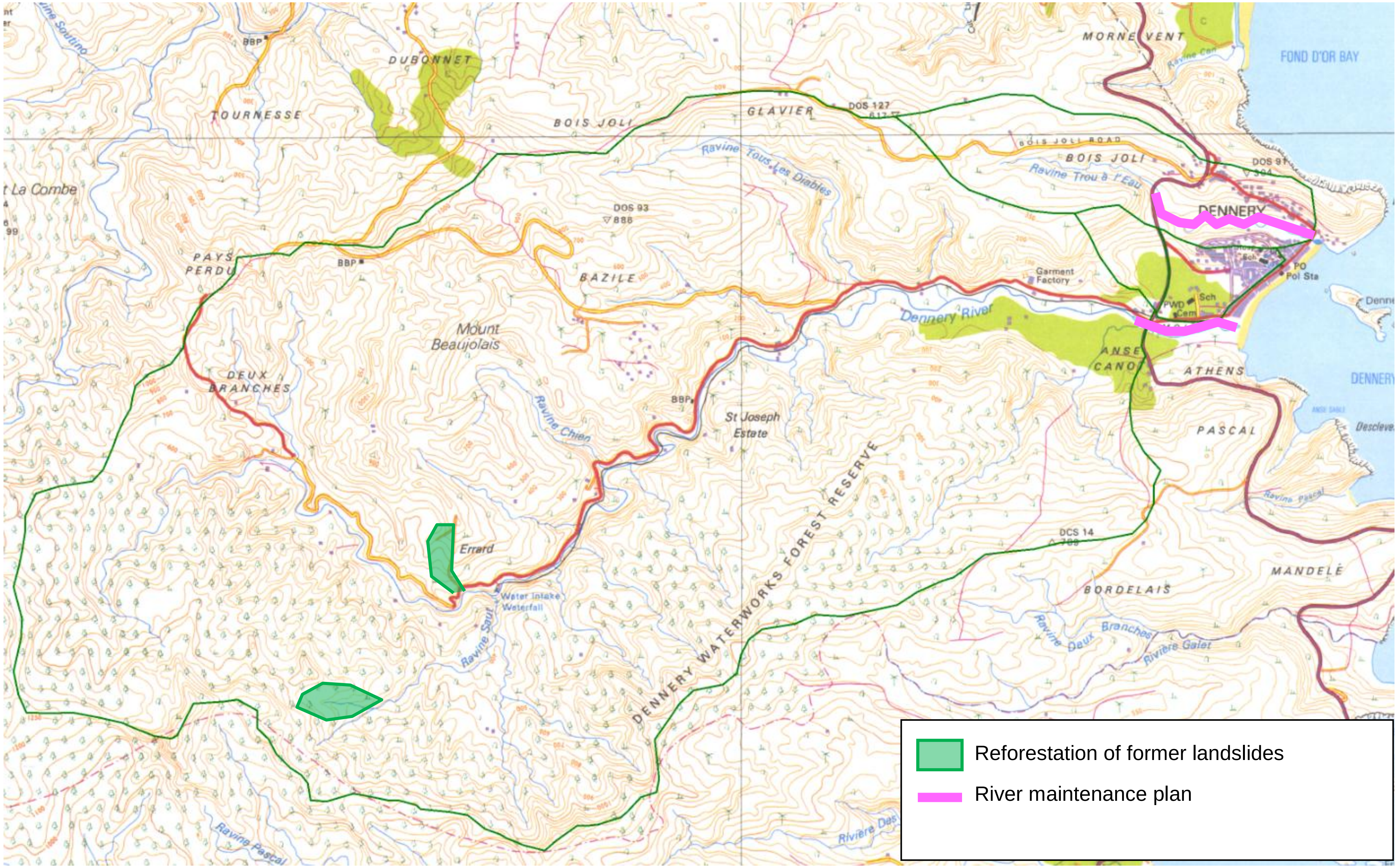


Figure 46 : Watershed management in Dennery catchment

3.1.1.4 In Soufriere Watershed:

Most part of the watershed is composed of steep slopes and the forest has to be preserved in these areas. We propose to reforest all zones where landslides have occurred during Tomas (delineated with the aerial photograph taken after Tomas), and avoid agricultural practice on them (even it is a common practice in Saint Lucia). The arable lands should be developed in the flat bottom of the streams valleys.

