Mauritius – Integrated Management of Flood Risks and land Drainage Master Plan (LDMP), Mauritius

D5.1 – Elaboration of the integrated Land Drainage Masterplan - Volume 1

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EXECUTIVE SUMMARY

OVERVIEW

The Land Drainage Masterplan was commissioned by the Agence Francaise de Development (AFD) for the Government of Mauritius with the main purpose of reducing vulnerability of the population and various activities to heavy rain and flood events in the context of climate change.

Its aim is to provide technical assistance to LDA in the form of vulnerability and feasibility studies, drafting of national policy, good governance and action plans as well as capacity building. It is also intended to support the LDA in their effort to provide guidelines and principles of stormwater management to designers in order to mitigate the impacts caused by their projects.

The first part of the Land Drainage Masterplan (LDMP) comprises six chapters, namely:-

Chapter	1	:	Introduction
	2	:	Main issues identified and existing measures of prevention
	3	:	Objectives for drainage and surface sealing for the next 20-25 years in consistency with an Adaptation Programme to climate change
	4	:	Definition of a reference hydrology at the scale of each sub-watershed, based on new IDF curves
	5	:	National rules in order to account for land drainage issues in territorial development
	6		Stormwater management plan and Governance recommendations

A. INTRODUCTION

The long term annual rainfall over the island is 2010 mm with a notable variance between precipitation on the central plateau which is of the order of 3600 mm and that on the coastal region which experiences some 1500 mm per annum.

The island's hydrography is such that the south and east part of the island abounds with rivers contrary to the northern part, commonly known as the Northern Plain, which has little run-off due to its geological formation made up of mild undulating and younger lava flows, basaltic intrusions and high permeability soil. 25 major rivers and a multitude of rivulets and drainage axes constitute the main drainage infrastructure of the island.

The existing drainage infrastructure does not have sufficient capacity to drain stormwater during heavy rainy spells and lack of preventive maintenance exacerbates the flooding problem. With increasing population and per capita income and rapid infrastructure development, there is a high pressure for forested and agricultural land to be cleared in favour of urbanisation, leading to increased surface runoff and ever increasing challenges for an efficient land drainage system.

Some sixty sites had been declared as being critical and prone to flooding by the National Disaster Risk Reduction and Management Centre (NDRRMC).

The study and the preparation of this Land Drainage Masterplan was conducted by a consortium comprising SUEZ, Mega Design Consulting Engineers, Acterra, DAY Marine and Scene-Ries Consult and monitored by a technical and committee chaired by the Land Drainage Authority.

The Masterplan comprises the following components:

- An inventory and mapping of all the existing natural and manmade drainage infrastructures;
- An identification of vulnerable areas, including the impact of future developments on potential flood prone areas;
- The definition of a reference hydrology at the scale of each rainfall sub-catchment, based on new IDF curves,
- The elaboration of flood mapping and associated vulnerability assessment;
- The proposal for national rules in order to account for land drainage issues in territorial development with the objective of flood risk reduction, taking into account water quality and biodiversity preservation to improve the resilience of the country in the context of climate change.
- The definition of broad protection objectives at the scale of the most vulnerable catchments, based on detailed studies conducted at a more localised level;

B. MAIN ISSUES IDENTIFIED AND EXISTING MEASURES OF PREVENTION

This Chapter deals with the following topics:

i. Inventory and mapping of the main existing natural and manmade drainage infrastructure

This exercise relates to the characterisation of main primary and secondary drains across the island with a view of assessing the drainage capacity of existing infrastructure to cope with land drainage. About 603 km of natural and manmade drains are characterised.

ii. Flood mapping of historical flood prone areas

Using the Digital Elevation Model (DEM), complemented by field topographical surveys, a flood mapping of historical flood prone areas was established based on hydraulic modelling.

iii. Identification of Vulnerable Areas

A vulnerability risk assessment has been carried out on critical sites prone to flooding, This assessment is a mapping between the sensitivity of the system to specific hazards (flood level, velocity, topography lowland, flood history), and the issues (life, property, infrastructure, agriculture)

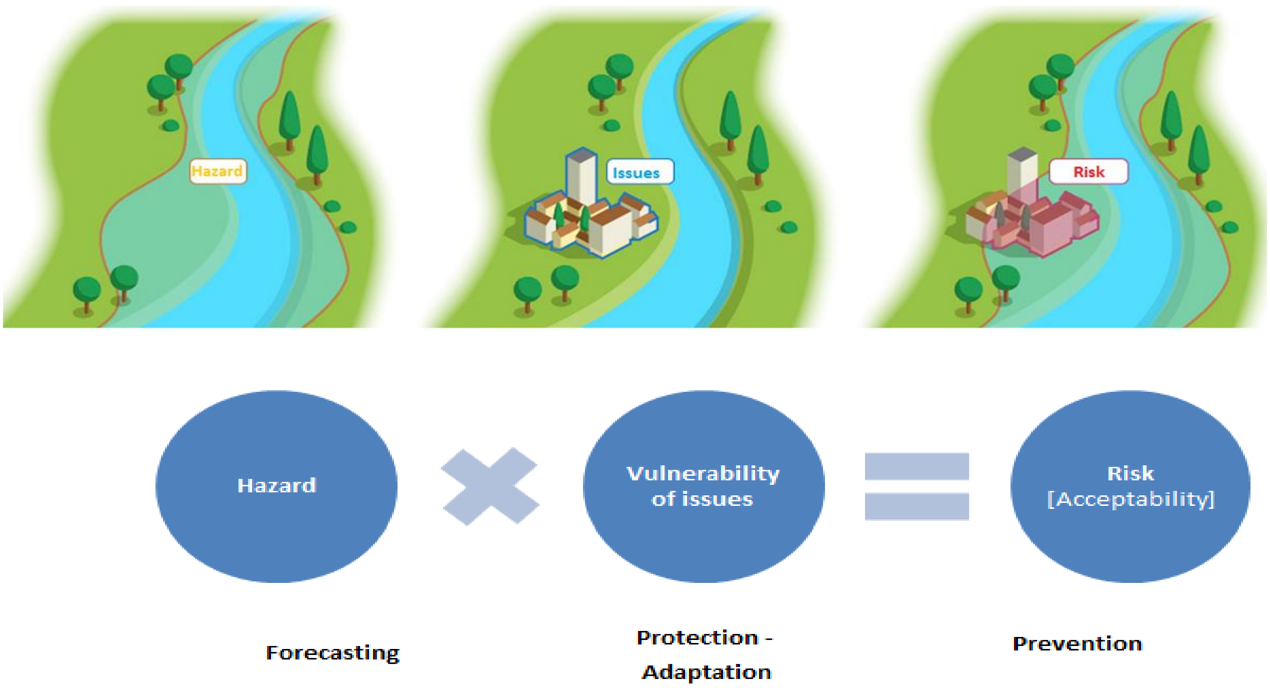


Figure 1: Flood Risk assessment

iv. Existing Preventive Measures

The main regulatory and preventive measures to control runoff are summarised below:-

- Watercourses (rivers, rivulets, feeders, streams) have to be protected to ensure their proper functioning, in particular, proper drainage of the different catchments they serve. In this respect, the Forest and Reserves Act provides the legal definitions and extent of water courses and their appurtenances, namely:-

Escarpment	:	The bank of a river, rivulet or feeder, the mean slope of which is equal to or more than 60º to the horizontal.
Feeder	:	The affluent of a river or rivulet.
River reserve	:	The land from the edge of a watercourse to the top of the escarpment where there is one;
Otherwise, River reserve	:	The land from the edge of a watercourse to a distance of 16 m measured on a horizontal plane.
Rivulet reserve	:	Ditto but 8 m.
Feeder reserve	:	Ditto but 3 m.
Streams	:	Any marshland from which a stream flows.

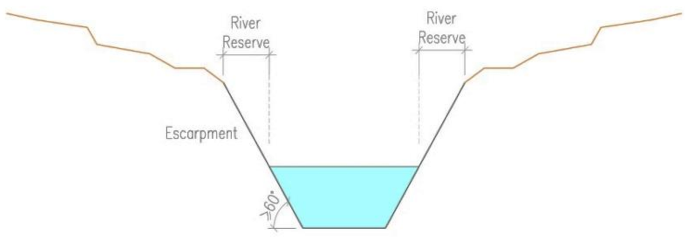


Figure 2: Watercourse with escarpment

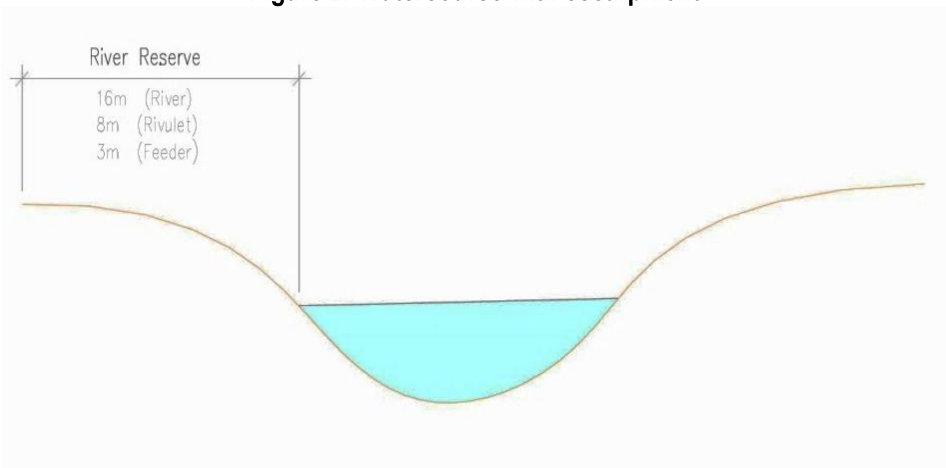


Figure 3: Watercourse without escarpment

- Under the Planning Policy Guideline (PPG 1), permit applications should include evidence that the drainage system has been designed in accordance with the recommendations contained therein, inter-alia:

  Appropriate precautionary measures and drainage facilities should be provided to ensure that:
  - The site itself does not flood
  - Other properties are not adversely affected by the proposed development
  - Essential groundwater recharge potential is not lost
  - Erosion of ground does not occur

  In this respect the law, Article 640 of the Civil Code is unequivocal:

  “Les fonds inférieurs sont assujettis envers ceux qui sont plus élevés à recevoir les eaux qui en découlent naturellement sans que la main de l'homme y ait contribué. Le propriétaire inférieur ne peut point élever de digue qui empêche cet écoulement. Le propriétaire supérieur ne peut rien faire qui aggrave la servitude du fonds inférieur”

"Lower sited properties are naturally subject to runoff emanating from properties located at a higher level without any human interference. Owners of lower sited properties cannot erect any structure to prevent free flow of this runoff; neither should the owners of properties at a higher level adversely interfere with the flow passage downstream"

- The protection and enhancement of **Environmentally Sensitive Areas (ESA)** as nature based climate change line of defense implies the following principles:

  - Enhancing environmental management according to specific units
  - Preserving/restoring ecological services to ensure sustainable development
  - Preserving/restoring wetlands

  Coastal marshlands play an important role in:

  - Flood mitigation
  - Wildlife habitat
  - Carbon storage and
  - Other values such as paleontological artifacts.

  It is estimated that there are some 1,160 ha of coastal marchland left in Mauritius, and these need to be preserved.

v. Limitation of traditional design of urban drainage infrastructures and future challenges for Mauritius

The topography and the tropical climate of Mauritius are such that the amount of stormwater is significant even for small rainfall events, necessitating large drainage infrastructure and major investments.

Combining drainage solution systems using more nature-based solutions could be an opportunity to enhance the efficiency of the drainage system and reduce the cost of drainage works and increase amenity and comfort in town and new built areas.

At source-control stormwater management for mitigating the impacts of urbanisation on baseflow should become a basic design principle.

vi. Needs for Preservation of ESA's

Recent backfilling activities for expansion of built environment have fragmented much of the natural marshland habitat.

From an environmental point of view, changes to landform in wetlands can lead to the malfunctioning of these buffer zones during floods, or even to their destruction. Modification to the land form as a result of backfilling, favours the establishment of invasive alien plant species, impacting on biodiversity and human health.

Wetlands are threatened by various activities such as drainage, backfilling, pollution, cultivation and invasive vegetation cover. Destruction of wetlands leads to droughts and flooding becoming more severe and the deterioration of water quality since they can no longer fulfill their role as a filtration medium.

It is therefore recommended that a buffer zone of prohibition of construction development be applied around wetlands.

Restrictions should be imposed on new urbanisation over wetlands and lowlands, viz:

- New development or any extension thereof should be prohibited on lowlands as a whole, be it urbanised or not. These lowlands will be included as No Go Zones.
- For lowlands in non-urbanised zones including all or part of wetlands: Development should not divert watercourses or run-off flows.
- For lowlands with no link to wetlands: Infrastructure works to protect built up areas permitted, provided there is no aggravation risk downstream and any area being backfilled should be restituted upstream or downstream of the work.

C. OBJECTIVES FROM DRAINAGE AND SURFACE SEALING FOR THE NEXT 20-25 YEARS

i. Objectives

Urbanisation increases runoff both in terms of volume and flow rates at the expense of infiltration in the soil.

Surface runoff is residual overland flow of rainfall after infiltration into the soil and evapo-transpiration.

The current practice consists in laying underground concrete structures for the systematic collection and evacuation of storm water downstream of the development

In opposition to the old hydraulic approach of systematically chanelling stormwater, this masterplan formulates an action plan aimed at:

- Reducing surface runoff at source - volume reduction
- Increases time of concentration of the run-off - velocity of flow reduction
- Reducing peak flow - spread the volume of flow over a longer period

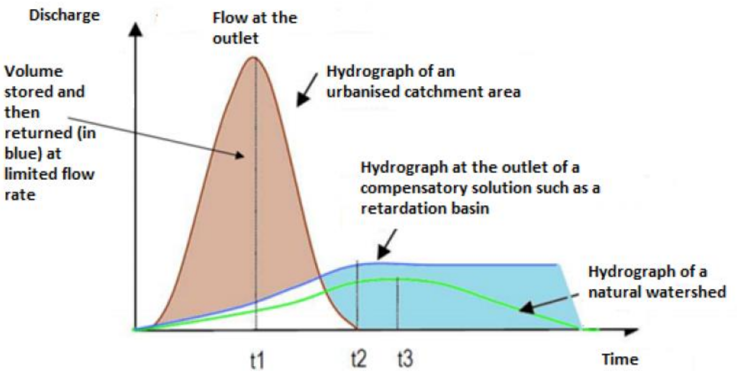


Figure 4: Principle of peak flow regulation by a compensatory device such as a retardation basin

Sustainable solutions no longer seek the quickest way of channelling stormwater into a river or watercourse as these require a large infrastructure. They consist nowadays in finding ways and means of controlling peak flows at source and breaking the peak flows as much as possible through retardation basins, flood infiltration or flood expansion zones along or off watercourses, terracing, vegetable cover and the like prior to releasing them in a controlled manner into the drainage infrastructure. It is equivalent to releasing the same quantity of water but over a longer period of time.

ii. Fundamental Concepts on Runoff and Stormwater Management

The primary cause of flooding is the overflowing of water courses, with the inevitable submergence of adjoining land. Other phenomena also cause flooding and chaos, namely overflowing of drainage networks, rise in groundwater, failure of drainage infrastructure and surface runoff.

In order to establish the source of any runoff problem, it is necessary to consider the watershed in its entirety and to precisely localize the runoff process and to establish corrective measures as close as possible to the source of the problem.

Stormwater occurs in different forms, namely as:

- Production zone - run-off where direct rainfall over a surface flows downstream
- Runoff transfer from the production zone characterised by high flow velocities
- Accumulation zone characterised by low flow velocities and significant water depths.

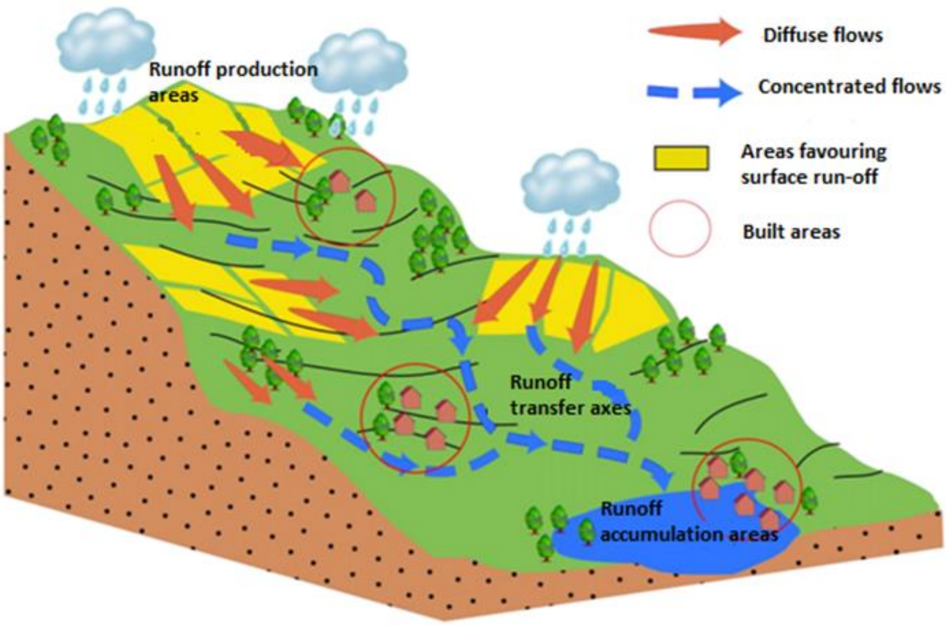


Figure 5: Runoff production, transfer axes and accumulation areas within a watershed

Upstream of Macadam Road, Baie du Tombeau	Macadam Road, Baie du Tombeau	Near Simla Way, Baie du Tombeau
Runoff production	**Runoff transfer**	**Accumulation zone**

Figure 6: Runoff – Production Transfer and Accumulation

Applications for stormwater disposal by a public or private body or an individual should address the following:

- the total project area, together with the area of the upstream natural catchment being intercepted,
- the discharge location, whether the discharge is:
  - periodical, eg a dry ditch
  - intermittent, eg the outlet of a retention basin,
  - controlled, eg the outlet of a retardation basin
  - surface areas, eg an infiltration swale

(i) Potential impacts of stormwater disposal from an urbanization project

Potential impacts of stormwater disposal from an urbanization project include:

- Obstruction in flow paths leading to upstream flooding
- Increase in surface run-off, flow velocities and flow rates leading to downstream flooding.
- Decrease of water infiltration into underground flows, interfering with local water balance.
- Increase in flows in the receiving bodies (watercourses) and bank erosion leading to increased flood frequencies.
- Sediment of river beds and water pollution.

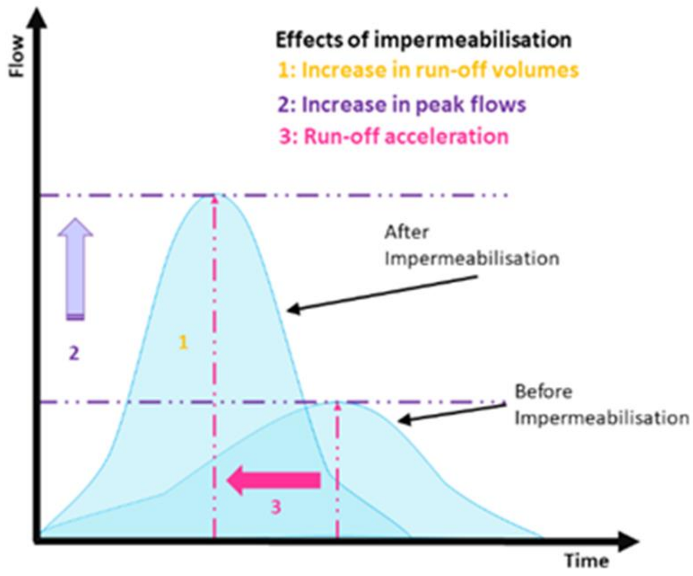


Figure 7: Impacts of soil impermeabilisation on natural flows for a typical storm event

(ii) Local Stormwater Management System

Stormwater Management involves:

- Increase in the range of mechanisms mobilized:
  - permeable or semi-permeable surfaces,
  - green roofs,
  - ditches and swales,
  - water basins,
  - rain gardens,
  - dedicated space for managed flooding, and
  - rainwater collection tanks for re-use, etc.;
- Diversify the services provided:
  - preservation of water and aquatic environment,
  - flood prevention,
  - landscape enhancement, and
  - rainwater reserve

- Maintain local water balance
- Stakeholders participation in the process, from inception up to implementation.

(iii) Level of service provided by local stormwater management system

The different levels of service to be provided by a stringent stormwater management system comprise:

- Level of service N1: For low rainfall - Prevent nuisances and pollution caused by stormwater
- Level of service N2: For average rainfall - Prevent nuisances caused by stormwater and limit impact on water quality of receiving water
- Level of service N3: For Heavy rainfall - Control of flood risks to people and properties and readiness to accept significant deterioration in quality of receiving water
- Level of service N4: For Exceptional rainfall - Prevent harm to people and damage to properties.

Under all circumstances, an action plan aimed at reducing runoff, increasing time of concentration and reducing peak flow, especially for projects located at the upper reach and midway of the catchment area, is recommended for future works.

iii. Principles of respect to natural areas with essential hydraulic functions in stormwater management

(i) Flood expansion zones and No Go Zones

Clearing river banks of vegetation or lining watercourse sections with concrete or steep sloping revetment only serves at speeding water flow and increasing risk of flooding downstream as well as interfering with groundwater recharge during dry periods and bank recharge during rainy periods.

No Go zones are flood expansion zones and are natural areas where overland flows can diffuse during a flood event. This zone provides a transitional storage of water and delays its peak flow. Natural wetlands serve this purpose and should be maintained at all costs and should be supplemented by floodplains maintained or created on lowlands. These areas must be protected from any attempt at urbanization or backfilling.

No expansion zones are zones subject to flooding around already urbanised areas where new development is subject to conditions and restrictions.

(ii) Nature-Based Solutions for Stormwater Risks

Nature-Based Stormwater Management Solutions can be categorised as follows:

- Preservation, restoration and creation of wetlands (to provide transitional storage of water during floods)
- Vegetation cover to the slope of the catchment (to stabilise the slope and slows down runoff). This also reduces the risk of landslides and mudflows.
- Vegetation cover and permeabilisation in urban areas (to promote infiltration and limit surface runoff)

Figure 8: Different types of Nature-based solutions for water related risks (Source IUCN)

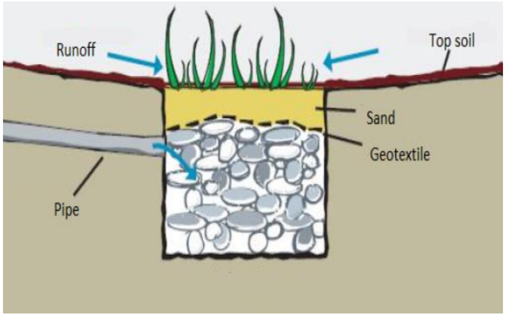
The action plan should not be restricted to the construction of drain networks within urbanised areas affected by flooding, but should intervene on the runoff production areas or upstream of the drain networks

The techniques used are based on the following principles:

1) Controlling runoff production through infiltration and slowing down runoff, such as green roofs, rain water harvesting, vegetation, soil modification, infiltration wells or trenches, use of porous material, surface or underground storage at individual plot level and grass cover to road verge,

2) Controlling runoff transfer by slowing runoff flow by means of fascines, hedges ,bushes and swales

3) Temporary storage upstream of drain networks to limit flow rate by means of retention basins, wetlands, and flood expansion zones within low productivity agricultural plots or marginal land.



Infiltration well/trench

Hedge

Stepped Ditches

Flood expansion zone

Fascine

Bioretention raingarden

Figure 9: Control of run-off production and transfer

Non-structural measures to reduce runoff and flow rates include restriction of urbanisation onto lowlands.

Consultative and participative discussions and communication are crucial elements leading to the establishment of Nature-based solution in a country. Any project is bound to succeed if it includes these elements for the implementation and operation to be well understood and acceptable. Moreover, political and institutional support is often of major advantage.

iv. Principles for Urban Development

The stormwater management plan should be structured in an holistic manner, taking into account antecedent studies which may have been carried out at catchment level, where appropriate, but also using a technological approach that advocates an integrated upstream to downstream visionary outlook.

Typical implementation techniques applicable to different locations within the drainage system can be summarised as follows:

- Source control (private property): Green roofs, rainwater harvesting and reuse, rain garden (bio-retention), porous paving, infiltration wells and trenches
- Source control (public property): Dry basin, filter belt, infiltration into grass land, ditches and swale
- Drain control (public property): Ditches with infiltration systems, swale

Any of these techniques should be incorporated at plot, project and water-catchment level, and should integrate Nature-Based Design Solutions.

v. Zoning Proposals

The main objective of stormwater management is to **"avoid, reduce or compensate".**

The programming tool for an effective stormwater management is zoning of stormwater and its associated regulations, namely:

- Preservation of natural flow axes
- Areas where soil imperviousness should be regulated to control stormwater flow, and
- Areas to provide collection, storage and treatment of pollutants

Rainfall zoning and stormwater zoning make it possible to establish regulations, inter-alia, to:

- Plan public investments
- Anticipate future impacts of new development
- Control of discharge per plot (litres per second per hectare)
- Compensation flows and volumes from newly imperious surfaces

The methodology for sizing regulation basins involves, inter-alia, estimation of runoff coefficients and reference to a rainfall system. Thus, a runoff coefficient of 0.80 to 0.95 can be retained for a 100 year rainfall depending on land use.

Risk reliability investment costs and return periods are fundamental elements in the design of Stormwater Management System. The dimensioning of a stormwater system is dependent on the choice of rainfall events and this choice in turn depends on how much inconvenience/risk users are prepared to assume in relation to the level of service expected against the cost of implementation of the service.

Thus, whilst the inconvenience imposed by overflowing of a stormwater drain may be acceptable on the average once every 25 years, overtopping of a bridge may not be acceptable at such recurrent frequencies, since the risk of eroding the bridge abutment is far more severe than that of a road being flooded.

Within the framework of the Land Drainage Masterplan the following frequency of events corresponding to the type of infrastructure are retained:

Table 1: Free board retained

S.N	Infrastructure	Minimum Rainfall Return Period[1] (years)	Minimum free-board[2] required in m
1	Drains (urban area)	25	0.3 m
2	Discharge into watercourses (including Feeders, Rivulets, Rivers)	100	0.5 m
3	Culverts	50	0.5 m
4	Bridges	100	1.0 m

Stormwater Management Design Guidelines are intended for developers, engineers, architects and planners preparing development plans, the aim being to comply with the stormwater management requirements and infrastructure design standards.

D. DEFINITION OF A REFERENCE HYDROLOGY BASED ON NEW IDF CURVES

i. Effect of Climate Change on Rainfall Intensity

To forecast the effect of Climate Change on rainfall intensity for the 2050 and 2080 horizons, climate projections emanating from CORDEX-Africa have been used. The spatial resolution is of 0.44^{o} x 0.44^{o} which is equivalent to 50 km x 50 km.

Simulations on the daily cumulative rainfall have been carried out and results show no significant change in the hydrological characteristics under future climate change by the end of the century. Being that no local topography has been taken into account in the climate projection (and therefore regional variations) because of the small resolution of 50 x 50 km with respect to the small size of Mauritius, the results have to be taken with caution.

BRIO has, however, made a forecast of a rise in temperature of 1.7 to 2.6˚C by the end of the century for Reunion Island. Using the Clausius-Clapeyron law which states that the water vapour content in the atmosphere increases on average by 7% for every ˚C rise in temperature and retaining the same increase for Mauritius, it can be presumed that rainfall quantiles would increase by 18.2% (2.6 ˚C x 7%/˚ C). Likewise the rainfall intensities generated by the new IDF curves may be increased by 18.2%.

[1] Higher return periods are recommended for regions with high vulnerabilities to flooding.

[2] Freeboard is the marginal height provided above the design water level to account for overtopping due to surges and uncertainties in estimation and operation..

ii. Hydrological Methods

Step 1: Design rainfall

A specific task (task D2.1) was devoted in the preparation of a new set of Intensity Duration Frequency (IDF) curves. In this respect two representative regions were defined, namely:

- Region I : With a daily rainfall (Pluie journalière - PJ) for a 10 year return period of greater than 230 mm, representative of the high plateau and windward coast, and

- Region II : With a PJ (10 year) of less than 230 mm, representative of the low altitude and coastal area to the north and the leeward coast.

The design rainfall, Hmm for different return periods of 10, 25, 50 and 100 years is thus calculated for the two regions.

This design rainfall is upgraded by a factor to account for the effects of global warning due to Climate Change (CC) as discussed hereinbefore.

Thus H_{cc} = 1.182 x H (IDF)

Step 2: Time of Concentration

The time of concentration Tc is defined as the time needed for storm surface water to flow from the most remote part in a catchment to the catchment outlet.

When the duration of the rainfall is equal to or exceeds the time of concentration for any particular catchment, maximum rainfall intensity occurs on the entire catchment, generating the maximum flow, called the peak flow and this is the value used to size the drainage infrastructure.

Different empirical formulae are used to estimate the time of concentration, namely:-

- Kirpich formula for catchment of less than 20 km^2.
- Kirpich and Passini formulae for catchment greater than 20 km^2.

Step 3: Determination of the Project Rainfall

A project rainfall is a synthetic rainfall defined by a standard hyetograph constructed from the statistical characteristics of rainfall, generally described by the IDF curves.

Step 4: Rainfall Run-off Calculations

Surface run-off is that part of rainfall that flows overland after what goes into the soil as infiltration and back to the atmosphere as evaporation.

The run off coefficient C_r is the fraction of rainfall converted into runoff. The run off coefficient is low for pervious surfaces such as agricultural land and high for semi-impervious or impervious surfaces such as built-up areas, roads or concrete. The run-off coefficient also increases when the rainfall intensity or its frequency increases.

Two methods are recommended for the calculation of flow rate from rainfall, namely the rational method and the Soil Conservation Service method (SCS method).

E. NATIONAL RULES FOR LAND DRAINAGE ISSUES

i. Rules for Sizing Drainage Structures

The following sizing criteria are recommended, taking into consideration local environment and hydraulic sizing challenges for new drain projects:

Table 2: Free board retained

Infrastructure	Minimum Rainfall Return Period (years)	Minimum Free-board (mm)
Drains	25	300
Discharge into water courses	100	500
Culverts	50	500
Bridges	100	1000

ii. Levels of Protection of New Buildings

The management and construction policy in flood prone areas sets the following objectives:-

- Preserve the storage and flow capacities of floods so as not to aggravate the risks for areas located upstream or downstream.
- Prohibit new human settlements in dangerous areas and limit them in other flood prone areas.
- Avoid any embankment or backfilling.
- Safeguard the quality of natural environments.

All new constructions should be designed to withstand flood (water depth and velocity):

- Their siting as well as the amenities such as fences, landforms must not hinder natural flow.
- Ground floor should be in excess of 0.50 m above natural ground.
- The habitable floor should be at least 500 mm above the highest 100 year flood, accessible from the inside and provided with an access permitting evacuation of the occupants from outside under all circumstances.

iii. Urban Planning Policy Recommendations

The aim of NO GO zones and No Expansion Zones is to prohibit and reduce all new urbanisation in high risk areas.

NO GO Zones should be established mainly in non-urbanised areas and in areas with isolated houses, in order to preserve flood expansion fields, the aim being to reduce flooding downstream by lowering flood water depths and to limit any obstructions to flow in order not to worsen the effects of the flood.

NO Expansion Zones should be established mainly in already urbanised areas or in spread habitable areas by prohibiting new constructions, except under special conditions such as extension of up to 50% to 20% of the floor area of an existing building, or for public utility works justifying the need for their immediate proximity to the watercourse.

The No Go zones are also completed via the application of a buffer on the flow axes, the width of the buffer depending on the catchment area drained by the natural axis.

Table 3: Urban policy recommendation – Buffer values

Type	Source	*Curent value of "River reserve"*	New buffer value		Comments
River	Fourth Schedule	**16 m**	**16 m and NGZ or NEZ**		The land extending from the edge of a watercourse to a distance measured on the horizontal plane
Rivulet	Fourth Schedule	**8 m**	**8 m and NGZ or NEZ**		
Feeder = affluent of a river or rivulet	Fourth Schedule	**3 m**	**5 m (*) and NGZ or NEZ**		
Natural path: 1 to 50 ha	LDMP	/	**7 m**		From the axis
Natural path: 50 to 100 ha	LDMP	/	**10 m**		From the axis
Natural path > 100 ha	LDMP	/	**10 m and NGZ or NEZ**		From the axis

(*): equivalent to 5+5 = 10 m minimum buffer as for natural path for WC > 100 ha

Following the 2021 Finance Bill Act, section 32 - Forests and Reserves Act – the "river reserve" in the case of a natural water path or natural drainage path is fixed at 2 metres.

F. STORMWATER MANAGEMENT PLAN AND GOVERNANCE RECOMMENDATIONS

This chapter deals with:

i. Stormwater Management Plan

(i) Stormwater management (SWM) Strategy and objectives:

SWM Strategy to:

- Assist in the development of Stormwater Quality Management plans
- Guide authorities in planning, designing, and operating stormwater infrastructure,
- Guide authorities in the integration of stormwater issues into other planning schemes.

SWM Objectives to:

- Protect/enhance receiving water
- Limit flooding to acceptable levels
- Acceptable social and economic cost
- Enhanced community awareness
- Engage the community in the development of parameters for the design and evaluation of stormwater management solutions.
- Minimise the quantity of directly connected impervious surface area where practical, surround impervious surfaces with porous surfaces such as gravel beds, lawns and gardens.
- Explore problems, issues and strategies openly
- Increase public ownership and acceptance of proposed solutions

Nature based sustainable solutions no longer seek the quickest way of channelling stormwater into a river or watercourse as these require a large infrastructure. They consist nowadays in finding ways and means of controlling flows at source and breaking the peak flows as much as possible prior to releasing them in a controlled manner into the drainage infrastructure.

Different methods are used to control stormwater peak discharge and volume at source or upstream of a catchment area, including but not limited to:

- Detention systems which delay the release and control stormwater flows, but do not reduce the volume.
- Retention systems which alter the volume of stormwater runoff by retaining a portion of the flow for a secondary use.
- Infiltration systems which reduce both the volume and flow rate by absorbing a portion of the flows into the ground.

Flood expansion zones can also be created along water courses to retard peak flows.

(ii) Stormwater Management Policies & Principles

The objective of a Stormwater Management Policy is to set the guidelines necessary to comply with the LDA's requirements and design standards to achieve a robust and efficient drainage infrastructure.

The guidelines make recommendations to assist a designer or a proponent in complying with the Authority's requirements, without for that matter relieving them of their responsibility for the integrity and design of the various facilities proposed, inclusive of a monitoring and an operation and maintenance plan.

(iii) Stormwater Drainage System Criteria

Well-designed stormwater conveyance systems are critical for ensuring that stormwater is safely conveyed away from roads and residential areas to appropriate drainage outlets. The objective of the Land Drainage Masterplan (LDMP) is to ensure that the existing drainage systems are characterised and upgraded and those for new developments are robust and designed to the highest standards of performance.

- All proposed developments or expansion of existing developments must assess their potential impacts on both local and regional flooding and mitigate accordingly.
- Proposals and mitigation measures shall consider the entire drainage area and the external flows.
- The minor drainage system typically includes roof leaders of individual lots and gutters, kerbs and roadside drains. Minor drainage systems shall be sized to capture and convey the 10 year storm..
- The major drainage system includes natural streams, swales, artificial drains, roadways and ponds. Major drainage systems shall be sized to capture and convey flows from a minor system as well as overland flows not captured by the minor system without flooding adjacent properties.
- For infill/redevelopment sites the proponent should demonstrate through a drainage system analysis that the downstream drainage system has sufficient capacity to safely accommodate design flows from the development site to a secondary drain or an existing outfall.

Stormwater Drain Design includes:

- Design Flow
- Drain Capacities
- Minimum Velocity to prevent sedimentation and vegetative growth.
- Maximum Velocity limitation for safety and to protect against scouring, erosion, and hydraulic jumps.
- Minimum Grades to minimise the likelihood of ponding and siltation within the drain.
- Maximum Grades limitation to prevent high flow velocity in the drain under all operating conditions
- Changes in Drain Alignment to be effected in sections to produce the required deflection.
- Catchbasins to collect drainage from both pervious and impervious areas.
- Outlet Structures to be designed to prevent erosion.

Roadway crossings shall be designed to accommodate peak flows from a storm occurring on the average (return period) of 1 in every 50 years for culverts and 1 in every 100 years for bridges. Culverts and bridges should also be provided with a minimum freeboard of 500 mm to 1000 mm to have sufficient capacity to avoid adverse backwater effects due to waves.

All developing or re-developing areas must assess their potential impacts on local and regional flooding and implement mitigation measures to prevent impacts. These include, but not limited to volume and peak flow control.

Post-development peak flows should be controlled to pre-development levels for the 10 year return period. The level of protection (sizing of imperviousness compensation basins) varies according to the location of the projects. Any design of stormwater infrastructure involving the determination of peak flows or runoff volume must be supported with acceptable hydrologic calculations signed by a Registered Professional Engineer experience in Water Resources Engineering.

(iv) Stormwater Management Design Guidelines

A treatment train approach to Storm Water Management is advocated, whereby the following sequence of multiple stormwater processes are adopted to control volume and peak flows, as well as pollutant load:

- Source Control
- Conveyance Control
- End-of-Pipe Control

The design of source, conveyance and outlet controls shall be in accordance with the policy of **Low Impact Development (LID)**, a stormwater management strategy that makes use of best management practices to reduce the impervious area associated with a development, while using lot level and conveyance controls to store stormwater for infiltration, re-use, evaporation etc. LID practices reduce runoff volume and improve water quality and include inter-alia, infiltration trenches, green roofs and permeable pavements.

The following figure also shows the preferential locations for implementation of stormwater best management practices, based on **Low Impact Development (LID)** in urban areas:

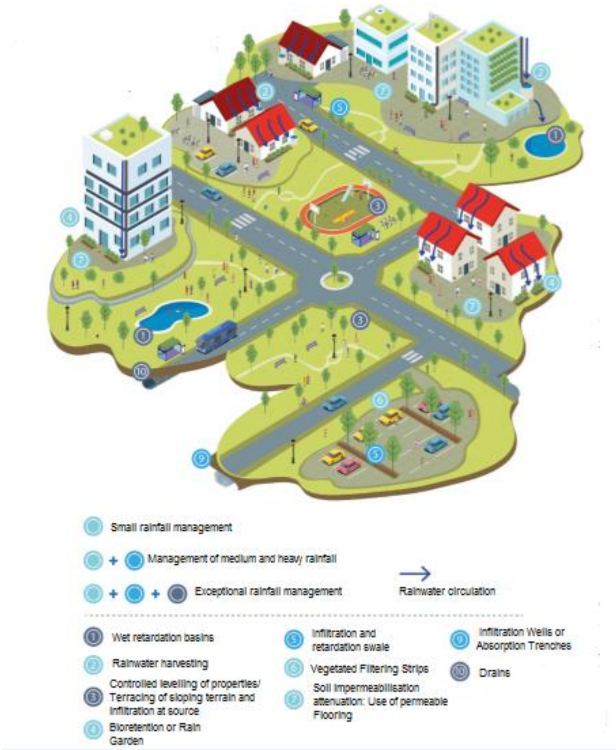


Figure 10: Stormwater management for new development - range of solutions (Adapted from Ile de France prefecture- France)

The Main Source Controls devices in urban areas include:

- Roof Discharge to Surface: All lots must have their downspouts connected to the storm drainage system via a pervious (grassed) area or a soakage pit provided with an overflow. The downspouts shall not discharge to impervious areas directly connected to the storm network (e.g., sidewalks, driveways, parking areas).

Figure 11: Roof discharge onto impervious surface

- Greenroofs: Green roofs are encouraged subject to them being properly designed as not to cause extended local ponding.

- Rooftop Storage: Rooftop storage for water quantity control is not encouraged due to the risk of it being breeding grounds for mosquitoes. Their use as a temporary detention basin when provided with a perimeter upstand and a control outlet would be acceptable.

- Surface Storage: Commercial, industrial, institutional and infill residential developments may use parking lots and/or ground storage to control post-development flows to the receiving storm water network systems. The connection from the site into the receiving storm water system shall be through an orifice tube which restricts the flow to the required rate.