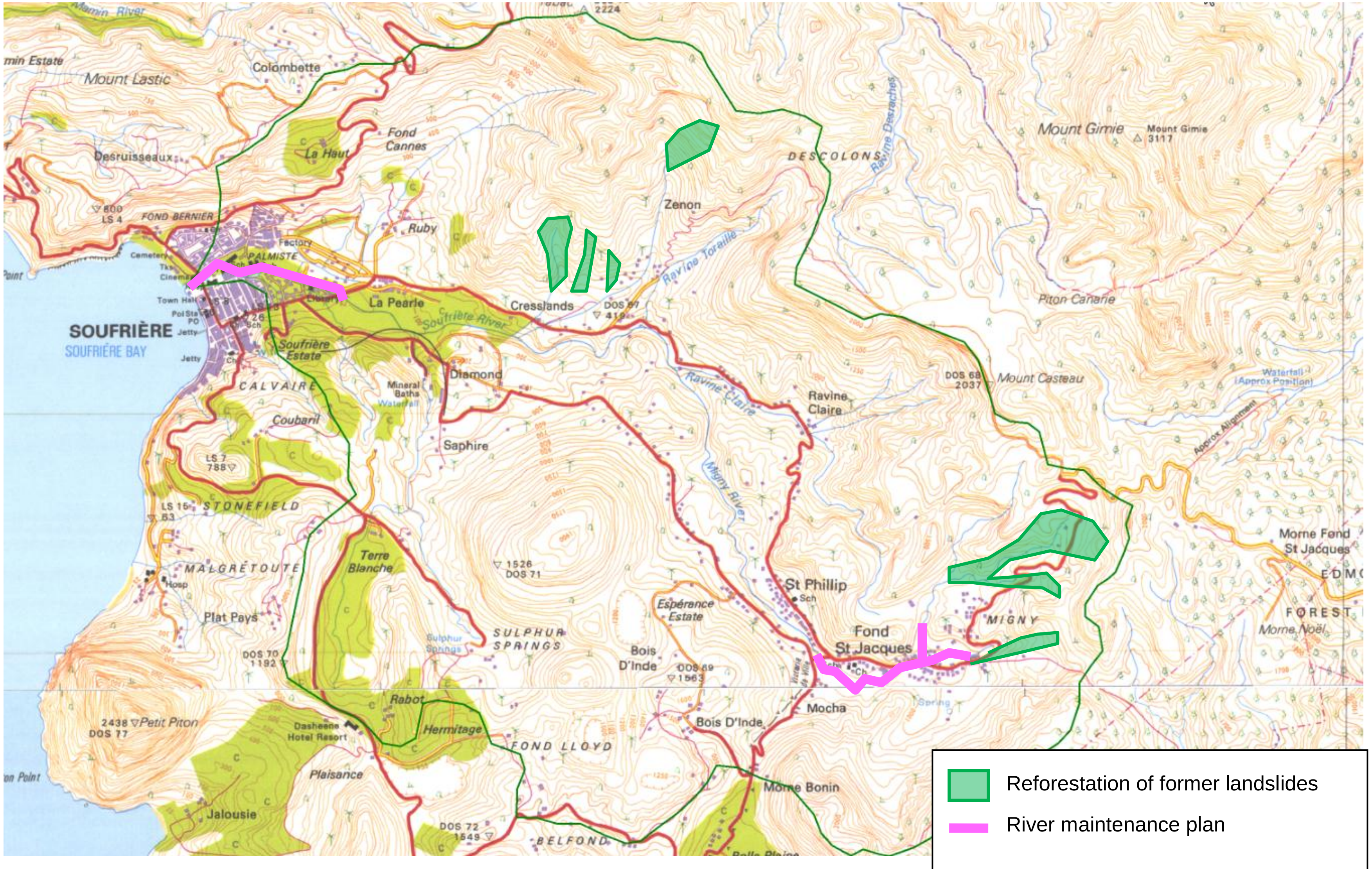


Figure 47 : Watershed management in Soufriere catchment

3.1.1.5 Focus in fond saint Jacques watershed:

Most part of the watershed is composed of steep slopes and the forest has to be preserved in these areas. We propose to reforest all zones where landslides have occurred during Tomas, and avoid agricultural practice on them (even it is a common practice in Saint Lucia). The arable lands should be developed in the flat bottom of the streams valleys.

In Fond Saint Jacques, the main problem is landslides, which cause devastating debris and mud flow in the community. As Fond Saint Jacques is situated in the upper part of the watershed, the distance between landslides areas and the first settlement is very short (less than 1km), meaning that the time between a landslide and the first damage in Fond Saint Jacques is extremely short (less than 10 min). This time is not enough to secure population: they will not have enough time to evacuate if there was an alert.

Another difficulty of landslides is that it is not possible to predict when and where it could happen.

This leads us to propose the following measures in Fond Saint Jacques.

1/ To avoid the return of inhabitant along the streams : a program of new settlements has been done after Tomas. The population most at risk (whose houses were damage during Tomas) is now living in a safe area. But the damaged houses are still in place. To avoid the possible return of inhabitant in the dangerous zone in the future, we propose to destroy those houses. (in the violet zone of the hazard map – *see Annex*).

Figure 48 : picture of relocation settlements in Fond Saint Jacques

Figure 49 : Houses in Fond Saint Jacques to destroy -> all houses between the Migny road and the stream

Figure 50 : Houses in Fond Saint Jacques to destroy view from the bridge 2b (see Figure 41 : Fond Saint Jacques critical infrastructures)

2/ To reduce landslide risk :

The measures described in the MoSSAic program in Saint Lucia should be applied in Fond Saint Jacques catchment area (see Figure 53 : Steep slopes in Fond Saint Jacques' catchment area with landslide hazard – zones where MoSSaiC program should be applied) :

- Capture and drainage of water before it reaches potential slope area
- Slopes drainage
- Reforestation, planting of deep rooting trees to prevent surface slips :no agricultural practice on landslides.
- To give farmers others places to plant, we propose for example to use the new free of settlement area of Fond saint Jacques (where houses have to be destroyed).

To make MoSSaiC more readily accessible to more communities with high vulnerability to landslides, MoSSaiC and the Latin American and the Caribbean disaster risk management team are currently preparing a book (*Managing disasters in small steps: Community-based landslide risk reduction*), to be followed by an ePractice web-based toolkit of resources for country practitioners and communities.

Figure 51 : Picture of a landslide in Fond saint Jacques converted in arable land: increase landslide risk -> to reforest