- Porous and Pervious Pavement: Porous and permeable pavement installations shall be encouraged, provided that they are not receiving runoff from high traffic areas or from source areas where land uses or activities have the potential to generate highly contaminated runoff (e.g., vehicle refuelling, handling areas for hazardous materials etc.).

Figure 12: Pervious pavement

- <u>Bioretention:</u> Bioretention areas are designed to store and infiltrate stormwater runoff. Water quality is improved through the use of bioretention, as particles are filtered out as water passes through the filter bed.

- <u>Soil Amendments:</u> Soil amendments are used to improve the quality of existing soils, where compaction and a reduction in available organic material have degraded the soil.

Conveyance Controls in urban areas include:

- Swales and Enhanced Grassed Swales to promote infiltration and provides flow control.

- Oversized Channels to serve as both detention and conveyance structures.

End of Conveyance Controls located at the end of a flow conveyance route includes:

- Infiltration Trenches to promote infiltration of runoff, wet ponds, constructed wetlands and other similar systems.

- Vegetated Filter Strips adjacent impervious areas to improve the quality of and reduce the velocity of stormwater.

Figure 13: Grassed strips adjoining impervious areas

- Oil/Grit Separators at locations where there is high incidence of stormwater contamination by spent or spilled oil/fuel.

- Extended Detention Wet Ponds

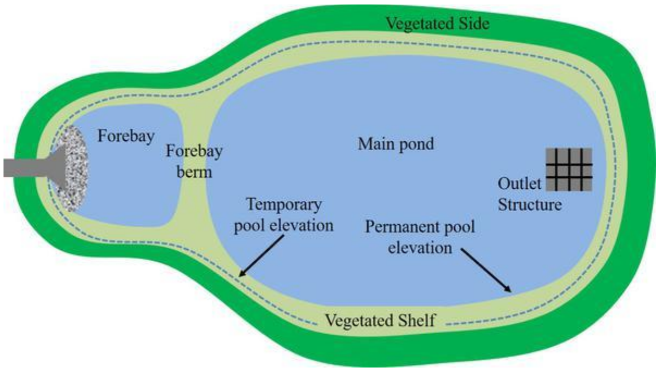



Figure 14: Wet ponds design

- Dry Ponds Dry ponds as part of a treatment train approach within parks.

(v) Guidelines for Hydrologic and Hydraulic Analysis

- Guidance on the Use of Computer Programs by Professional Engineers: All practitioners who plan to use computer models or programs in their designs shall familiarise themselves with the engineering principles, equations, models, algorithms and assumptions used in the software.

- Hydrology: Sound hydrologic modelling standards of practice should be followed in developing an event based hydrologic model.

(vi) Hydraulics

The hydraulic capacity of the storm drainage system can be determined through hydraulic modelling and for certain applications through the use of standard "hand calculations".

Standards of practice for hydraulic modelling may include inter-alia:

- identifying the study objectives and how they relate to the hydraulic modelling.

- providing the purpose for the hydraulic modelling, the model selection criteria, plans clearly presenting the closed and/or open hydraulic system, the downstream and, if applicable, upstream boundary conditions for each storm modeled, the parameters used for hydraulic losses such as Manning's "n", inlet and outlet losses, bend losses and other appropriate losses, the selection of procedures for determining the computed energy grade line and water surface elevations and the input and output data in a logical manner

- documenting potential impacts on existing infrastructure and possible mitigation measures.

(vii) Engineering Submission Reporting Requirements

A complete submission package must be delivered to the LDA for detailed engineering review of SWM Plans for both the conceptual/preliminary design stage and the detailed design stage. Reports must be signed by a Registered Professional Engineer or the legal representative of a firm of Engineers registered at the Construction Industry Development Board (CIDB).

The operation and maintenance manual of the SWM facility shall include inter-alia:

- A general description describing the operation of the SWM facility and applicable water quality, erosion and quantity control criteria
- A description of the various design elements of the SWM facility
- Details as to who is responsible for the SWM facility maintenance.
- SWM Facility Inspection and Maintenance Procedures
- Recommended maintenance procedures

(viii) Stormwater Management Facility Performance Monitoring

The purpose of the monitoring program is to confirm to the satisfaction of the LDA that the SWM facilities have been constructed and are functioning in accordance with the design specifications.

Performance monitoring of the SWM facilities shall commence after 90% of the development have been constructed, within the facility's catchment area. The facilities shall be monitored until two (2) years with the occurrence of four (4) significant rainfall events as defined below. A "significant rainfall event" is defined as an event where greater than 40 mm of rain has fallen in 4 hours.

A list of deficiencies, if any, and related data with respect to the SWM facilities will be required following each year of monitoring.

(ix) Legal Aspects of Stormwater Management

Legal issues may arise under the following circumstances:

- Legal disputes are most commonly associated with actual or perceived changes in stormwater runoff.
- Urban development can change the location, volume, rate, frequency, duration, velocity and quality of stormwater runoff.

Drainage issues are governed by Civil Law, in particular, Article 640, which states that:

« Les fonds inférieurs sont assujettis envers ceux qui sont plus élevés à recevoir les eaux qui en découlent naturellement sans que la main de l'homme y ait contribué. Le propriétaire inférieur ne peut point élever de digue qui empêche cet écoulement. Le propriétaire supérieur ne peut rien faire qui aggrave la servitude du fonds inférieur »

The case Gartner versus Kidman (1962) in Australia provides precedence on this issue:

- An up-slope property owner must take reasonable steps to manage his stormwater runoff in a manner that allows the down-slope property owner to enjoy the 'normal' use of his land, and

- The down-slope property owner must manage his property in a manner that allows the up-slope property to enjoy the 'normal' use of his land.

Unfortunately, common law issues are not commonly understood and often require legal advice to resolve. A person or organisation may be liable under common law principles for nuisance where there has been an unreasonable interference with a person's use or enjoyment of his land.

Figure 15: Holes drilled into wall to release hindered flow during flood event at Nouvelle France

Figure 16: Boundary walls diverting flows along street and to down- slope properties at Chemin Grenier

Gatner v Kitman outlined the following principles:

- The person from whose land the water flows is not liable merely because surface water flows naturally from his land onto another person's land.

- The up-slope landowner is liable if water flows from his land in a more concentrated form than it naturally would due to man-made alteration to the topography or the landform.

- By putting in place measures to prevent the natural unconcentrated flow of water on his land, the down-slope landowner cannot divert the water onto the land of a third party to which it would not have naturally flowed.

It will be necessary for the land owner to investigate the potential impacts of changes to the location, peak discharge, frequency, duration, velocity, volume and water quality of stormwater runoff:

- A change in location where stormwater runoff enters a down-slope property may adversely affect the value of that property.

- A change in peak discharge would likely cause nuisance to a down-slope property if the property is prone to inundation of buildings as a result of local runoff.

A change in frequency of stormwater runoff would likely cause a nuisance to a down slope property if the property has waterlogged soils.

If a proposed land development is likely to increase the peak stormwater runoff, and the development incorporates flow attenuation systems, then the development would increase the duration of stormwater flows and this may, in isolated cases, cause an inconvenience to down-slope properties already suffering from water logged ground.

A change in the velocity of stormwater runoff, e.g. through concentrated flows by a boundary wall would likely cause a nuisance to a third party through soil erosion.

A change in the quality of stormwater runoff would likely cause a nuisance to a down-slope property or a watercourse, e.g. soil transport and sedimentation by construction activities.

ii. Governance Recommendations

Good governance measures include:

- Preventative measures and pro-active preparedness to reduce vulnerability due to climate change.
- Education, awareness and public participation. Public awareness campaign on hazards, issues/vulnerability, risks and adaptation/resilience and shared responsibilities.
- Proper Land Use Planning through regulations governing the quantity and quality of stormwater run-off and the extent of impervious areas to be connected directly to the main drainage network by controlling production at source by means of micro controls spread over individual sites rather than the traditional approach of channelling it to large facilities.
- Information management system and data sharing for implementing a common line of defence against disaster risks.
- Provision of a map of the main drainage axes whether flowing, ephemeral or dry should be provided to all municipalities and District councils as reference for permit issuance.
- Regulations to reduce the release of contaminants such as pesticides and hazardous household wastes into stormwater.
- Removal of contaminated sediments from drains and preventing, locating and removing illegal connections and controlling leaks from wastewater sewers.
- Adoption of good operation and maintenance practices by municipal workers and the public for the storage, handling and transport of materials liable to be washed into the stormwater system.
- Monitoring of construction activities through the submission of documents to describe the specific planning and management of activities aimed at reducing the construction impacts on the quantity and quality of stormwater by such measures as control of erosion, disposal of sediments, control of wastewater from the site, storage and maintenance of plant, storage of construction materials and control over the illicit dumping of waste.
- Standard procedures for submission of stormwater management plans in support of site subdivision and development applications at conceptual/preliminary design stage, including stormwater management targets and objectives, pre-development conditions, post development conditions, storm drainage system design, facility design and water quality control for industrial development.
- Standard procedures for comparison of pre-development, unmitigated post development and mitigated post-development water balance volumes and infiltration volumes.
- Stormwater management facility inspection & maintenance requirements and schedule & frequency of maintenance activities to ensure that the facilities will continue to operate as designed,

- Maintenance activities such as cleaning of streets, storm drains and streams, garbage collection, cleaning of infiltration sumps

iii. Environmental Conservation

(i) Organisation: Main Government Entities Responsible for Management of ESAs

Table 4: Responsibility for Management of ESAs

G. ESA Type	Main Entity Responsible for ESA in Mauritius	Government's responsibility / evolution and needs for reinforcement and adaptation of governance
1. Coastal marshlands	MAIFS*	The National Parks and Conservation Service has set up a Wetlands Unit to deal with clearances for proposed developments. This unit will be reinforced with the passing of the proposed Wetlands Act.
2. Upland marshlands	MAIFS*	
3. Lakes and reservoirs	MEPU*	Lakes and Reservoirs have been merged with upland marshlands, although as separate categories due to their specificity. The Water Resources Unit and the Central Water Authority currently manage these ESAs**.**
4. Rivers and streams	MEPU*	The Water Resources Unit and the Central Water Authority currently manage these ESAs while the River Reserves are managed by the Forestry Department of the Ministry of Agro-Industry and Food Security.
5. Mangroves	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. Mangroves are protected and special permission should be asked before tampering with any mangrove tree.
6. Intertidal mudflats	MBEMRFS*	Often associated with mangroves, **they should form part of the areas managed by the Ministry and its technical arm, the Albion Fisheries Research Centre as it is located below the line of high water mark, and therefore forms part of the lagoon/sea**
7. Sand beach and dunes	MHLUP & MESWMCC*	The sand extraction act prevents any tampering with sand dunes. Sand dunes are explicitly mentioned as ESAs in the Outline Planning Schemes and any development thereon should be subject to an Environmental Impact Assessment Licence issued by the Ministry of Environment prior to any Building and Land Use Permit issued by the local authority.
8. Seagrass and algal beds	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. Seagrass beds are protected and special permission should be asked before tampering with any seagrass bed.
9. Coral reefs	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. corals are protected and special permission should be asked before tampering with any coral
10. Islets	MAIFS*	Managed by the National Parks and Conservation Division of the Ministry and its director, any access or tampering is restricted and strictly managed by the said Division.
11. High native content (flora)	MAIFS*	Managed by the National Parks and Conservation

G. ESA Type	**Main Entity Responsible for ESA in Mauritius**	Government's responsibility **/ evolution and needs for reinforcement and adaptation of governance**
		Division of the Ministry and its director, any access or tampering with native flora is restricted and strictly managed by the said Division.
12. Native fauna content (endemic birds, bats, and lizards)	MAIFS*	Managed by the National Parks and Conservation Division of the Ministry and its director, any access or tampering with native flora is restricted and strictly managed by the said Division.
13. Boreholes (aquifer wells)	MEPU*	The Water Resources Unit and the Central Water Authority currently manage these ESAs and issue licences to ensure that their use is sustainable. 200 m buffer zones are generally laced around boreholes to prevent any contamination.
14. Steep slopes (soil stabilisation, viewscape)	MHLUP*	Development on Steep Slopes exceeding 20% is normally not permitted. Control is effected through the requirement for an Environmental Impact Assessment Licence to be issued by the Ministry of Environment, Solid Waste Management and Climate Change as they are considered as ESAs, and through the issue of Building and Land Use Permits while some steep slopes are protected due to the presence of native fauna or flora or their location on mountain reserves.

* In Mauritius, the MESWMCC has an overarching role of overseeing development on ESAs through the EIA Process.

(ii) Develop new governance mechanisms

- Governance mechanisms based on an integrated approach – "from ridge to reef approach"

  These measures advocate recourse to planning as well as environmental and building regulations to reduce the release of toxic chemicals into stormwater. This is generally achieved by modifying certain activities, the use of certain products, and the associated handling and disposal practices. Pesticides and hazardous household wastes are examples of chemicals that can be controlled and managed through regulations and programmes.

- `Governance mechanisms based on control at source (Structural and non Structural Measures):

  The action plan should not be restricted to the construction of drain networks within the urban areas being affected by flooding, but should intervene on the runoff production areas or upstream of the drain networks in order to attenuate the damage (floods, drain network overflow, etc.). These actions should be carried out in consultation between, the Ministry of Environment, the Ministry of Agro Industry, the owners and the LDA. It is recommended to create an inter-ministerial committee between the Ministry of Agro-industry and the Ministry of Environment (among others) in order to implement with the agricultural owners the installation of NdS (hedges and fascines) on the areas of runoff production: control of runoff, land erosion and participation in the creation of a green frame and ecological corridor.

  In order to provide an appropriate framework for the development of Nature-based solutions and best management practices, the Government of Mauritius will have to adopt a strategic approach of creating the necessary policy frameworks and removing the obstacles to enable the widespread use of nature-based solutions by decision-makers in all situations and territories where it is relevant.

1 INTRODUCTION

1.1 Background

Mauritius is a volcanic island in the Indian Ocean with a surface of about 1865 km^2, situated about 900 km to the east of Madagascar and at latitude 20° South and longitude 58° East in the Indian Ocean. Mauritius has a resident population of 1,266,030 (Statistics Mauritius, 2020) and almost an equal number of tourist arrivals per year. The Gross Domestic Product (GDP) for the year 2019 was MUR 498 billion (13b USD) (Statistics Mauritius). The economy of Mauritius is a mixed developing economy based on agriculture, exports, financial services, and tourism.

It lies near the edge of the southern tropical belt and has a tropical climate with two distinct seasons: a hot and humid season from November to April and a cold dry season from June to September, with the month of October and May known as the transition months. January and February are the warmest months with average day maximum temperature reaching 29.2 degrees Celsius while July and August are the coolest months with the average night minimum temperatures dropping down to 16.4 degrees Celsius.

The Long term mean annual rainfall (1971-2000) over the Island is 2010 mm. February and March are the wettest months while October is the driest month. Mean summer rainfall (1971-2000) is 1344 mm, which is 67% of the annual amount over the Island. Mean winter rainfall (1971-2000) is 666 mm. Although there is no marked rainy season, most of the rainfall occurs during summer months. (MMS,2021). Across the island mean annual rainfall varies between a high of 3600 mm in the central plateau to 800mm on the leeward coastal zone

In 2019, Mauritius received 3,972 million cubic metres (Mm^3) of precipitation (rainfall). Annual evaporation has been estimated at 30% (1,192 Mm^3), surface runoff at 60 % (2,383Mm^3) and the groundwater recharge at 10% (397 Mm^3) (Statistics Mauritius, 2019).The island further has an annual potential evapotranspiration varying between 1100 mm and 1600 mm with small inter - annual variations. The relative humidity has an average value of 80%.

According to statistics, Mauritius gets directly hit by a cyclone once every 5 years on average, although occurrence has been less frequent in recent years. Still, every year the island is hit by the remnants of 3 to 5 storms, which form on the Tropic of Capricorn where the body of water heats up to 26°C for longer periods of time, bringing in their wake a lot of rainfall.

The island's hydrography is such that the south and east part of the island abounds with rivers contrary to the northern part, commonly known as the Northern Plain, which has little run-off due to its geological formation made up of mild undulating and younger lava flows, basaltic intrusions and high permeability soil. 25 major rivers and a multitude of rivulets and drainage axes constitute the main drainage infrastructure of the island.

The existing drainage infrastructure does not have sufficient capacity to drain stormwater during heavy rainy spells and lack of preventive maintenance exacerbates the flooding problem. With increasing population and per capita income and rapid infrastructure development, there is a high pressure for forested and agricultural land to be cleared in favour of urbanisation, leading to increased surface runoff and ever increasing challenges for an efficient land drainage system.

Floods resulting from overflowing watercourses and drains inundate properties and public utilities, causing not only damage to infrastructure but also degradation of water quality, leading to serious health hazards and adverse impacts on the economy. Increased urbanization with the associated compaction and sealing of the ground surface further increases the risk of flooding. In February/March/April 2019, heavy rainfall hit the country, flooding several districts and reminding the population of the painful memory of the 2013 floods that killed 11 persons.

The adverse impacts of climate change in terms of temperature rise and increase in rainfall intensities have been experienced over the last 10 years, during which period, a number of flash floods had occurred which had inundated many localities including Port Louis, Fond du Sac, Cottage, Vacoas, Nouvelle France, Riviere des Creoles, Bamboux Virieux and Flacq.

Some sixty sites had been declared as being critical and prone to flooding by the National Disaster Risk Reduction and Management Centre (NDRRMC).

1.2 Land Drainage Authority (LDA)

The LDA has been set-up as an independent authority charged with the coordination, policy development and implementation of measures related to land drainage and watershed management, including soft and hard measures which could allow for co-benefits in climate risks alleviation.

The LDA's mandate is to ensure synergy and coherent actions on Mauritius Island and to focus on the improvement of flood risk characterisation, flood risk understanding and flood risk management considering its impacts on the mainland of Mauritius in the context of climate change (additional risks and associated uncertainty).

The main objectives of the LDA are:

- the development and implementation of a land drainage master plan;
- coordinating the construction of drainage infrastructure by the local authorities, the NDU, the RDA and any other relevant stakeholders; and
- ensuring that there is a routine and periodic upgrading and maintenance of the drainage infrastructure.

As detailed in section 5 of the LDA Act (2017), LDA's mandate shall be to:

- carry out an inventory and mapping of all the existing natural and manmade drainage infrastructure;
- undertake a study based on a hydro-meteorological and hydrographic survey and produce and keep under review a flood risk map and a Land Drainage Plan;
- conduct and coordinate research and development on land drainage and watershed management and share all available information with relevant stakeholders;
- identify, in collaboration with the local authorities, the National Development Unit (NDU), the Road Department Authority (RDA), the National Disaster Risk Reduction Management Centre (NDRRMC) and any other relevant stakeholders flood risk areas;
- cause any work related to land drainage to be carried out by the local authorities, the National Development Unit, the Road Development Authority and any other stakeholders;
- cause to be carried out the upgrading and maintenance of the drainage infrastructure to be carried out by the local authorities, the NDU, the RDA and any other relevant stakeholders;
- prepare and implement land drainage schemes;
- advise the Minister on the formulation and implementation of land drainage policies and strategies;
- advise and update the Minister on any matter relating to land drainage; and
- take any other action deemed necessary in line with the provisions of the Act.

1.3 Enhancing Resilience to Climate Change (ER2C)

In the wake of COP21 and the Paris Climate Agreement, the Parties drew up "Nationally Determined Contributions" (NDCs)—voluntary commitments to fight climate change and adapt to its effects

Following the Paris Climate Agreement, the Agence Française de Development (AFD) has launched Adapt'Action to support countries seeking technical assistance for the institutional, methodological and operational implementation of their commitments to fight the effects of climate change in the form of vulnerability and feasibility studies, guidance in drafting national policy and action plans, as well as capacity-building actions

Higher temperatures, increasingly variable rainfall, and more pronounced droughts are all effects of climate change

Although their contribution to greenhouse gas emissions is negligible, the Indian Ocean States are on the front line of climate change. Their environments, economies, and societies are suffering from significant and potentially irreversible damage from its effects. Island States are moreover highly exposed to extreme climate events (cyclones, floods, etc.) and to coastal erosion and marine flooding.

The ER2C project consists the integration of climate change adaptation and risks in the government's public policies and sectors such as coastal zone land planning, disaster risk management, and drainage and the main objectives were as follows:

- Assess climate change vulnerability for five high-priority sites.
- Draft preparatory studies and terms of reference for the Land Drainage Master Plan.
- Provide technical assistance, training, and institutional development support to the Land Drainage Authority staff.
- Formulate the national disaster risk reduction policy and action plan for mainland Mauritius and its outer islands.
- Assessed the functionality of current drainage infrastructure and designed a rehabilitation programme.

1.4 The Land Drainage Master Plan (LDMP)

The main objective of the assignment is the elaboration of the Integrated Land Drainage Master Plan as a basis to the strategy, to be implemented by the Authorities and all stakeholders to reduce vulnerability of the population and various activities to heavy rain and flood events, in the context of climate change and uncertainty.

The Master Plan will include:

- An inventory and mapping of all the existing natural and manmade drainage infrastructures;
- An identification of vulnerable areas, including the impact of future developments on potential flood prone areas;
- The definition of a reference hydrology at the scale of each rainfall sub-catchment, based on new IDF curves,
- The elaboration of flood mapping and associated vulnerability assessment;
- The proposal for national rules in order to account for land drainage issues in territorial development with the objective of flood risk reduction, taking into account water quality and biodiversity preservation to improve the resilience of the country in the context of climate change.
- The definition of broad protection objectives at the scale of the most vulnerable catchments, based on detailed studies conducted at a more localised level;
- And finally, an action plan on the short and middle term.

1.5 Project Team

The Land Drainage Master Plan was carried out by a multi-disciplinary team comprising SUEZ of France as the main consultant in association with Mega Design Consulting Engineers of Mauritius. Sub-consultants included Acterra of France, and DAY Marine and Scene-Ries of Mauritius.

The Project Team comprised in the main:

- Arnaud Bonnafe-Team Leader
- Dharmanand Sooredoo-Deputy Team Leader
- Mathieu Ropert- Senior Hydraulic Engineer
- Aurelien Deconnick-Hydraulic Engineer
- Gopal Chand Khushiram-Civil Engineer
- Blandine L'hévéder- Climate Change Expert
- Vassen Kauppaymuthoo - Environmental expert

1.6 Workplan

The project started contractually in January 2020 and was scheduled to be completed within 15 months by end March 2021. Due to various delays, the most significant being the lockdown due to Covid19 both in Mauritius and in France, the Workplan had to be revised with completion of the study rescheduled for September 2021.

1.7 Structure of the LDMP report

Following the different activities constituting the assignment, various interim reports have been prepared and compiled into the main Land Drainage Masterplan Report, viz

Report	Description
D1	Report on the existing situation including land drainage issues and vulnerability assessment
D2	Hydrology study report, including new IDF curves, hydrological methodology for different return periods and risk and vulnerability due to climate change.
D3	Report on Existing Drainage Capacity including topographical survey and Flood maps on 5 priority sites and 11 most vulnerable sectors
D4	Feasibility Assessment Report

The LDMP report D5 comprises two parts; namely

- Report D5.1- Land Drainage Master Plan-First Part, comprising, inter-alia, hydrology framework, zoning and rules on territorial development and sizing of drainage infrastructure.
- Report D5.2-Land Drainage Master Plan-Second Part, comprising detailed hydraulic study reports on the priority sites and the most vulnerable sectors.

This document constitutes Report D5.1 and addresses the Terms of Reference, viz:

- Executive Summary
- Chapter 1: Introduction
- Chapter 2: Main issues identified and existing measures of prevention (partial data), including
    - Inventory and mapping of all the existing natural and manmade drainage infrastructure (1:10000 scale),
    - Flood mapping of historical flood prone areas (1:10000 scale),
    - Identification of vulnerable areas (1:10000 scale).
- Chapter 3: Objectives for drainage and surface sealing for the next 20-25 years in consistency with an Adaptation Programme to climate change:
    - with respect to natural areas with essential hydraulic functions in stormwater management,
    - for urban development: general principles applicable to built-up and growth zone for the control of waterproofing in urbanised areas, stormwater zoning and stormwater management modes,
    - present the zoning and main recommendations for each zone.
- Chapter 4: Definition of a reference hydrology at the scale of each sub-watershed, based on new IDF curves,
- Chapter 5: National rules in order to account for land drainage issues in territorial development:
    - Confirm with updated hydrology data
        - rules for sizing drainage structures, defined by type of development: main and secondary rainwater network, linear infrastructure, etc.
        - levels of protection of new buildings or structures when their construction is authorized in flood risk areas,
    - Urban Planning policy recommendations,
    - Governance recommendations: reminder of the principles of governance and regulations established under the ER2C assignment (Climate Change adaptation measures) and governance recommendations and clarification.

List of Acronyms, Conventions and Abbreviations

AFD	Agence Française de Développement
BRIO	Building Resilience in Indian Ocean
CC	Climate Change
CCVA	Climate Change Vulnerability Assessment
CGDD	Commission Génerale pour le Developpement Durable
CORDEX	Coordinated Regional Climate Downscaling Experiment
C1	Component 1
C2	Component 2
C3	Component 3
CCVRA	Climate Change Vulnerability and Risk Assessments
CWP	Center for Watershed Protection
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
DTM	Digital Terrain Model
D1	Deliverable 1
EIA	Environmental Impact Assessment
ER2C	Enhancing Resilience to Climate Change
ESA	Environmentally Sensitive Areas
GIS	Geographic Information System
ICZM	Integrated Coastal Zone Management
IDF	Intensity Duration Frequency
IOC	Indian Ocean Commission
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
LDMP	Land Drainage Master Plan
LIDAR	Light Detection And Ranging
MAIFS	Ministry of Agro Industry & Food Security
MBEMRFS	Ministry of Blue Economy, Marine Resources, Fisheries and Shipping
MEPU	Ministry of Energy and Public Utilities
MESWMCC	Ministry of Environment, Solid Waste Management and Climate Change
MoH & LUP	Ministry of Housing and Land Use Planning
MMS	Mauritius Meteorological Services
MOI	Mauritius Oceanographic Institute
NbS	Nature Based Solution
NDC	Nationally Determined Contribution
NDRRMC	National Disaster Risk Reduction and Management Centre
NDU	National Development Unit
NHDC	National Housing Development Company
ROM	Republic of Mauritius
PDS	Property Development Scheme
SCS - (NRCS)	Soil Conservation Service renamed Natural Resources Conservation Service)
SLR	Sea Level Rise
TA	Technical Assistance
VAT	Value Added Tax
VRA	Vulnerability Risk Assessment
WMA	Wastewater Management Authority
WRCP	World Climate Research Programme
WRU	Water Resources Unit
RDA	Road Development Authority
SuDS	Sustainable Drainage Systems
ToR	Terms of Reference
USDA	United States Department of Agriculture
VRS	Voluntary Retirement Scheme
WIO	Western Indian Ocean (WIO):
1D/2D	1 Dimensional / 2 Dimensional

2 MAIN ISSUES IDENTIFIED AND EXISTING MEASURES OF PREVENTION

2.1 Inventory and mapping of the main existing natural and manmade drainage infrastructure

This activity comprises the identification and characterization of primary and secondary drains as defined by LDA. It was undertaken in the sequence shown below:

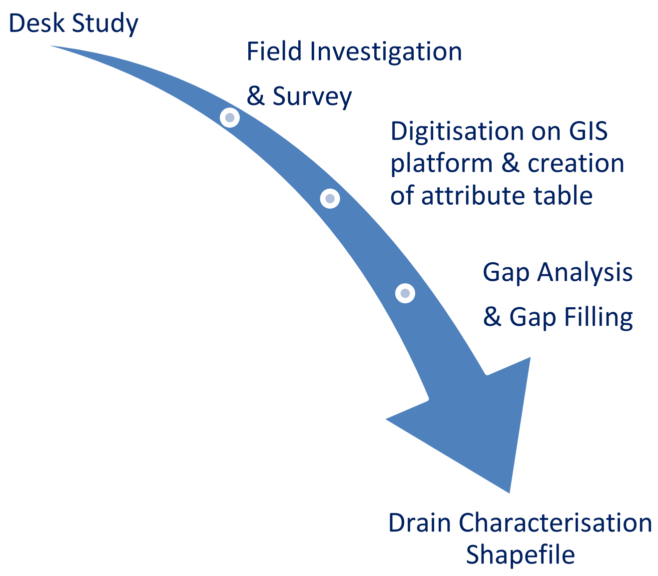


Figure 17: Methodology for drain identification and characterization

2.1.1.1 Desk study

Desk study comprised the collection of all available data pertaining to drain networks including data extracted from NDU's design and as constructed reports.

2.1.1.2 Field Survey

Field survey was undertaken on a zone wise basis by teams of two to three persons alternating between field and desk work monitored by one supervisory personnel. As a trial run in the region of Quatre Bornes, all drains (Primary, Secondary and Tertiary) were inventoried, irrespective of their classification and including irrigation canals (La Ferme canal and Trianon Grosses Roches) which form an integral part of the land drainage system.

Following discussions and an ensuing decision by LDA, only Primary and Secondary drains were inventoried.

2.1.1.3 Drain Mapping on GIS

The surveyed data were digitized in batches on a GIS platform and entered into an attribute table listing different fields described below:

Table 5: GIS drain characterization attributes

Field	**Description**
Authority	Municipal Council, District Council, RDA, etc.
Name	Name/ location of the drain
DrainType1	Roadside drain, urban drain, irrigation canal or river
DrainType2	Material and type of drain (e.g. covered RC U-drain, open stone masonry Drain)
Class	Primary, Secondary or Tertiary Drain
EntryX_Coo	The WGS 84 UTM Zone 40S X coordinates at the upstream section of a particular drain
ExitX_Coo	The WGS 84 UTM Zone 40S X coordinates at the downstream section of a particular drain
Botwidth_mm	The bottom width of a particular drain section
Topwidth_mm	The top width of a particular drain section
Depthup_mm	The upstream depth of a particular drain section
Depthdw_mm	The downstream depth of a particular section of the drain
Diameter_mm	Diameter of drain, where applicable (e.g. conduits)
EntryY_Coo	The WGS 84 UTM Zone 40S Y coordinates at the upstream section of a particular drain
ExitY_Coo	The WGS 84 UTM Zone 40S Y coordinates at the downstream section of a particular drain
Length_m	The length of a particular drain section
Remarks	Remarks on the drain section
Source	Mega Design or Day Marine

Separate polylines were drawn on the GIS environment to demarcate different drain classes, types, widths and changes in direction. To visualise the flow direction from the shape file, the drain line type should be selected as 'Arrow Right Middle'.

2.1.1.4 Extent of Drain Characterised

The extent of drain surveyed for the different regions across the island is as follows:

Table 6: Extend of drain surveyed for the different regions

Region		Length of Drains Characterised (km)
1	Baie du Cap	0.16
2	Baie du Tombeau	0.99
3	Bel Air Riviere Seche	4.43
4	Bel Ombre	5.89
5	Bramsthan	1.74
6	Cascavelle	2.24
7	Centre de Flacq	0.52
8	Clemencia	12.56
9	Cottage	1.82
10	Esperence Trebuchet	0.23
11	Flic en Flac	4.01
12	Fond du Sac	2.58
13	Grand Bay	1.72
14	Grand Gaube	0.17
15	La Gaulette	1.32
16	Le Hochet	2.99
17	Mapou	2.36
18	Moka	8.51
19	Municipal Council of Beau Bassin Rose Hill	63.63
20	Municipal Council of Port Louis	146.89
21	Municipal Council of Quatre Bornes	53.40
22	Municipal Council of Vacoas Phoenix	150.12
23	Municipal Council of Curepipe	123.28
24	Nouvelle France	4.54
25	Piton	2.16
26	Poste de Flacq	0.61
27	Petite Riviere	0.11
28	Queen Victoria	1.34
29	Richelieu	2.02
30	Seizieme Mille	0.39
	Total Length of Drains Characterised	**602.34**

2.2 Flood mapping of historical flood prone areas

The flood zone maps for different return periods (10, 25, 50 and 100 years) are provided in **D5.2** for all the sectors that have been modelled, i.e., the following sectors:

- **Priority sites :**
  - Port Louis:
    - Sector 73- Rivière Lataniers and Canal Anglais;
    - Sector 75 - Rivière du Pouce, La Poudrière Stream, Ruisseau des Créoles and Cut-off drain; and
    - Sector 77 - Canal Dayot and drains within its urbanised zone.
  - Sector 65 - Flic-en-Flac;
  - Sector 32 - Bel Ombre;
  - Sector 47 - Nouvelle France;
  - Sector 5&6 - Grand Baie / Pereybere.

- **Others sites (complementary sites) :**
  - Sector 1 - Mapou Piton Cottage;
  - Sectors 25 and 102 - Clemencia Bel Air Olivia Pont Lardier;
  - Sector 43 - Flacq;
  - Sector 59 - Coteau Raffin;
  - Sector 72 - Terre Rouge;
  - Sector 74 - Port Louis La Paix;
  - Sector 78 - Pointe aux Sables;
  - Sector 82 - Henrietta Malakoff;
  - Sector 85 - Vacoas Quatre Bornes;
  - Sector 86 - Curepipe aval.

The map below shows the location of all the catchment areas and surfaces modelled in the LDMP.

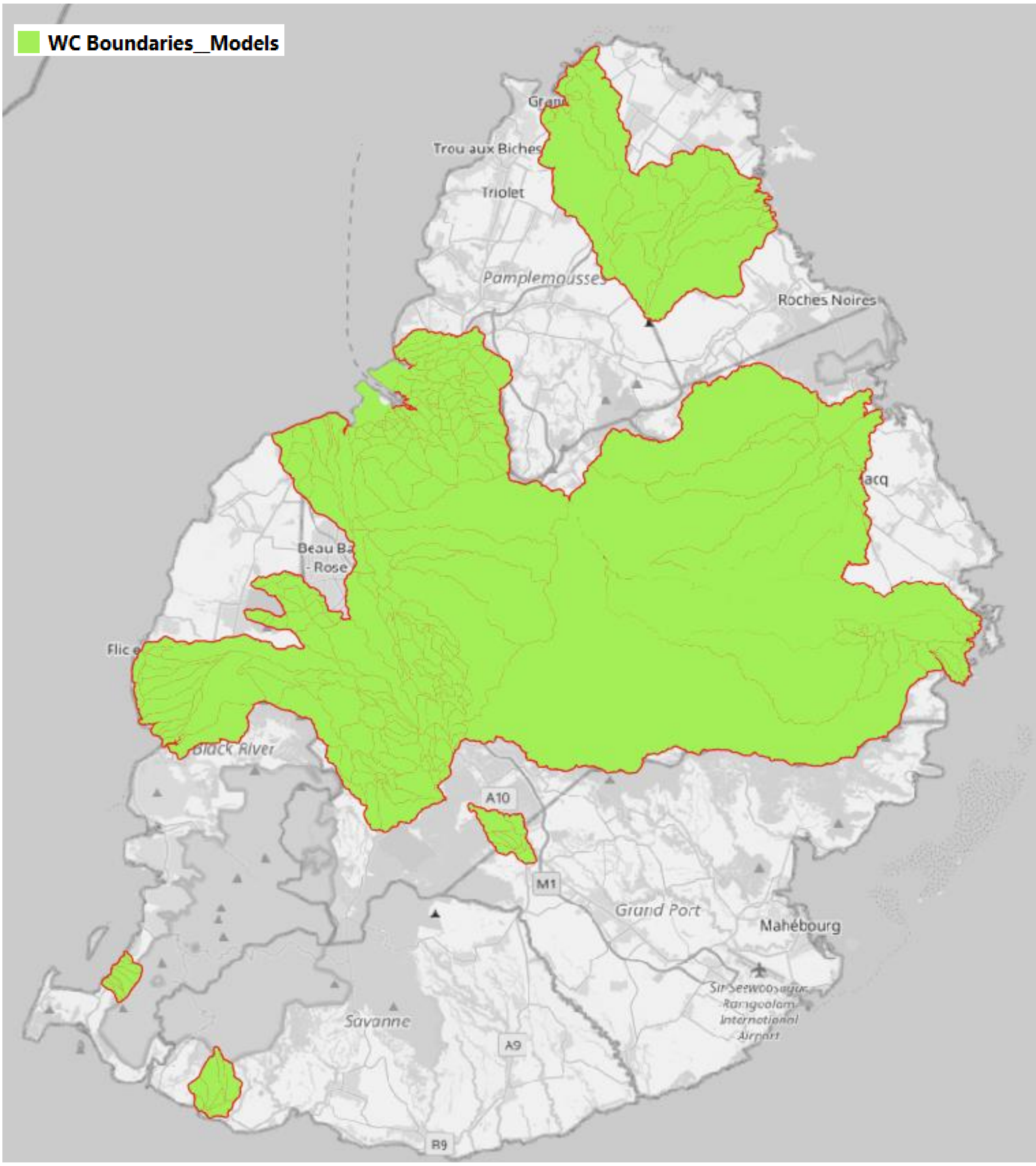


Figure 18: Land Drainage Master Plan modelled areas priority and complementary sites - Catchment areas modelled (5+11 areas)

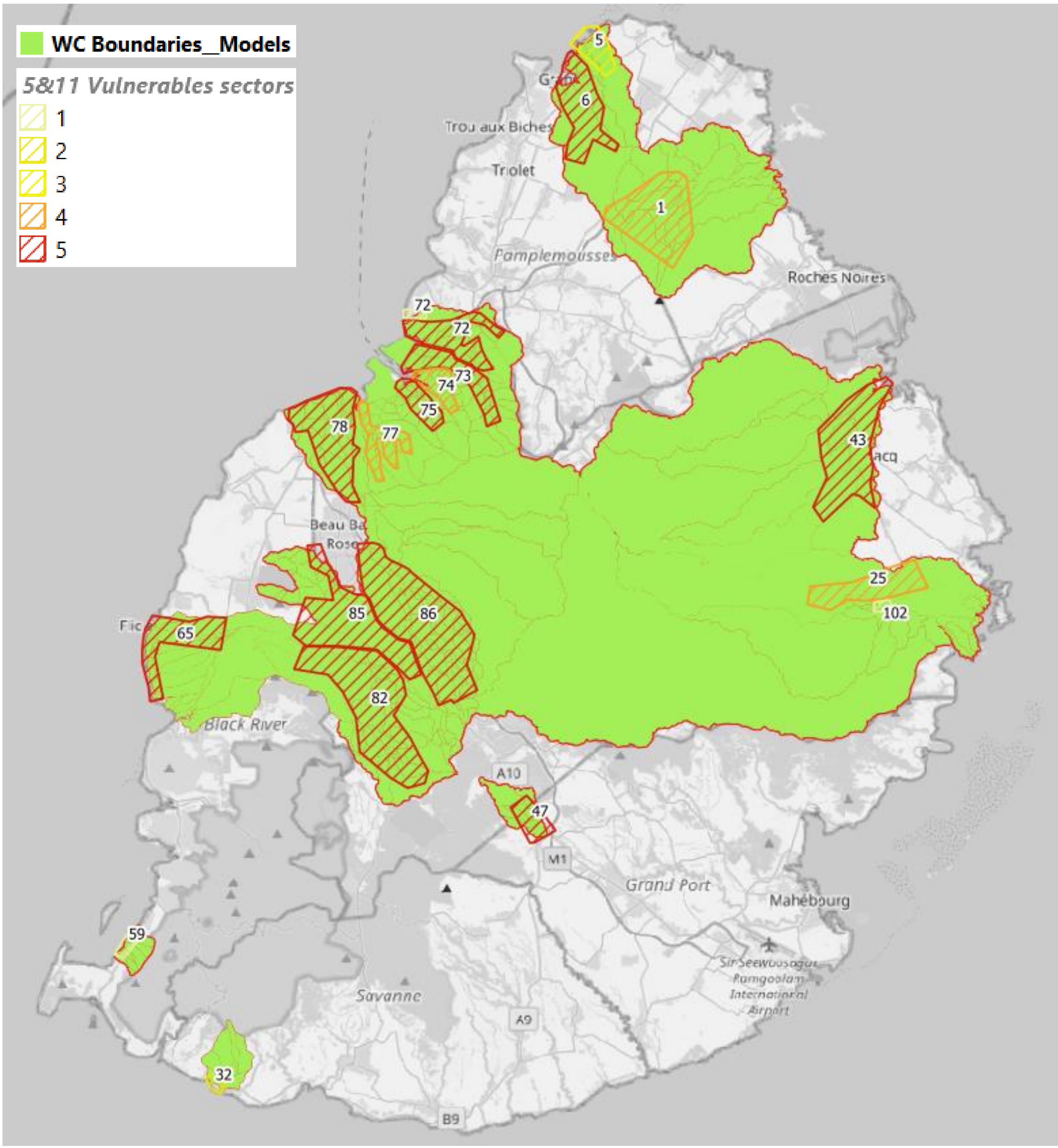


Figure 19: Land Drainage Master Plan modelled areas priority and complementary sites - Catchment areas modelled and boundaries of vulnerable sectors (5+11 areas)

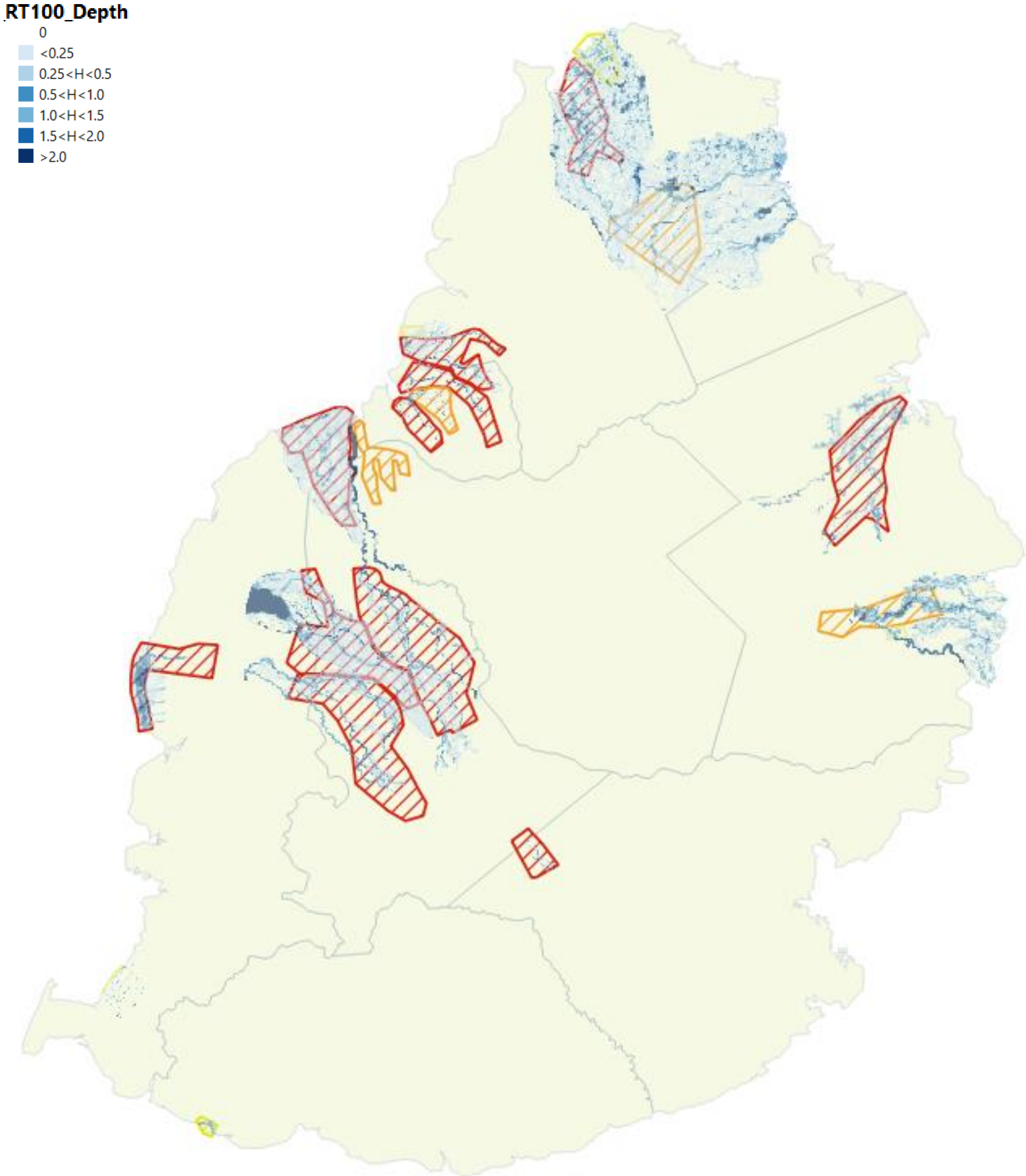


Figure 20: Land Drainage Master Plan modelled areas priority and complementary sites - T100y hazard Modelling (5+11 areas)

This is completed by an understanding of the hazard, at the scale of the whole island, by:

- Information on past floods (known to date, i.e., September 2021):
  - **flood marks** (224)
  - **flood prone area** (305)

- Potential flood zone information by **hydrogeomorphological analysis** (EXZECO)
  The **hydrogeomorphological** method is essentially used for the diagnosis of flood-prone areas. It is now one of the tools recommended by different ministries all over the world (nearest example in Reunion Island) responsible for flood prevention. This method is a favourite tool for mapping flood-prone areas, as it perfectly matches the requirements of this type of study. It provides information on the natural unfurling of floods over large linear areas.

  The following figure synthesises these hydrogeomorphological units.

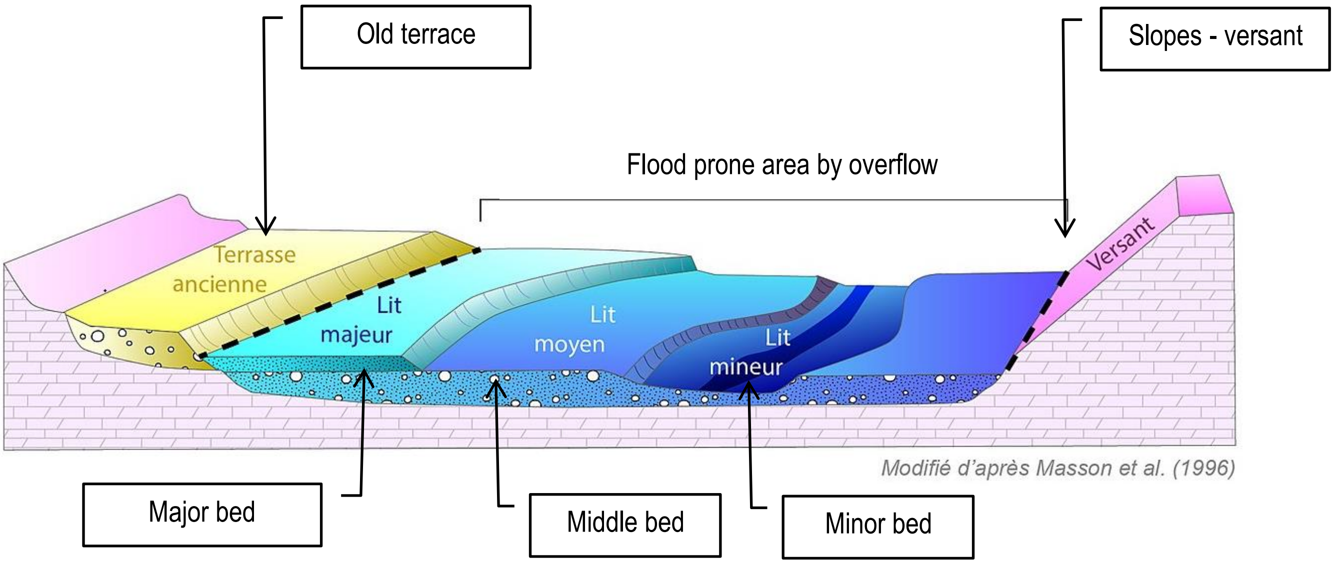


Figure 21: Hydrogeomorphological units (source Masson and al. 1996)

For a global analysis at the scale of the whole island, the characterisation of potentially flood areas was carried out by the ExZEco method.

This method is based on topographic analysis which highlights flow accumulation areas using a random effect on the DEM[3]. This method is equivalent to filling thalwegs with an enforced height of water.

The hydrogeomorphological coverage, by definition, representing the complete topographical framework of the area, gives an envelope which is globally superior in coverage than those resulting from urban runoff by modelling, taking into account the open drains and the flow in networks.

[3] reference: https://www.asprs.org/wp-content/uploads/pers/1988journal/nov/1988_nov_1593-1600.pdf - K. Jenson and]. O. Domingue - 1988

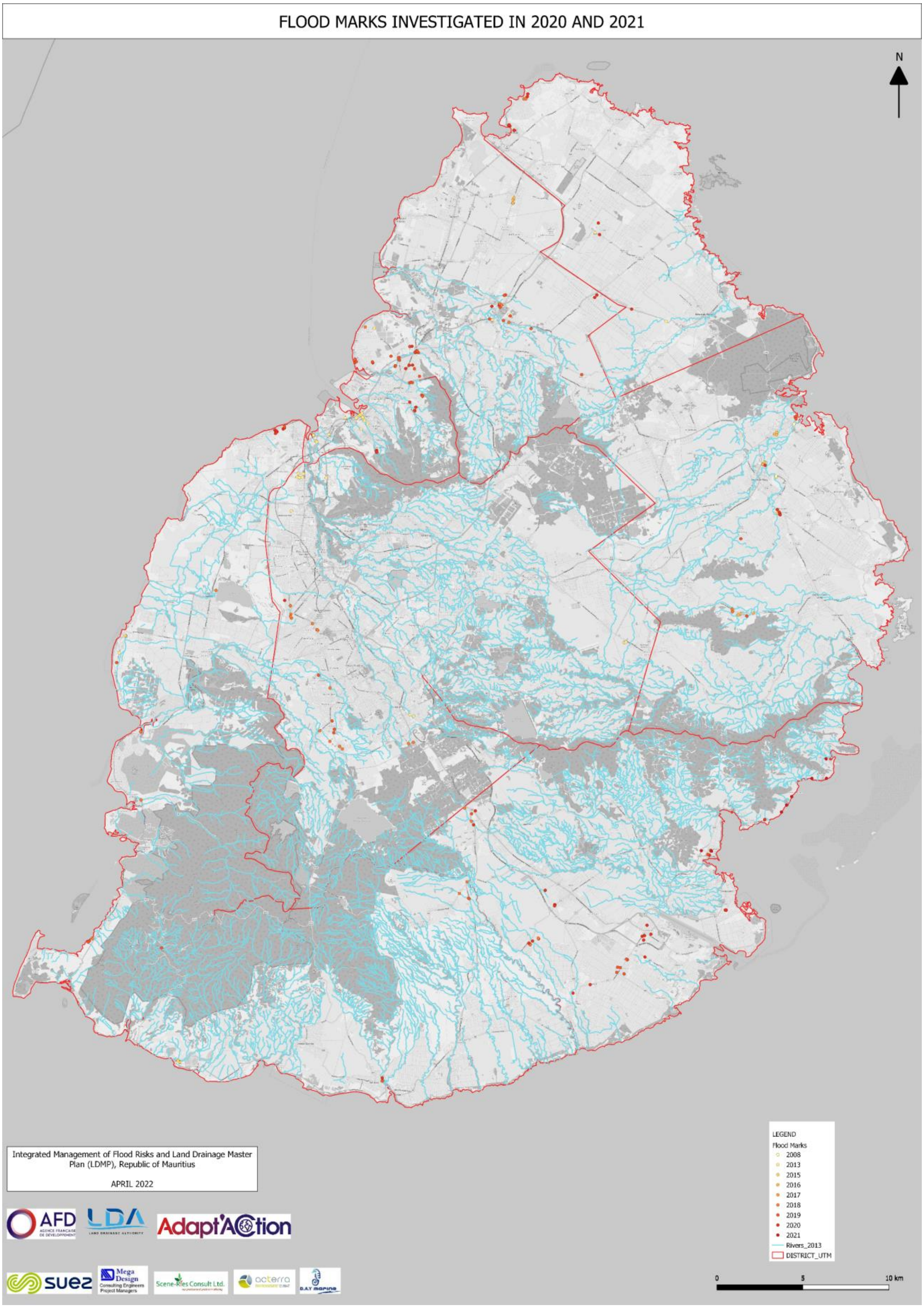


Figure 22: Flood marks investigated (224) in 2020 and 2021 – classification by date of events

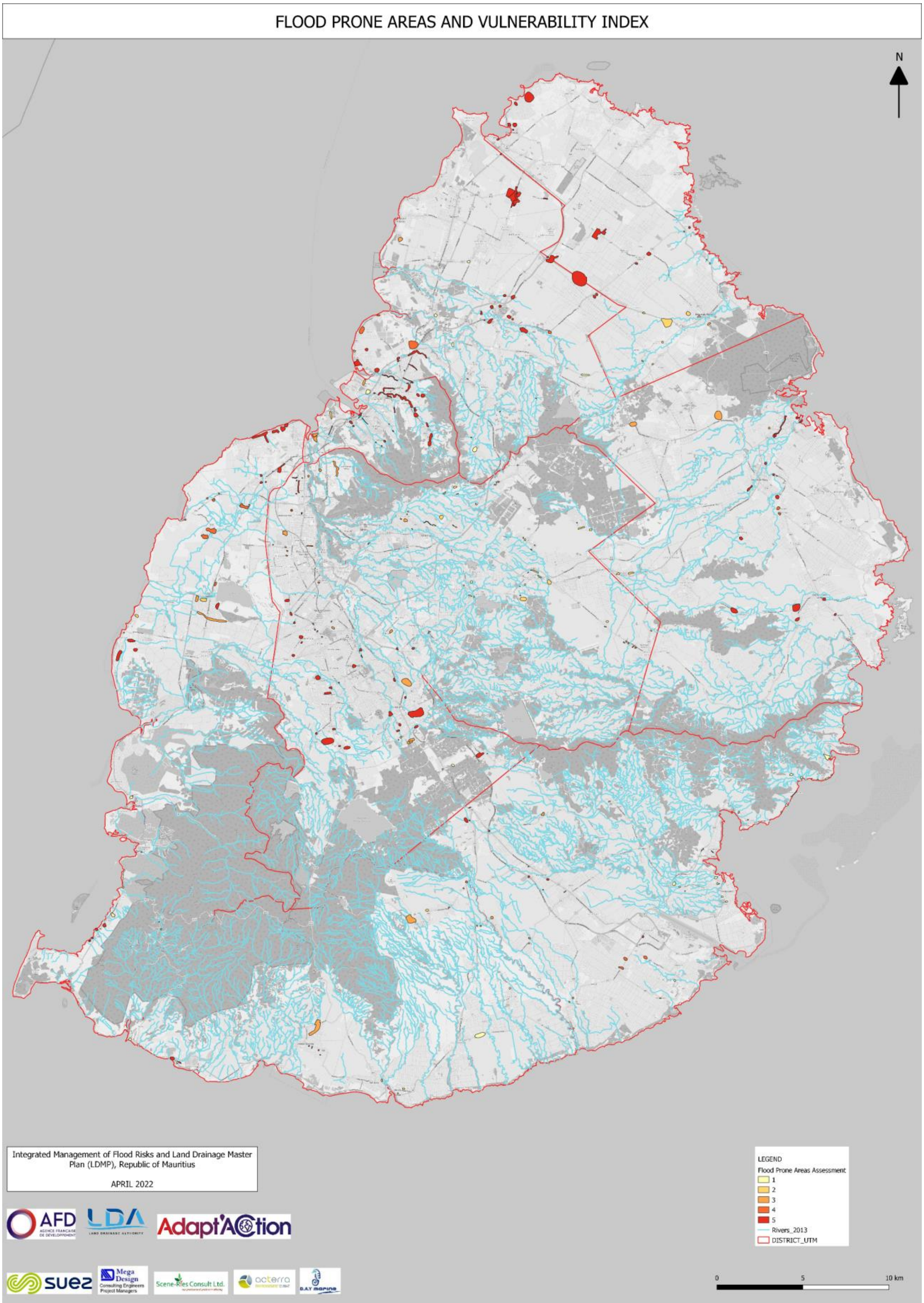


Figure 23: Flood Prone Area and vulnerability (305) – status September 2021

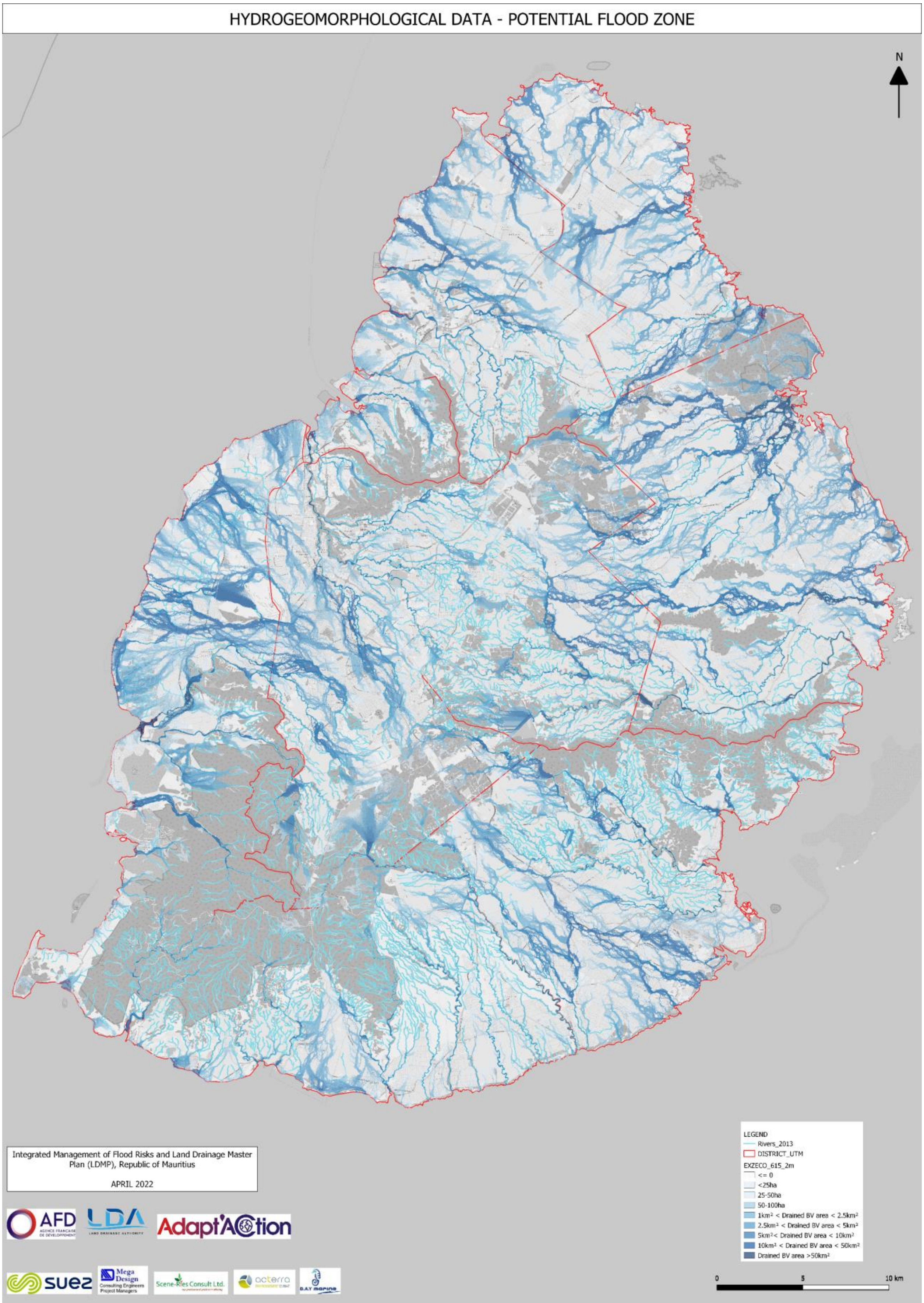


Figure 24: Hydrogeomorphological data – Potential flood zone

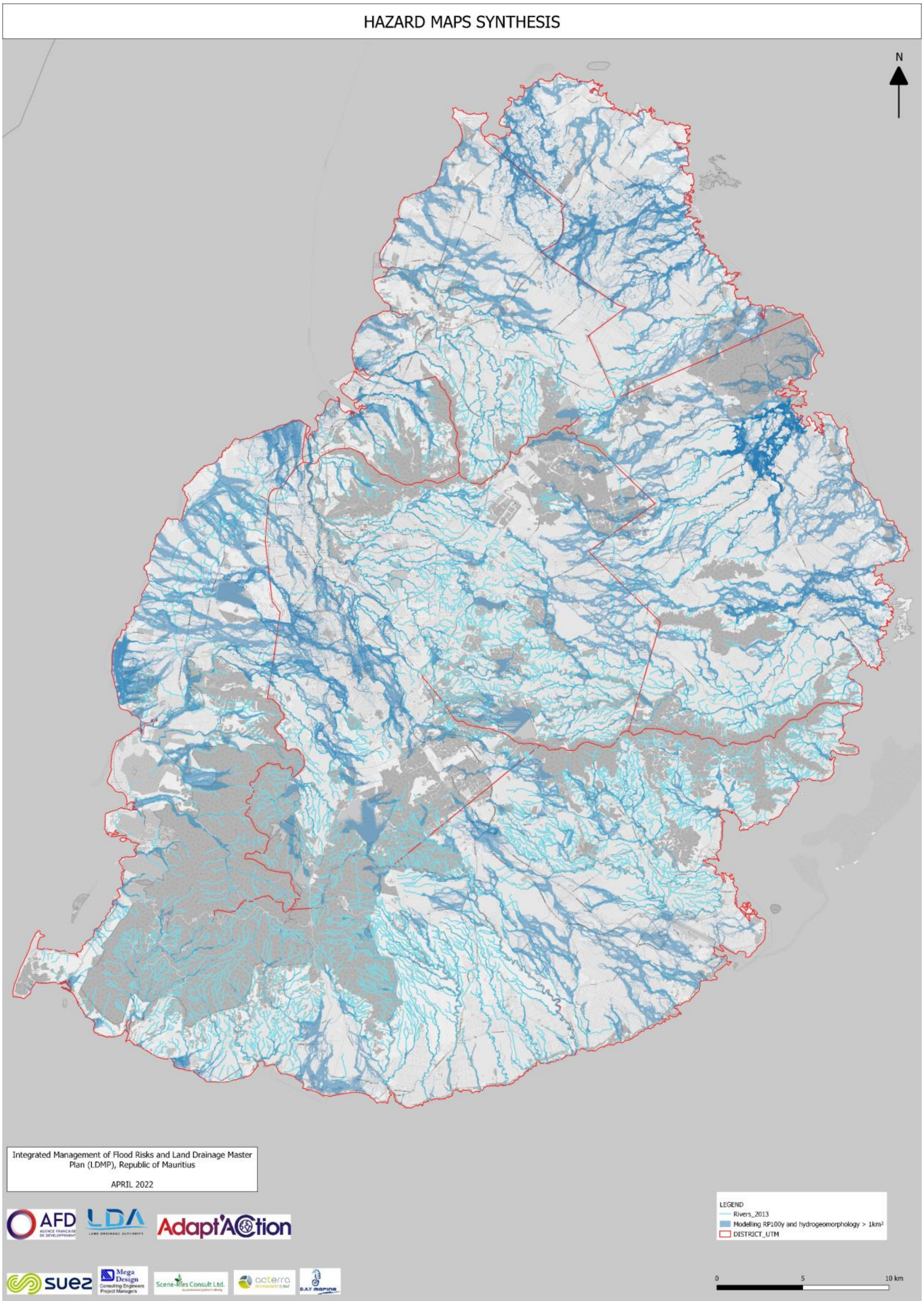


Figure 25: Hazard map synthesis – Modelling RT 100 y and hydrogeomorphological data

2.3 Identification of vulnerable areas

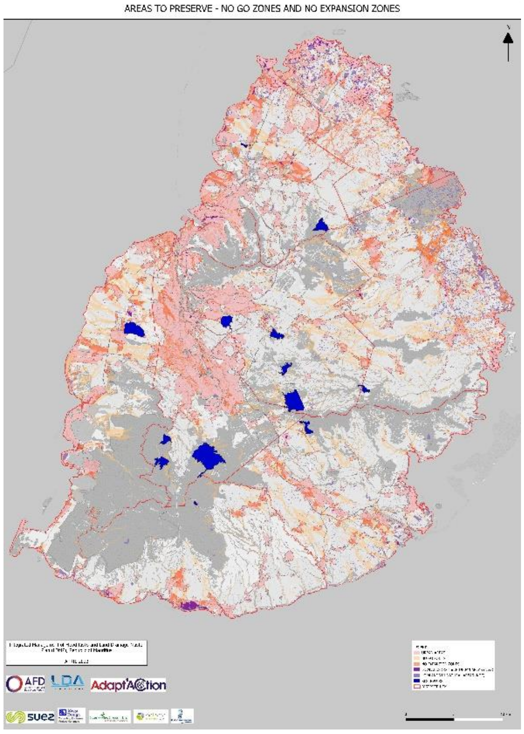


Figure 26: NGZ and NEZ

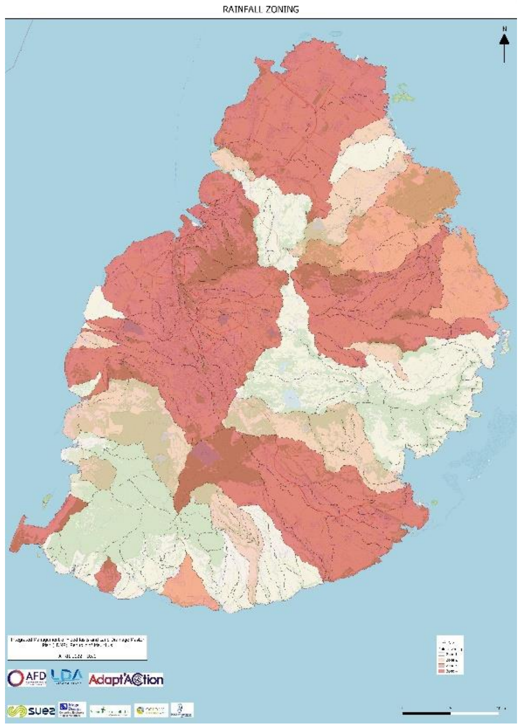


Figure 27: RAINFALL ZONING

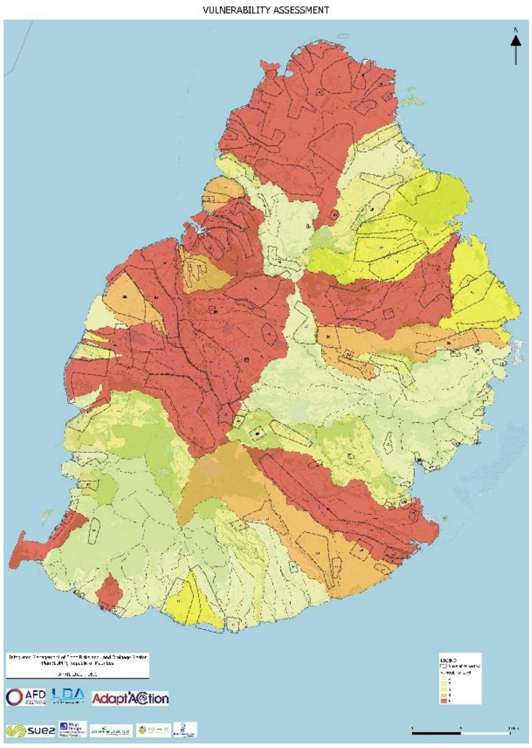


Figure 28: Vulnerability Sectors

(See higher resolution digital files in folder mapping)

2.4 Existing preventive measures and focus on ESAs hydraulic function

Rivers and Catchment Areas - Legal and Institutional Framework

The LDMP must be compatible with the environmental laws of the land.

▷ Protection and Definition of Rivers

The Forests and Reserves Act (Act No. 41 of 1983 which came into force on 1 May 1984) provides:

Legal definitions of rivers and escarpment (section 2 sub-sections (1)) as follows:

- "escarpment" means the bank of a river, rivulet or feeder, the mean slope of which makes an angle of not less than 60 degrees with the horizontal line;
- "feeder" means the affluent of a river or rivulet;
- "river" means a river specified in the Fourth Schedule[4]; "river reserve" means— (a) where there is an escarpment, the land extending from the edge of a watercourse to the top of the escarpment; (b) where there is no escarpment, the land extending from the edge of a watercourse to a distance measured on the horizontal plane— (i) in the case of a river, of 16 metres; (ii) in the case of a rivulet, of 8 metres; (iii) in the case of a feeder, of 3 metres; "rivulet" means a rivulet specified in the Fourth Schedule;
- "stream" includes— (a) any marsh or morass situated on State land from which a stream flows; (b) any marsh or morass not situated on State land declared to be a stream by the Minister, by regulations;

It is noted that the natural flow axes outside the rivers, streams and named feeders are not concerned, which leads to problems with regard to the free flow of water (see Article 640 of the Civil Code of 1804 cf. 2.4.1).

▷ Definition and Protection of Catchment Areas

The Central Water Authority enacted the Central Water Authority (Designation of Catchment Areas) Regulations 1986 (Government Notice No. 44 of 1986) on 24 May, 1986.

[4] This schedule defines Rivers and Rivulets

The map attached to the said regulations is reproduced hereinafter (Source: Ministry of Energy and Public Utilities, Government of Mauritius, Hydrology Data Book 2006 – 2010, http://publicutilities.govmu.org/English/Pages/Hydrology-Data-Book-2006---2010.aspx).

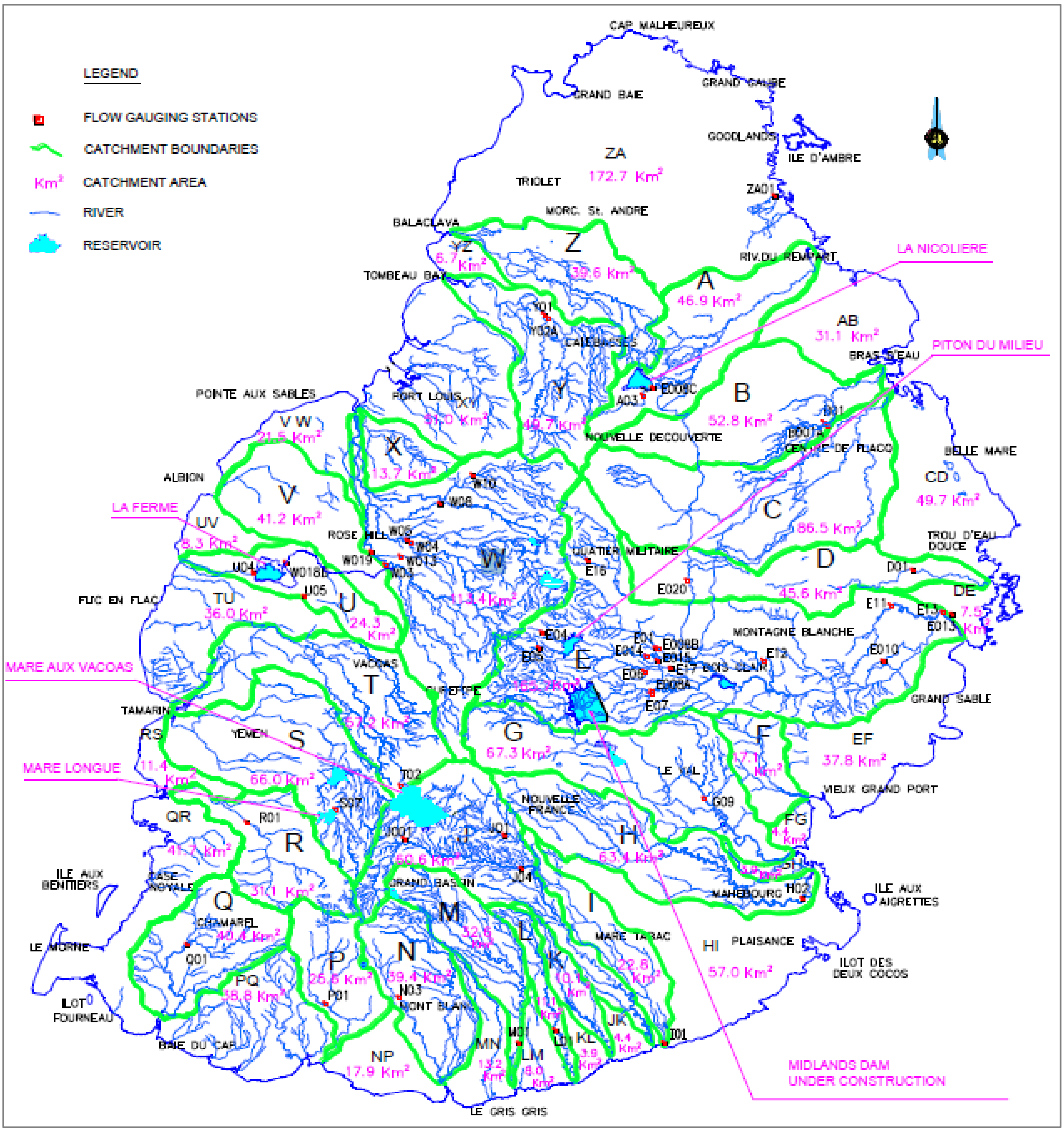


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Figure 29: Definition and Protection of Catchment Areas - Central Water Authority (Designation of Catchment Areas) Regulations 1986

2.4.1 Drainage measures - Civil Code and Drainage Impact Assement (recent provision)

With regard to water flows, the law in force results from the Civil Code:
Article 640 le Code Civil de 1804 « Les fonds inférieurs sont assujettis envers ceux qui sont plus élevés à recevoir les eaux qui en découlent naturellement sans que la main de l'homme y ait contribué. Le propriétaire inférieur ne peut point élever de digue qui empêche cet écoulement. Le propriétaire supérieur ne peut rien faire qui aggrave la servitude du fonds inférieur ».
The law on the protection of natural land drainage (Code Civil) does exist as a matter of fact but is not applied.

It should be noted that as from May 2019, a Drainage Impact Assessment is required for developments above 5 arpents (i.e. approximately 1.7 ha) to "analyse the impacts on the drainage and stormwater system".

2.4.2 Urban Planning Policy recommendations – Existing Basic Preventative Measures

(Source: ER2C Guideline)

First of all, planners and local authorities responsible for permit delivery have to ensure that the project complies with the basic measures recommended in the Planning Policy Guideline (PPG 1) part A from the Ministry of Housing and Land Use Planning, technical sheet "drainage."

These measures are recommended for use by developers during the planning phase of proposed developments. **Permit applications should include evidence that the drainage system has been designed in accordance with these recommendations.**

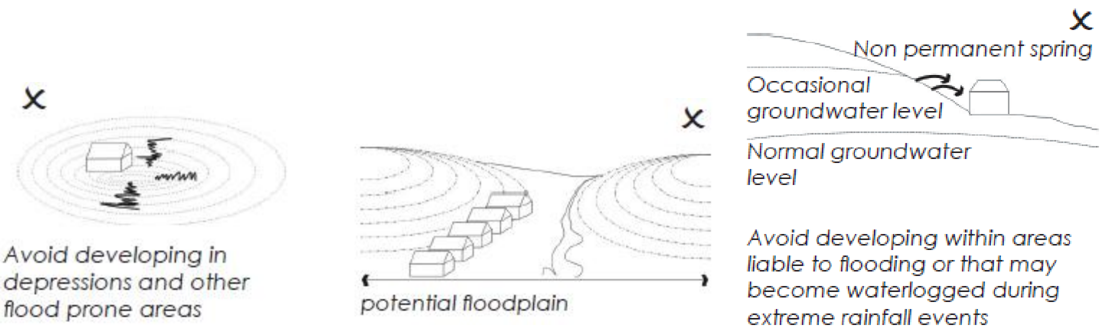


Figure 30: Recommendations for an efficient drainage system

Appropriate precautionary measures and drainage facilities should be provided to ensure that:

- ▷ The site itself does not flood
- ▷ Other properties are not adversely affected by the proposed development
- ▷ Essential groundwater recharge potential is not lost
- ▷ Erosion of ground does not occur

According to this technical sheet, and in order to ensure compliance with these principles, "the developer should properly map the proposed development (1:2000 scale) and surrounding area (1:10 000 scale) to ascertain the extent of all the catchment that contribute to water flows through and from the development. Such mapping should also include all streams and show contours at:

- ▷ 1m intervals for land with a slope of <5%
- ▷ 5m – 10m intervals for land steeper than 5%"

In case of doubt, the developer may query the local authorities, who in turn can seek advice from the LDA, to specify the constraints linked to the areas at risk.

The following **check list** below will help the developer and local authorities to verify if the project will be in accordance with these basic principles, and to ensure that any new development will not be at risk or exposed to damage due to flooding:

- ▷ "keep all drainage channels free of structures, trees, vegetation and other obstructions
- ▷ keep access for maintenance purposes
- ▷ ensure that any plot access "bridge" does not impede the performance of the drainage system
  - Normal operation of the development will not be susceptible to disruption as a result of flooding from any recurrent event;
  - Safe access to and from the development will be possible during the appropriate design flood event;
  - The development will not increase flood risk anywhere else;
  - The development will provide safe access for maintenance of watercourses or maintenance and operation of flood defences by Local Authorities and the Land Drainage Authority;
  - The development will not lead to the degradation of the environment;
  - The development will meet all the outlined criteria for its entire lifetime including consideration for climate change."

The following extracts from PPG1 refer to flood risk management (Technical Sheet Drainage):

Drainage

A written statement must be secured from the local authority stating that they have no objections to the development with respect to the provision of drainage.

Consideration of the provision of drainage facilities to developments will be undertaken by the Ministry of Environment National Development Unit (MoE-NDU) on a case-by-case basis. There are however, general requirements and guidance that should be considered by prospective developers when preparing development schemes.

Study of the Land Drainage System of the Island of Mauritius

The Ministry of Public Utilities commissioned a study into land drainage issues, which was completed in 2002. The report contains guidance on the control of surface water runoff and suggests how drainage systems should be implemented in development projects.

The proposals are recommended for use by developers when planning the layout of proposed developments. Permit applications should include evidence that the drainage system has been designed in accordance with these proposals.

Need for Drainage Provision

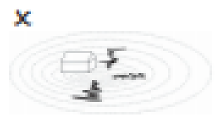
Most new development will change the surface water runoff regime. Changing land use from rural to urban (soft landscape to hard) means an increase in impermeable areas (roofs, drives, roads). Consequently rainwater that falls on the area will run off quicker than it did previously.

A small development of a house or two, taken in isolation, may be perceived to have a negligible effect on runoff. However, when several such developments are added together in one area, a significant change in runoff regime may occur.

It is essential that surface water runoff is adequately controlled to ensure that downstream land and settlements are not adversely affected and that soil erosion and subsequent environmental damage does not occur. (Note. This may require both on site and off-site measures to be implemented).

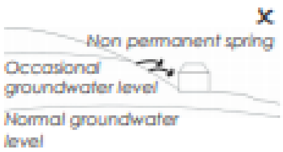
Areas Liable to Flooding

Whilst it is recognised that it is not normally practical to design for extreme rainfall events, consideration should be given to the areas that are liable to flooding during such events. These areas should be identified as early as possible in the design process and development should be laid out accordingly to minimise any potential damage.



Avoid developing in depressions and other flood prone areas

potential floodplain



Avoid developing within areas liable to flooding or that may become waterlogged during extreme rainfall events

Drainage

Appropriate drainage facilities should be provided to ensure:

- **The site itself does not flood**
- **Other properties are not adversely affected by the proposed development**
- **Essential groundwater recharge potential is not lost**
- **Erosion of ground does not occur**

General Approach to be Adopted for Drainage Design

The developer should properly map the proposed development (1:2000 scale) and surrounding area (1:10 000 scale) to ascertain the extent of all the catchment areas that contribute to water flows through and from the development. Such mapping should include all streams and show contours at:

- 1m intervals for land with a slope of <5%
- 5m – 10m intervals for land steeper than 5%

The development proposals need to deal with drainage of storm water that flows through the development from surrounding areas and settlements in addition to that which is generated from the development itself. Proposals should also demonstrate that no significant harm will be caused to properties or land downstream as a consequence of the proposed drainage system.

Each property within the development should be able to discharge into the drainage system by gravity. The entire surface water drainage of the development should be achieved by gravity.

The sub-division of land can involve interference with the natural surface drainage patterns of overland flows and flows through small streams.

For small catchment areas, e.g. less than 5 hectares, it may be acceptable to utilise roadside drainage channels to intercept and convey surface water.

For larger catchment areas the construction of suitable drains would be very costly and it would be preferable to plan the road network and plot layouts to integrate with the natural streams and watercourses and use these to continue to carry surface water through the development.

The attached drawings, which have been developed from those included in the Land Drainage Study report, indicate how a drainage system might be laid out in accordance with the above principles.