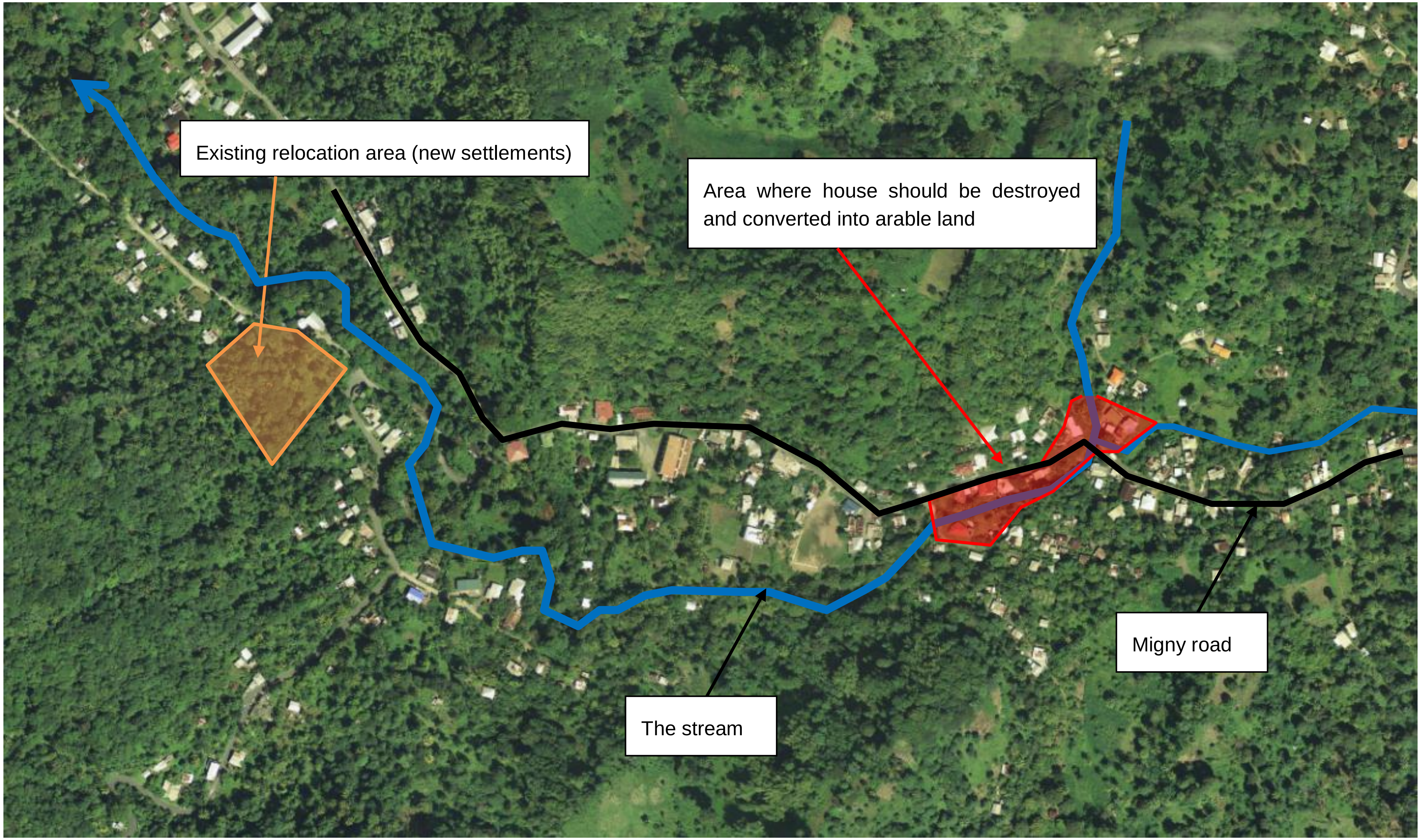


Figure 52 : proposed measures in Fond Saint Jacques

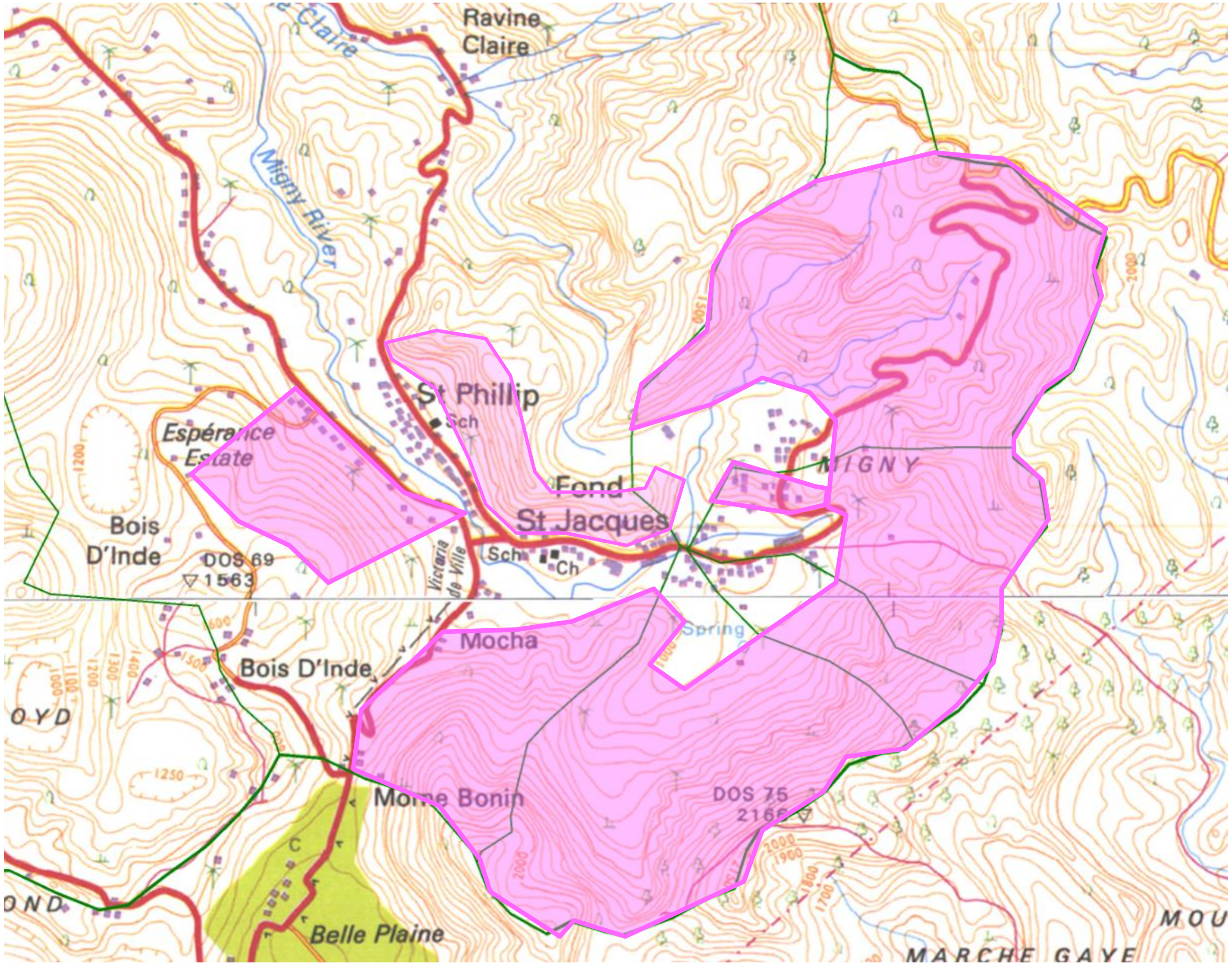


Figure 53 : Steep slopes in Fond Saint Jacques' catchment area with landslide hazard – zones where MoSSaiC program should be applied

3.1.2 Floodplain management and flood area regulation

3.1.2.1 Generalities

Floodplain management includes flash flood hazard mapping, which shows the areas that will be impacted by a flood of a particular return period and enables delimitation of flood areas. Flood hazard mapping can be conducted to different degrees of detail. A very simple flood hazard map shows the area of inundation. In addition, the depth of inundation, the velocity of flood water at a given location, elements at risk, and others can be provided.

– One important activity is the **delimitation of flood areas and securing of flood plains**. Based on the technical study on flash flood hazard mapping, streams should have adequate buffer areas to safely cater for flood waves. The floodplain can for example be divided into different zones were constructions/activities should be prohibited, limited or authorized with prescriptions, or fully authorized.

– Land use regulation : it is designed to reduce danger to life, property, and development when flash floods occur. The following elements should be addressed while implementing land use control in a watershed. Many of the elements mentioned here are directly related to planning and policy makers, although flash flood managers should also have a good understanding of these issues.

- **Prohibiting development in areas of high risk**: No major development should be permitted in these areas. Areas of high risk can be used for functions with a lower risk potential such as nature reserves, sports facilities, and parks. Functions with high damage potential such as hospitals should be permitted in safe areas only.
- **Relocation of elements that block the flood passage**: In addition to the obvious danger of being damaged or washed away, buildings and other structures blocking the floodway may cause damage by trapping floodwaters which then overflow into formerly flood-free zones.
- **Implementation of a building code**: The design of buildings and choice of building materials should consider the probability and severity of flash floods.
- **Provision of escape routes**: Land use plans should have clear escape routes and provide refuge areas on higher ground.
- **Natural ponds** in the watershed retain the runoff and dampen the peak discharges in the stream. The ponds should be maintained properly and filling the depressions for development purposes should be avoided.

3.1.2.2 Flood hazard mapping in the three studied communities

The INTERREG IV "Caribbean" program was approved by the European Commission on 27 March 2008, for the benefit of the Caribbean regions.

As part of this program, Egis has participate with the redaction of "**Guide for disaster risk prevention and reduction plan (PPR) in the Caribbean"**

In this guide, the recommendation for risk mapping it a crossing between the flood levels map and velocity map. The maps have to be done for the 1-in-100 years return period or the highest flood known. In the three studied communities, Tomas event is higher than the 1-in-100 flood event.

This is why for Dennery, Soufriere and Fond Saint Jacques, the flood hazard maps are done with Tomas event.

FLOOD HAZARD Based on Tomas Event	Velocity	
Height	Low and interm. between 0 et 1 m/s	High over 1 m/s
H < 1 m	Medium risk	High risk
1 < H < 3 m	High risk	High risk
H > 3 m	Major risk	Major risk

Table 3 : Flood hazard mapping criteria for Dennery, Soufriere and Fond Saint Jacques

The corresponding Flood Hazard maps in Dennery, Soufriere and Fond Saint Jacques are given at the end of the report (*see Annexes*).

- **Major Flood Risk (purple)** : exceptional hazard – riks and damages are extremely severe - human lives are threatened.
- **High Flood Risk (red)** : risks and damages are important. Protection measures are difficult and expensive to implement. Human lives are threatened.
- **Medium Flood risk (orange)** : lot of damages but bearable and protection measures are possible.
- **Low Flood Risk (no color)** : flood risk are very low.

Constructions rules must been associated to every zone of this map. Those rules, written with international engineering best practice, are given hereunder.

- <u>**Flood Major Risk zones (Purple zones)**</u>

In purple zones, rules must be made to remove exposed population and properties.

The principle are :

- NO CONSTRUCTIBILITY (This means no new construction, no reconstruction of destroyed buildings.)

- DESTRUCTION OF EXISTING BUILDINGS AND RELOCATION OF PEOPLE ALREADY LIVING IN THE ZONE.

- <u>**High Risk zones (Red zones)**</u>

In red zones, rules must be made to enhance risk management, improve the security of people already living in the zone and not increase exposed population and properties.

The principle is NO CONSTRUCTIBILITY.

This means <u>no new construction</u> and <u>no reconstruction of destroyed buildings.</u>

But some projects, activities or works could be authorized in order to let people go on with their lives, if they are compatible with the described objectives.

For existing constructions with floor lower than Tomas water level, push for:

- a shelter level (second floor or operable roof window)

- and cofferdams at all the outside doors.

- <u>**Medium Risk zones (Orange zones)**</u>

In orange zones, rules must be made to enhance risk management, improve the security of people already living in the zone and new inhabitants.

The principle is CONSTRUCTIBILITY WITH PRESCIPTIONS.

Prescriptions are :

- For new constructions : first floor level 0.50m above Tomas water level

- For new constructions : construction on silts (to let the water pass under the building)

- For existing constructions with floor lower than Tomas water level : add a shelter level (second floor or operable roof window) and put cofferdams at all the outside doors.

3.2 Mitigation strategies

The following sections provide some examples of non-structural measures that can be used to reduce the intensity, frequency, and impacts of flash floods.

3.2.1 Reducing discharge through natural retention

Studies on water flow have identified the early securing of areas for flood control purposes, so as to have them available in emergency situations, as a crucial aspect. To this end, natural retention areas must be identified and improved, although this is in contrast with the desire to use them for industrial, economic, settlement, and transport purposes. Specific regulations should be made to avoid exploitation conflicts that may arise. Agricultural practices or sports fields for example can be allowed in those areas.

In the three studied communities, we have identitified:

- **In Soufriere : the sport fields (in green hereunder)**. The level of the ground is here higher than the ground of the opposite bank, which is urbanized. We propose to lower the sports field in order to let the river outflows in the sports field instead of flooding the settlement areas

Figure 54 : Natural retention in Soufriere

- **In Dennery central zone : the sport fields (in orange hereunder)** and the **wetlands (in yellow)**- Note that some former wetlands have been filled and must be re-dug to regain their capacity. The sport fields can be lowered too to increase the storage capacity.
- **In Dennery along le Mole River : the agricultural flat bottom of the valley must be kept available for natural retention along the Mole river flood plain (in red hereunder).** It is situated mainly on the right hand side of the river.
- **There is no natural retention zone identified along the Ravine Trou à l'Eau (steep slopes, inappropriate for retention).**