Property developers should require plot purchasers to:

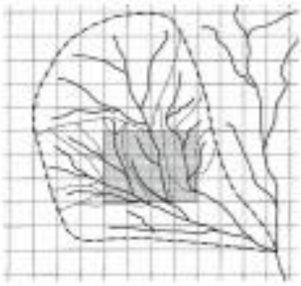
- **keep all drainage channels free of structures, trees, vegetation and other obstructions**
- **maintain access for maintenance purposes**
- **ensure that any plot access "bridges" do not impede the performance of the drainage system**

Basic Design Parameters

The following parameters are suggested as general rule-of-thumb criteria that could be adopted. However the overall drainage system will need to be designed by a qualified engineer. The parameters identified are for guidance:

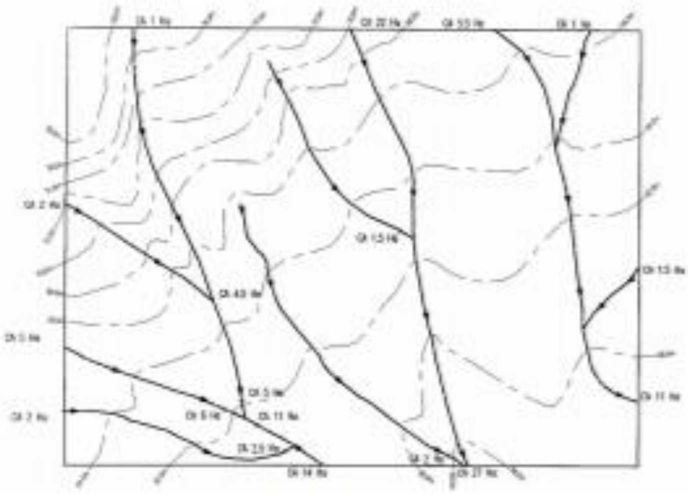
- Open roadside drains should not exceed 400mm width and 500mm depth
- Larger drains should be covered with suitable provision for water to enter and for maintenance access

Drainage



Overall Catchment Plan

Plan the road network and development layout so that the major natural surface water drainage patterns are maintained



Proposed Development Area Within Catchment

Possible Development Layout Maintaining Main Natural Surface Water Drainage Channel or Route

Drainage

- Open drains are unlikely to be able to drain areas greater than:
  - 2 ha in flat areas (<1%)
  - Up to 5ha for steeper areas (up to 6%)
- Under design conditions velocities above 0.75m/s must be achieved
- Maximum flow rates must not exceed 4m/s

Possible Arrangement of Services

A separate Technical Sheet: Combined Utility Services Summary plans provides indicative groupings for arrangements of the various utilities that generally need to be laid within the road and utility reserve. These drawings are for **information only** and are not intended to cover every eventuality. They do, however, serve to demonstrate why it is important to consider all the utilities and how they relate to each other when preparing layout plans.

It is important to carefully consider the manner in which roadside drains inter-relate with other services, particularly with regard to:

- the need for other services to pass under the drains - so deep drains may have a significant effect on how those services are installed
- the way drains cross roads (for example at road junctions)

Piped drains, for example, may be necessary at some points in order to allow other services to pass under or over the drain rather than channels.

In relation to slopes, PPG 9 states:

- Definition of Steep Slopes:

  Steep slopes: Gradient above 20 % in Category 1 of ESA classification requiring protection through strict control on land use.

  Moderate slopes: Gradient 10 – 20% in Category 2 of ESA classification where some degree of alteration permitted with sites maintained in a healthy state.

  Steep slopes are defined as lands in their **natural state that have a slope angle of 20% or greater for a minimum horizontal distance of 10 metres.**

- Stability and slopes

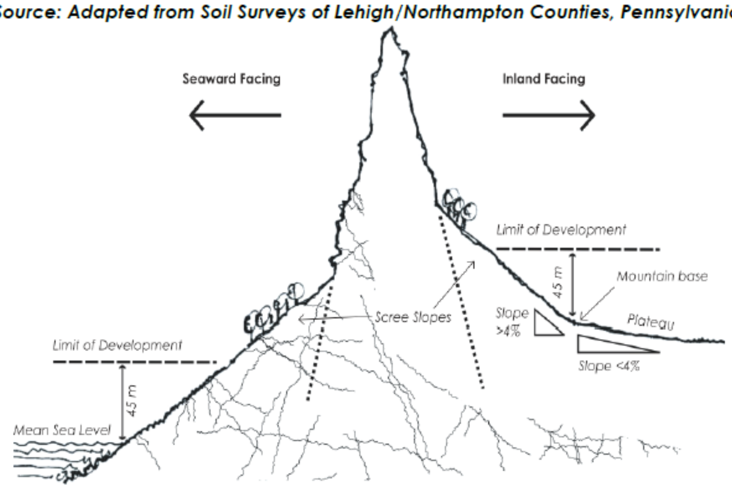
  This Design Guidance should be applied to proposals for development on the slopes of the Mountain Ranges as listed in the First Schedule of the Forest and Reserves Act 1983 or as subsequently amended and as defined in the Environmentally sensitive maps and any other locations where steep (>10%) slopes exist.

  - As a general guide development should not be any higher than 45 metres above the mountain base, or in the case of slopes facing the sea, 45 metres above Mean Sea Level.
  - Development is not allowed on slopes greater than 20%
  - Development is not allowed in landslide hazard zones (yellow zone) – (Section 8).
  - Development is not allowed in special hazard zones (red zone) – (Section 8).

TABLE 1: General guide on Degree of slope / Development Potential

0% to 3%	Generally suitable for all development and uses.
3% to 8%	Suitable for medium density residential development, agriculture, industrial and institutional uses.
8% to 20%	Suitable for moderate to low-density residential development, but great care should be exercised in the location of any commercial, industrial or institutional uses.
Over 20%	Only used for open space, limited agricultural and certain recreational uses.

Source: Adapted from Soil Surveys of Lehigh/Northampton Counties, Pennsylvania,



Height limitation of development on mountain slopes

2.4.3 Environmentally Sensitive Areas (ESA) as nature based climate Change line of defence to climate change impacts

2.4.3.1 Nature-Based Solutions

The protection and enhancement of **Environmentally Sensitive Areas (ESA)** have been identified as **key nature-based solutions in order to increase climate-change resilience for the island of Mauritius**.

Applying nature-based solutions for climate change implies the following principles:

- ▷ Managing at relevant environmental units for coastal zones by reinforcing Integrated management at relevant environmental scale
- ▷ Promoting a ridge to reef approach by preserving/ restoring ecological services to ensure sustainable development and natural protection and functions to cope with climate change
- ▷ Preserving/ restoring ecological services recognising their contribution towards sustainable and climate-resilient economic development
- ▷ Preserving, restoring and managing wetlands by adopting integrated approaches (integrated water resources management at watershed scale (IWRM) and integrated coastal zone management (ICZM) – multi-sector, multi-stakeholder etc.

An illustration of the main ecosystems and how IWRM and ICZM inter-connect is provided below.

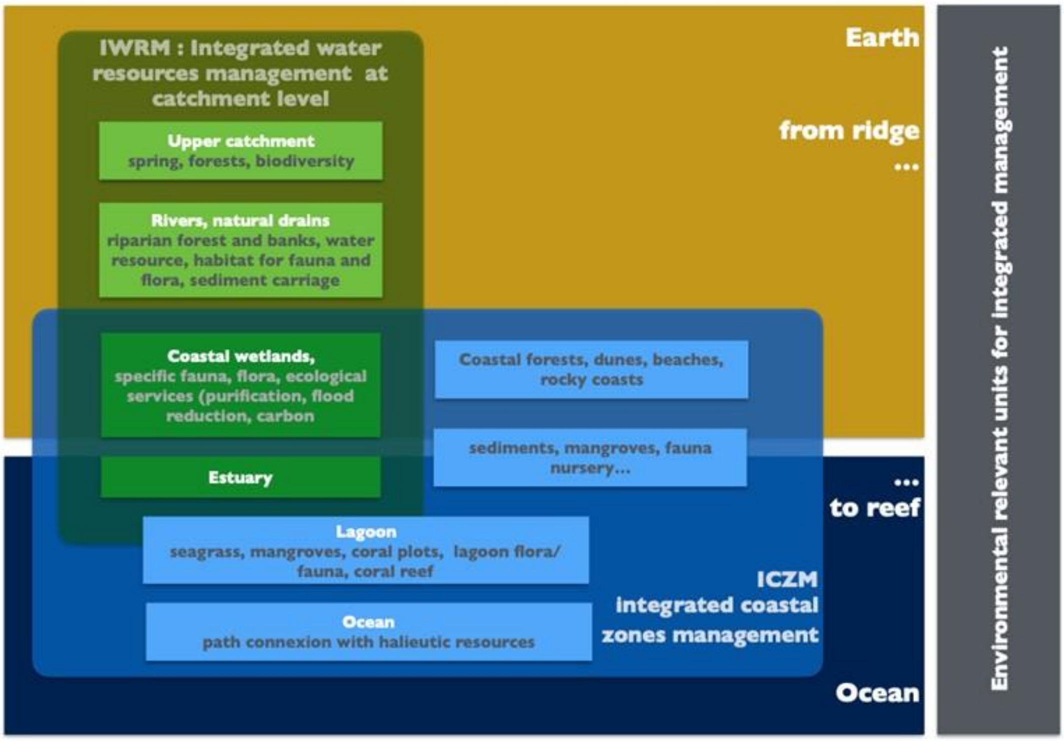


Figure 31: IWRM and ICZM overlap in small island states (Millenium Ecosystem Assessment)

2.4.3.2 Hydrological function of different types of ESAs and their response to flooding

2.4.3.2.1 Introduction – ESA in Mauritius

ESAs in Mauritius include coral reefs, islets, seagrass and algal beds, inter-tidal mudflats, mangroves, sand beach and dunes, lava and calcarenite caves, forests with high native fauna or flora content, coastal marshlands, upland marshlands and lakes, reservoirs, rivers and streams and boreholes. The responsibility of ESAs is fragmented as described below:

- The Ministry of Blue Economy, Marine Resources, Fisheries and Shipping deals with ESAs located below the line of high water mark, i.e. coral reefs, seagrass and algal beds, inter-tidal mudflats, mangroves
- The Ministry of Agro-Industry and Food Security manages islets declared as nature reserves, forests with high native fauna or flora content, coastal marshlands and upland marshlands, rivers and streams reserves and lava and calcarenite caves (with a high biodiversity value)
- The Ministry of Energy and Public Utilities manages lakes and reservoirs, rivers and streams and boreholes in terms of water resources
- The Ministry of Housing and Land Use Planning looks after non classified islets, sand dunes, lava and calcarenite caves (unless containing a high biodiversity value).

Among those ESAs, **only:**

- **coastal marshlands,**
- **upland marshlands and lakes and reservoirs,**
- **rivers and streams**
- **and borehole**

  have a critical hydrological function which is relevant to land drainage and flooding, while sand beach and dunes, lava and calcarenite caves, forests with high native fauna or flora content have a minor hydrological role but a major role against the adverse impacts of flooding.

▷ **Coastal marshlands**

In fact, coastal marshlands form in low depressions in the coastal backwash region behind sand dunes and berms or where lava flows have generally led to areas of low soil permeability and storage capacity. Many marshlands have also developed in the artificial depressions created through past mining and agricultural activities. Marshes are wetlands that are dominated by herbaceous rather than woody plant species. In Mauritius, coastal marshlands are dominated by a few cosmopolitan water plants such as *Typha* (cattail) and *Acrostichum* (fern). The most important value of these areas rests with their hydrological function and flood mitigation role. The value of those marshlands adjacent to build up areas increases since the spread of impermeable surfaces prevents stormwater runoff in areas with low stream densities. The most recent survey carried out in 2019 confirmed that this area has been underestimated as 1,164 hectares of coastal marshlands were mapped in the context of this project. Coastal marshlands are found only on the island of Mauritius with more than half of these occurring in the north and northeast regions. **The long land use history of the island and more recent backfilling activity for expansion of the built environment have fragmented much of the natural marshland habitat, especially in the northern part of the island**.

Coastal marshlands provide a number of important environmental services that remain largely non-remunerative.

- Flood mitigation
- Wildlife habitat
- Sediment trapping, water treatment before release
- Carbon storage

- Other values –paleontological value as they hold subfossil

The backfilling of coastal marshlands for developments has been identified as a major cause of flooding, as the subsoil below this Environmentally Sensitive Area has retained part of its functions and some form of interconnection within a network of larger coastal marshland systems. Most of the developments which have occurred on such ESAs have been insufficiently backfilled and they are therefore located on lowlands which are subject to flooding during high rainfall events. **This has been the case at Flic en Flac, Pereybere and Grand Baie for example**.

On 10 June, 2021, the Cabinet of Ministers agreed that the Fourth Schedule of the Environment Protection Act 2002 be amended to designate the Permanent Secretary, responsible for the National Parks and Conservation Service, as the enforcing agency in relation to wetlands. The Ministry of Environment, Solid Waste Management and Climate Change has taken steps to amend regulations applicable to wetlands under section 13(6) of the Environment Protection Act 2002 accordingly. It is understood that the Ministry of Agro-Industry and Food Security is currently preparing a Wetlands Bill which will be presented to Parliament in order to prevent any construction or development on coastal marshlands with a minimum buffer of 30 metres[5] in order to preserve the hydrological and ecological functions of coastal wetlands.

▷ Upland marshlands

Upland marshlands are the natural parallel of lowland marshland. They arise as a result of a similar interaction between physiographic relief and hydrological conditions and perform similar environmental functions. They may also have developed as a consequence of past mining or earthworks that have created artificial depressions where surface flows accumulate. **Some water reservoirs have been built on upland marshlands and they have retained the ecological functions of the said marshlands such as Mare aux Vacoas or Mare Longue**, the term "mare" referring to a marsh in French. However, the flora and fauna forming upland wetlands is considerably different from that found along the coast due to the clear biophysical differences between their respective positions within a topographic gradient. The changes in temperature, humidity and nutrient conditions between the top and bottom positions within the watershed has yielded very different biological communities, both native and invasive, and for this reason these two typologies are classified as separate ESAs within the Wetlands System. In Mauritius, upland marshlands are dominated by hydrophytic sedges and grasses inter–mixed with hammocks of drier, rocky ground occupied by heath (*Erica*) forest transitioning into thickets of *Sideroxylon*[6]. Changes in land use and introduction of non–native plants has led to much of the original area becoming dominated by exotics, such as guava, ravenala or converted into pine and eucalyptus plantations. An important value of these areas rests with their hydrological function and role in storing water. **The storage value of those marshlands, however, has largely led to a decline in their biological value through their conversion into reservoirs (e.g. Mare aux Vacoas), plantations and irrigation networks**. The updated extent of upland marshlands based on the 2019 surveys is 2,120 hectares including lakes and reservoirs.

Many upland marshlands occur in prime areas for water storage and most of these have been converted for this purpose. They are also located in areas of remaining forest cover, many of which have been degraded by invasive species. The primary pressure placed on remaining marshlands is for use in development of water storage facilities. Many of the most conspicuous upland marshlands have also become dominated by exotic plantation crops and

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[5]However, due to difficulties of implementation on the territory with regard to island constraints, the Ministry of Agro-Industry and Food Security could ultimately decide to retain 30 m in the future wetlands bill.

[6] Vaughan & Wiehe, 1937

invasive herbs and trees. The primary impact of the conversion process has been damage to a large swathe of Mauritius' endemic biota, particularly affecting a large number of marshland Pandanus species.

In the most recent classification, upland marshlands have been merged with the numerous natural lakes are found across Mauritius, such as Bassin Blanc and Grand Bassin which have formed in volcanic craters after the underlying magma chambers collapsed to create a bowl–shaped depression ideally suited for collection of water. There are equally 7 major impounding reservoirs[7] with a total capacity of 92.2 Mm^3 producing an annual yield of 164.4 Mm^3. The largest of these artificial reservoirs, Mare aux Vacoas having a capacity of 25.89 Mm^3, followed by Midlands Dam with a capacity of 25.5 Mm^3 and Bagatelle Dam with 14 Mm^3 underpin the supply of freshwater in the country. These impounding eservoirs which supply domestic water to the population have been classified into a separate category of upland marshlands due to their specificity. Most impounding reservoirs are located on state land, although some smaller features are attached exclusively to irrigation in sugar estate lands. The main value of lakes and reservoirs is delivered through their water storage function which underpins freshwater supplies to the country. These stores contribute to meeting present and future freshwater needs attached to human consumption (domestic and tourism–related), industrial (mainly textile) and agriculture, mainly as irrigation.

As for coastal marshlands, the backfilling of uplandl marshlands for developments has been identified as a major cause of flooding, as the subsoil below this Environmentally Sensitive Area has retained part of its functions and some form of interconnection within a network of larger coastal marshland systems. Most of the developments which have occurred on such ESAs have been insufficiently backfilled and they are therefore located on lowlands which are subject to flooding during high rainfall events. However, the issue of further development of reservoirs in the context of full protection of ESAs does not arise in as much as water supply needs to be protected to ensure safe drinking or irrigation water. In case of extension or upgrading of reservoirs, those could be considered as ESA rehabilitation or extension works.

The Ministry of Agro-Industry and Food Security has taken steps to pass the Wetlands Bill in order to prevent any construction or development on upland marshlands within a minimum buffer of 30 metres in order to preserve the hydrological and ecological functions of these wetlands.

▷ Rivers and streams

Rivers and streams carry water that comes from precipitation runoff from the land surface. The area of land between ridges that collects precipitation is a watershed, catchment, or drainage basin. Most, but not all, precipitation that falls within a watershed runs off directly into rivers, with part of it soaking into the ground to recharge groundwater aquifers (some of which can then seep back into riverbeds), and part lost to evaporation. Rivers form from water moving from higher to lower elevation due to gravity. Flowing water finds its way downhill initially as small creeks, which merge to form larger streams and rivers. Rivers eventually end up flowing into the sea. If water flows to a place that is surrounded by higher land on all sides, a lake will form. If people have built a dam to hinder a river's flow, the lake that forms is a reservoir. According to NWFS 2009, Mauritius possesses some 8,290 ha of rivers and creeks (made up of 1,540 ha used for drinking and water purposes) and 6,750 ha defined as "other". The principal threats are from excessive groundwater abstraction leading to salt water intrusion, water pollution dur to the seepage of untreated domestic or industrial wastewater in unsewered areas and climate change which may lead to an increase in sea water level and salt water intrusion. As such the economic policy instruments for eliminating subsidies and instituting marginal cost pricing are very relevant to rivers and streams. The capacity of individual streams to accommodate pollutant discharge is not known.

Tampering with rivers and streams is common in Mauritius, with developments occurring up to the edge of the watercourse or sometimes on it. Those developments are therefore directly impacted during heavy rainfall events, as the natural flow of the said rivers and streams is restricted.

[7] https://publicutilities.govmu.org/Pages/Water%20Sector/WRU.aspx#WRM

The Ministry of Agro-Industry and Food Security should therefore enforce the provisions of the Forests and Reserves Act in order to ensure that any person tampering with a, river, a rivulet or a stream or its reserves is immediately taken to task to prevent any flooding of the affected area as well as the upstream area.

▷ **Boreholes**

Boreholes are generally protected by a 200 m buffer. They equally play a role during heavy rainfall events.

▷ **Others ESA**

Sand beach and dunes, lava and calcarenite caves, forests with high native fauna or flora content have a minor hydrological role but a major role against the adverse impacts of flooding by breaking the energy of the storm water runoff and increasing absorption. These functions need to be preserved.

▷ **Conclusion**

Based on the above analysis, it is critical that the aforementioned ESAs be provided with the necessary protection and enforcement mechanisms to allow them to maintain their hydrological functions and serve as nature-based solutions against the adverse impacts of flooding.

2.4.3.2.2 Consider ESA in their territorial context

In an integrated approach to flood prevention, ESAs are located at various points in the catchment and in relation to the river or coastal areas. It is important to note that environments with flood prevention functions are not necessarily located in the immediate vicinity of rivers or coastlines.

There are in particular:

- the heads of catchment areas,
- flood expansion zones (grassland, marshlands, alluvial forests, ...),
- water reservoirs (lakes, ponds, ...),
- river annexes (backwaters, wetlands located at springs, ...),
- coastal wetlands influenced by the tides,
- coastal lagoons.

Consideration of these environments must therefore be analysed longitudinally, from upstream to downstream of the catchment area, integrating the vertical interactions between the environment, the groundwater and the watercourse, in continental areas and between the environment and the sea, when in coastal areas. The ESAs involved in the hydrological functions must therefore be carried out in a three-dimensional spatial framework, taking into account the hydrogeological connections with fresh or salt groundwater.

Consideration must also be in a temporal framework. The precision of the transverse position of the ESA must allow the water level to be recorded in order to flood the environment during floods or marine submersions. It is necessary to identify the periods of interconnections between the environments located in the floodplain of the watercourse or the coast (by hydrogeomorphological coverage).

More generally, their location (agricultural areas, urban areas, mountainous areas, coastal areas, etc.) will require responses and expectations in relation to their hydrological function and their response in periods of rainfall and flooding.

- **<u>ESA in agricultural areas</u>**

Many agricultural areas are in strategic areas of the hydraulic functioning of the territory in terms of:

- watercourse dependencies,
- flood expansion zones,
- wet grasslands,
- exploited marshlands, etc….

Thus, the actions to be promoted and preserved are:

- Preserve ESAs and agricultural wetlands and their hydraulic and hydrological functions through appropriate agricultural practices

  The preservation of wetlands present on agricultural plots has a double interest:

  - to maintain these spaces which have a role as flood expansion zones,
  - to maintain areas with soil that has a good infiltration capacity.

- Preserve the quality of agricultural soils to avoid runoff and promote water infiltration. In these agricultural areas, it is essential to promote the natural infiltration capacity of the soil. This function is essential when rainfall occurs. Indeed, a degraded infiltration capacity of the soil will cause water to accumulate or run off on to the plots of land, thus increasing the risk of flooding. Agricultural soils with a high capacity to infiltrate water are generally soils rich in organic matter, on which rooted vegetation develops both in the most superficial parts and at depth. Water flows vertically along the roots. Infiltration is therefore favoured and surface runoff is strongly reduced

- Respect the seasonality and proximity of the water table:

  The capacity of the soil to allow water to infiltrate varies according to the seasons or the existence of a connection between the plot and the water table.A soil that is saturated with water due to frequent rainfall during the rainy season or due to the seasonal rise of a surface water table will not have the same capacity to infiltrate and store water as during a dry period. In all cases, after a period of heavy rainfall or flooding, it is necessary to consider a period of time for the soil to dry out before the agricultural plots recover all their infiltration and runoff slowing functions, in the same way that a period of time is necessary before the plots can be farmed again.

- **<u>ESA in urban area</u>**

The uncontrolled development of urbanisation has contributed to the increased exposure of the population to flood risk.

- **The impermeabilisation of urban soils aggravates the effects of flooding**

In urban areas, in particular, the increasing impermeability of soils, associated with the expansion of urban surfaces, has significantly reduced the capacity of soils to infiltrate rainwater and has accelerated the speed of runoff flows. This has also saturated the urban stormwater networks.

These phenomena have aggravated flooding in urban areas by increasing both the speed and volume of runoff produced by rainfall. Furthermore, the development of activities and stakes (housing, economic activities) has increased the number of exposed sectors and the vulnerability of these sectors in periods of flooding

In this context, it is important to guide the development of urbanisation in a more reasonable way, so as not to expose new populations to the risk of flooding. In this respect, it is essential to promote flood-prone areas in their role as flood expansion zones

- by giving them a **function compatible with flooding**, such as maintaining farms for example,
- **by prohibiting all new construction or the development of activities**
- and, in specific cases, **by encouraging the relocation of people and assets to less exposed areas**.

- **Urban areas that can also host flood prevention actions**

The density of construction in urban areas generally offers little free space to carry out flood prevention actions.

However, urban areas are also strategic for implementing such actions, as they are generally the areas at stake in the point of view of the protection of people and assets. As part of an integrated approach to flood prevention, **the development of urbanisation must be adapted to the territorial constraints and in particular to the natural risks of flooding.**

In urban areas where the difficulty of mobilising or acquiring land is less important, practical actions to preserve pre-existing natural flood expansion areas or to renaturalise wetlands can be carried out to mitigate the effects of flooding.

Furthermore, **as part of the upstream/downstream management of the catchment area**, all areas of the catchment must be involved in flood risk management. It is the establishment of a solidary flood risk management that must systematically preponderate in the definition of actions, especially in urban areas. **Residents must be made aware that the risk of flooding also exists in the city, that wetlands are present in the city and that these environments can help reduce the risk of flooding.**

- **<u>ESAs in mountain areas</u>**

In mountain areas, floods are most often characterised by torrential flooding phenomena, marked by very high flow speeds. The ESAs encountered correspond to wetlands at the head of the catchment area, which are either strongly sloped or have little topographical variation, i.e. they form a flat area.The wetlands on the slopes participate in small proportions in the retention of water and the reduction of flow speeds by reducing flows. Wetlands with little topographical variation, on the other hand, are strategic for flood prevention. Due to their hydraulic functions, they play an essential role upstream of the catchment area and help to reduce flooding downstream.

Their functions which are useful for flood prevention are as follows:

- storage of water volumes produced during floods,

- reducing the flow of floods,
- slowing down the flow velocity of floods,
- increasing the transfer time of flows from upstream to downstream of the catchment area.

These functions are all the more crucial as mountain areas are also characterised by increased rainfall. Thus, mountain wetlands are the environments that receive large volumes of rainfall, compared to downstream areas.

Their preservation as well as the implementation of adapted management are therefore essential in the flood prevention strategy.

- **ESAs in coastal areas**

Coastal wetlands are transitional spaces between land and sea. Due to this particular position in the ecosystem, coastal areas and coastal wetlands are subject to hazards of different origins, in particular marine submersion and coastal erosion, which must be considered in a coherent way to manage natural coastal risks.

- **An interface between land and sea**

Coastal wetlands have the particularity of being at the interface between land and sea. In this context, they not only have remarkable ecological functions but also play a useful role as buffer zones in the event of marine flooding. Indeed, coastal wetlands are areas to be preserved for their significant biodiversity as they offer exclusive habitats for wildlife and vegetation. In addition, these areas, which contribute to the coherence of the coastal system, absorb the energy of the wave and constitute water retention zones that stop the sea waves from flooding.

- **Exposure to hazards of different origins**

The coastline is a special area in that it is subject to three influences:

- the continental influence, which conditions the geomorphology of the coasts in direct link with their resistance to erosion;
- the maritime influence, which generates marine submersion phenomena which, in addition to flooding the land, also contribute to hydro-sedimentary transfers (erosion or sedimentation)
- the atmospheric influence (wind, temperature, etc.), which also contributes to coastal erosion through the transfer of sediments from the coast to the land and can increase the vulnerability of the coast to flooding

Coastal areas are also subject to flooding from different sources, which can occur simultaneously (estuarine floods). These floods can occur:

- either upstream of the catchment area due to the overflow of rivers flowing into the estuaries,
- or downstream of the catchment area due to tidal ingress into the land, which creates marine flooding phenomena.

- **Coastal risk management strategies that are changing to return to the natural functioning of ecosystems**

The tendency is to renaturalise the coastline in order to return to a natural functioning of the coastline while taking hydraulic protection measures as close as possible to the stake. This renaturation of territories will recreate coastal wetlands in areas where they were naturally present. The aim is to leave these new areas free of any stakes to flood during episodes of marine submersion and thus constitute natural flood expansion zones. The occurrence of intermittent flooding by marine submersion of this new land open to the tides will then lead to the creation of additional coastal wetlands with, for example, water storage functions.

Among those ESAs, **coastal marshlands** (as described hereabove) **and mangroves play a critical role as nature-based ecosystem features in the context of coastal squeeze and coastal submersion.**

Mangroves are trees and shrubs that grow in saline coastal habitats including estuaries and marine shorelines of the tropics and subtropics. Mangrove plants are found in depositional coastal environments where fine sediments, often with high organic content, collect in areas protected from high energy wave action. A mangrove is a plant and mangal is a plant community and habitat where mangroves thrive. Mangal plants are diverse but all are able to exploit their habitat by developing physiological adaptations to overcome the problems of anoxia, high salinity and frequent tidal inundation. About 110 species have been identified as belonging to mangroves. Each species has its own capabilities and solutions to these problems; this may be the primary reason why, on some shorelines, mangrove tree species show distinct zonation. Small environmental variations within a mangal may lead to greatly differing methods of coping with the environment. Therefore, the mix of species, in vast mangrove forest, within the intertidal zone is partly determined by the tolerances of individual species to physical conditions, like tidal inundation and salinity, but may also be influenced by other factors such as predation of plant seedlings by crabs.Despite their benefits, the protective value of mangroves is sometimes overstated. Wave energy is typically low in areas where mangroves grow, so their effect on erosion can only be measured in the long-term. Their capacity to limit high energy wave erosion is limited to events like storm surges and tsunamis. Erosion often still occurs on the outer sides of bends in river channels that wind through mangroves, just as new stands of mangroves are appearing on the inner sides where sediment is accreting[8].Mangroves support unique ecosystems, especially on their intricate root systems. Once established, they help to impede water flow, thereby enhancing the deposition of sediment in areas where it is already occurring. Usually, the fine, anoxic sediments under mangroves act as sinks for a variety of heavy (trace) metals which are scavenged from the overlying seawater by colloidal particles in the sediments. In areas of the world where mangroves have been removed for development purposes, the disturbance of these underlying sediments often creates problems of trace metal contamination of seawater and biota. Mangroves protect the coast from erosion, storm surges, especially during cyclones, and tsunamis. Their massive root system is efficient at dissipating wave energy. The extent of mangroves which has been surveyed in 2019 has been found to be of an extent of 234 hectares, representing an increase of more than 61.24% between 2009 and 2019. This increase is linked to the extensive sensitisation and mangrove plantation programmes carried out by NGOs throughout Mauritius and the effective protection of Mangroves by the authorities.

The main pressure on the mangroves around Mauritius is coastal development. With the tourism policy of the government targeting increasing numbers of tourists, hotel development has shown a net increase. As available land with sea frontage is becoming scarce, construction is being undertaken in areas where such development was never considered before, including cliffs, rocky shores, muddy lagoons, and mangrove areas. Several recent hotel developments have sought approval from the government for removal of some tree stands and some of them have been approved. However, at the beginning of 2008, the government recognised the importance of preserving mangrove trees that are present around the coast and has taken a decision at the Cabinet level not to allow any mangrove trees to be cut for any future development.

[8] Dahdouh-Guebas, 2005

The Ministry of Blue Economy, Marine Resources, Fisheries and Shipping is the custodian Ministry responsible for the protection of Mangroves under section 69 of the Fisheries and Marine Resources Act, the enforcement of which is tantamount to protecting our coastal zone from the impacts of coastal squeeze or submersion.

2.4.3.2.3 Hydrological services due to ESA in the areas to preserve

The term "service" used in this paragraph refers to all the natural processes involved in the functioning and maintenance of ecosystems, which take place with or without the presence of man.

Due to their hydrological, geomorphological, pedological, botanical and climatic characteristics, wetlands provide ecological functions that play an essential role for water supply: in particular, they contribute to hydraulic regulation, to the improvement of water quality and maintain an ecosystem of great ecological diversity.

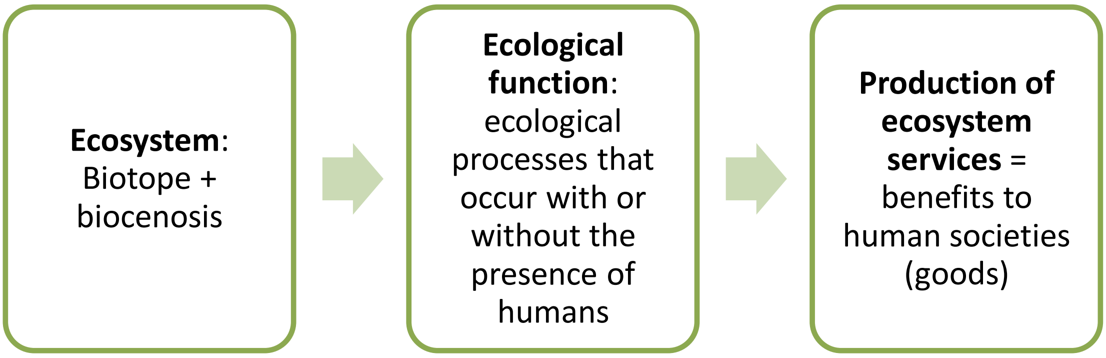
There are three main categories of functions:

- **Hydrological and hydraulic functions :**
    - flood control and desynchronisation,
    - temporary water storage (longitudinal and transversal),
    - water transfer: recharging of water tables and support of low water levels,
    - supply of solid flow to watercourses,
    - slowing down runoff and dissipating erosive forces;

- **Biogeochemical functions :**
    - interception and retention of suspended solids,
    - buffer against saline intrusions,
    - retention and transformation of toxic micro-pollutants,
    - recycling of nutrients,
    - thermal interaction and contribution to a more stable hygrometry;

- **Biochemical and ecological functions :**
    - maintenance and creation of habitats, supporting biodiversity,
    - positive influence on oxygen production,
    - ecological corridor,
    - biomass production,
    - carbon storage.

The concept of ecosystem services is used to refer to the benefits derived by humans from the current or future use of various natural ecosystem functions, while ensuring that these benefits are maintained over time.
The following illustration shows the relationship between the ecosystem, the ecological functions it performs, and the ecosystem services it provides.



Examples of ecosystem services provided by wetlands.

Table 7: Examples of ecosystem services provided by wetlands

FUNCTIONS of wetlands (= Processes)	Examples of SERVICES DELIVERED (= benefits for humans)
Hydrology / Hydraulics	○ Decrease in flood risk ○ Mitigation of drought effects ○ Provision of water for drinking water supply ○ Provision of water for agricultural, industrial and ○ Domestic non-food uses
Biogeochemicals	○ Water purification ○ Drinking water supply ○ Maintenance of soil quality,
Biological/Ecological	○ Biodiversity ○ Rich land for agricultural and forestry crops and pastoral activities ○ Energy supply (wood, energy crops) ○ Climate regulation ○ Improvement of the living environment and cultural heritage ○ Landscaping ○ Support for tourism, education and recreational activities, ...

2.4.3.2.4 Focus hydraulic functions useful for flood prevention

The functions of wetlands for flood prevention can be divided into two main categories:

- the flood regulation function,
- the function of a flood expansion area.

2.4.3.2.4.1 The flood control function

During periods of high water, wetlands along the banks of rivers and streams slow down the flow of water, thereby reducing the risk of flooding. In the case of coastal wetlands, they also play a role in the natural protection of coastal issues by absorbing wave energy and thus reducing the risk of marine submersion. In addition, the gradual restitution of water by continental wetlands located upstream of watercourses, in addition to its role of slowing down and attenuating floods (buffer zone by temporary storage of water), favours the recharging of water tables, and subsequently of drinking water resources, and contributes to the support of low water levels in watercourses. It should also be added that these wetlands constitute obstacles to the flow of water, which reduce the erosive forces of water on the soil, whatever their position: upstream, on the banks or in the coastal zone.

Wetlands with an important role in flood regulation are not only those that are regularly flooded or directly connected to the river system or to the water table along rivers. Other types of wetlands contribute to flood regulation, notably by intercepting rainwater, slowing runoff and reducing erosion.

However, not all wetlands are equivalent in terms of their natural flood control function. This regulation function will be more or less important depending on the position of the wetland in relation to the watercourse or the coastline, on its capacity to retain and store water, even temporarily, and to slow down runoff by its roughness.

The hydrological functions of wetlands therefore depends on :

- their location in the catchment area,
- their relative form in relation to the direction of flow,
- their relative size in relation to the volume of water to be retained,
- the importance of the wetland's connections with surface and groundwater (conditions their reactivity),

- their nature and the state of their surface or vegetation cover (conditions seasonal fluctuations in roughness).

These morphological characteristics, as well as their mode of insertion in the landscape, which determine the dominant water entry and exit paths, influence their ecological functions and consequently their hydrological functions.

2.4.3.2.4.2 The floodplain functions

Wetlands are the site of numerous flow exchanges with the river, the water table and/or the associated catchment area.

They provide lateral storage (water from the catchment area) and longitudinal storage (expansion of flood water from the river system). These wetlands thus play an essential buffer role for water resources and human activities.

A flood expansion zone is a natural or developed area where water spreads out when rivers overflow into their major bed.

The temporary storage of water reduces the flooding by extending the duration of its flow. This storage contributes to the functionality of aquatic and terrestrial ecosystems. In general, we speak of flood expansion zones for sectors that are not or only slightly urbanised and little developed. In some cases, artificial flood expansion zones can be developed outside the major riverbed or lead to the spreading of water outside the major river bed. The maintenance and restoration (if necessary) of these expansion zones is essential because of their interest and their role from the hydraulic and ecological viewpoints.

2.4.3.2.5 Conclusions

The hydrological functions of Environmentally Sensitive Areas should be preserved at all costs through the application of existing laws and the passing of the Wetlands Bill in order to prevent flooding in Mauritius.

In fact, Environmentally Sensitive Areas, and more particularly mangroves, sand beach and dunes, lava and calcarenite caves, forests with high native fauna or flora content, coastal marshlands, upland marshlands and lakes and reservoirs, rivers and streams and boreholes should be fully protected and given their true value in terms of ecosystemic services.

In this case, no development zones should be proclaimed to ensure that those functions are maintained and protected for future generations.

2.4.3.3 Coverage and Distribution

Updated figures of ESA coverage calculated based on the 2019 mapping are provided in the following Table. The extent of the ESA's may increase based on additional data being collected since 2019 and following bilateral discussions with representatives of the National Parks and Conservation Service of the Ministry of Agro-Industry and Food Security.

Table 8: Updated ESA Coverage (2019).

ESA type (area in ha)	ESA system	Mauritius	Rodrigues	Total
Seagrass and algal beds	Offshore	5,016	7,917	12,933
Coral reefs	Offshore	7,289	4,877	12,166
Sand beach and dunes	Shore	2,335	184	2,519
Intertidal mudflats	Wetlands	453	302	755
Coastal wetlands	Wetlands	1,164	N/A	1,164
Upland Wetlands (including reservoir) (*)	Wetlands	2,120	N/A	2,120
Upland Wetlands (without reservoir)	Wetlands	753	N/A	753
Mangroves	Wetlands	234	31	265
Native Forest (Rodrigues)	Forest	N/A	787	787
Total ESA areas (including reservoir)		**18,611**	**14,099**	**32,708**
Total ESA areas (without reservoir)		**17,244**	**14,099**	**31,342**

(*) – Reservoirs classified in upland Wetlands : Mare au Vacoas, Mare Longue, Tamarind Falls, Eau Bleu, Midland, Piton du Milieu, Valetta Lake, Bagatelle Dam, La Nicolière. ***These impounding reservoirs have been classified as Upland Wetlands because of their ecological interest and the intention of the custodian Ministry to protect them. -*** *The use of a separate category of ESA for upland marshlands (reservoirs being a sub-category) has been proposed in order to prevent misunderstanding.*

Based on the 2019 survey, it is estimated that there are some 1,164 ha of coastal freshwater marshlands in Mauritius. Coastal marshlands are found exclusively on the island of Mauritius with more than half of these occurring in the north and northeast plains. The long land-use development of the island and more recently, backfilling activities for expansion of the built environment have fragmented many of the natural marshland habitats, leading to an apparent increase in the number of marshes while in fact decreasing the overall marshland areas.

The total area covered by ESA and assessed in 2019 is higher than the area determined in 2009. This increase has been confirmed during the bilateral meetings held with the National Parks and Conservation Service of the Ministry of Agro-Industry and Food Security. This increase is not due to an increase of development of ESAs, but to technological advancement linked to higher precision mapping using drone technology (Accuracy less than 10 cm/pixel) and extensive ground truthing. This higher count should not conceal the significant impairment of ESAs by human activities such as the backfilling of wetlands.

2.4.3.4 Legal Status of ESAs

Based on international obligations and commitments, and local legislation, the various categories of ESAs fall under the responsibility of different ministries and organisations, depending on the general management category and type of area. The legal commitments of government with respect to protection of biodiversity, as well as the institutional mandates of relevant government agencies, have been discussed in detail in other reports within the UNDP GEF funded project entitled "Mainstreaming Biodiversity into the Management of the Coastal Zone in the Republic of Mauritius".

Table 9 summarises the main government entities responsible for the management of ESAs in Mauritius and Rodrigues.

Table 9: Main Government Entities Responsible for Management of ESAs (by ESA/management category).