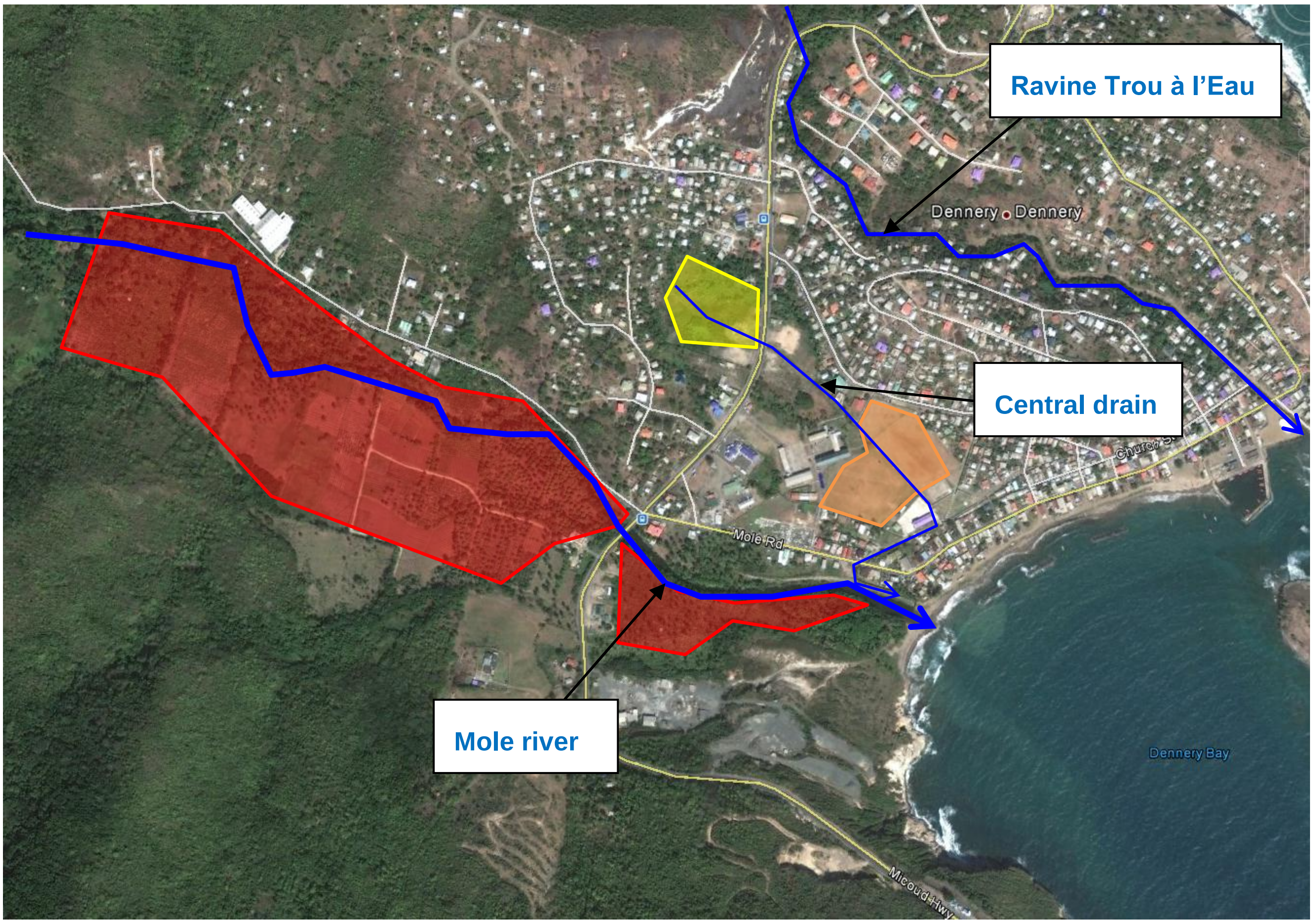


Figure 55 : Natural retention in Dennery

In Fond Saint Jacques, no natural retention zones have been identified (steep slopes, inappropriate for retention).

3.2.2 Monitoring, warning, and response system (MWRS)

3.2.2.1 General overview

Actions based on monitoring, warning, and response systems (MWRSs) can be a very effective form of nonstructural flash flood management. MWRSs include many components, all of which contribute towards the mitigation of flash floods. MWRS is often referred to as an end-to-end flash flood mitigation system. Each component in the system is explained below. Failure of any of these components to function can hamper the effectiveness of the whole system (See Figure 56 : Scheme of possible monitoring, warning and response system.)

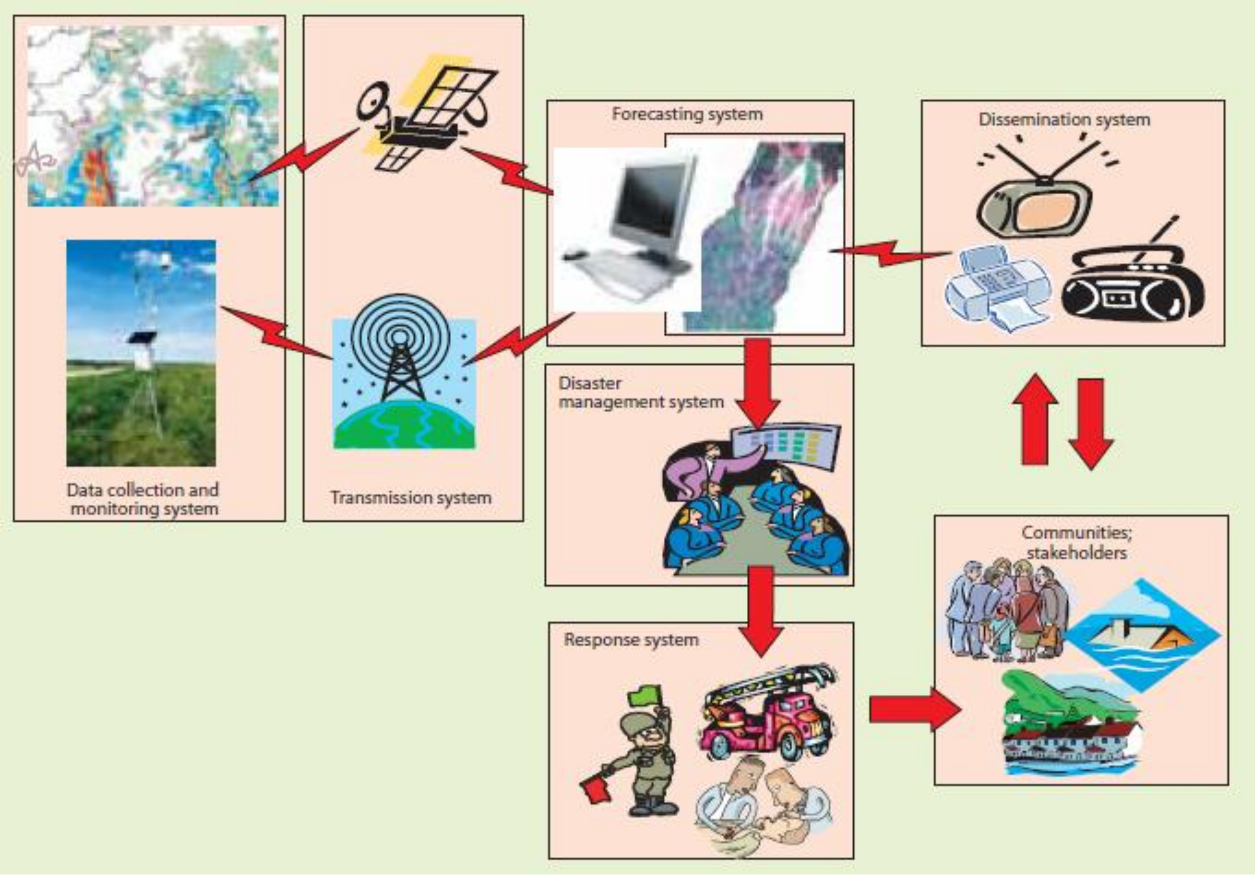


Figure 56 : Scheme of possible monitoring, warning and response system

- Data collection and monitoring system

Monitoring extreme hydrometeorological events is the first step towards understanding what could happen in the future and choosing from possible alternatives. Collection of hydrometeorological data, such as rainfall, temperature, and streamflow, is essential for simulating the natural phenomena. Ground observation networks are commonly used to collect rainfall and other meteorological data. However, radar-based precipitation estimation may be the only source of rainfall data due to scarcity of hydrometeorological networks, long delays in data transmission. A ground-based network seldom has the density sufficient to reflect the natural spatial variability of precipitation, particularly in mountainous terrain. Radar estimation can be a valuable complement in such cases. On the other hand, radar estimates are sometimes biased due to different limitations such as orographic effects and warm cloud processes. Thus, it is not possible to rely on radar rainfall estimates alone. A combined radar and surface-based rainfall estimate provides the best input for flash flood forecasting and early warning systems.

- Data transmission system

An efficient data transmission system is necessary for timely data transfer from the monitoring site to the centre where the data are analysed. After analysis, the forecasts and warning messages should be relayed to end users in a timely manner. A wide range of data transmission systems are available. Automatic transmission of data from the gauge to the centre through different digital media such as terrestrial telephone, GSM, or satellite connections is the most reliable, although the high cost of such systems can be a limitation.

- Forecasting system

Forecasting systems can also vary in complexity. Normally, a forecasting system consists of models (hydrological, hydraulic, and so on) that predict scenarios of potential flash flood events and closely follow the evolution of key parameters that could trigger them. The model may be complicated and can result in very accurate forecasting, but may be of no use if the computation takes so long that it does not provide sufficient lead time before the flood event. Flash floods are rapid processes and often lead time is very small. Further, lack of sufficient data regarding land characteristics hinders the application of sophisticated models. Flash flood managers should consider all these aspects while selecting models for flash flood forecasting. More simplistic models, such as flash flood guidance tables, may be preferable.