ESA Type	Main Entity Responsible for ESA in Mauritius	Government's responsibility
1. Coastal marshlands	MAIFS*	The National Parks and Conservation Service has set up a Wetlands Unit to deal with clearances for proposed developments. This will be strengthened with the proposed Wetlands Bill which may be under the aegis of the Ministry responsible for the National Parks and Conservation service, namely the Ministry of Agro-Industry and Food Security.
2. Upland marshlands	MAIFS*	
3. Lakes and reservoirs	MEPU*	Lakes and Reservoirs have been merged with upland marshlands although in a separate sub-category. The Water Resources Unit and the Central Water Authority currently manage these ESAs.
4. Rivers and streams	MEPU*	The Water Resources Unit and the Central Water Authority currently manage these ESAs while the River Reserves are managed by the Forestry Department of the Ministry of Agro-Industry and Food Security.
5. Mangroves	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. Mangroves are protected and special permission should be asked before tampering with any mangrove tree.
6. Intertidal mudflats	MBEMRFS*	Often associated with mangroves, they should form part of the areas managed by the Ministry and its technical arm, the Albion Fisheries Research Centre as it is located below the line of high water mark, and therefore forms part of the lagoon/sea
7. Sand beach and dunes	MHLUP & MESWMCC*	The sand extraction act prevents any tampering with sand dunes. Sand dunes are explicitly mentioned as ESAs in the Outline Planning Schemes and any development thereon should be subject to an Environmental Impact Assessment Licence issued by the Ministry of Environment prior to any Building and Land Use Permit issued by the local authority.
8. Seagrass and algal beds	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. Seagrass beds are protected and special permission should be asked before tampering with any seagrass bed.
9. Coral reefs	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. corals are protected and special permission should be asked before tampering with any coral
10. Islets	MAIFS*	Managed by the National Parks and Conservation Division of the Ministry and its director, any access or tampering is restricted and strictly managed by the said Division.
11. High native content (flora)	MAIFS*	Managed by the National Parks and Conservation Division of the Ministry and its director, any access or tampering with native flora is restricted and strictly managed by the said Division.
12. Native fauna content (endemic birds, bats, and lizards)	MAIFS*	Managed by the National Parks and Conservation Division of the Ministry and its director, any access or tampering with native flora is restricted and strictly managed by the said Division.
13. Boreholes (aquifer wells)	MEPU*	The Water Resources Unit and the Central Water Authority currently manage these ESAs and issue licences to ensure that their use is sustainable. 200 m buffer zones are generally laced around boreholes to prevent any contamination.
14. Steep slopes (soil	MHLUP*	Development on Steep Slopes exceeding 20% is normally not

ESA Type	Main Entity Responsible for ESA in Mauritius	Government's responsibility
stabilisation, viewscape)		permitted. Control is effected through the requirement for an Environmental Impact Assessment Licence to be issued by the Ministry of Environment, Solid Waste Management and Climate Change as they are considered as ESAs, and through the issue of Building and Land Use Permits while some steep slopes are protected due to the presence of native fauna or flora or their location on mountain reserves.

* In Mauritius, the MESWMCC has an overarching role of overseeing development on ESAs through the EIA Process.

2.4.4 Synthesis and main comments

Following a working session with the Land Drainage Authority on 9 August, 2021, the following relevant additional information on wetlands has been provided.

1. Number and extent of wetlands before and after the study
The number of coastal wetlands recorded in 2009 was 201 while the number of coastal wetlands recorded in 2019 was 652. It is understood that this figure may increase following subsequent technical meetings and updating of the data collected after 2019.
2. Justification behind the increase in the number and extent of wetlands
The mapping of wetlands in 2019 was carried out using two types of drone imagery, visible and multi-spectral, during the wet season with one centimetre resolution. The combination of multi spectral and visual drone imagery allowed the team to detect wet area using Normalized Difference Water Index (NDWI). The Normalized Difference Water Index (NDWI) (Gao, 1996) is a satellite-derived index from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels. The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content (Ceccato et al. 2001). The amount of water available in the internal leaf structure largely controls the spectral reflectance in the SWIR interval of the electromagnetic spectrum. SWIR reflectance is therefore negatively related to leaf water content (Tucker 1980). The NDWI is a remote sensing based indicator sensitive to the change in the water content of leaves (Gao, 1996). NDWI is computed using the near infrared (NIR – MODIS band 2) and the short wave infrared (SWIR – MODIS band 6) reflectance's. $$NDWI_t = \frac{NIR_t - SWIR_t}{NIR_t + SWIR_t}$$ The combination and integrated analysis of NDWI images and visible images taken during the wet season allowed the team to detect wet areas where the simple visible analysis of the LAVIMS 2008 aerial imagery taken during the dry season failed. The use of new high centimeter precision drone imagery technology combining multi-spectral analysis allowed the team to detect features which have been missed in the 2009 study.

3. Definition of the different types of wetlands including artificial wetlands

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. They occur where the water table is at or near the surface of the land, or where the land is covered by water. The Ramsar Convention takes a broad approach in determining the wetlands which come under its aegis. Under the text of the Convention (Article 1.1), wetlands are defined as: **"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres".**

In addition, for the purpose of protecting coherent sites, the Article 2.1 provides that wetlands to be included in the Ramsar List of internationally important wetlands: **"may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands".**

Five major wetland types are generally recognized:

In addition, there are **human-made wetlands** such as fish and shrimp ponds, farm ponds, irrigated agricultural land, salt pans, reservoirs, gravel pits, sewage farms and canals. The Ramsar Convention has adopted a Ramsar Classification of Wetland Type which includes 42 types, grouped into three categories: Marine and Coastal Wetlands, Inland Wetlands, and Human-made Wetlands.

Some categories of upland marshlands are artificial, or extensions of existing natural wetlands such as Mare aux Vacoas and Mare Longue. Some wetlands have been formed in former sand quarries, as it is the case at Flic en Flac and Les Salines.

However, the primary factor in determining whether an area is a wetland is based on its ecological functions and the plants and life which is present.

4. Location of the wetlands that have been tampered and he reasons behind the tampering of wetlands

Most of the wetlands around Mauritius have been tampered with, and more specifically coastal wetlands due to the pressure exercised by coastal developments, historically in Grand Baie and Flic en Flac, but equally at Bain Boeuf and in the south eastern and southern parts of the island such as Pointe d'Esny and Bel Ombre.

Some wetlands have equally been tampered with for agricultural purposes, such as for the plantation of pineapple at Trou d'Eau Douce during our surveys, and for the plantation of sugar cane at a time when laws and regulations did not provide adequate protection to such environmentally sensitive areas.

Finally, some wetlands have been tampered with for the construction of hotels or public infrastructure such as the construction of roads at Les Salines, in the District of Black River. In the latter case, the hotel has proposed to compensate the use of the wetland by constructing a larger wetland.

5. The impacts of tampering wetlands and the different causes
Wetlands are clearly identified as flood prone areas, hence the need to protect them from development. Even in locations where no wetland has been found during the 2009 or 2019 ESA mapping exercises, it has become obvious that some urbanised areas of the coastal zone have been constructed on wetlands. In fact, two residential morcellements at Flic en Flac, including Morcellement Bismic and Morcellement Safeland which have been built on former sand quarries are regularly flooded during heavy rainfall events. Such is equally the case in Grand Baie and Pereybere where rising waters have even been pumped into the lagoon. Some sugar cane fields and some agricultural lands are equally flooded regularly during heavy rainfall events. In fact, at Belle Mare, onion plantations are affected by heavy rainfall events, and some sugar cane fields at Pointe d'Esny are equally impacted by heavy rain events. Some infrastructural works such as coastal roads have cut some wetlands in two, including at Bel Ombre and Les Salines, preventing the free flow of water in a once unique Environmentally Sensitive Area feature. These infrastructures are at risk, while equally putting the surrounding area at risk of flooding.
6. Methodology to further protect the wetlands
Any development on wetlands generally requires an EIA Licence under item 24 of the Fifth Schedule (section 15(2)) Part B of the Environment Protection Act 2002 which reads as follows: "Land clearing and development, **including** [but not limited to] installation of high tension lines in environmentally sensitive areas such as water catchment areas, waterlogged areas, wetlands, mountain slopes and islets". However, very few EIA applications for development on wetlands have been received by the Ministry of Environment, Solid Waste Management and Climate Change due to the lack of adequate approved available maps. Moreover, a Wetlands Bill is currently under preparation with the support of the GEF/UNDP project entitled: "Mainstreaming Biodiversity into the Management of the Coastal Zone in the Republic of Mauritius". An international consultant has already been recruited to that effect. The proposed legislation provides for a total protection of wetlands in the Republic of Mauritius with the establishment of a 30 m buffer zone around each feature. The Cabinet of Ministers of the Republic of Mauritius has recently, in the Cabinet Decision taken on 10 June, 2021, decided to make new regulations to designate the Permanent Secretary responsible for the National Parks and Conservation Service as the enforcing agency in relation to wetlands. (https://pmo.govmu.org/CabinetDecision/2021/Cabinet%20Decisions_taken_on_10%20June%202021.pdf). This new decision, combined with the passing of the Wetlands Bill will provide the necessary legal framework in order to protect wetlands and their buffer zone. Furthermore, the local authorities which should normally determine applications based on the Outline Planning Scheme, should not normally issue any Building and Land Use Permit for any project located on or around a wetland based on Policy EC1. In fact, this policy clearly states that no development should be allowed on or around any ESA and that in case of any doubt there should be a presumption **against development**. However, the precise mapping of wetlands has never been incorporated in the said Outline Planning Schemes. However, those laws and regulations are poorly applied, resulting in the destruction and backfilling of wetlands, with the obvious consequences related to flooding. The Land Drainage Authority and NPCS should therefore have a site monitoring and enforcing unit in order to monitor the extent of wetlands regularly using aerial technology in order to ensure that any person who contravenes the laws is promptly prosecuted. Another possibility would be to physically demarcate all wetlands in

Mauritius.

7. What are the sites where severity of flooding has increased due to tampering of wetlands

The sites where the severity of flooding has increased due to tampering of wetlands are mainly located at Grand Baie, Pereybere, Flic en Flac, Les Salines, Bel Ombre, Chemin Grenier, Pointe d'Esny, Belle Mare/Palmar and Bain Boeuf. In those locations, surveys carried out within a few months interval showed the reduction in the surface of wetlands due to backfilling for the construction of morcellement access roads or houses.

8. To undertake ground truthing and to ensure that the boundary/extent of wetlands demarcated in the shapefile provided corresponds to the extent on site

The shape files which have been generated from high precision drone imagery are accurate as they are based on ground truthing and centimeter precision visual and multi spectral imagery.

9. Number of wetlands that need to be preserved

The approach which has been proposed in the study of ESAs in the context of the GEF/UNDP project entitled: "Mainstreaming Biodiversity into the Management of the Coastal Zone in the Republic of Mauritius" is a "no go" conservative precautionary approach, whereby no wetland which has been mapped, or its buffer zone, should be tampered with. Wetlands, either natural or artificial, having the characteristics mentioned in the Ramsar Convention play an important role in terms of biodiversity and protection against flooding.

10. What are the mitigating measures for the tampering of wetlands; the number of wetlands that need to be restored and the methodology for the creation of new wetlands

Some wetlands which have been tampered with should be reinstated by removing backfilled material and connecting them to the remaining parts of the wetland, if available, in order to ensure colonisation by the fauna and flora and the reestablishment of the hydrological functions of this Environmentally Sensitive Area. However, some wetlands which have been tampered with a long time ago, including those located at Flic en Flac, are located below residential dwellings. In this case, the Government of Mauritius could use compulsory purchase mechanisms to acquire and restore the wetlands while protecting the population from flooding. This mechanism, although financially heavy, would provide positive ecological and financial benefits in terms of protection against the human and financial impacts of flooding. Those wetlands which have disappeared have not been mapped during the 2019 exercise, and they should be delimited based on historical aerial imagery.

For the existing wetlands, the only efficient methodology to be used in order to prevent any tampering would be the establishment of a flying squad in order to enforce existing and future regulations, and the passing of a regulation to force any person to make a declaration to the local authority whenever he decides to start works, even of a smaller scale, in order to capture projects detrimental to wetlands which do not fall within the ambit of the Local Government Act and the Building Act.

11. What is the current practice in the protection of wetlands in SIDS and internationally

In Greece, WWF Greece launched the **Conservation of Aegean Island Wetlands** project in 2004, undertaking the initiative to record the situation and bring to light the importance of Greek island wetlands and the requirements for their preservation. WWF managed to record 703 wetlands in 67 Aegean islands and 104 in 8 Ionian islands while also setting up a series of activities for their preservation. WWF created a new website dedicated to disseminating environmental information regarding island wetlands. Through an interactive database, users now have the opportunity to embark on a virtual journey to the Greek islands' most threatened ecosystems, wetlands. All citizens and, especially the ones involved in education, research and the conservation and management of the Greek natural environment are, thus, offered a useful information tool, which includes statistical, geographical and other data and representative images of these ecological jewels. A network of volunteers was gradually developed across 6 Aegean islands (Limnos, Lesvos, Paros, Andros, Skyros and Kos) to promptly identify degrading activities and inform the project's scientific team. Following relevant training, the volunteers would visit the wetlands to monitor their status and report to the scientific team. In Crete, where the project headquarters are, monitoring was most intensive. In the beginning, monitoring activities in Crete were carried out by members of the project team with the help of individual concerned citizens. Since 2011, a new and very active network of volunteers was developed in the context of the environmental program Mission Water (in Greek). The network contributed to many awareness activities directed to the general public and the local institutions of Crete. The program's success allowed the network to spread with its new and more organized form to Paros and Lesvos. For every degrading activity that the project researchers and monitoring network volunteer identified, an official letter was drafted, in collaboration with the Citizen Support Legal Team of WWF Greece, documenting the case, analyzing the legal framework, and posing specific questions to the relevant services and authorities. Overall, WWF handled more than 70 cases of degradation in 12 islands. Correspondence exchanged to date adds up to roughly 700 letters. In many cases, considerable fines were imposed, while 5 cases (4 in Crete and 1 in Euboea) involving dozens of accused individuals have been brought to court.

WWF talk with citizens and pay attention to their concerns and inform them of the value of their area's wetlands, in the hope that they will join us in fighting for their conservation. A particularly gratifying development was the establishment of a new institutional framework that, provided that it is consistently implemented, fortifies these valuable ecosystems. Law 3937/2011 "on the conservation of biodiversity and other provisions" paved the way for drafting a Presidential Decree on wetland protection. The Presidential Decree **Approval of a list of small island wetlands, and provision of terms and conditions for the protection and conservation of small coastal wetlands included therein**, signed in June 2012, emanated from that law. According to the Decree, 380 natural island wetlands in 59 islands, covering up to 80,000 square meters, are protected under strict provisions. An important step towards the protection of island wetlands at a local level was the effort to have them included in the Open City Spatial and Residential Development Plans. In 2009, memoranda were sent to the competent authorities of all levels (central and regional, prefectural and municipal) requesting that wetlands be included in Open City Spatial and Residential Development Plans and/or General Urban Plans. By 2012, after the positive response of the pertinent services, 69 wetlands had been included as protected areas in Open City Spatial and Residential Development Plans and General Urban Plans in Crete (48 wetlands), Ammouliani (1), Limnos (11), Paros (8) and Leros (1). After 9 years, many late nights, dozens of meetings, and thousands of kilometers on the ground in the islands we have achieved many important victories. Establishing the institutional protection of 380 natural wetlands, mobilizing citizens and spreading knowledge are only a few of them.

In the US Virgin Islands, the demands for space by a rapidly growing human population of over 100,000 humans have resulted in extensive loss and degradation of natural ecosystems, especially on densely populated St. Thomas. Sprawling residential communities and commercial centers have replaced or fragmented much of the native forest. Hotels, condominiums, and marinas have been constructed on coastal wetlands and marine recreational activities have damaged fragile mangrove swamps, coral reefs, and seagrass beds. The natural ecosystems are subject to the effects of short- and long-term wet and dry climatic cycles and to periodic disturbances from hurricanes, including the recent hurricanes Hugo in 1989 and Marilyn in 1995. Although protected under federal and local regulations, the wetlands in the USVI are under pressure from encroaching development and stressed by upland sources of contamination and sediment loads. The VI Department of Planning and Natural Resources (DPNR) has the primary responsibility for managing these resources. Within DPNR, the Division of Environmental Protection (DEP) manages water quality and administers several programs for watershed protection. The Non-point Source Pollution Program aims to identify and reduce sources of contaminants in USVI coastal waters and wetlands and is jointly managed by DEP and the VI Coastal Zone Management (CZM) Program. The Division of Fish and Wildlife is mandated to protect the natural resources within these habitats. In the USVI, there are four main types of terrestrial wetlands: mangroves, salt ponds, "guts" (riparian stormwater drainage ravines), and freshwater ponds. An additional wetland type, seagrass beds, is also present in the nearshore marine environment. Each resource has significant wildlife and cultural value and each suffers similar threats from encroachment, non-point source pollution, sediment, and alteration. A plan was set up to identify ten objectives for managing USVI wetlands defined by these broad headings: inventory, monitoring, data management, watershed management, pollution control, education, landowner participation, prioritization, and coordination. Actions and potential partners are identified, with a "first step" implementation priority of creating a wetlands working group. For each wetland type, specific threats and conservation actions are also identified. As part of the process of developing this wetland conservation plan, a prioritization system was developed that examines the condition, value to wildlife, and threats for each wetland, and identifies potential conservation actions and opportunities. Based on these criteria, priority watersheds are identified based on conservation need and urgency, value of wetland systems contained within the watershed, and feasibility for action. The priority watersheds on St. Thomas are identified as Jersey Bay, Red Hook Bay, and Perseverance Bay. On St. John the priority watersheds are identified as Rendezvous Bay and Coral Bay. Two offshore islands were also identified: Great St. James and Little St. James.

In Seychelles, a National Wetland Conservation and Management policy was developed with the intention to regulate the developments in and around the wetland areas and support EIA process through its classification system. The policy is presently under review to make it more fitting in dealing with the wetland related developments and regulations with the support of the new Environment Protection 2016 as well as the Protected Area Policy. Since 2004 the Seychelles has become member of the International Ramsar convention on Wetlands and so far has declared three Ramsar sites of wetlands of international importance from Seychelles. Port Launay – Port Glaud coastal wetland areas, Mare Aux Cochons high altitude wetland areas, and Aldabra Atoll – a UNESCO World Heritage site as the third one. Protection of those sites are of international significance. Given that the maintenance works in wetlands and rivers may be very labour intensive, CAMS award contracts to small contractors to undertake the cleaning and maintenance of wetlands and rivers using the procurement systems defined by the Procurement Act 2008. Tenders are awarded for the 11 zones identified on Mahé, Praslin and La Digue using a national tendering process. Contracts are for a duration of 2 years. The monitoring and evaluation is done by the staffs of CAMS and the District Administrations to ensure that the works are completed as per the specification of the Ministry. Apart from the outsourcing works for the cleaning and maintenance of wetlands, CAMS also handles the ecological restoration and management of wetlands and rivers through its annual capital projects. Such projects are implemented in various wetlands on Mahé (i.e. Anse Boileau, Sweet Escott, Anse Aux Pins and Pointe Larue), Praslin (Anse Kerlan, Grand Anse & Baie Ste Anne) and on La Digue (Lanmar Soupap). Other works include the desilting of the wetlands. **In order to show the importance of the wetlands, the Ministry Commemorates wetlands day on the** 2nd February each year. Through it Community Education and Public Awareness campaigns, the Ministry raises awareness on the importance of wetlands and positive actions that our citizen should take to ensure that the roles and functions of wetlands are not jeopardise by our actions.

The Anguilla National Trust has been set up for the preservation for Generations. In the country, Dog Island is a 207 hectare uninhabited, privately-owned island 15 km from the Anguilla mainland. The Dog Island Restoration Project seeks to bring Dog Island as close to its original glory as possible based on private funding. Besides enabling existing native wildlife populations to recover, the removal of these alien mammals has also created invaluable opportunities for Dog Island to be re-colonized by other rare indigenous species. Through this rat eradication project, Dog Island has become the largest island to be cleared of rats and restored in the Eastern Caribbean to date.

2.5 Limitation of traditional design of urban drainage infrastructures and future challenges for Mauritius

2.5.1 Traditional design of urban drainage infrastructures - Current situation in Mauritius

2.5.1.1 Principle of the first drainage infrastructures: systematic collection and evacuation of surface runoff to watercourse (Source ER2C Guildeline)

In most urban developments in Europe, Asia, Oceania or America, the very first infrastructure made provision for drainage network to collect and channel off stormwater. The design of the storm water networks of new urban developments was mainly based on the principle of systematic collection and evacuation of surface, runoff to watercourses. In urbanized areas, with an increase in impervious surface the growing imbalance between the various components of the local water balance (infiltration, runoff, evapotranspiration) has led many communities to face difficulties related to frequent flooding in the 1970s and 1980s. All these communities have, in the past twenty years, drawn up policy to control and mitigate flows generated by new developments.

This situation and basic approach to stormwater management is currently still applied in Mauritius: design of the storm water networks was mainly based on the principle of systematic collection and fast evacuation of surface runoff to watercourses without taking into consideration the ecological functionality of those systems.

Mauritius is located in a tropical zone and the amount of storm water quickly becomes significant even for small events, depending of the watershed area, which may require large structures and major investments to ensure high levels of service (for example in Port Louis - Domaine les Pailles, 105.6mm within 1 hour in March 2013 and 50.6mm within 1 hour on Mon Loisir Sugar Estate in May 2017, 375 mm in 10 hours the 16 April 2021 in Plaisance, a value never recorded since the rain gauge station was operational some 60 years ago).

In Mauritius many areas do not have concrete drainage infrastructure, and the capacity of unlined drains is limited by natural factors such as:

- relatively flat slopes: This is the case, for example, in the North Lowlands;;
- absence of appropriate outlets: This is the situation of all the coasts with a dune ridge which is today urbanised and without an outlet or with outlets of insufficient capacity due to construction, as for example in Flic en Flac or Baie du Tombeau.

While urban development is still important, whether for **smart cities** or **already authorized morcellement**, there are major hazards and issues to set up adapted and efficient drainage systems for the protection of these future developments and for the areas downstream.

2.5.1.2 Example of existing configurations in Mauritius

Built-up areas need to be drained to remove surface water runoff. Traditionally this has been achieved by using gullies and underground drain systems designed to convey the water away as quickly as possible. The alteration of natural flow patterns can lead to problems elsewhere in the catchment.

Water quality issues have become increasingly important, due to pollutants from urban areas being washed into rivers or the groundwater. Once polluted, groundwater is extremely difficult to clean up. Traditional drainage systems cannot easily control poor runoff quality and may contribute to the problem.

During the survey/ investigation, the team observed several main causes and/or contributing factors which provoked recurrent flooding in these critical sites. These factors are often aggravated by the traditional management of stormwater: mostly covered concrete drains to evacuate stormwater downstream as quickly as possible, and often without an outlet.

These causes /contributing factors for traditional drainage are listed in the following categories:

- **Poor Drain Network**

The absence or under capacity of the drain sections arising out of poor design in many locations are the prime causes of flooding. In some areas the drains are either not properly connected, or poorly maintained; this is further aggravated by illegal dumping which causes further obstruction and flooding. Typical examples follow:

Figure 32: Poor drain network

- **Inadequate Culvert Capacity**

The team also observed that because of poor design or under-design, the culvert capacity cannot cater for the peak flow which actually occurs. Furthermore, these culverts are very often obstructed by branches/ fallen trees, through lack of proper regular maintenance.

Figure 33: Inadequate Culvert Capacity

- **Insufficiency and Covered design of Roadside Drains**

This has been observed along both classified and non-classified roads. Roadside drains are designed to capture only the surface run-off and not the surrounding upstream water catchment areas. In many places, it was observed that there are no roadside drains at all and if ever there are, they are just under-sized. Morever, it was also observed that gullies along the roads are blocked/clogged and not cleaned and maintained regularly. In some places, the team also noticed that the road cuts the natural landscape into two parts which are not linked at all, leaving either parts flooded. The team finally observed that whilst the roads may have been designed, the profiles of the roads have been raised and the topography has been altered leaving houses on both sides below the road surface level, which then become prone to flooding.

Figure 34: Insufficiency of Roadside Drains

- **Illegal Construction / Non-Observance of Set Back Distance**

This is yet another very critical factor that causes flooding and in turn affects inhabitants.

Many locations are flooded due to non-observance of set- back distance. Houses and buildings have been constructed on the natural water paths and within river / watercourse flood plains.

In many locations, it has been observed that drains/ canals, especially mountain reserve natural drains, are running across the yards / premises of inhabitants without proper access for maintenance by Local Authorities.

This observation may imply and lead to the conclusion that the Local Authorities are issuing Building and Land Use Permits without taking these aspects and facts into consideration; and in some cases there is evidence and/or sign that there has not been any supervision and enforcement of building codes.

Figure 35: Illegal Construction / Non-Observance of Set Back Distance

Figure 36: Illegal Construction / Non-Observance of Set Back Distance bis

2.5.2 *Future challenge and future approach*

The amenity aspects of drainage such as water resources management, community facilities, landscaping potential and provision of varied wildlife habitats have largely been ignored by traditional urban drainage. Therefore, we should embrace Sustainable Drainage Systems (SuDS) to deliver a more holistic approach to managing surface water and wherever possible mimic natural drainage.

Over recent decades, the international urban drainage literature has seen the development and adoption of a range of 'new' terms (and jargon) that attempt to describe the management of urban water and surface water runoff in a more holistic manner.

Better surface water management should then be promoted through Sustainable Drainage Systems (SuDS)

These solutions are further developed in Chapters 3 and 5.

Combining drainage solution systems using more **nature-based solutions** will be an opportunity to enhance the efficiency of the drainage system and reduce the cost of drainage works and increase amenity and comfort in town and new built areas.

A source-control stormwater management for mitigating the impacts of urbanisation on baseflow should become a basic design principle (ref. 3.3).

In addition, the provisions relating to the setbacks necessary for the free flow of water along rivers, streams and feeders are not always respected. Moreover, the mapping of these watercourses is not representative of all the axes of runoff at risk and which must be preserved. It will be necessary to review these measures in order to extend their application and ensure that they are respected (cf. chapter 2.6.3.2).

2.6 Territorial issues associated with the protection of the hydraulic functions of the ESAs and risks consideration associated with Lowlands – Needs for preservation and recommendations

2.6.1 Recap on current situation

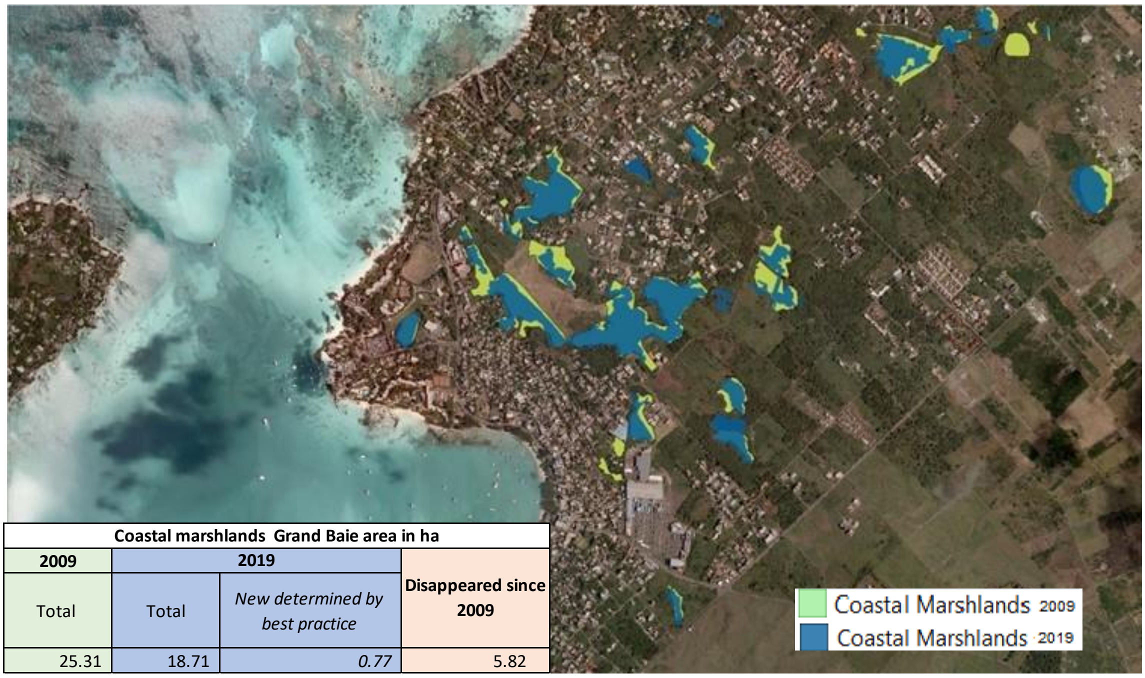
▷ **Present situation**

Coastal marshlands are found only on the main island of Mauritius with more than half of these occurring in the north and northeast regions. The long land use history of the island and **more recent backfilling activity for expansion of the built environment have fragmented much of the natural marshland habitat**, especially in the northern part of the island as illustrated in the map of Grand Baie below**. All the areas shown in green had been backfilled** and the residual coastal marshlands are in dark blue.

Recent survey carried out by the ESA Study project team in 2019 confirmed that there were coastal marshlands in Mauritius extending over 1,164 hectare. This extent may be increased following additional data collected after 2019 and subsequent bilateral technical meetings held with representatives of the National Parks and Conservation Service of the Ministry of Agro-Industry and Food Security.

The figures related to the mapped areas of wetlands are misleading. It can be noted that the total surface areas mapped in 2019 are greater than those recorded in 2009: this increase in surface area is merely an artefact of the survey methodology: the techniques used today, in particular with the contributions of the DEM and more precise aerial photographs, make it possible to survey wetlands more accurately.

This should not preclude the fact that a large extent of wetlands have been backfilled or degraded in various ways over the last ten years.



Coastal marshlands Grand Baie area in ha			
2009	2019		Disappeared since 2009
Total	Total	*New determined by best practice*	
25.31	18.71	*0.77*	5.82

Figure 37: Evolution off Wetland mapping – Grand Baie - area

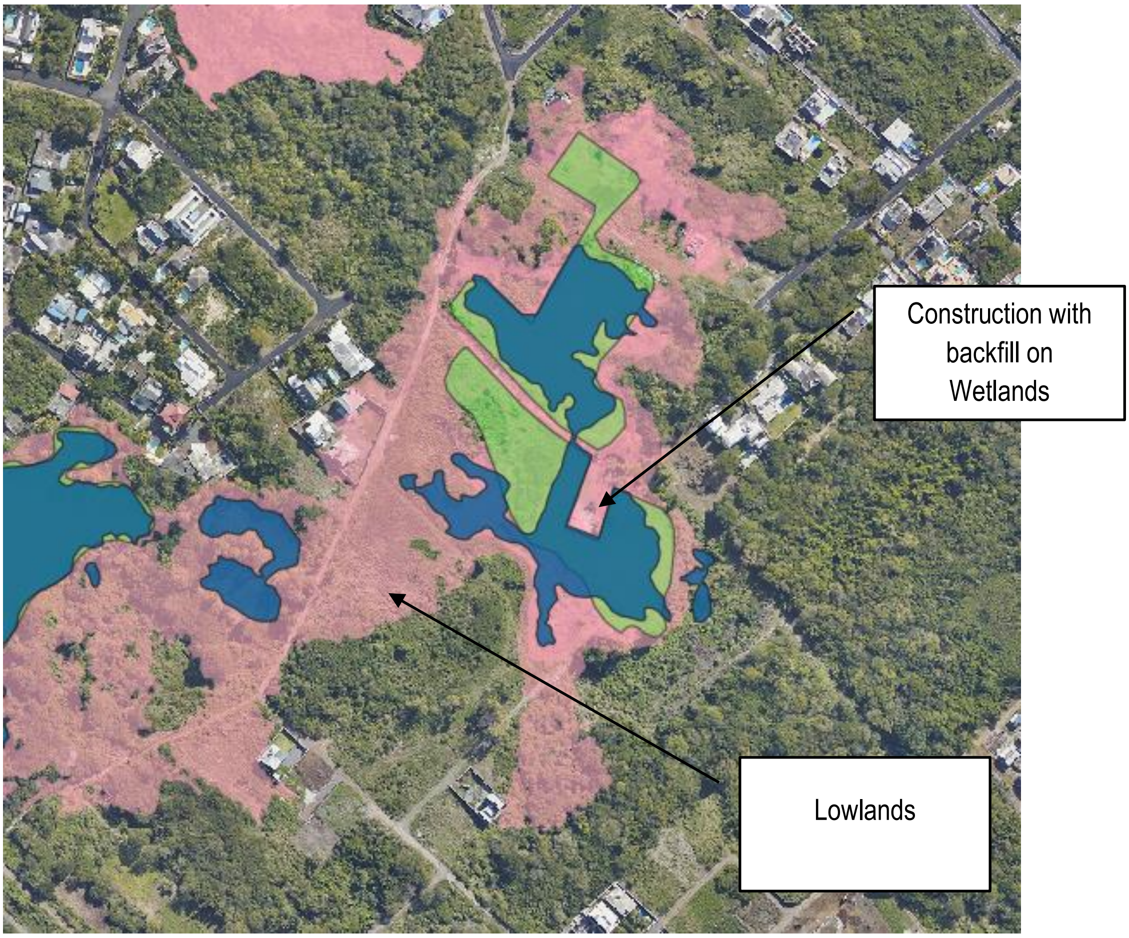


Figure 38: Evolution of Wetland mapping – Grand Baie – local Example and lowlands

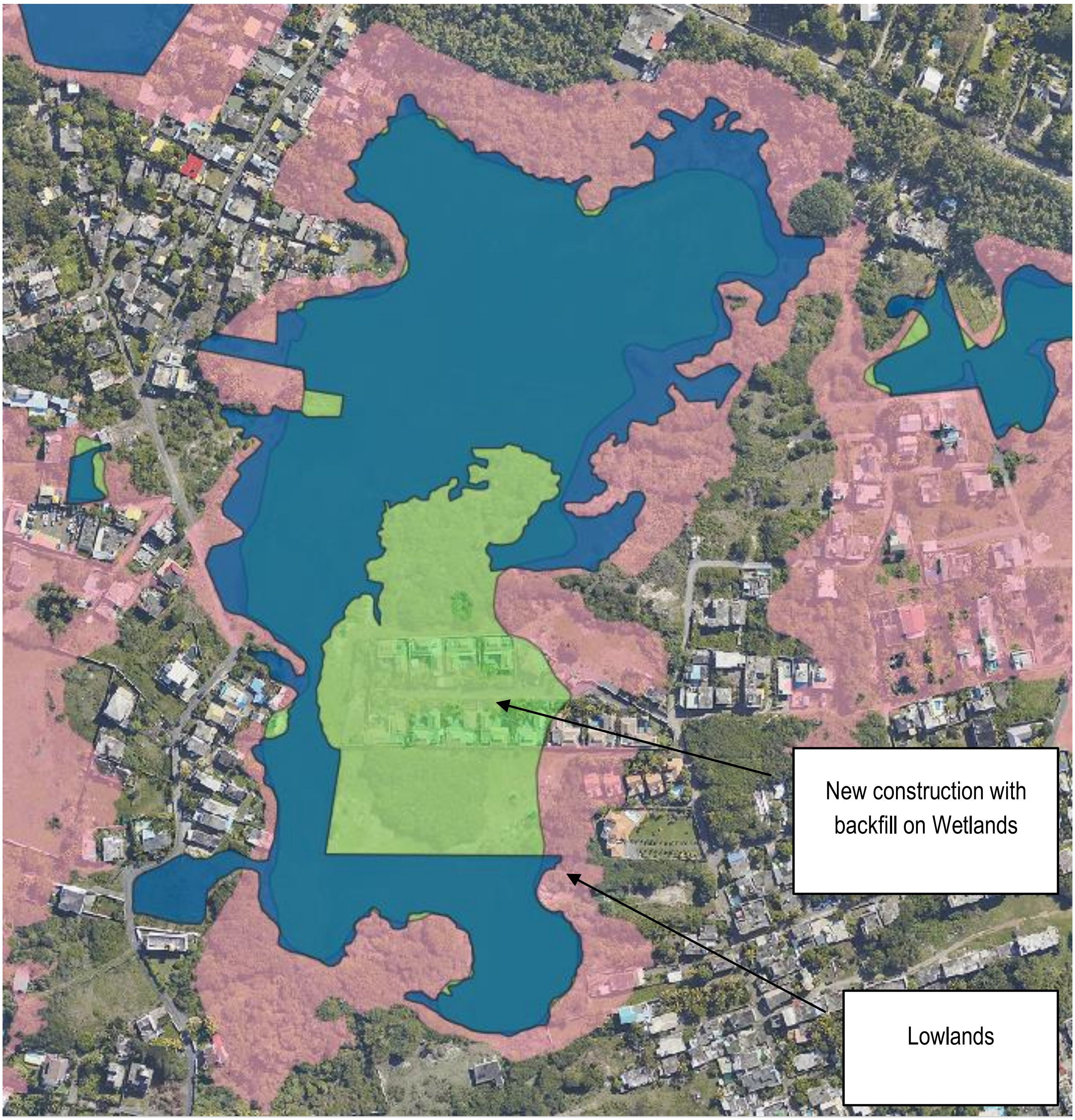


Figure 39: Evolution of Wetland mapping – Pereybere –Example of new construction, backfiling and lowlands

It can also be noted from the figures that these wetlands are very often associated with the presence of lowlands. The challenge of preserving wetlands clearly involves maintaining the flow conditions towards these wetlands (maintaining a near constant supply of water to the wetlands) and generally to all the unconstructed lowlands. Diverting runoff water to avoid the lowlands (protection objective) goes against the functionality philosophy of the wetlands.

The recommendations shall distinguish between lowland areas covered (or not) by ESA-type environmental issues.

▷ **Pressures and Threats**

Coastal marshlands in Mauritius are often located in areas with potential for residential and commercial property development, especially areas that are attractive for the tourism sector. As a result, marshlands are easy prey to a number of development temptations.

Backfilling – The primary threat to the remaining marshlands is backfilling driven by lobbies to create stable land area suitable for construction or agricultural activities.

Rubbish dumping – Marshlands have been widely utilised as solid waste dumping grounds, with much of the material generated from construction wastes. These materials, consisting primarily of waste concrete and stone, are in turn often used as the aggregate base for backfilling.

Pollution – Some marshlands have been affected by heavy pollutant loads from untreated wastewater originating from agricultural lands and residential areas. Pollution is especially problematic during seasonal dry periods when dilution is insufficient to prevent algal blooms.

Climate change – Possible rise in sea level could cause saltwater intrusion, raising the salinity of coastal soils within marshlands and thus affecting ecology and species composition. Coastal marshlands play an important role in the protection of the island against the impacts of climate change.

Focus on Sea Level Rise:

As part of the analysis of the stress and threats on the coastal environment, a synthesis of the lessons of the 2019 report of the Intergovernmental Panel on Climate Change (IPCC) - Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) is given below:

Sea levels continue to rise at an accelerating rate. Extreme sea level rise, historically rare events (one event per century), are anticipated to recur frequently (at least one event per year) in many locations by 2050 under all RCP (Representative Concentration Pathways) scenarios, and particularly in tropical regions (high confidence). The increasing frequency of high sea levels may have severe impacts in many exposed locations (high confidence). In the projections, sea level rise will continue after 2100 under all RCP scenarios. In the event of high emissions (RCP8.5), projected global mean sea level rise in 2100 will exceed that of the Fifth Assessment Report due to a larger contribution from the Antarctic ice cap (medium confidence). Over the following centuries, sea level rise is projected to continue at a rate exceeding several centimetres per year in the case of RCP8.5, leading to a rise of several metres (medium confidence), while this would be contained to around one metre by 2300 in the case of RCP2.6 (low confidence). Extreme sea levels and coastal hazards will be exacerbated by the projected increase in the intensity of tropical cyclones and the associated precipitation (high confidence). Projected changes in waves and tides will vary according to regions and may either aggravate or mitigate these hazards (medium confidence).

The interactive map[9] provided by the IPCC in August 2021 confirms this value for the study area.

Sea level Rise synthesis (2100): 0.4m amsl plus level due to climate change (CC – RCP8.5), +0.84 m ~ **1.30 m amsl**.

[9] https://interactive-atlas.ipcc.ch/

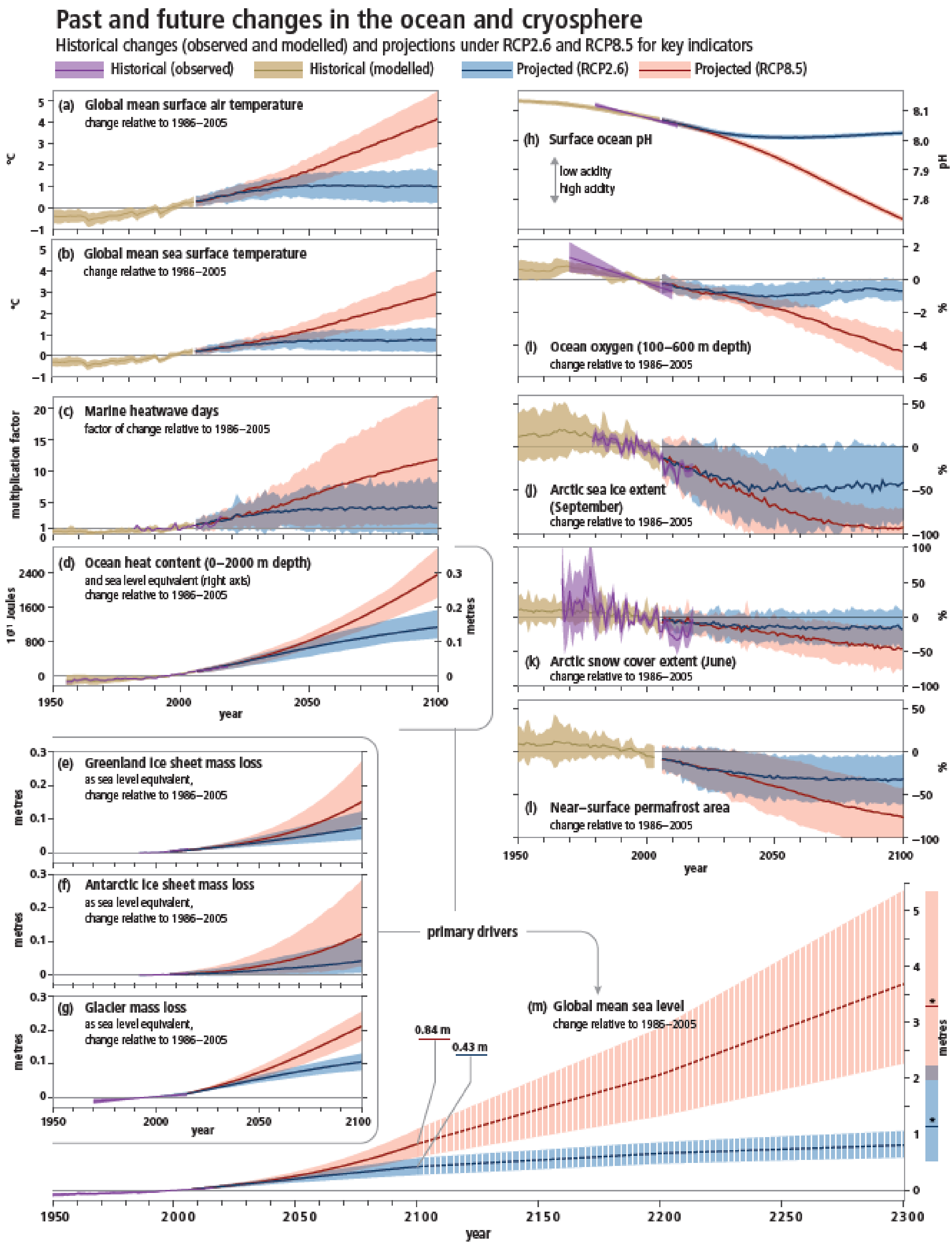


Figure 40: Observed and modelled historical changes in the ocean and cryosphere since 1950, and projected future changes under low (RCP2.6) and high (RCP8.5) greenhouse gas emissions scenarios. (IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate)

▷ **Integration of past topographic changes**

It is worth noting that past modifications (backfilling) of wetlands and lowlands form an integral part in the analysis of flood risk and vulnerability of the island. Indeed, DEM 2019 (on the sectors covered) provides a good account of the revised land form and the adverse impacts of backfilling of wetlands on their hydraulic performance. These impacts are :

- Modification of the natural drainage axes
- Reduction of natural retention and flood expansion volumes reproduced in the flood zones maps processed using hydrogeomorphological approaches or advanced hydraulic modelling.

2.6.2 Hydraulic impacts caused by wetlands degradation

This section deals with ground movement in lowlands and the natural wetland environment.

Any ground disturbances in flood-prone areas aggravates, in one way or another, **the flooding impacts**. Indeed, they **magnify the flood volume** resulting in an **aggravation of the flood hazard**. These embankments also **cause significant modifications** to the topography of the land and to **the natural flow axes**, resulting in uncontrolled storm water flows.

From an environmental point of view, changes to landform in wetlands can lead to the malfunctioning of these buffer zones during floods, or even to their destruction. Modification to the landform as a result of backfilling, favour the establishment of invasive alien plant species, impacting on biodiversity and human health.

Currently, wetlands are threatened by various activities:

- Drainage (drains or ditches)
- Backfilling
- Transformation into a water body (by sealing)
- Impermeabilisation due to urbanisation
- Excessive water abstraction
- Stripping of the floor surface
- Point source pollution
- Artificialisation of watercourses
- Intensive cultivation
- Invasive vegetation cover

Destruction of wetlands leads to droughts and flooding becoming more severe and the deterioration of water quality since they can no longer fulfill their role as a filtration medium.

It is not possible to quantify this phenomenon because it depends on the topographical and hydrogeological configuration and the position of the wetlands in the catchment area. However, it can be said that wetlands immediately upstream and close to urban areas play the most important role in preventing flooding, because these wetlands can intercept large catchment areas. As an illustration, a 2 ha wet and with 1m of freeboard before overflowing can naturally store 20,000m^3, i.e. the totality of a 40mm rainfall with 50% runoff over a 1km^2 catchment area.

It should be noted that this function of peak flow attenuation by the ESAs (wetlands and lowlands in particular) is taken into account in the modelling used to characterise the territory's flood hazard (by taking into account the topography and filling conditions of these areas).

The following figure illustrates how these ESAs are considered in the modelling, by filling in. It should be noted that the distributed hydraulic models ("full2D") make it possible to consider these ESAs by directly capturing the rainfall on the topographic meshes covered by the ESAs.

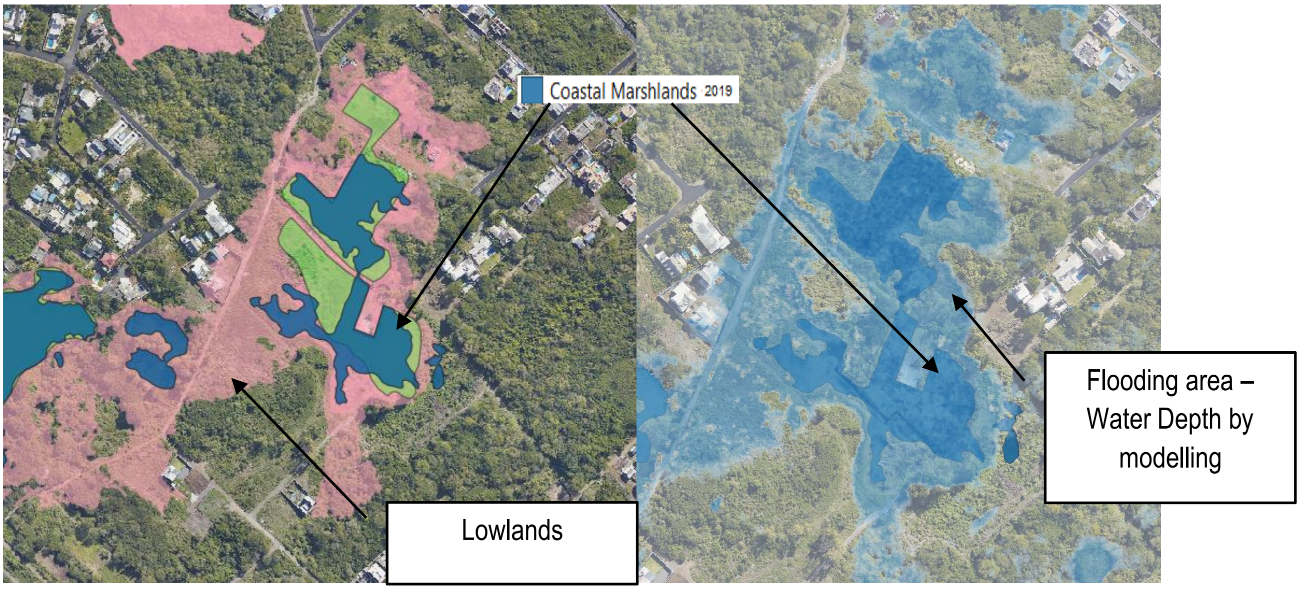


Figure 41: Wetland (ESA) mapping and hydraulic modelling – Grand Baie – local Example in lowlands

2.6.3 Recommendations

2.6.3.1 Law enactment on changes of land form in floodplains, lowlands and wetlands

The **national legislation** should enable government to impose laws for the preservation of flood expansion fields and undertake measures, either prohibition or authorisation, with regard to **changes in land form** with special requirements (absence of hydraulic impact, transparency and compulsory compensation in flood expansion zones) and subject to compliance with other environmental regulations.

- **In accordance with the respect of the natural flow axes**

The law on the protection of natural land drainage (Code Civil) do

es exist in actual fact.

It is then necessary to give ourselves the means to enforce the existing laws, to be able to relocate constructions the most at-risk, to demolish illegal constructions in order to restore the free flow of water in the most natural way possible, based on the existing topography and not modified by the work of man.
:
It is recommended to use the topographic axes of the DEM2019, starting from a threshold of 1ha, to define buffer values of inconstructibility and free water flow.

- **For Drainage Impact Assement**

Reminder: Drainage Impact Assessment is required for developments above 5 arpents (approx. 1.7 ha) to "analyse the impacts on the drainage and storm water system".

This new provision is very interesting and above all necessary to be able to control the application of the pluvial zoning. therefore, to make this evaluation effective, we recommend:

- **To set the threshold** not at the project area, but **at the catchment area intercepted by the project** in order to take into account the natural function of the sub-catchment (see Chapter 3.2.4);
- **To set the lower limit of 1ha of intercepted catchment area for the need of the assessment**,
- **Specify the technical needs for hydraulic compensation of the project** (through storm zoning, based on nature-based solutions see chapter 3.4 and 3.5) through **clear specifications specifying the expectations**
- **To have a Technical Hydraulic Service in charge of the technical control of these files but also in the implementation phase** ("drainage police").

▷ **For developments on sloping sites**

The current regulations are adapted but must be applied without exception, for slopes bigger than 20% and in compliance with the maintenance of the natural flow axes.

▷ **For the lowlands**

As a general rule, no backfilling should be authorised in flood expansion zones located in non-urbanised areas.
Development and construction can be made permissible in built-up areas, subject to compensation measures against water loss.
It is therefore recommended to:

- **Prohibit all construction and works** (**such as backfilling) in all lowlands outside urban areas**, as these lowlands contribute to flood control upstream and downstream of urbanised areas;
- **Limit construction and works to the least risky lowlands In already urbanised areas**,, i.e. those of limited depth for which drainage works can be effective without negatively influencing the downstream area.

Cf. chapter 2.6.3.3

▷ For the protection of ESAs

With regard to ESAs, they are to be preserved regardless of their location (in the lowlands or outside the lowlands). Indeed, their environmental and hydraulic functions (see Chapter 2.4.3) both contribute to the water cycle in the area. However, the buffers to be established and enforced around ESAs will have priority objectives:

- - Preservation of the hydraulic, hydrological and environmental functions of wetlands, coastal wetlands but also uplands marshlands, often associated with lowlands.
- - Objectives of preserving environmental functions mainly for other ESAs (such as actions to maintain the coastline for mangroves).

For needs strictly related to runoff management, wetlands and all lowlands not classified as wetlands will be specifically preserved.

Additional example of a decision to promote:
The Government of Mauritius has taken the decision to prevent the issue of Building and Land Use Permits in Chitrakoot, Deux Freres and Quatre Soeurs due to the risks associated to landslides**. In the same manner, and based on the most recent mapping of Environmentally Sensitive Areas including coastal marshlands and upland marshlands and lakes and reservoirs and the existing available data on rivers and boreholes, no development zones should be implemented, superseding the provisions of the Outline Planning Schemes Inset Plans and Development Plans in order to prevent any further damage and risks linked to flooding**.
The provisions of the proposed Wetlands Bill, as well as the Fisheries and Marine Resources Act and the Environment Protection Act and the Planning Development Act should be used and amended accordingly to enforce and create no development zones and buffer zones around all lowlands and floodplains in Mauritius.

2.6.3.2 Conservation devise and recommendations on natural path

As we have indicated, it is necessary to regulate construction within a setback distance, including for runoff phenomena, by protecting the natural flow axes from any obstacles (urbanisations, infrastructures without hydraulic recovery works, etc.).

It is therefore recommended to define natural path thresholds in order to define buffer values adapted to the risks.

From the hydrological analysis, the specific flows of the territory (flows per surface of drained catchment area) have been defined: for a reference flood type T100 years, the specific flows vary from 35m³/s/km² to 25m³/s/km² for catchment areas of size varying from 20 to 100 ha. With climate change impact, the specific flows could be increase by 1.182 factor (cf. chapter 4.1).

The following table shows the flow width values taking into account the free flow for a reference flow:

Table 10: Free flow reference

Drained catchment area	Speciphic Discharge T100y: Q/S in m³/s/km²	Discharge T100y: Q in m³/s	Mirror width according to capacity study (*) in m	Mirror width according to capacity study with CC(*) in m
1 ha = 0.01 km²	35 to 40	Max : 1	**1.3 m**	**1.5 m**
25 ha = 0.25 km²	33	8.5	**4.7 m**	**5.4 m**
50 ha = 0.50 km²	30	15.0	**6.6 m**	**6.9 m**
100 ha = 1.0 km²	25	25.0	**9.7 m**	**9.9 m**

(*) : according to the capacity modelling approach in a uniform regime, trapezoidal channel with a 3/2 H/V slope for a slope of 1 to 2%, a water height of the order of 100 cm with velocities of the order of 2.8 to 3.4 m/s for a natural flow.

Note: For axes in rural, non-urban areas, and in order to definitively preserve these flood fields, it is recommended to keep a threshold of 50 cm. For this threshold, the buffer widths should be doubled.

In order to make the measure applicable on the ground, it is recommended to retain:

- The threshold of 1 ha is the limit for mapping. Feedback from past and recent events (April 2021, intense rainfall in the South East and South) on the territory shows that from 1 ha, damage and obstructions to flow are already problematic on the territory. Furthermore, this threshold is in line with the recommendations for Drainage Impact Assessment
- An intermediate threshold between 1 and 100 ha,
- A threshold of 100 ha, i.e. 1km², beyond which the flood risk is taken into account and covered by No Go Zones and No Expension Zone in addition

These recommendations made on the natural axes, make it possible to respect the width of the buffer from the axis: inside this buffer, all constructions or obstacles to the flows are prohibited (buildings, embankments, walls, etc.) except for drainage works and infrastructure hydraulic installations (roads, etc.), subject to being hydraulically transparent (without any impact) for the T=100 years flood.

Table 11 : Buffer values

Type	Source	*Curent value of "River reserve"*	New buffer value	Comments
River	Fourth Schedule	**16 m**	**16 m and NGZ or NEZ**	The land extending from the edge of a watercourse to a distance measured on the horizontal plane
Rivulet	Fourth Schedule	**8 m**	**8 m and NGZ or NEZ**	
Feeder = affluent of a river or rivulet	Fourth Schedule	**3 m**	**5 m (*) and NGZ or NEZ**	
Natural path : 1 to 50 ha	LDMP	/	**7 m**	From the axis
Natural path : 50 to 100 ha	LDMP	/	**10 m**	From the axis
Natural path > 100 ha	LDMP	/	**10 m and NGZ or NEZ**	From the axis

(*) : equivalent to 5+5 = 10 m minimum buffer as for natural path for WC > 100 ha

NGZ = No Go Zone and NEZ = No Expension Zone, see chapters 3 and 5.

Warning: caution on the display and use of these natural axes below 25 ha: the quality of the DEMs but also the limits of validation taking into account embankment infrastructures such as roads often result in giving information that must therefore be taken with caution in the vicinity of sea outlets and urban and road infrastructures.

Following the 2021 Finance Bill Act, section 32 - Forests and Reserves Act – the "river reserve" in the case of a natural water path or natural drainage path is fixed at 2 metres.

2.6.3.3 Conservation devise and recommendations on lowlands and flood-prone areas

The following distinction should be made on lowlands:

- **New development or any extension thereof should be prohibited on lowlands as a whole (**and not just avoid as the PPG1 currently suggests**) in non urbanised areas, and in urbanised areas where lowlands depth is above 50 cm. These lowlands will be included as No Go Zones.**

- **For lowlands located in non-urbanised zones, their natural role to retain runoff volumes must be maintained. Any works involving diversion of water courses or run-off water flows, dewatering and backfilling should be prohibited.**

- **For lowlands located in urbanised areas (or low points without an outlet) comparison shall be made as follows:**
  - **Lowlands including all or part of wetlands**: in order to preserve the environmental and hydraulic role of the Lowlands-Wetlands, **any works involving diversion of water, dewatering, backfilling, or aims to modify run-off water flows shall be prohibited**. **The 30 m buffer zone around the wetlands,** complemented by field visits, shall be used to make the distinction between lowlands and wetlands. The protection of existing buildings within these zones can only be carried out within the building (raising of sensitive equipment, localised protection, etc) without impacting on the functioning of the wetland.

- **Lowlands with no link to a wetland (based on 30 m buffer strip analysis and field investigation)**: in order to protect built-up areas, infrastructure works aimed at limiting water accumulation zones, both in depth and frequency **may be authorized, provided that this does not aggravate risks downstream**. Moreover, the search for solutions shall concentrate on the following types of works:
    - Vegetation and land use planning on its slopes
    - Controlled land levelling
    - Upstream retention devices: infiltration and retention swales
    - Protection at building level and relocation of buildings
    - Construction of new outlets (new drainage of subcatchment) by limiting the area of the catchment intercepted

  In the case of using controlled land levelling, the extent of lowlands being reclaimed shall be restituted upstream or downstream of the working zones.

  Solutions should be based on development at source as elaborated in Chapter 3 and more fully in Chapter 3.3), and should only be authorised if they do not aggravate the risks downstream.

The table below summarises different measures for protection of lowlands and wetlands.

Table 12: Summary of recommendations relating to wetlands and lowlands

<table>
<tr><th rowspan="2">Wetlands / Lowlands</th><th rowspan="2">Whole</th><th colspan="2">Lowlands in urbanized areas</th></tr>
<tr><th>Lowlands including all or part of wetlands / Lowlands out of urban area</th><th>Lowlands not associated with a wetland / lowlands in already urbanised area</th></tr>
<tr><td rowspan="3">New urbanisation</td><td colspan="3">Prohibited (with buffer Zone 30 m for Wetlands)</td></tr>
<tr><td></td><td rowspan="2">Prohibited</td><td>Prohibited if Lowland Depth > 50 cm</td></tr>
<tr><td></td><td>Authorised with Worth if lowland Lowland Depth < 50 cm</td></tr>
<tr><td>Any Works</td><td>/</td><td>Prohibited - only with few exceptions</td><td>Authorised, works aimed at contracting water accumulation zones</td></tr>
<tr><td>Authorised work</td><td>/</td><td>The protection of existing buildings within these zones can only be carried out within the building (raising of sensitive equipment, localised protection, etc)</td><td>Vegetation and land use planning on its slopes

Controlled land levelling

Upstream Retention devices: infiltration and retention swales

Protection at building level and relocation of buildings

Construction of new outlets by limiting the area of the catchment intercepted</td></tr>
<tr><td>Under condition</td><td>/</td><td>Without influencing the functioning of the wetland.

Provided that risks are not aggravated downstream</td><td>Provided that risks are not aggravated downstream

The extent of lowlands being reclaimed shall be restituted upstream or downstream of the working zones.</td></tr>
</table>

2.6.3.4 Spéciphic case of Wetlands (Coastal and upland marschland wetlands)

In order to preserve the natural functioning of wetlands and their role in flood management, **it is recommended that a buffer zone of prohibition of construction development be applied around wetlands**. The extent of this buffer zone depends on many parameters: hydraulic and environmental considerations, extent of movement of fauna present, etc.

Nature conservation makes use of buffer zones to enhance protection of areas earmarked for restoration and for protection and management of biodiversity (source: IUCN on the term and in particular IUCN categories V or VI - category VI promotes the sustainable use of natural resources. Category V applies to areas where the landscape has been tampered with as a result of human intervention; category VI areas remain as predominantly natural ecosystems.)[10].

The proposed Wetlands Bill has made provision for the establishment of a **site specific but not less than 30 m wide buffer zone**, taking into consideration the current situation on the island. This value is also concordant with the treatment of lowland areas associated with wetlands. **The site specific of no less than 30 m buffer zone makes it possible to integrate hydraulically the lowlands in its entirety with the wetland to be protected.**

Due to difficulties in implementation due to land constraints, the Ministry of the Environment could decide to ultimately retain (maintain) 30 m in future wetlands bill (as currently included in the PPGs). This value should presently be enforced as a minimum, without exception.

The latest mapping exercise carried out in the context of the UNDP/GEF funded project entitled: Mainstreaming Biodiversity into the Management of the Coastal Zone in the Republic of Mauritius has produced reliable georeferenced maps indicating the exact boundaries of all Environmentally Sensitive Areas, including those relevant to flood mitigation. Those maps will be inserted as Inset Plans into the Outline Planning Schemes which are currently under review in Mauritius. The passing of the Wetlands Bill combined with the insertion of the said maps in land planning documents will therefore constitute a powerful tool to enforce the protection of wetlands and an adjacent buffer around it.

However, some difficulties will be faced concerning existing developments located on or within the buffer of those wetlands and the Government of Mauritius will have to warn the inhabitants of the said area that they live in a flood prone area. It will however equally be the responsibility of the Government of Mauritius to pass and enforce the Wetland Bill to prevent any new development on any mapped wetland or buffer.

[10] https://www.biodiversitya-z.org/content/buffer-zones

2.6.3.5 Conservation devise and recommendations on ESA

The current regulations give a minimum buffer value of 30 m for wetlands (Coastal and Inland - source Policy EC3 Outline Planning Scheme).

For coastal floodplains this buffer can be extended until the elevation exceeds 3 m AMSL (administrative). This is therefore a minimum buffer.

The new Wetlands Bill 2021 has made provision for a site specific of no less than 30 m buffer.

The following table indicates the buffers currently in application, source, and new proposal (recommendation).

Table 13: Buffers for ESA

Type	Source	***CuurentBuffer value in m***	Buffer Value recommended (and regulated by law) in m	Comments
Coastal and Inland	Policy EC3 Outline Planning Scheme	*30*	**At least 30 m**	*Wetlands Bill 2021 – Discussions of a value 100m*
Coastal floodplains	Policy EC3 Outline Planning Scheme	*Buffer extended until the altitude exceeds 3 m AMSL*	**Buffer extended until the altitude exceeds 3 m AMSL**	
Lake - reservoir	Policy EC2 Outline Planning Scheme	*30*	**At least 30 m - combined with the obligation of local protection embankments if necessary.**	High water line - 500 m
Mangroves	Policy EC3 Outline Planning Scheme	*30*	**At least 30 m**	
River	Forests and Reserves Act 1983	*16*	**16**	
Rivulet	Forests and Reserves Act 1983	*8*	**8**	
Feeder	Forests and Reserves Act 1983	*3*	**3**	
Boreholes	Policy EC2 Outline Planning Scheme	*200*	**200**	Or higher according to the conclusions of specific hydrogeological studies of the catchment area (hydrogeology)

Following the 2021 Finance Bill Act, section 32 - Forests and Reserves Act – the "river reserve" in the case of a natural water path or natural drainage path is fixed at 2 metres.

For wetlands already backfilled, the recommendation that can be made is as follows:

- the person responsible of the backfilling, has the obligation to create a new wetland in the excavation, with a compensation of 200% in surface in case of residual destruction of a wetland, after having tried to avoid, then to reduce any impact (application of the sequence Avoid, Reduce, Compensate (Cf. chapter 3.4.2).

2.6.3.6 Relocation of buildings: criteria for decisionmaking

Relocation of buildings can be made applicable in the following instances:

- where there are serious risks to human life. The notion of risk will be assessed particularly in regard to the probability of its occurrence and the warning time for the advent of the natural event, which time is necessary to alert and evacuate the population, etc,
- in the event of significant degradation of ESAs which play a significant role in the water cycle within the catchment.

With regard to the risks to human life the buildings subject to relocation will be:

- buildings located within natural flow axes without any possibility to open up any right of way for buffers and setbacks to divert the drain. The risks in this instance are linked to the runoff velocity and the effects of obstructing the free flow of stormwater.

- buildings located within low-lying areas with no possibility of stormwater disposal by gravity, and with water retention depths exceeding 1 m from the habitable floor level. Removal of such buildings would enable the creation of retention ponds (eg rain gardens), allowing a reduction in flood depths for neighbouring buildings, and

- Groups of buildings located in low-lying areas with no possibility for gravity outlet, and for which in the event of frequent rainfalls (less than 10 years return period), inundation of the living floor is greater than 50 cm, in which case a cost-benefit analysis will be carried out for comparison with the cost of protection measures if they are feasible.

In the case of buildings located within ESAs, relocation will be mandatory, regardless of the degree of risk, the objective being to restore the wetlands to their natural function

3 OBJECTIVES FOR DRAINAGE AND SURFACE SEALING FOR THE NEXT 20-25 YEARS CONSISTENT WITH ADAPTATION CLIMATE CHANGE

3.1 Introduction : Context, Challenges and Objectives

In the framework of stormwater drainage, the main impacts of climate change are summarised below:

- **Climate change trends, increased variability:**
  One of the most significant impacts of climate change will be increased variability and changes in average conditions (temperature, precipitation, humidity, seasons).
- **Increased number and intensity of hazards:**
  As a result of global warming, climate-related natural hazards such as floods, droughts, heat waves and storms are expected to become more frequent and, in some cases, more intense, e.g. tropical storms and hurricanes may include more precipitation and stronger winds, cover larger areas and affect places previously unaffected.
- **Rising sea levels,** caused by the expansion of warmer waters in the oceans and the melting of land ice from ice caps and glaciers, will have a significant impact on the lives of coastal populations by increasing the salinisation of water sources. It will also exacerbate coastal erosion and land loss, as well as coastal flooding from storms and high tides.

Confronted with the inevitable impacts of climate change, **it is necessary to adapt urban and peri-urban environments** with the main objective of reducing the vulnerability of their territory and their population.

Adaptation can be seen as taking the necessary measures to deal with the current and future effects of climate change. This can be done at different levels and scales. In relation to the specific topic of stormwater drainage, it is important to

- prepare for more violent or unusual hazards;
- take measures to deal with changes in flood risk
- continue current activities in the context of increased risk of disasters, the emergence of new problems.

This includes increasing resilience to climate change and ensuring that Mauritius is prepared for the additional and specific effects that climate change will produce.

Therefore, anticipating the effects of rainfall intensification in the design of drains, solutions to reduce run-off (low imperviousness, solutions to increase concentration times by abandoning of all-concrete draining devices) and land-use planning through the introduction of No Go Zone and No Expensaion Zone, are some of the axes to be developed to cope with the new changes caused by the effects of climate change on stormwater resources

3.1.1 Impacts of urbanisation and changes in land use

(Source : Principes généraux de gestion des eaux pluviales – CEREMA 2014)

Urbanisation leading to a decrease in the permeability of the soil causes significant changes in the water cycle. It increases **runoff** in terms of volume and flow rate at the expense of soil infiltration. These effects may have been accentuated by certain practices: backfilling of thalwegs and wetlands, covering ditches, and re-routing of streams, etc. Such practices are requisites for the rapid expansion of built areas as a result of economic growth.

The current practice consists in laying underground concrete structures for the systematic collection and evacuation **of storm water downstream of the development.** The drainage networks are sized according to national guidelines, usually for a return period of 10 and even 25 years. However, the sprawling towns and villages have resulted in a concentration of existing drainage infrastructure. Experimental studies carried out on hydrological units subject to urbanization, have concluded that both **impermeabilisation** (roofs, roads), and **man-made drainage infrastructure** (gutters, ditches, drains have resulted in **a decrease in the time of concentration by a factor of 3 to 6** once urbanization of these units was completed (Moore and Morgan, 1969[11]).

There are no in situ measures on Mauritius, but these orders of magnitude and their conlusions remain valid in all urbanisation configurations, whatever the territories. Moreover, such occurrence may have been locally accentuated with agricultural practices, in particular **derocking** operations associated soil mechanisation (cf. 3.2.2.2) [12].

In Mauritius, changes in land use pattern has been impacted by construction (morcellement, activities, ..) but also by by changing farming practices (mechanisation).

Such limitations necessitate **new solutions for storm water management**. A few projects (often associated with corrective measures to existing problems) integrate detention (retardation) basins generally at the outlet of the storm water networks. **These corrective solutions must be completed by other "alternative" techniques to the drainage networks or "compensatory" measures against soil impermeability.**

These works are generally classified into two categories either in isolation or in combination:

- ▷ Retardation structures reduce the flow and slow down runoff.
- ▷ Infiltration structures also help to reduce the volumes being transferred downstream.

These structures include a multitude of techniques: ditches and swales, drainage trenches, infiltration wells, etc.

Issues are also being raised due to pollution by stormwater, a potential cause of degradation of the aquatic environment. Contaminant concentration can be reduced by selecting low emission materials (eco-materials for constructions and plublics works) and adopting maintenance practices for buildings and amenities (zero phyto, etc.). **Limiting runoff also prevents contaminant concentration.** Source reduction necessitates changes in current practice by stakeholders in the development chain as well as beneficiaries.

In fact, the Central Water Authority and the Water Resources Unit of the Ministry of Energy and Public Utilities have a network of surface water quality monitoring stations in order to ensure that the water characteristics comply with the Water Quality Regulations passed under the Central Water Authority Act. The National Environmental Laboratory equally carries out water analyses for the Ministry of Environment, Solid Waste Management and Climate Change.

[11] Effects of watershed changes on stramflow – Univ. Of Texas Press, Austin - 1969
[12] Punctual signs of erosion, typical of the transfer axes areas, are visible on 2019 orthophotography

Moreover, the the UNDP/GEF funded project entitled: Mainstreaming Biodiversity into the Management of the Coastal Zone in the Republic of Mauritius has made provision for the drawing up of **Integrated Coastal Zone Management plans for Mauritius and Rodrigues with a concept of "ridge to reef" approach by the Ministry of Environment, Solid Waste Management and Climate Change.**

In view of the above, it would be beneficial to vest the surface water quality monitoring powers into the Ministry of Environment, Solid Waste Management and Climate Change which has the appropriate structure, legal framework and enforcing agency through the Police de l'Environnement to ensure full compliance with the law.

Specifically in Mauritius, waste and illegal dumping in open drains are unfortunately all too common. Beyond the direct effect on the limitation of the capacity of the drains and the works being blocked, it is also the quality of the water of the environment (rivers, wetlands, sea) which is strongly impacted.

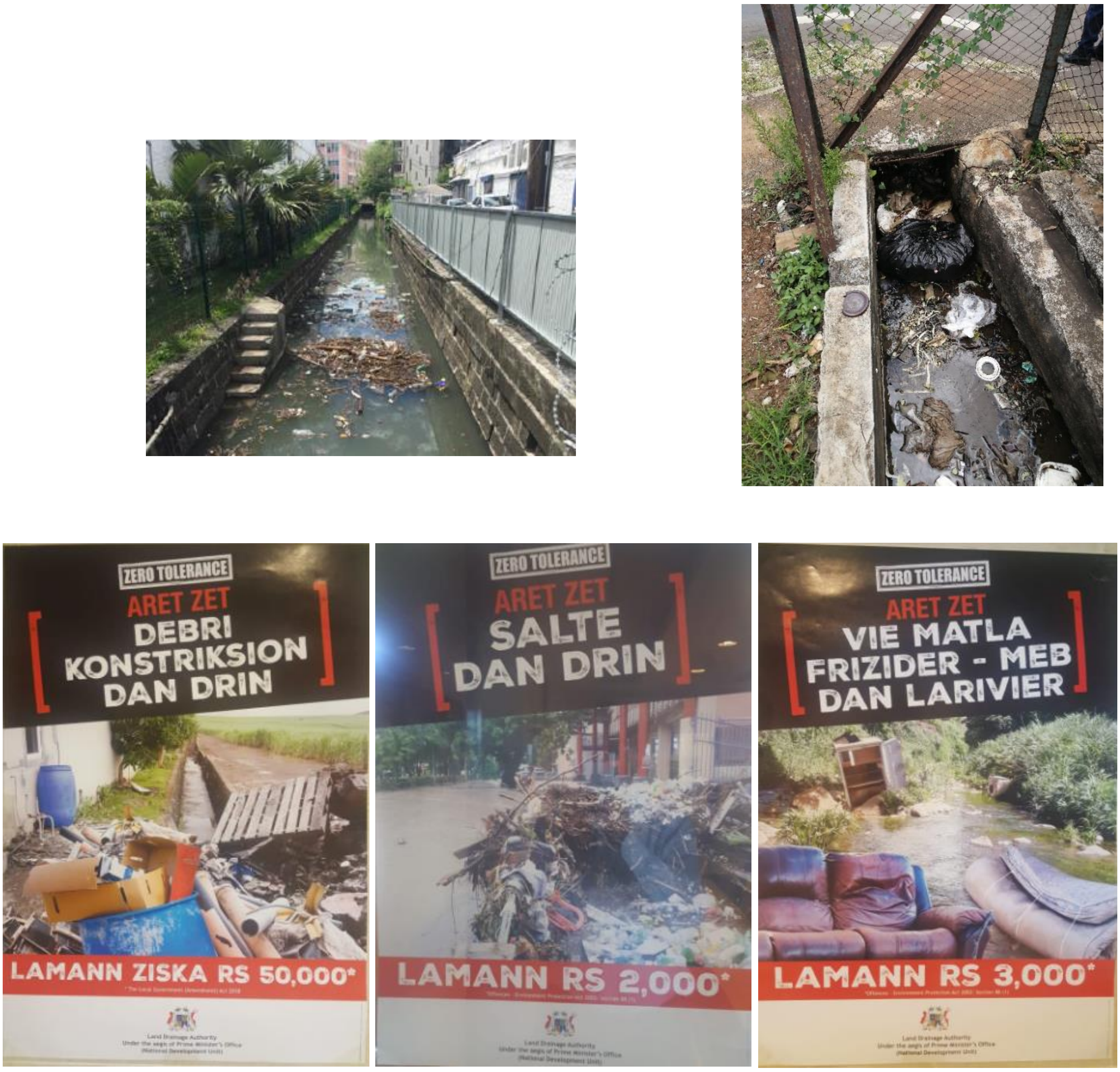


Figure 42: Typical types of waste in drains found in Mauritius

Public information and educational campaigns are well conducted, clearly indicating the risks involved for offences, but this problem remains.

Under the Local Government Act of 2003, a case of illegal dumping is punishable by a fine of Rs 5,000 to Rs 15,000; and in the case of a repeat offence, it will be a fine not exceeding Rs 25,000 + imprisonment not exceeding five years. For littering, the fine ranges from Rs 500 to Rs 2,000. And in case of a repeat offence, the fine will be Rs 10,000 + imprisonment not exceeding one year.

Legislation and monitoring devices should be geared to encourage such practice.

Finally, the need for compensation or even reduction or avoidance of the hydrological impacts of projects should be considered in the context of climate change, even if it cannot be quantified at present at the level of developed projects.

3.1.2 Reinforcement of environmental requirements & Need for regulatory measures

The main regulatory and preventive measures in force in the country are summarized in chapter 2.4.

The needs to control runoff essentially rest on individual responsibility. **A natural flow passage** between neighbouring properties **must be based on the principle of non aggravation of runoff flows**. It should be ensured that "*lower sited properties are naturally subject to runoff emanating from properties located at a higher level without any human interference. Owners of lower sited properties cannot erect any structure to prevent free flow of this runoff; neither should the owners of properties at a higher level adversely interfere with the flow passage downstream*[13] "

For a proper implementation of this principle, it is necessary to define precisely the surface area of the project being considered as well as the intercepted catchment area for discharge of stormwater into the natural environment. These concepts will be elaborated in chapter 3.5.1.

[13] Source : Article 640 le Code Civil de 1804— République Française « Les fonds inférieurs sont assujettis envers ceux qui sont plus élevés à recevoir les eaux qui en découlent naturellement sans que la main de l'homme y ait contribué. Le propriétaire inférieur ne peut point élever de digue qui empêche cet écoulement. Le propriétaire supérieur ne peut rien faire qui aggrave la servitude du fonds inférieur »

3.1.3 *Stormwater – a new urban resource*

These enhanced environmental regulations, although perceived as being constraints, constitute **an opportunity for an integrated stormwater management benefitting the quality of projects.**

Management of stormwater at source constitutes a way of restituting the city to its physical geography: soil, climate, water, landscape, etc. Flow retardation, stormwater infiltration, soft measures and rehabilitation works illustrate these concepts. Prevention at source of the different event types thus leads to contemplate the level of service that stormwater management is called upon to achieve, depending on the rainfall frequency. Stormwater management thus contributes to **sustainable urban development and ecosystem services (refer to table below).**

Table 14: Contribution of integrated stormwater management to types of sustainable development

Type	Main services expected from integrated stormwater management
Environmental Protection and enhancement	• Control of local water balance. • Pollution transfer Control • Preservation and enhancement of wetlands, rivers and vegetation and ecological sustainability. • Control of soil modification and its use.
Social inclusion	• Quality of the living environment, user friendliness of public spaces, urban comfort. • Heritage value and local identity. • Awareness campaign to users and residents on water management (noticeable improvements).
Economic development	• Pooling and optimisation of investment and operating costs. • Land valuation. • Adaptation of urban projects to global changes, urban resilience.

3.1.4 Reminder of objectives of Land Drainage Master Plan

This report aims at supporting the LDA in in their effort to provide guidelines and principles of stormwater management to designers in order to mitigate the impacts caused by their projects. To this end, the Land Drainage Master Plan:

▷ **Specifies fundamental concepts on integrated stormwater management (Ref section 3.2):**

- Definitions: runoff, vulnerability and resilience;
- Stormwater discharge and authorization for its disposal;
- Event types;
- Stormwater management system for a development and;
- Level of service of stormwater management.

▷ **Describes the principles to preserve natural areas with essential hydraulic functions in the management of stormwater (chapter 3.3),** on the basis of:

- Management of flows at source;
- Nature-based stormwater management methods.

▷ **Provide general rules to be adhered to for future urban areas (chapter 3.4)**, viz:

- General principles to be adhered to by applicants seeking discharge permit: avoid, reduce, compensate;
- Optimal stormwater management systems;
- Management practices for thetransfer and retardation of stormwater.

▷ **Provide references on rainfall hydrology for the country (chapter 4);**

▷ **Presents zoning of stormwater management and the main related recommendations (chapters 3.5 and 5):**

- Set out the objectives to limit the impact of stormwater disposal;
- Specifies the methodology to compensate the effects of urbanization;
- Specifies maintainance directives for flood and runoff expansion zones and zoning of **"No Go Zones"** (non-buildable zones) and and **"No Expansion Zone"** (Zone where new urbanisations are subject to conditions and restrictions). **The aim of these zones is to preserve the natural functioning of the floodplain, but also to reduce new risks for both existing buildings and future developments.**
- Specifies Stormwater zoning and presents the links between zoning and its requirements;
- Identifies requirements to be adhered to by applicants as well as general and particular checks to be carried out by the Land Drainage Authority.

3.2 Fundamental concepts on runoff and stormwater management

3.2.1 Rainfall and runoff

Rainfall refers to atmospheric precipitation, in liquid form. Studies for any development project should take into account local rainfall conditions.

Runoff is that part of rainfall which does not infiltrate or evaporate and which flows on the ground surface either by sheet flow or concentrated along flow axes. It can be rainfall falling directly on the project area or originating from uphill.

Runoff does not only result from impervious surfaces created by human activities. Runoff from natural soils results from either:

- **Hortonian runoff:** Runoff that occurs when the rainfall intensity exceeds the infiltration capacity of the soil. In general, Hortonian runoff occurs over poorly permeable soils (or soil already saturated by previous recent rainfalls), initially in a dry state and poorly vegetated;
- **Runoff accentuated by soil crusting.** Under the compacting influence of rain, a crust could be formed on the ground surface which then changes from a porous state to a compact state, reducing the infiltration rate and promoting runoff and erosion

Stormwater is surface runoff water which is the subject of its management and disposal within the framework of development projects. This excludes wastewater.