- Warning system

The general public may not be able to interpret quantitative flash flood forecasts, in which case qualitative warnings have to be issued. Floods are classified into different categories of warnings, which communities and stakeholders should be able to interpret in terms of impact on them. Flash flood guidance can be the volume of rainfall in a given duration over a given small catchment that is just enough to cause minor flooding at the outlet of the draining stream. Any rainfall in excess of the flash flood guidance is considered a flash flood threat.

- Dissemination system

After a flood forecast and warning are prepared, they must be disseminated effectively. In the majority of cases, good forecasts fail to prevent damage and loss of life due to poor dissemination systems. The forecasts and warnings should reach agencies related to the disaster management system in a timely and understandable manner. These agencies should issue forecasts and warnings by appropriate media such as radio and television and to different levels of disaster management units down to the lowest level. The warning should be clear and concise to be understandable by communities and should use language that will not cause unnecessary panic. The warning may be in text or use diagrams and maps. It is necessary to conduct community awareness raising programmes to help people understand the warnings. In some communities, small inexpensive radios can be distributed in risk areas so that they have access to warnings.

- Disaster Management System

Even where there is accurate and timely issue of forecasts and warnings, flash flood damage can happen. A disaster management system should be well-prepared for such events. The disaster management system should have an overall vision of the crisis situation. It is the task of the system to alert key action groups, which is part of the response system.

- Response System

A response system consists of actions by groups such as

● police and fire brigade (e.g., assisting vulnerable groups such as the elderly and the handicapped in flood-proofing their houses, evacuation procedures, and so on)

● civil protection authorities (e.g., dissemination of targeted information)

● voluntary groups (e.g., assisting the injured, allocating resources)

● military (e.g., preparing sandbags, constructing temporary structures)

● media (dissemination of information).

3.2.2.2 Proposed MWRS in the three communities

In the three studied communities, the main problem is the very short time between rainfall and correlated floods :

- In Dennery : less than 2h30min
- In Soufriere : less than 1h
- In Fond saint Jacques : less than 10 min

This means that in the 3 communities, flash floods are rapid processes and lead time is very small.

In the light of the previous paragraphs and We propose several actions :

- Use the real-time data of the radar of Martinique
- Add rain gauges in the studied watersheds (automatic rain gauges, maximum time-steps of 30 min – and 10 min for Fond Saint Jacques) ,
- Add discharge gauges on the Mole river and on the Soufriere river
- Connect all the gauges (existing and proposed ones) to NEMO center which should be responsible of all the real-time data collection, transmission, warning, dissemination and response system.

In Saint Lucia, rain gauges and water level stations are now operated by WRMA and the automatic weather stations are operated by Met Office.

A combined radar and surface-based rainfall estimate provides the best input for flash flood forecasting and early warning systems.

The principle is to have a minimum of 2 rain gauges in the catchments of Dennery and Soufriere (Fond saint Jacques is situated in the Soufriere catchment).

Two rain gauges will secure the rainfall measures, even if one of them is not operational.

A minimum of 2 discharges gauges is necessary too, on the Mole river and on the Soufriere river, one upstream were the flood are often , and one downstream, near the towns.

The rain gauges and the upstream discharge gauges are necessary to warn people as soon as possible that there is a flood risk.

The downstream discharge gauges are necessary to alert people of flooding threat. These gauges should be linked to a siren placed in the center of Dennery and Soufriere (for example on the roof of the fire station in Soufriere and on the roof of Dennery school or church). The siren should sound if the level in the river is increasing and reach a specific threshold level.

All data should be collected during several years. The aim is to set an accurate hydrological model in the studied communities, based on the collected data. This will lead to a reliable forecasting system for the communities, improved every year with local events and measurements.

Rain gauges should be placed near a road (for an easy access), in an open area where there are no obstacles, such as buildings or trees, to block the rain. This is also to prevent the water collected on the roofs of buildings or the leaves of trees from dripping into the rain gauge after a rain, resulting in inaccurate readings.

- **In Dennery :**

There is an existing rain station, Errard Estate, in the middle of the catchment. We propose to use this station and equip it with automatic rain gauges if not.

We also propose to add two more automatic rain gauges in the catchment :

- One in the upper part of the catchment, near the “Deux Branche” road.

- One in the downstream part of the Catchement, in the Ravine Trou à l'Eau watershed

Moreover, 2 discharge stations should be placed on the Mole river : one near Errard road , and one on the bridge of the main road in Dennery. If the water reach a threshold level, population should be worn with a siren.

Their location is shown in the "Figure 57 : Proposed locations for monitoring and warning system in Dennery Catchment" and is indicative.

- **<u>In Soufriere / Fond Saint Jacques :</u>**

There are two existing rain stations, Desraches and Soufriere, in the middle of the catchment. We propose to use these stations and equip them with automatic rain gauges if not.

We also propose to add one more automatic rain gauge in the Fond Saint Jacques catchment.

Moreover, 2 discharge stations should be placed on the river :

- one on the new Fond Saint Jacques bridge (Mocha road) ,
- and one on the bridge in Soufriere (Fond Saint Jacques road). If the water reaches a threshold level, population should be worn with a siren.

Their location is shown in the "Figure 58 : Proposed locations for monitoring and warning system in Soufriere Catchment" and is indicative.

In Fond Saint Jacques, time is too short for an early warming. The best way to increase the delay is to follow the real-time radar data (Martinique radar), linked it with local rain gauges to calculate a correcting parameter if needed (in order to correlate radar images and local rain gauges measurements).

But the delay between a potential alert and the flash and debris flood arrival will be very short (few minutes).

This is why we propose to relocate people living along the streams in Fond Saint Jacques as much as possible.