In terms of frequency, stormwater discharge is intermittent. Compensatory measures involve **increasing the time of concentration of this discharge**, under similar rainfall conditions.

Stormwater discharges are also characterized in terms of volumes, **discharge flows and pollution transfer flows**, for any given rainfall condition and the associated return period.

3.2.2 Runoff in its global context: Origin and mitigating measures

3.2.2.1 Introduction

The primary cause of flooding in Mauritius is the overflowing of water courses, with the inevitable submergence of adjoining land. **Other phenomena also cause flooding and chaos**, namely:

- overflowing of **drainage networks**,
- **failure of drainage infrastructure** (lack of maintenance, debris)
- **generaliszed surface runoff,** predominantly surface runoff in areas without drains
- accumulation of water
  - in low-lying areas,
  - in areas without outlets,
  - behind dune ridges in coastal aeres, areas without outelts or sufficient capacity outlets
- rise in groundwater, ,

Although surface runoff may be temporary and very often not conspicuous it can become apparent and even invasive in the event of intense or long rainfall duration, especially if the soil is already saturated; it forms gullies in its path, and transport materials in the process (mud, stones, etc.). Convergence of small gullies flood roads and villages, causing severe damage in its wake.

In order to establish the source of any runoff problem, it is necessary to consider the watershed in its entirety and to precisely localize the runoff process and to establish corrective measures as close as possible to the source of the problem.

3.2.2.2 Runoff Diagnosis Island Wise

In order to understand the runoff process and thereby to find solutions to limit it, it is necessary to differentiate between the plots and the watercourse (outlet), the following zones:

▷ **Runoff production Zones** :

During a rainy period, these zones, by the nature of their soil characteristics and their topography, will limit water infiltration and increase surface runoff by gravity. At the start of a rainfall event, the ground, due to its roughness, will retain a thin layer of water, called a puddle. If the rainfall event intensifies or persists over time, this water puddle will grow and will overflow downstream in a diffused manner and at low speeds.

▷ **Runoff transfer:**

Runoff produced following a rainfall event will flow downstream in a diffused and disorderly manner. As it flows, this sheet flow will agglomerate other sheet flows resulting into a more linear dynamic flow with increased speed and depth. The runoff will then concentrate in the lower areas (dry thalwegs, ditches, etc.) where it will flow in the direction of lower resistance, be it natural or artificial. The dimension of the drainage axes varies according to the distance between the areas being drained (production areas) and the runoff collection areas (accumulation areas) or the watercourse.

▷ **Runoff accumulation**, which can cause flooding to accumulation areas even remote from watercourses.

These accumulation areas through their storage capacity will retain runoff if it has not been returned to the water course. Contained within or located in natural or man-made depressions (retention basins), runoff accumulation areas are characterized by low flow velocities and significant water depths.

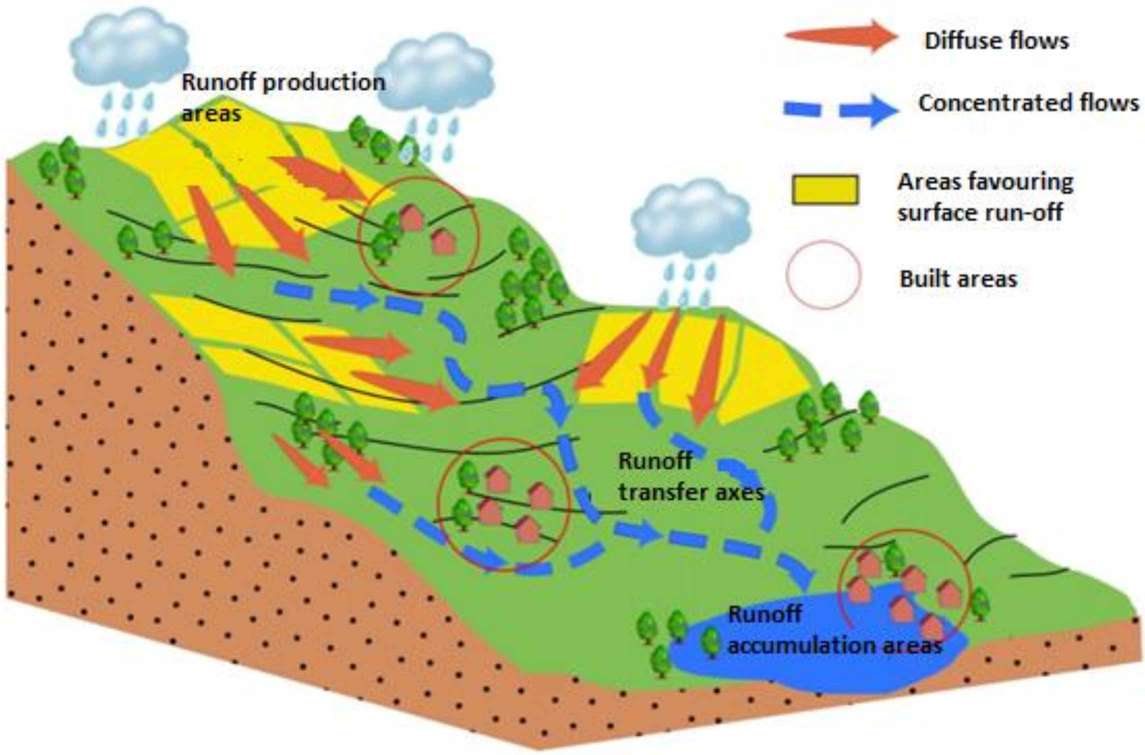


Figure 43 : Runoff within a watershed - production, transfer axes and accumulation areas

Runoff transfer axes and accumulation areas are easily identified through field investigations, whether during the rainy period or afterwards:

- **erosion** footprints (gully formation, transfer of solid matter, etc.), uprooting of vegetation cover along transfer areas, or
- wet soils, still inundated ground, deposits of fine sediments over accumulation areas.

Figure 44: Typical examples of runoff transfer axes and accumulation areas - Baie du Tombeau (Source: L'Express.mu, flooding February 2019)

In contrast to runoff transfer and accumulation areas, **it is much more complex to identify runoff production areas**. The role of production areas ceases when rainfall stops and the sheet flow produced is evacuated instantly without leaving any "real" trace on a small or larger scale.

It is therefore a real challenge to spot these high risk areas.

Indeed, **these production runoff areas are of great interest in the context of watershed management by relevant authorities since it is in these areas that measures to attenuate runoff and its impacts downstream can be implemented.**

It can also be observed that surface flows can infiltrate along the way, on permeable or flat areas, whereas subsurface flows can feed small temporary springs created by slope breaks and/or impermeable rock outcrops.

Conversely, signs of erosion, typical of the transfer axes areas, are visible following:

- **modifications to the natural topography of the catchment,** such as**:**
    - derocking works;
    - land mechanization works, creation of furrows in the direction of the slope causing concentration of flows.

      Drainage structured by paths or ditches along the axis of the steepest slopes in land flows with speeds much higher than the natural surface flow.

- **changes in land use pattern of the catchment:**
    - Construction of morcellement - residential;
    - Construction of economic activities – economic and industrial activities;
    - Construction of infrastructures (road, metro line, ...);
    - Construction of drains for morcellement projects, with terminal outlet into agricultural slopes.

The following figures illustrate such types of land modifications, resulting in:

- an increase in runoff velocities: drainage structured by paths or ditches along the axis of the steepest slopes with velocities much higher than natural surface flow,
- a decrease in the time of concentration,
- an increase in peak flow rates as a consequence, and
- an increase in the extent of runoff and flow accumulation areas downstream.

Note:

Because of the lower degree of accuracy provided by the 2008 DEM, a direct comparison between the 2008 DEM and the 2019 DEM does not necessarily identify whether natural drains have been filled in or whether catchments have been modified by mechanisation.

Identification can only be made locally based on the 2019 DEM reflecting the current situation (as of the date of the LIDAR flight, i.e. 2019).

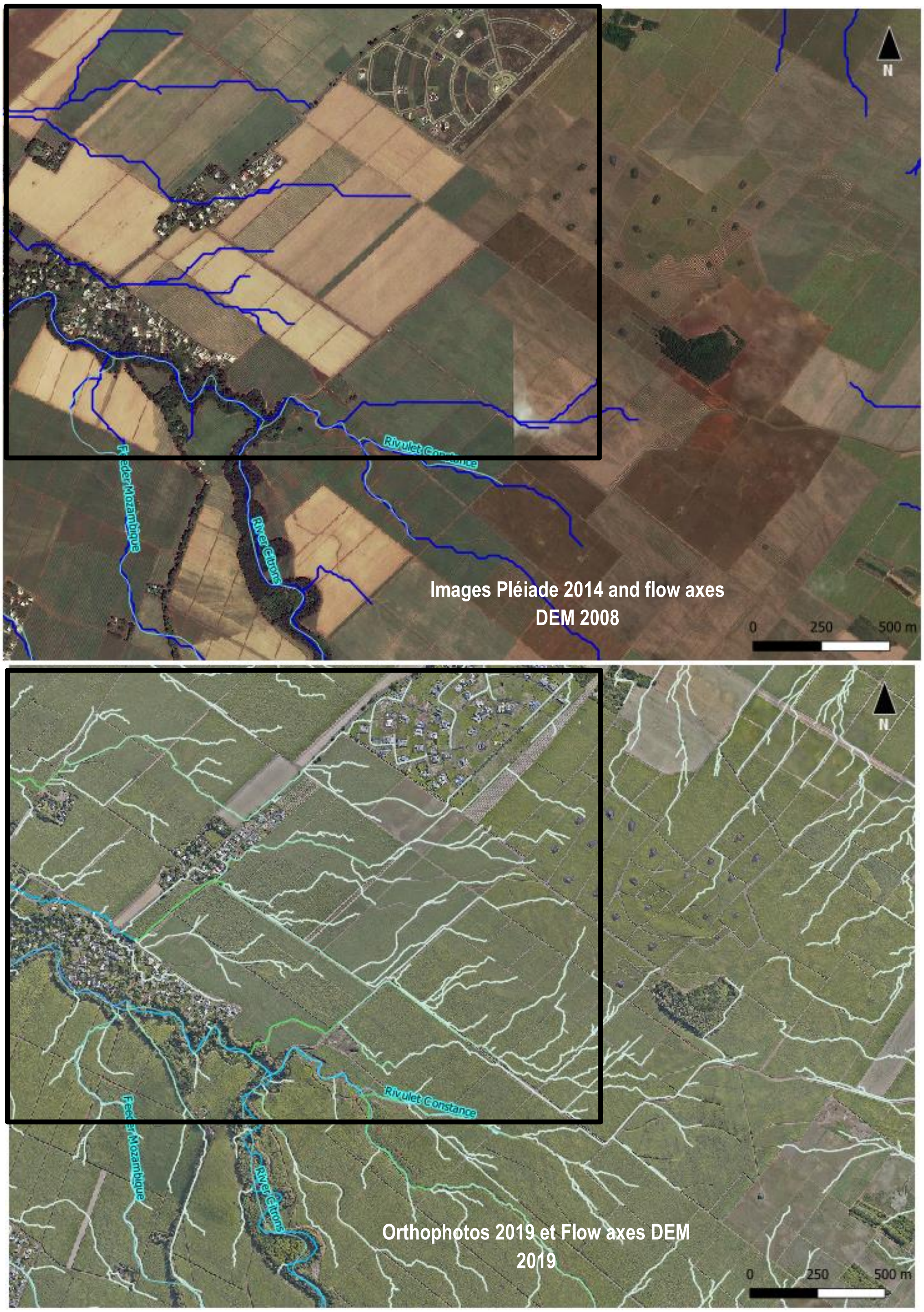


Figure 45: Typical examples of changes in runoff production and transfer axes areas associated with soil mechanisation and derocking, Sector Mon Piton, Mon Gout

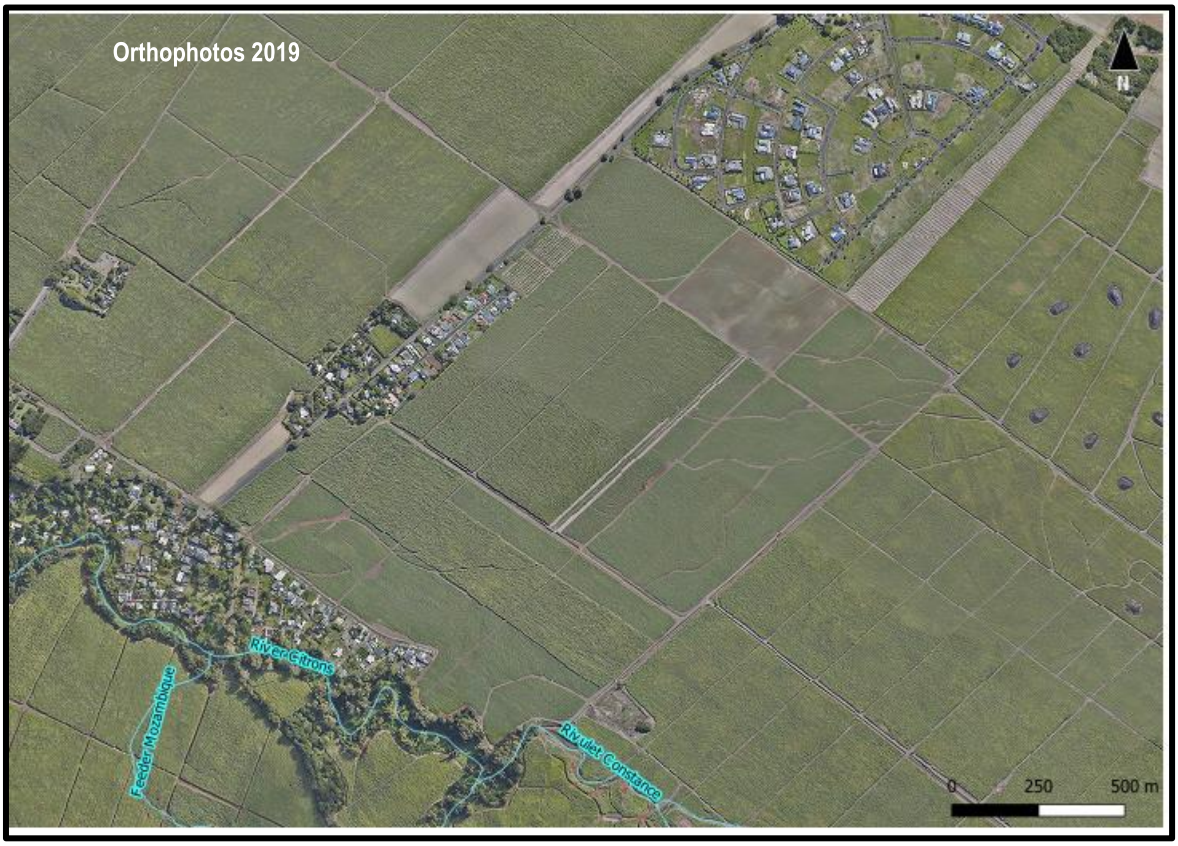


Figure 46: Typical examples of changes in runoff production and transfer axes areas associated with mechanisation and derocking works- Sector Mon Piton, Mon Gout- Blowup showing erosion ditch on sugarcane field.

3.2.3 *Main concepts: Risk, vulnerability and adaptation*

Flood vulnerability can be assessed by overlapping hazard situation with human issues. An initial assessment of vulnerability serves to define the level of service and the objectives of the drainage system.

Figure 47: Flood risk assessment process

The following definitions serve to understand the levels of action to manage the risks of flooding and stormwater runoff:

▷ **Hazard** [Natural hazard]:

Predictable natural event / phenomenon to a certain degree of accuracy, out of control. A hazard is described by its nature, location, frequency (probability and/or date of occurrence) and intensity.

▷ **Vulnerability** of assets / issues**:**

The fragility (foreseeable harmful effects) of an issue (population, human activity and/or construction) in the face of a hazard.

▷ **Risk**:

The possibility of the occurrence of a damaging event related to the exposure of vulnerable issues to a hazard. The hazard is then perceived as a danger.

Note: if there is no stake, there is no risk. For example, there is no risk if earthquakes (even frequent and intense ones) affect an unpopulated, unexploited area.

This combination of hazard and assets/issues, or risk, can be likened to an exposure factor.

▷ **Main external hazards:**

Torrential rains, floods, hurricane, ...

This combination of hazard and issue is described in another way by the "exposure factor".

Forecasting is the study of the hazard (nature, frequency, location, intensity, even date of major events) allowing a more accurate assessment of the risk.

Protection is the set of measures taken to reduce the potential impact of a hazard on a given issue (population, construction, etc.), thus reducing the risk by reducing vulnerability.

Risk prevention is the set of measures aimed at anticipating hazards and impacts by various means (learning how to act or instructions to follow in the event of a problem, setting up and respecting rules or action protocols, etc.) in order to reduce the overall risk.

Adaptation is the reduction of vulnerability by reducing both exposure to the hazard and its potential effects by taking into account the characteristics of the hazard (setting up specific measures due to the presence of a given hazard at a given location). The search for a reduction in exposure is the limitation, while the search for a reduction in harmful effects is the mitigation.

Prevention involves, among other things, training people and decision-makers during awareness-raising actions (a risk exists, "protection" exists and must/should be considered) or education (information and learning of preventive and/or emergency actions or gestures).

Acceptability is the threshold of tolerance (the capacity to bear the consequences) of a person, group or society in the face of a risk. This threshold depends on the stakes involved, the potential damage, the information available (enabling the risk to be estimated as accurately as possible) but also on personal, cultural or economic considerations (for "purely" financial risks). Acceptability may therefore differ according to the level envisaged (personal, group, state), the place (culture, available information) and the time (cultural and societal developments, education, etc.).

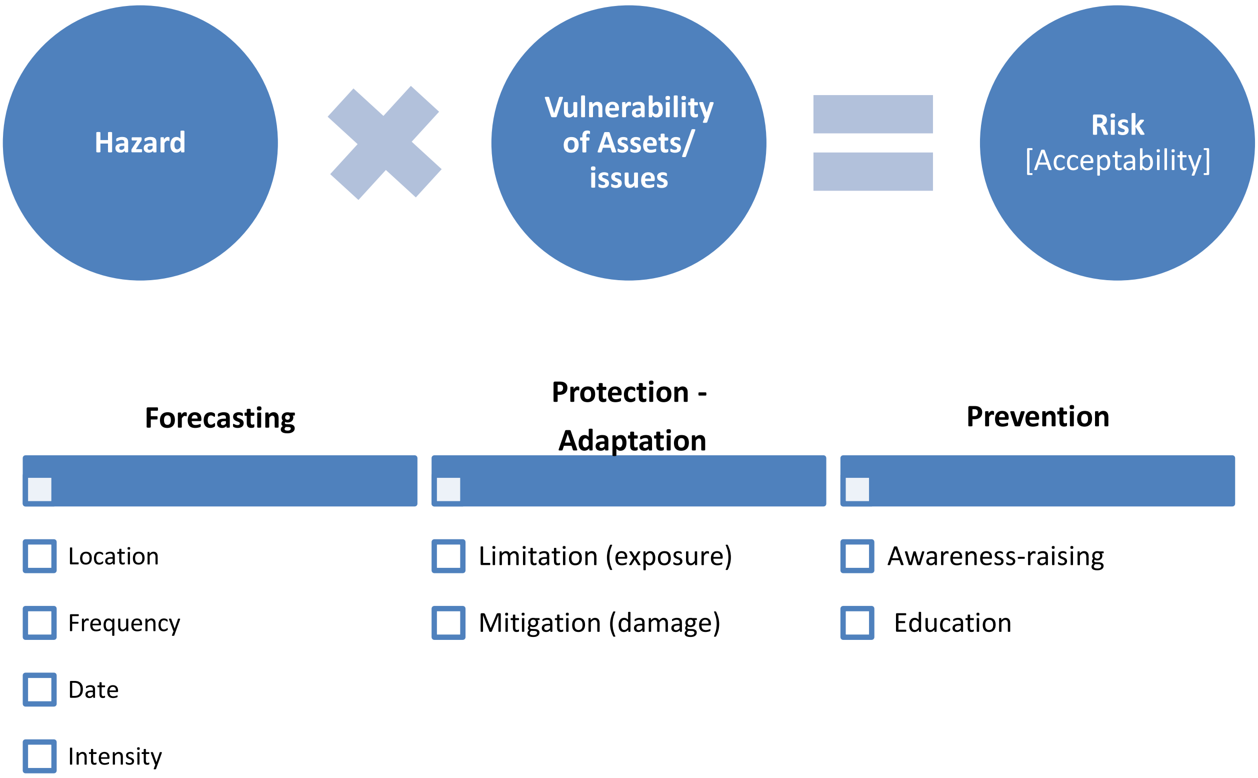


Table 15: Hazard, vulnerability and risk

The actions carried out and to be carried out in the framework of the risk management policy are the following:

Table 16: Risk Management Action Plan

Action plans to be implemented		
Forecasting	**Protection - Adaptation**	**Prevention**
Mapping of potentially flood-prone areas established over the whole island (hydrogeomorphology) (EXZECO)	Implementation of No Expension Zone for the whole island (flows and lowlands in uraban area) - definition of building conditions adapted to the level of hazard	Implementation of No Go Zone and for the whole Island (flow and accumulation on lowlands)
Natural flow axes mapped over the whole territory from 1ha (DEM 2019 and 2008)	Implementation of Stormwater Best Management Practices and national rules for design Implementation of stormwater Zoning	Implementation of an inconstructibility buffer on both sides of the natural flow axes
Mapping of flood events by flood mark surveys	For new development, obligations for Sustainable Urban drainage development	Implementation of buffer for Wetlands – No Go Zone
Mapping of flood risk areas on the main vulnerable catchment areas of the territory. 5 +11 sectors were the subject of hydraulic modelling in LDMP	Structural works for hazard reduction for 5 +11 sectors	Recommendations for governance and implementation of risk management policies and urban planning
Additional areas to be mapped according to vulnerability	Structural works for hazard reduction for other sites	Evaluations of planning and policing policy for risk prevention

In green, action taken in current LDMP

In orange, remaining actions to be taken

3.2.4 Application for Stormwater Disposal

To date, no formal request for discharge of stormwater into the stormwater network or the natural environment is required on the territory. One of the first recommendations concerns the implementation of this procedure: this document is called a **discharge authorisation request**.

In order **to address any application for authorsation to discharge into the drainage network under the responsibility of the LDA**, this discharge authorisation request:

- ▷ must be lodged by a public entity or private person, natural or legal entity (local authority, developer, etc.),
- ▷ shall deal with stormwater discharge into fresh surface water or over, into or under ground by infiltration

  However, infiltration will not be used in the following cases:

  - protection of boreholes (within the limits of the recommended buffer zones);
  - in presence of a high-water table (high water table less than 1 m deep);
  - if the infiltration capacity of the soil is too low. In practice, minimum values of 20 to 35 mm/h are to be taken into account (Cf. chapter 3.4).

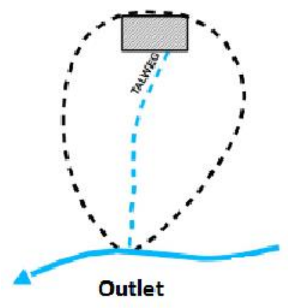
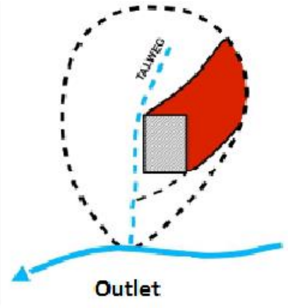
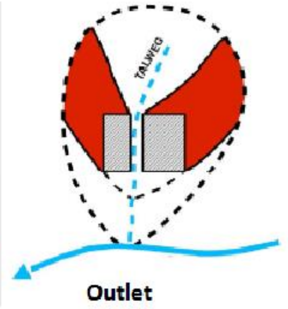
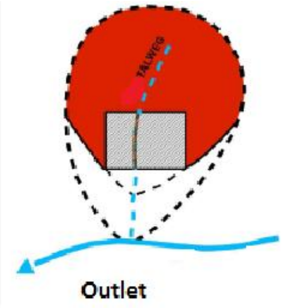
    Chapter 5.4.3 presents the zoning of potential soil suitability for infiltration, and the provisions for in situ measurements to be carried out as part of any project integrating infiltration devices.
- ▷ shall indicate precisely:
  - the total project area, together with the area of the upstream natural catchment being intercepted,
  - the discharge location, whether it is:
  - periodical, eg a dry ditch
  - intermittent, eg the outlet of a retention basin,
  - controlled, eg the outlet of a retardation basin
  - surface areas (spreading area), eg an infiltration swale.

The notion of "project area including the area of the upstream natural catchment being intercepted " is an important concept.

The following table describes this concept precisely and enable to define the area to be taken into account in the impact analysis and the subsequent compensatory measures.

The natural catchment, whose flows are intercepted by the project, is shown in red. **The scenario "d" generating hydrological and hydraulic discontinuities should be avoided.**

Table 17: Representation of project area within a watershed

Geographichal Configuration				
Analysis	**a :** The project area does not intercept upstream natural flows : • Project area at the upper end of the catchment • project area within an alluvial plain	**b :** The project area intercepts upstream natural sheet flows • Project within the valley	**c :** The project area intercepts upstream natural sheet flows but allows concentrated throughflow in the valley (thalweg..): • Project on a preserved thalweg	**d :** The project area intercepts upstream natural sheet flows and obstructs concentrated throughflow (thalweg..) • Project on a modified thalweg
Total Surface area to consider	Project area	Project area+ Intercepted upstream catchment area (overland sheet flow)	Project Area+ Intercepted upstream catchment areas (overland sheet flow)	Project Area+ Intercepted upstream catchment areas (overland sheet flow) + **Catchment area drained by the upstream drainage axis of the project**

3.2.5 Potential impacts of stormwater disposal from an urbanization project

3.2.5.1 Modifications to Runoff flows

Modifications to runoff regimes are induced by a master plan layout (localisation of buildings and roads, soil mechanization) and land uses, including those during the construction phase. These modifications vary according to rainfall conditions and the initial soil saturation state.

These modifications are likely to affect:

▷ **the flow path within the project and its environment,**

- obstructions or reduction in flow capacity leading to upstream flooding,
- abstraction, diversion or concentration resulting in the dehydrating of wetlands, in particular,
- backfilling, causing reduction in flood expansion zones;

▷ **Runoff,**

- increase in runoff volumes, acceleration of flows and increased flow rates, all of which are likely to flood the areas downstream and the project itself (refer to figure hereinafter),
- reduction in water infiltration, evaporation or evapo-transpiration, leading to modification to the local monthly or annual water balance;

▷ **Hydromorphological functioning of receiving water bodies,**

- Increased flood flows,
- bank erosion and increased flood frequency,
- Soil erosion and suspended solids transport leading to siltation of river beds, clogging up of habitats and slowing down flows and rise in upstream water levels,
- resuspension of deposits and sediments (accumulated pollutants);

▷ **Underground flows:**

- dewatering during the construction phase,
- reduction in groundwater infiltration,
- backfilling of lowlands and wetlands,
- obstructions to underground flows.

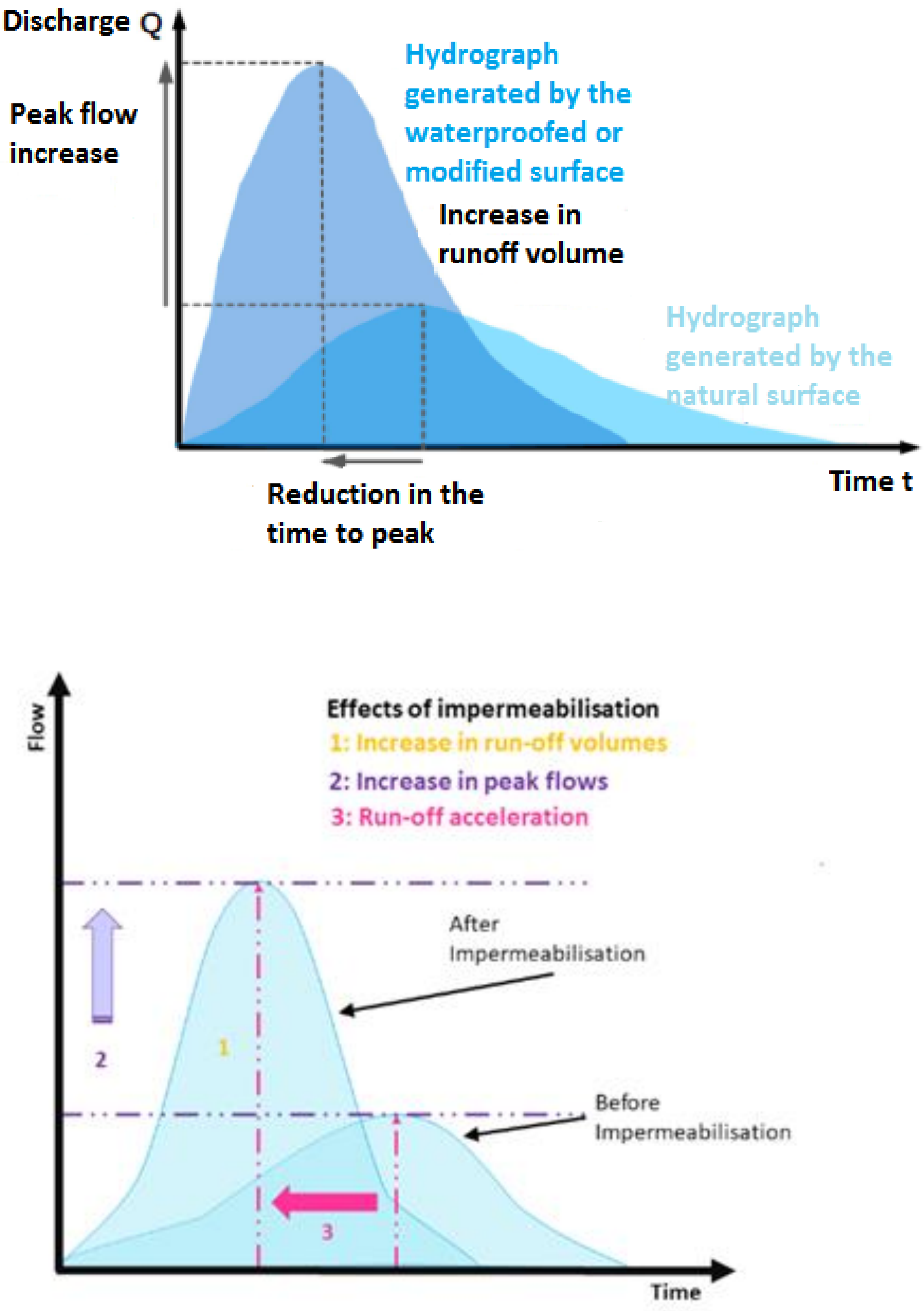


Figure 48: Impacts of soil impermeabilisation on natural flows for a typical storm event

3.2.5.2 Transfer of contaminants, water quality and aquatic environment

Rain and Stormwater are vectors for the transfer of contaminants from different sources, and which are **mobilized during the rain trajectory**:

- ▷ during the rain transit through the atmosphere, the rain gets loaded with air pollutants,
- ▷ during runoff, the stormwater carries contaminants deposited on the ground by atmospheric dustfall and processes, or emitted by materials in use,
- ▷ during its transport in ditches or drainage networks, the stormwater gets loaded with contaminants resuspended from deposits.

There is big variance in the characteristics of these contaminants due to the nature of the project, its surroundings and its use on one part and the rainfall conditions (duration of dry weather spell prior to the rainfall event etc.) on the other part. The impact on the receiving water and environment can take different forms:

- ▷ **shock effects**, linked to a rainfall event: these are immediate or slightly delayed effects causing short term degradation of the water and the environment, linked to a sudden increase in concentration of any toxic contaminant, turbidity, bacteria, etc., or a drop in dissolved oxygen content, even to the extent of causing death to the aquatic fauna and interruption in use (water collection, swimming, shellfish farming, etc.). **In Mauritius, the schock effects are the most visible and predominant;**
- ▷ **Stress effects**, linked to chain rainfall events: they represent an aggravation in the discharge impacts due to their repetitive nature, given that the environment does not have time to "recover" between two rainfall events;
- ▷ **Cumulative effects,** linked to a series of intensive rainfall events: these involve contaminants having long lasting effects, such as heavy metals or certain toxic micro pollutants long stored within sediments and which could progressively or suddenly be released into the water

The extent and duration of these different effects depend on the stress being exerted (importance, frequency, etc.) and on the vulnerability of the environment, particularly during low flows, and on users sensitivity. These effects can be difficult to assess in view of the many parameters coming into play.

3.2.6 Local Stormwater Management System

A system is defined as a group of interacting or interrelated entities that form a unified entity.

This concept is mostly used to reflect the changes observed in urban storm management which consists of four types, viz:

- ▷ **Increase in the range of mechanisms mobilized** in a more efficient management: permeable or impermeable surfaces, green roofs, ditches and swales, water basins, rain gardens, space for managed flooding, rivers, rainwater collection tanks for re-use, etc.;
- ▷ **Diversification of services provided**: preservation of water and aquatic environment, flood prevention, landscape enhancement, urban island, establishment of rainwater reserve, water supply for plants, etc. ; and **the diversification of the functions to be provided**: collection, infiltration, retention, evaporation, evapo-transpiration, flow, transport, storage, etc.;
- ▷ **Taking into consideration local rainfall conditions**, likely to gradually influence the system, from frequent to exceptional rainfall in a modular and continuous operation of the system;
- ▷ **A range of public and private stakeholders** involved in this management, from the inception stage up to the implementation and operation stage.

3.2.7 *Level of service provided by local stormwater management system*

This **concept of level of service**, defined in the urban management context, can be applied to the design of local stormwater management system for a development project. The primary objectives and main functions of the system are classified according to rainfall conditions.

For design purposes, collector drains or retention basins may be sized for small return periods, generally 10 years, coupled with a stormwater management system likely to progressively respond to a series of conditions, from small to exceptional rainfall events.

The table below specifies, according to the level of service, the following:

- **Targeted priority objectives;**
- **Main functions performed** through the stormwater management system;
- **Alternative solutions to adopt** for a particular project and in the local context.

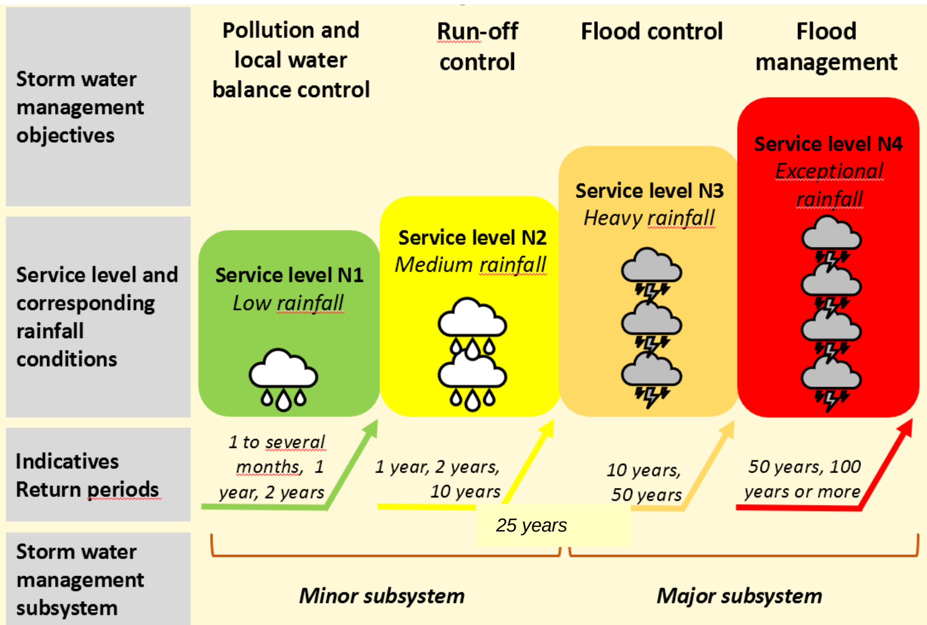


Figure 49: Stormwater management objectives according to rainfall conditions - Concept of level of service

Appropriate objectives should be defined for a particular return period, together with appropriate criteria and specific alleviation measures, based on a good assessment of the existing situation and the likely impacts of the project:

- **The capacity of the drainage infrastructure and the vulnerability downstream** must also be taken into account to define an appropriate return period, this in order not to increase the risk of flooding;

- **The level of service expected** from the design criteria of drainage projects located in vulnerable areas must be defined, taking into account issues related to the catchments and in consultation with local authorities such as LDA, NDU, Ministry of Environment and WRUs, NDRRMC.

Table 18: Level of service provided by a stringent local stormwater management system associated with a development project.

Level of Service	Targeted Priority Objectives	functions provided by the storm water Management system	Alternative solutions to be adapted to the project and local context
N1 Low Rainfall < 2 years or even 10 years	• Prevent impacts of stormwater disposal on water quality and the receiving aquatic environment**; control of pollution by stormwater.** • Prevent nuisances caused by stormwater and control runoff. • Limit modifications to the local water balance; if necessary, maintain low water flows. .	• Limit pollutant emissions, their concentration and transfer, and effect appropriate treatment if necessary, before discharge. • Limit runoff, collection of stormwaters from built-up areas and retention at source. • Restoration of the ground water reserve through infiltration, rain water capture and storage if necessary. • Evapo-transpiration by vegetation cover, evaporation by water surfaces and wet lands.	• Selection of low-emitting pollutant materials; adapted maintenance. • Retain open ground or vegetation cover, implementation of permeable coatings. • In situ stormwater infiltration works, controlled flow discharge after temporary storage (swales, rain gardens, gullies, etc.). • Sedimentation, filtration of stormwater if necessary. • Recycling system of stormwater for outdoor and eventually indoor use.
N2 Average Rainfall from 2 to 20 years or even 25 years	• Prevent nuisances caused by stormwater**, control runoff.** • Limit impacts of stormwater disposal on water quality and the receiving aquatic environment.	• Limit runoff, collection of stormwater from built-up surfaces and in situ retention, restitution by infiltration or by means of controlled flow. • Limit pollutant emissions, and if necessary partial treatment prior to discharge.	• In situ infiltration works and/or stormwater retention structures for public and/or private: swales, retention basins, etc. • Associated drainage system to transport stormwater to these works/structures.
N3 Heavy rainfall from 25 years to 50 years	• Prevent damage to people and property**: Control of flood risk.** • Readiness to accomodate *a significant deterioration in water quality and the receiving aquatic environment*	• Stormwater management by drainage and/or storage that partially mobilizes the major subsystem (depth and velocity of flow and storage depths compatible with the storage area).	• Localized flooding of less vulnerable public and private spaces within safety thresholds (flood heights).
N4 Exceptional rainfall 50 years to 100 years and above	Preventing harm to people and limiting damage to property: **flood risk management.**	Stormwater management by drainage and/or storage that mobilizes the entire major system (depth and velocity of flow and storage depths compatible with the storage area)	Stormwater Management in public and/or private areas which are less vulnerable to damage; • Interaction with flood management tools (preventative information, Community Safeguard Plans, etc.).

Under all circumstances, **an action plan aimed at reducing runoff, increasing time of concentration and reducing peak flow**, especially for projects located at the upper reach and midway of the catchment area, **is recommended for future works.**

As detailed in the following chapters, with implementation in Chapter 5, this action plan will focus on:

- encouraging the use of nature-based stormwater management techniques,
- the definition of a stormwater zoning aiming at reducing peak flows by the implementation of rainwater retardatin devices

3.3 Principles of respect to natural areas with essential hydraulic functions in stormwater management

3.3.1 Introduction: Stormwater management at source

Source ER2C Guideline

Faced with the findings of flooding, several local authorities all around the World (namely in France, Australia, New Zealand, Singapore), supported by scientific organizations and local partners, wanted to think the management of stormwater otherwise.

The following principles are well developed already in the vulnerable areas of tropical countries such as the Caribbean islands, Réunion Island or Singapore,...:

- ▷ **Preserve or re-establish the hydrological functions of the natural areas** involved in the drainage functions of the territory.
- ▷ **Limit, reduce and mitigate the effects of soil impermeabilization:**
  - **Limit the impermeabilisation of soils** in order to preserve areas suitable for stormwater infiltration and to limit the additional contributions to existing sewer networks during rainy weather (applicable only to combined sewers),
  - **Avoid concentrating and accelerating natural runoff**, in opposition to the old hydraulic approach aimed at systematically channelling stormwater,
  - in areas where it is relevant (for example, upstream of an area sensitive to runoff risks), **create retentions for storing stormwater to delay its peak discharge**
  - **promote rainwater harvesting** from roof tops and reuse.