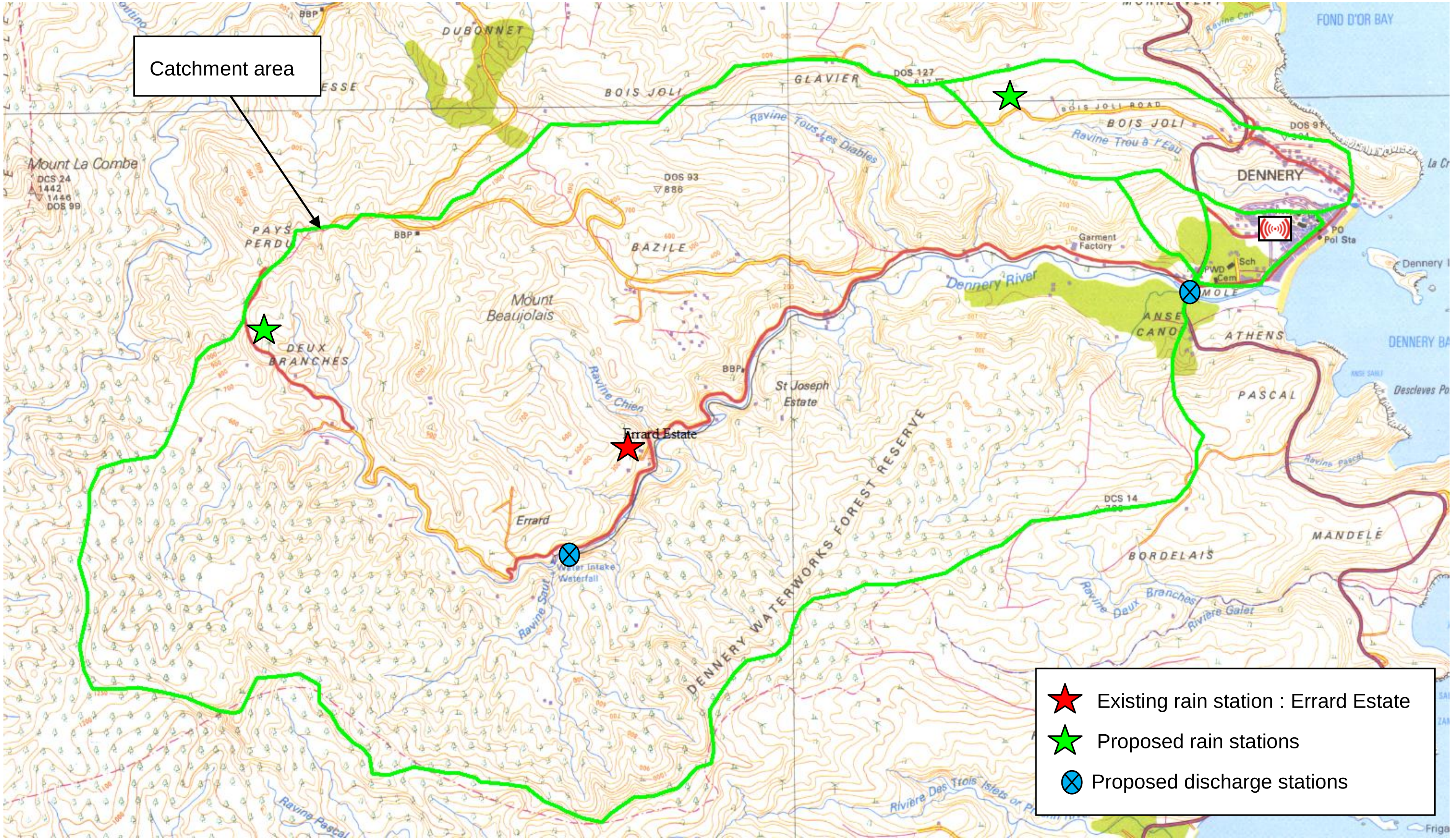


Figure 57 : Proposed locations for monitoring and warning system in Dennery Catchment

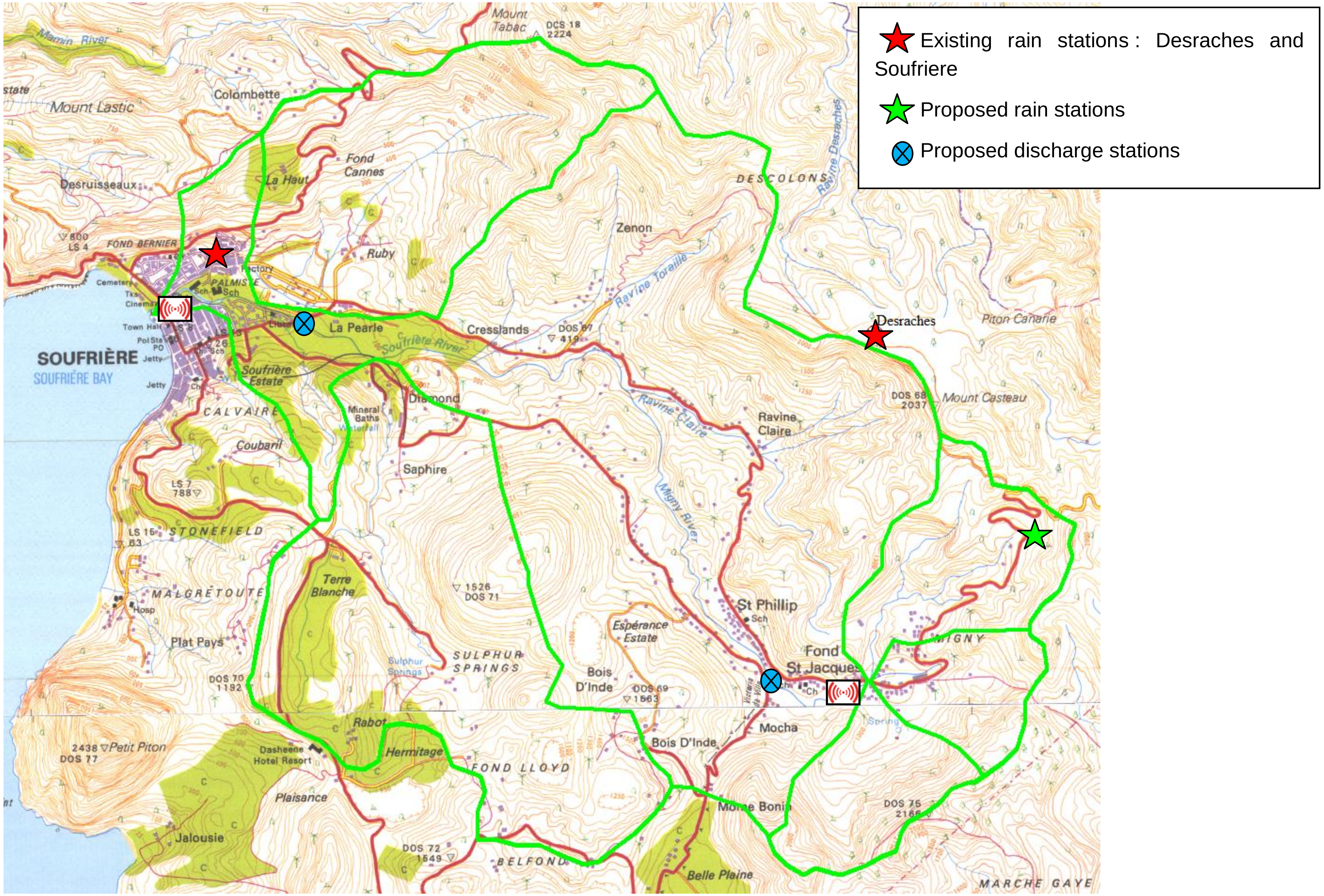


Figure 58 : Proposed locations for monitoring and warning system in Soufriere Catchment

3.2.3 Public information and education

Maximum community involvement is essential for effective preparedness towards mitigating flash flood risk. Awareness must be created about the hazard and existing resources. Various awareness campaigns can be done to inform and unite the community. Methods to influence people can include:

- posters
- brochures
- school arts and essay competitions
- Memory museum/flood marks to keep in mind past events
- audio-visual methods
- training and demonstrations
- regular drills

This section will be detailed in report #5 and #6.

Chapter 4. Costs and prioritization

4.1 Return period definition

A **return period**, also known as a recurrence interval is an estimate of the likelihood of an event, such as flood to occur.

The theoretical return period is the inverse of the probability that the event will be exceeded in any one year (or more accurately the inverse of the expected number of occurrences in a year). For example, a 10 year flood has a 1/10 = 0.1 (or 10%) chance of being exceeded in any one year and a 50 year flood has a 0.02 or 2% chance of being exceeded in any one year.

This does not mean that a 100 year flood (also called 1-in-100 year flood) will happen regularly every 100 years, or only once in 100 years. Despite the connotations of the name "return period". In any given 100 year period, a 100 year event may occur once, twice, more, or not at all.

- **A 10 year flood as 10% chance of being seen in a year**
- **A 50 year flood as 2% chance of being seen in a year**
- **A 100 year flood as 1% chance of being seen in a year**

4.2 In DENNERY

The prioritization of structural and non structural measures proposed in Dennery is given hereunder.

1/ The first thing to do is to apply a **flood area regulation** (see chapter 3.1.2) in the community of Dennery, based on the flood hazard map provided in this report. This regulation will have to be explained to the population, and therefore associated with **public awareness raising campaigns and education**.

2/ Organize a **river and drainage maintenance plan** in Dennery

3/ Then structural measures have to be done. There is no prioritization of them, as they are all necessary to protect the community of Dennery against floods:

- **Mole river structural measures**
- **Central drain structural measures**
- **Ravine trou à l'eau structural measures**

The client should only choose the return period for each structural measure, and the type of solution/hypothesis.

The structural measures for a "x" return period had been calibrated to have NO OVERFLOW for rainfall events lower than the "x" return period event. For more intense rainfall events, there will be overflow in the community (and associated flood damages).

Type of work	Flood return period	Cost in USD ($)
Mole river Dike and wall on the left bank Hypothesis 1 : large outlet	T = 50 years	2 850 000
	T = 100 years	2 900 000
	Tomas event	2 970 000
Mole river Dike and wall on the left bank Hypothesis 2 : hotel on the right bank	T = 50 years	2 860 000
	T = 100 years	2 950 000
	Tomas event	3 100 000
Recalibration of the Central drain Solution 1 : no storage pond	T = 50 years	4 600 000
	T = 100 years	5 200 000
	Tomas event	5 200 000
Recalibration of the Central drain Solution 2 : storage pond	T = 50 years	4 000 000
	T = 100 years	4 500 000
	Tomas event	4 500 000
Ravine trou à l'eau embankment protections	All return periods	485 000
Ravine trou à l'eau recalibration Solution 1 : widening on the right bank	T = 50 years	3 300 000
	T = 100 years	3 600 000
	Tomas event	3 900 000
Ravine trou à l'eau recalibration Solution 2 : widening on the left bank	T = 50 years	2 700 000
	T = 100 years	2 800 000
	Tomas event	2 900 000

Table 4 : costs of structural measures in Dennery

4/ Reforestation plan

5/ Monitoring program

6/ Warning system

4.3 In SOUFRIERE

The prioritization of structural and non structural measures proposed in Soufriere is given hereunder.

1/ The first thing to do is to apply a **flood area regulation** (see chapter 3.1.2) in the community of Soufriere, based on the flood hazard map provided in this report. This regulation will have to be explained to the population, and therefore associated with **public awareness raising campaigns and education**.

2/ Organize a **river and drainage maintenance plan** in Soufriere

3/ Then structural measures have to be done. There is no prioritization of them, as they are all necessary to protect the community of Soufriere against floods:

The client should only choose the return period for each structural measure. The structural measures for a "x" return period had been calibrated to have NO OVERFLOW for rainfall events lower than the "x" return period event. For more intense rainfall events, there will be overflow in the community (and associated flood damages).

Type of work	Flood return period	Cost in USD ($)
Damming the Soufriere River	T = 50 years	8 900 000
	T = 100 years	9 700 000
	Tomas event	10 500 000
Upstream bends embankment protections	All return periods	835 000
"Ruby" stream recalibration	T = 10 years	7 900 000
	T = 50 years	9 200 000
	T = 100 years	9 600 000
	Tomas event	9 700 000

Table 5 : costs of structural measures in Soufriere

4/ Reforestation plan

5/ Monitoring program

6/ Warning system

4.4 In FOND SAINT JACQUES

The prioritization of structural and non structural measures proposed in Fond St Jacques is given hereunder.

1/ The first thing to do is to apply a **flood area regulation** (see chapter 3.1.2) in the community of Fond St Jacques, based on the flood hazard map provided in this report. This regulation will have to be explained to the population, and therefore associated with **public awareness raising campaigns and education**.

2/ Organize a **river and drainage maintenance plan** in Fond St Jacques

3/ Reforestation plan

4/ Then structural measures have to be done. There is no prioritization of them, as they are all necessary to protect the community of Fond St Jacques against floods:

The client should only choose the return period for each structural measure. The structural measures for a "x" return period had been calibrated to have NO OVERFLOW for rainfall events lower than the "x" return period event. For more intense rainfall events, there will be overflow in the community (and associated flood damages).

Type of work	Flood return period	Cost in USD ($)
Bridges re calibration	T = 50 years	131 000
	T = 100 years	565 000
Streams embankments protections	All return periods	3 000 000
Jap traps	All return periods	3 000 000

Table 6 : costs of structural measures in Fond St Jacques

5/ Monitoring program and Warning system

Chapter 5. Conclusion

Success in managing flood areas depends on selecting suitable measures based on flood characteristics, physical and morphological characteristics of flood areas, economic and social conditions, political and environmental conditioning, or flood-control works planning. Structural measures cannot reach these objectives if they are used alone; non-structural measures such as land use control and planning can be tools not only to reduce flood risk, but also to develop a sustainable approach to flood management

In this report, various type of structural measures have been proposed. A large scale of structural measures has therefore been proposed, calibrated and cost estimated in a first approach for various return periods.

Once the client will have chosen the type of structural measures and their associated return periods, we will perform the corresponding Preliminary Design, as per the terms of references, and produce the final flood exposure maps for the 3 studied communities.

But as said in the report, first priority should be to adopt and enforce a building code for the 3 communities associated with hazard zoning maps should be adopted and enforced.

At various times in Saint Lucia's history building codes have been proposed, written, and edited. Such a document can be a major advance for disaster mitigation and would offer considerable increase in long-term cost savings from future disasters at modest current increases in construction costs.

- Études générales
- Assistance au Maître d'Ouvrage
- Maîtrise d'œuvre conception
- Maîtrise d'œuvre travaux
- Formation

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