In the most vulnerable areas, reducing effects of impermeabilisation can be defined by **an objective of leakage flowrates** from urban areas or urban development adapted to the downstream capacity, by an appropriate strategy of management of stormwater: **the most appropriate tool is a land drainage master plan** of sanitation **and stormwater zoning associated** with the regulation and reorganization of drainage system linked to local urban plan, taking into account drainage vulnerable areas.

3.3.2 *Preservation of hydrological functions of the natural areas: flood expansion zones and No Go Zones prescriptions*

3.3.2.1 Introduction

No Go zones are flood expansion zones and are natural or developed areas where overflow water can diffuse during a flood event. This zone provides a transitional storage of water and delays its peak flow. The wetlands in the major streambeds play this role. Flood expansion zones can also play a role in the ground water recharge as well as in the proper functioning of wetlands.

These areas must be protected from any attempt at urbanization or backfilling.

Many river improvement works carried out in the past were intended to speed up water transport and to limit the phenomena of river overflow (eg: river training/straightening, construction of canals, clearing river banks of vegetation, etc.). These works are starkingly visible: watercourse sections are "lined" with concrete in rectilinear fashion, or by steep sloping revetment. Yet, expansion of the watercourse, especially during winter, is a natural phenomenon, which favours biodiversity, water quality improvement, ground water recharge, and limits the risk of flooding in downstream urbanized areas by slowing down the flow of the watercourse.

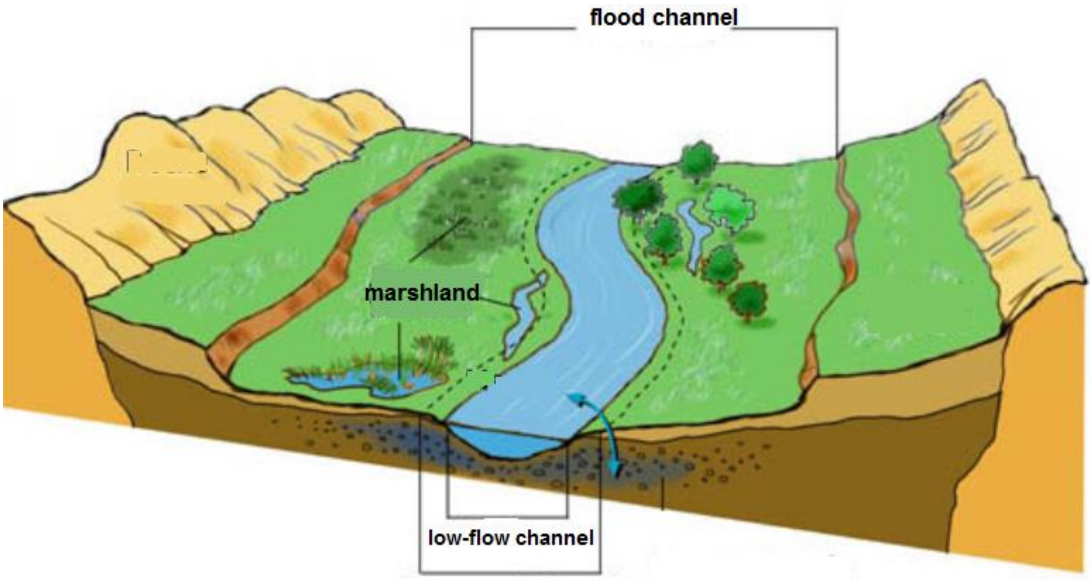


Figure 50: Flood Expansion Zones

Thus, the following principles will be adopted in the context of the LDMP:

- ▷ **Identify and map functional flood expansion zones:**

  The mapping of flood expansion zones is defined in chapter 5.4.1.

  These maps are based on the following information:

  - Extent of non-urbanized areas, natural or agricultural;
  - mapping of flood zones by hydraulic modelling, using a 100-year return period flood;
  - Besides zones generated by hydraulically modelling, an additional hydrogeomorphological layer established by the EXZECO method. **A threshold of catchment area retained for the No Go Zones is set at 100 ha, this in order to permit new urbanizations coherent with the risks of flooding and runoff. Below this threshold, the No Go zones will be limited to the buffer on the natural flow paths.**

3.3.2.2 Hydrogeomorphic and topographic approach –by EXZECO

The hydrogeomorphological method is essentially used for the diagnosis of flood-prone areas. It is now one of the tools recommended by different ministries all over the world (for exemple in reunion Island) in charge of flood prevention:

This method is a privileged tool for mapping flood-prone areas, as it perfectly matches the requirements of this type of document. It provides information on the natural functioning of floods over large linear areas. It is often coupled with a historical study of floods, of which it is a good complement. It can be used as the main tool or as a preliminary and complementary tool to the hydraulic study when it is necessary to quantify the flood hazard in the framework of the elaboration of No Go Zone and No Expension Zone

▷ **The basis of the method**

This "naturalistic" approach is based on the observation and interpretation of the natural terrain. An alluvial plain is made up of several topographic beds that the river has shaped in the valley bottom over successive floods: these are the hydrogeomorphological units framed by the enclosing units. They result from a combination of sediment accumulation and erosion. The progressive accumulation of sediments builds the hydrogeomorphological units while erosion marks their limits (slopes).

▷ **Hydrogeomorphological (floodable) units**

The minor bed is the main channel of the river. It is generally made up of a low water channel and landings. It contains **annual to frequent floods**.

The middle bed is located near the minor bed. It consists of a bumpy surface formed by depressions and small hills, often colonised by the riparian vegetation. It is **flooded by frequent to moderately frequent floods**. It is unsuitable for urban development because of the frequency and dynamics of flooding.

The major bed is formed by a flat topographic level, generally made up of very fine sediments: silts. **Flooded by rare to exceptional floods**, it is sometimes mobilised by more frequent floods but generally remains less often submerged than the middle bed.It is sometimes dominated by an **exceptional major bed**.

▷ **The « encaissant » units (non-floodable)**

The hydrogeomorphological units are framed by more or less marked reliefs which are grouped together under the term " encaissant ". The substratum or slope corresponds to the rock in place, visible or hidden by a soil. The terraces are topographical forms situated above the floodplain. They are ancient alluvial formations built up by the accumulation of materials brought by rivers. Colluvium is a variety of materials resulting from the erosion of mountain and hill slopes, which slide down the slopes due to gravity or water erosion and accumulate at the foot of the slopes.

▷ Synthesis

The following figure synthesises these hydrogeomorphological units.

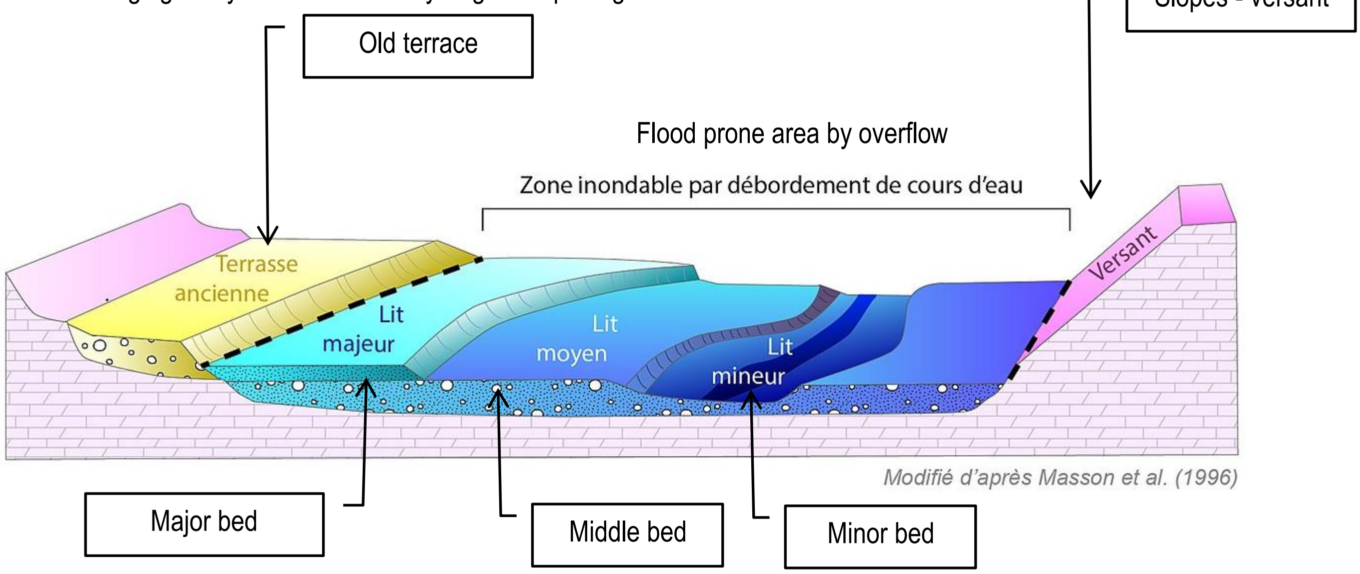


Figure 51: Hydrogeomorphological units (source Masson and al. 1996)

▷ Boundary delineation by topographic method – ExZEco

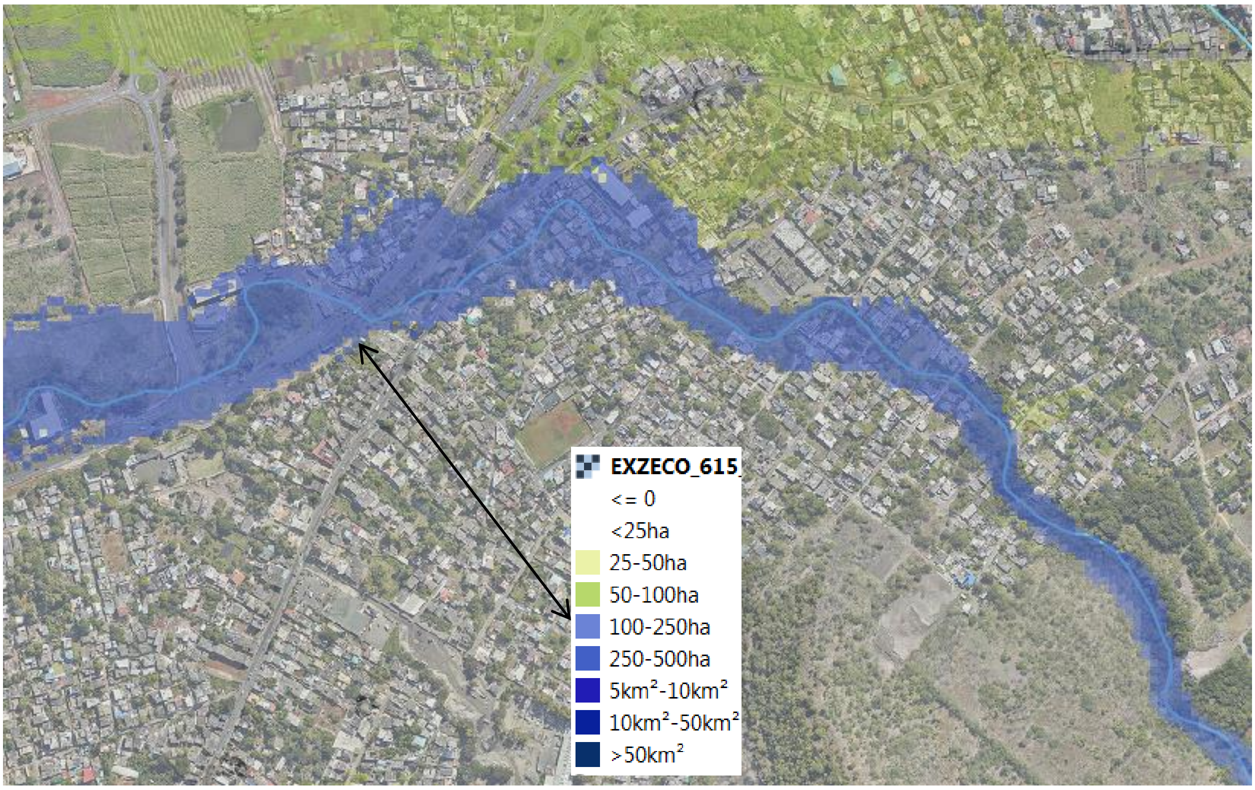
For a global analysis on the scale of the whole island, the characterisation of potentially flood areas was carried out by the ExZEco method.

This method is based on topographic analysis which extracts flow accumulation area using a random effect on the DEM[14]. This method is equivalent to filling thalwegs with an enforced height of water.

The following maps show examples of EXZECO hydrogeomorphic areas, for a 100 ha (1 km²) threshold compared to the modelling results for the 100 years flood return period. The hydrogeomorphological coverage, by definition, representing the complete topographical framework of the area, gives an envelope which is globally always superior in coverage than those resulting from urban runoff by modelling, taking into account the open drains and the flow in networks.

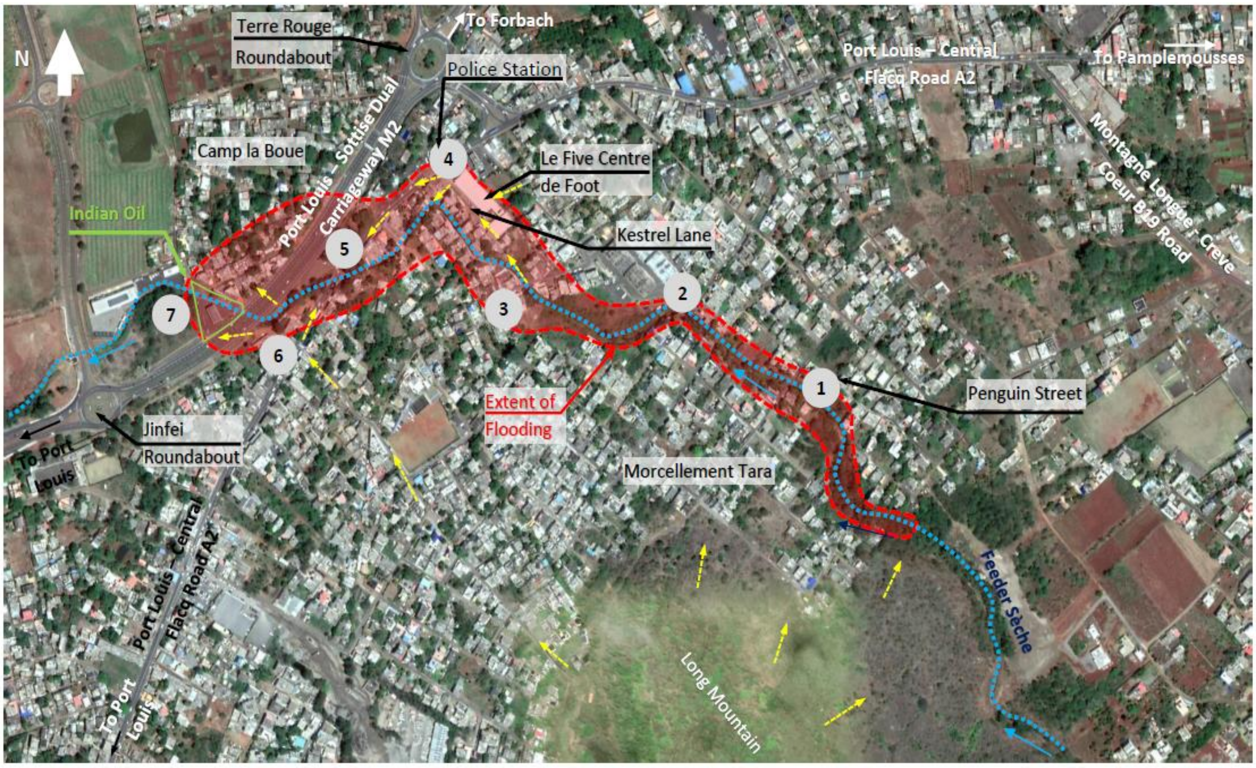
[14] *For more detail on the basis reference:*https://www.asprs.org/wp-content/uploads/pers/1988journal/nov/1988_nov_1593-1600.pdf - K. Jenson and]. O. Domingue - 1988

Extent of flooding problem at Riche Terre Roundabout – (source Reconstruction of Culverts and Enlargement of Drains at Kestrel Lane, Terre Rouge - Revised Preliminary Design Report SJP January 2020 – NDU)

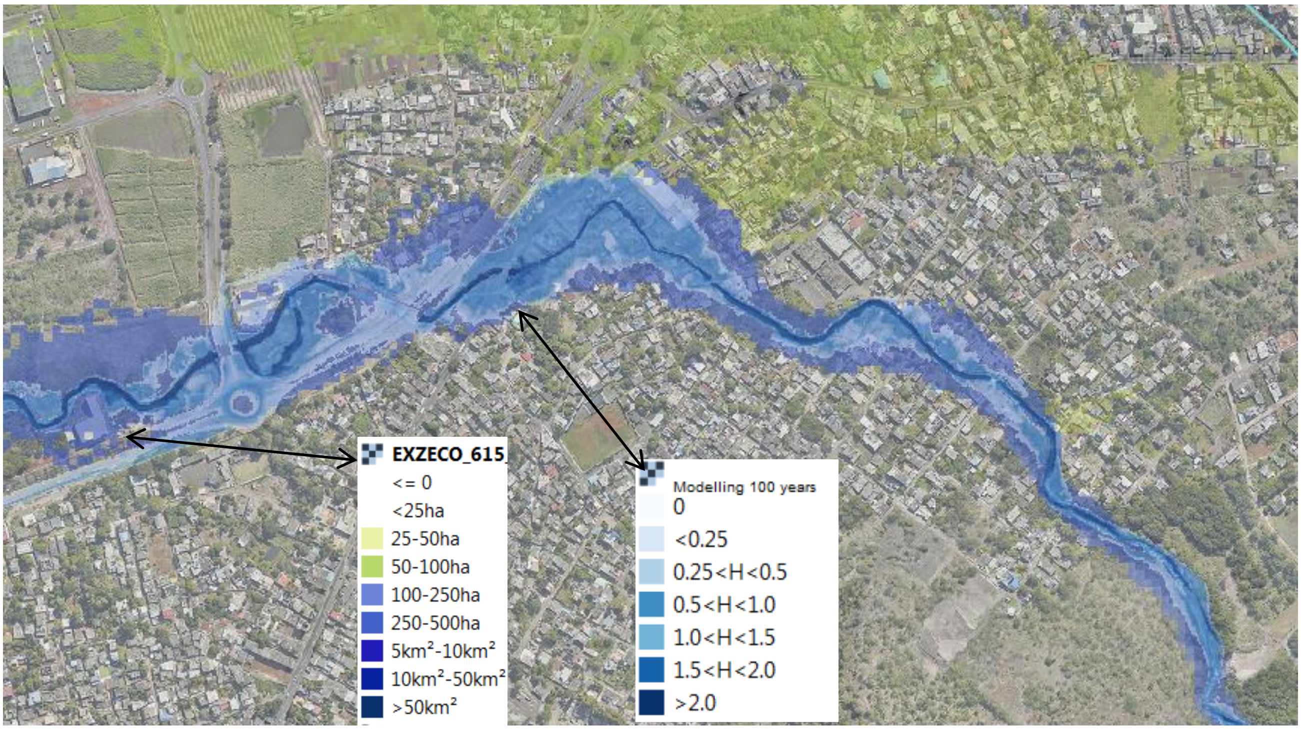


EXZECO application with upstream catchment area detail.

Figure 52: Exzeco extraction example and flood information: Ravine sèche, Kestrel Lane



Extent of flooding problem at Riche Terre Roundabout – (source Reconstruction of Culverts and Enlargement of Drains at Kestrel Lane, Terre Rouge - Revised Preliminary Design Report SJP January 2020 – NDU)



EXZECO application with upstream catchment area detail.

Figure 53: Exzeco extraction example and flood modeling T100 years information: Ravine sèche, Kestrel Lane

▷ **Consideration of the No Go Zones in urban planning (in non-urbanised areas), including all lowlands:**

- **The objective is to preserve natural flood expansion areas**, those located upstream but also those downstream which often correspond to accumulation zones under the direct influence of upstream urbanisation. More importantly to prohibit any backfilling and dyking in these areas, which is not justified for protecting existing urbanized areas. The restitution of these natural areas must also be registered as an objective;
- Prohibit human settlements in the riskiest areas where, regardless of the facilities, the safety of people cannot be fully guaranteed; limit human settlements in other flood-prone areas;
- Maintain the flow and flood expansion capacity so as not to increase the risk to settlements located upstream or downstream;
- Maintain the natural drainage paths free of all constructions;
- Safeguard the equilibrium of environments dependent on small floods and the beauty of landscapes by virtue of their proximity to water bodies and pristine valleys.

▷ **Compensatory measures for authorized backfilling to maintain flood expansion conditions**

The preservation of the natural conditions for flood expansion for different return periods, for frequent and exceptional events is set as an objective.

In addition, in already urbanised areas, it is also necessary to limit urbanization extensions in areas at risk. Thus, in these already urbanised areas, we define **No Expansion Zones** (Zones where urbanisations are subject to conditions and restrictions). This possibility of building must be done outside the flow axes, high flows and deepest lowlands.

The No Go Zones (NGZ) and No Expansion Zones (NEZ) are elaborated in chapter 5.4.1.

3.3.3 Nature-based Solutions (NbS) for Stormwater Risks

(Source: International Union for Conservation of Nature (IUCN)

3.3.3.1 Nature Based Solutions - Introduction

Nature-based solutions are actions meant to **protect**, **sustainably manage** and **restore natural and modified ecosystems** in ways that address challenges posed to society in an effective and adaptive manner, while still providing both human well-being and benefits to biodiversity.

In 2016, the IUCN World Conservation Congress adopted a motion on definition[15] for Nature-based Solutions and encouraged states to integrate Nature-based Solutions into climate change strategies[16].

A non-exhaustive list of the main categories of **Nature-Based Solutions** called upon to respond to water related natural hazards are:

- ▷ **Preservation, restoration and creation of wetlands** and **hydromorphological restoration** of water courses that contribute in regulating floods and preserve water resources during droughts,

- ▷ **Vegetation cover to the slope of the catchment** (hedge planting, grass planting, trees, etc.) stabilizes the soil and slows down runoff. This also reduces the risk of landslides and mudflows.

- ▷ **Vegetation cover and permeabilisation in urban areas** (planting over the banks of developed watercourses, creation of wetlands) reduce the risk of flooding by promoting **stormwater infiltration into the soil and limiting runoff.**

These different categories can be presented within the same project to provide a combination of benefits.

The figure below illustrates these solutions on a typical catchment area.

Figure 54: Different types of Nature-based solutions for water related risks (Source IUCN)

[15] UICN, 2016. Ibid.
[16] UICN, 2016. Motion 62 : intégrer les Solutions fondées sur la Nature dans les stratégies de lutte contre les changements climatiques. https://portals.iucn.org/congress/fr/motion/062

3.3.3.2 Inter-linkages between stakeholders

The table below shows the interactions in terms of governance on the management of water related risks by categories of nature-based solutions in Mauritius.

Table 19: Nature-based solutions, Objectives & Governance

Categories of Nature-based solutions	Objectives	*Governance/Stakeholders*	Regulatory tools
Preservation, restoration and creation of wetlands and hydrogeomorphological restoration of watercourses	Maintain or establish a proper functioning of the natural environment, in particular the following: • Water infiltration from stream overflows and runoff. The ecosystems thus constitute a buffer zone during floods. • Storage of water which is subsequently returned to the natural environment and feeds the ground water and watercourses. This reduces incidence of drought. • reduction in water depth and flow velocity, reducing the impacts during floods (erosion, flooding) *Measures include the restoration and creation of wetlands and the restoration of water courses to respond to the risks caused by flooding, erosion and drought.*	**NPCS/Ministry of Agro-Industry and Food Security** * / WRU – LDA*	Proposed Wetlands Bill / Protection and Definition of Rivers Rivers and Canals act Forests and Reserves Act
Vegetation cover to the slope of the catchment area	Providing a vegetation cover to the slope of the catchment helps to stabilize the soil and to slow down runoff by the roots of trees and plants. This is of particular importance where slopes are steep or where agricultural practice poses little obstruction to flow. *Measures include providing a vegetation cover to the slope in order to respond to the risks of erosion, flooding by runoff, landslides and mudflows.*	**Ministry of Housing and Land Use Planning/** *Ministry of Agro Industry and Food Security – LDA - MSIRI*	ESA

Categories of Nature-based solutions	Objectives	*Governance/Stakeholders*	Regulatory tools
Vegetation cover and permeabilisation in urban areas	The restoration or creation of wetlands in urban areas, coupled with vegetation cover and permeabilisation in urban areas, promote stormwater infiltration into the soil, reducing runoff and the risk of flooding. These measures also contribute to an increase in evapotranspiration thus cooling the atmosphere, particularly during hot weather. *Measures include vegetation cover and permeabilisation in urban areas to respond to the risks of flooding by runoff and overflowing of drains.*	**Ministry of Housing and Land Use Planning/** – *LDA*	LDMP

3.3.3.3 Classification of solutions applicable to drainage basins from runoff production areas

3.3.3.3.1 Actions to be implemented to address surface runoff

On the basis of the sources of the phenomenon described in chapter 3.2.2, the action plan should not be restricted to the construction of drain networks within the urban areas being affected by flooding, but should **intervene on the runoff production areas or upstream of the drain networks in order** to attenuate the damage(floods, drain network overflow, etc.).

These actions should then be carried out in consultation between, the Ministry of Environment, the Ministry of Agro Industry, the owners and the LDA. For example, biodiversity corridors in agricultural areas should be promoted (see the chapter on hedges for examples). It is recommended to create an inter-ministerial committee between the Ministry of Agro-industry and the Ministry of Environment (among others) in order to implement with the agricultural owners the installation of NdS (hedges and fascines) on the areas of runoff production: control of runoff, land erosion and participation in the creation of a green frame and ecological corridor.

This type of action plan is often referred to "alternative techniques" in urban areas`, implying alternatives to exclusive network, while in rural areas it is referred to as "soft hydraulic", "slope action" or "dynamic slowdown".

The diversity of construction and operation techniques makes it difficult to focus on a single type of action plan: Different techniques can be applied to plots, slopes, valleys and networks, etc.

These techniques will, however, be based on the same three principles as follows:

- **(1) controlling runoff production** by promoting infiltration: cultivation practices, underground drainage, / green roofs, rain gardens, porous surfaces (pervious pavements, infiltration swales) and / or storage facilities (cisterns);

- ▷ **(2) controlling runoff transfer**, drainage axes are created with the aim of **slowing down runoff flow**: hedges, thalwegs, bushes, ditches and swales with flow restrictors and / or cusps (including agricultural drainage ditches receiving water from underground drainage collectors) ... ;
- ▷ **(3) temporary storage by limiting flow rate** within a structure provided for this purpose or in a location where temporary flooding is acceptable, with a receiving area. Storage can be carried out by means of a multitude of structures of all sizes, on the slope or in dry thalwegs: obstacle with a regulation orifice in ditches or in dry thalwegs, dam with open sluice, lateral lockers/ reservoir structures, storage basin with controlled outlet, wetlands, low productivity agricultural plots / marginal public spaces, etc. These techniques are basically similar to conventional structures built over watercourses: lateral lockers, dams with open sluices, etc.

A technical solution can elect one or a combination of the above described principles to meet the requirements of the storm management system for any particular catchment area.

Typical solutions adapted to the Mauritian context are presented in the chapters which follow.

All retention structures are characterised by design to flow limitation and storage, with infiltration serving to reduce further stormwater flow. Swales and ditches, primarily designed for storm water transfer, will also behave like a cascade of retention structures when they are equipped with flow limiting devices.

Thus, irrespective of their size and location, whether urban, sub-urban or rural, the infrastructures are eventually very similar, and their sizing is based on the same principles:

- Starting from an estimate of the incoming flows**, the storage volume and the dimension of the outlet orifice are calculated so as to achieve the expected flow attenuation**. The design calculation must cover different event return periods, from the lowest at which the structure can operate, up to the event exceeding the capacity of the structure, at which the excess inflow should be expelled (overflow).
- **Maintenance is an essential feature of the stormwater management plan** (clogging, erosion, introduction of foreign matter) are likely to impair its operation.

These examples are geared towards the management of stormwater by the Land Drainage Authority.

3.3.3.3.2 Vegetative cover and land development planning on sloping sites

▷ **<u>Introduction:</u>**

The solutions described hereunder respond to the problems of **runoff from non-built areas, particularly agricultural areas.** The aim is to provide mitigating measures against the consequences of changes in practice, in particular **derocking** and **mechanization** of **agricultural land**.

High surface runoff and soil erosion are recurrent phenomena observed in catchments having large-scale cultivation. On land prone to erosion, storm runoff should call for the implementation of strategies and action plan which are based on several components, one of which aims in particular **to reduce the hazard**. This component is generally divided into two parts:

- The first classical part deals with **the creation of flood routing structures**, termed "**structuring**", to reduce peak flows and protect the population and human activities.
- The second part is based on the development of a **combination of preventative measures**, the first one favouring infiltration of rainwater at source, irrespective of whether the water is agricultural or urban, the second one being the creation of small hydraulic installations, such as **fascines, hedges, swales (grass**

lined ditches) which constitute **Buffer Zones**. These small developments are commonly referred to as "Soft Hydraulic Installations".

These installations form an integral part of measures favouring infiltration and routing amenities. They are a fundamental tool in the prevention of erosion and flooding through their hydraulic functions: slowing flows, runoff infiltration and trapping of suspended matter.

They perform multiple functions:

- Slow down flows to the downstream areas;
- Reduce sediment transport;
- Reduce the transfer of suspended particles and associated elements (such as certain phytosanitary products) away from the plots, thereby protecting water courses and the groundwater aquifer;
- Infiltrate part of the flows thereby optimising the extent of structural works, which has economic benefits;
- Significantly reduce siltation of drains downstream and therefore cleaning costs;
- Enhance biodiversity in the surrounding regions;
- Diversify the landscaping.

▷ **Fascines (brushwood fences):**

A Fascine is a linear arrangement made up of brushwood. Placed across a drainage axis, it forms a permeable obstruction that slows down the water flow. Fascines in this context are bundles made up of 2 rows of stakes in between which the brushwood is stacked.

Fascines are generally distinguished either as dead fascines, having all its components made of dead wood (stakes and bundles) or live fascines having at least one component made up of green matter

The Manning coefficient of this type of fascines is in the range of n = 0.40 to 1.20 s/m$^{1/3}$ (*Source : mesures de vitesse sur un modèle physique en Allemagne - MATHEJA et STOSCHEK 1998*[17] *- Fascines & haies pour réduire les effets du ruissellement érosif Caractérisation de l'efficacité et conditions d'utilisation : AREAS France – 2012).*

Figure 55: Sediment accumulation upstream of a fascine located at the low point of a plot subject to several gully outlets in the catchment area (France)

[17] MATHEJA A., STOSCHEK O., 1998. Influence of extreme events on sedimentation in sedimentation fields enclosed by brushwood fences. Conf. on Hydroinformatics, Copenhagen, 24.-26. August 1998, 8 p.

The efficiency of sedimentation of particles by a fascine is dependent on 5 main factors, namely, the quality of the bundle filler, the absence of short circuiting of flow, the steepness of the land upstream, the particle size and the flow rate.

▷ **Hedges:**

The anti-erosive hedge comprises a row of closely spaced shrubs or a combination of shrubs and trees, growing over a vegetative cover of width not exceeding a few meters wide.

For hedges, the density of the stems coming off the ground dictates the hydraulic efficiency.

Hedges are qualified as dense when they contain more than 40 to 50 stems that come out of the ground per linear meter. This density is generally achieved after 10 years. This type of hedges constitutes a very effective vegetative barrier against concentrated flow.

Manning's coefficients for this type of hedge vary between 0.016 and 0.09 $s/m^{1/3}$, with most values between 0.030 and 0.070 $s/m^{1/3}$, for a density of 0.3 to 12 shrubs per m² (*source: FREEMAN et al. (2000))*. These results still indicate a high permeability between the shrubs.

The UNDP/GEF funded project entitled: Mainstreaming Biodiversity into the M**anagement of the Coastal Zone in the Republic of Mauritius has made specific recommendations in the Integrated Coastal Zone Management Plans** for Black River and Rodrigues for the setting up of **biodiversity corridors within agricultural areas**. It is therefore proposed to intrduce **vetiver** (Chrysopogon zizanioides) and **fataque** (Panicum maximum) **as nature-based solutions in those areas.** The said species can also be used for the production of perfume base and for co-gheneration in the existing cane/bagasse power plants in Mauritius.

▷ **Optimum siting of fascines and hedges**

Of prime interest are fascines and hedges sited immediately downstream of small runoff surfaces which are highly erodible as exemplifies in the following situations:

- at the foot of slopes affected by gully erosion, generally slope greater than 5%;
- at the foot of milder slopes (2 to 5%) but subject to intense rain on bare land or with a cover of low friction coefficient, or even more if the plots are cultivated in the direction of the slope;
- perpendicular to the 1st and 2nd order Strahler thalwegs, or on axes of concentrated flows (corner of the plot) subject to gully erosion, mostly those with a slope steeper than 1%.

Fascines and hedges can be included as part of the works to be implemented to reduce suspended solids load of flows that disrupt habitable zones, roads, hydraulic structures, rivers and water resources (ref figure below). They serve as protective shields between erodable zones and the sectors at risk.

1 - At the foot of slopes with a gradient > 5 % which suffer from gully erosion

2 - Perpendicular to a runoff axis

3 - In the corner of the plot

4 - At the interface between cultivated plot and meadow

5 - In close protection of an urban area

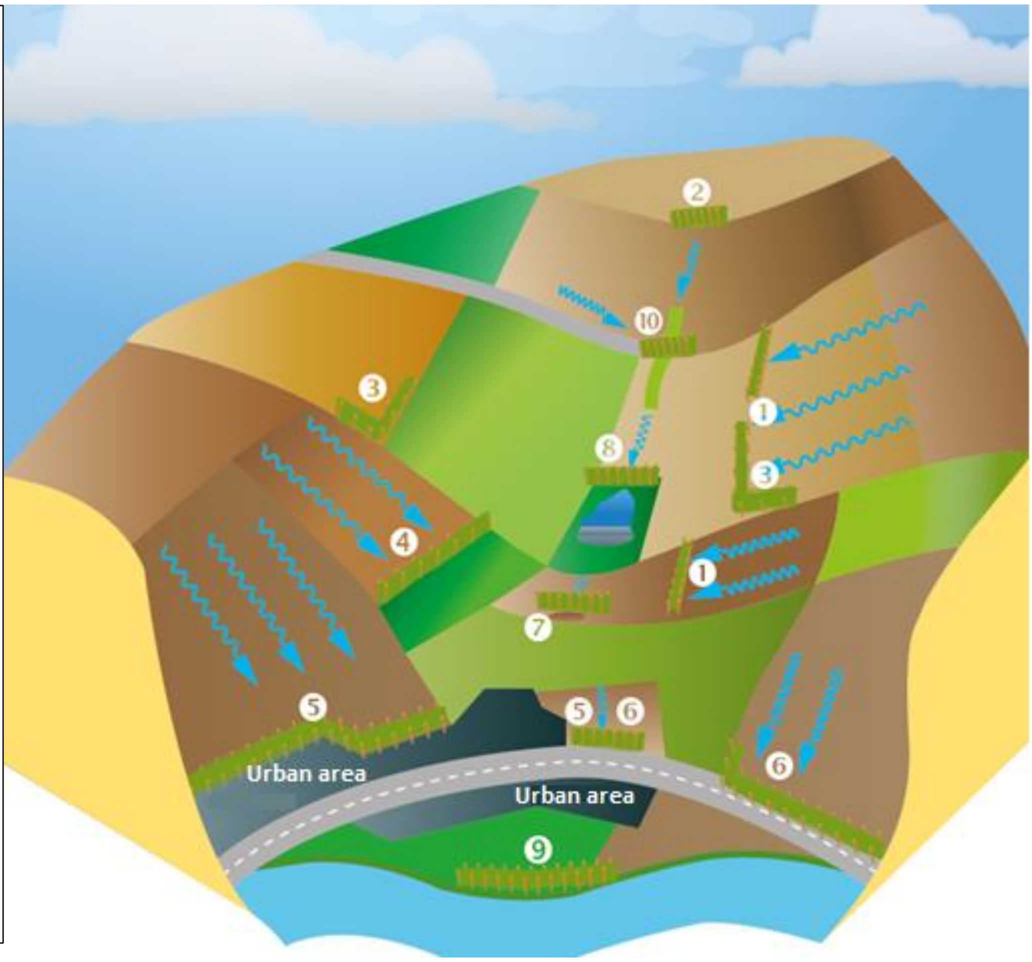
6- In close protection of a road

7 - In close protection of a reservoir

8 - In close protection of a flood control structure

9 - Reinforcement of a grassed strip along the river

10 - In combination with a thalweg grass strip



Example: In close protection of an urban area

Figure 56 : Optimum siting of hedges and fascines to minimise erosion

▷ Swales or grass ditches as flow slowing mechanism

- ***General description***

  This type of arrangement is intended as runoff transfer and on-line dynamic storage. Swales and grass ditches are designed with a view to protecting infrastructure and built-up areas and to combat soil erosion. Ditches have a fundamental role to play in water evacuation; they must imperatively be a continuity of the hydrographic network. They can be managed in different ways: grassed, terraced, combined with a berm, etc.

- ***Installation and maintenance***

  Ditches are constructed along the periphery of drainage axes to collect and direct flows. The receiving installation downstream should be designed to receive the peak flow.

  Maintenance of ditches involves desilting and upkeeping of banks. In the case of ditches with grass cover, maintenance should include mowing and shredding 2 to 3 times a year to a height between 5 and 10 cm.

  Stepped ditches (or swales) are typical ditches, in which small barriers (cogs) made of stones or timber are placed. The steps allow a small throughflow (minimum infiltration flow) and fill up progressively in the event of a heavy rainfall. Their threshold is lower than that of the banks of the ditches.

Principle

Design

	Dike spacing	
	H 30 cm	H 60 cm
2 %	15 m	30 m
6 %	5 m	10 m

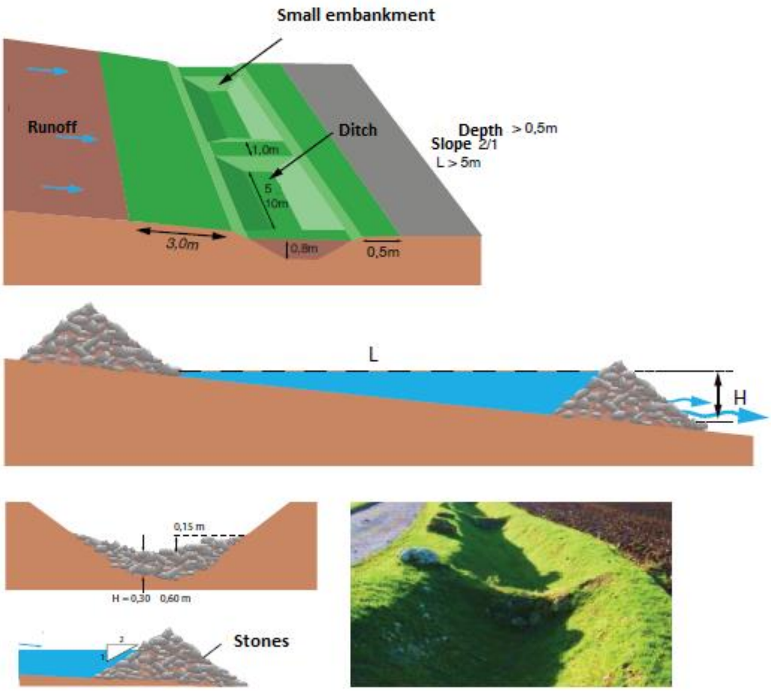


Figure 57: Stepped ditches - schematic diagrams

Ditches have a long lifespan, as long as they are properly maintained through regular cleaning, mowing of the edges and upkeeping of the outlets.

Details on the implementation of this type of arrangement are further described in chapter 3.4.3.3.

▷ **Flood plains**

- ***General description***

  Floodplains provide an alternative to flood expansion zones (No Go Zone): The flooding incidence of certain plots which are naturally subject to flooding during intense rains are amplified by the construction of a small bund, the non-maintenance of drain networks and the opening of a barge bead, etc.

  Flooding of the plots is of a temporary nature and is compatible with the agricultural practice of the floodplains.

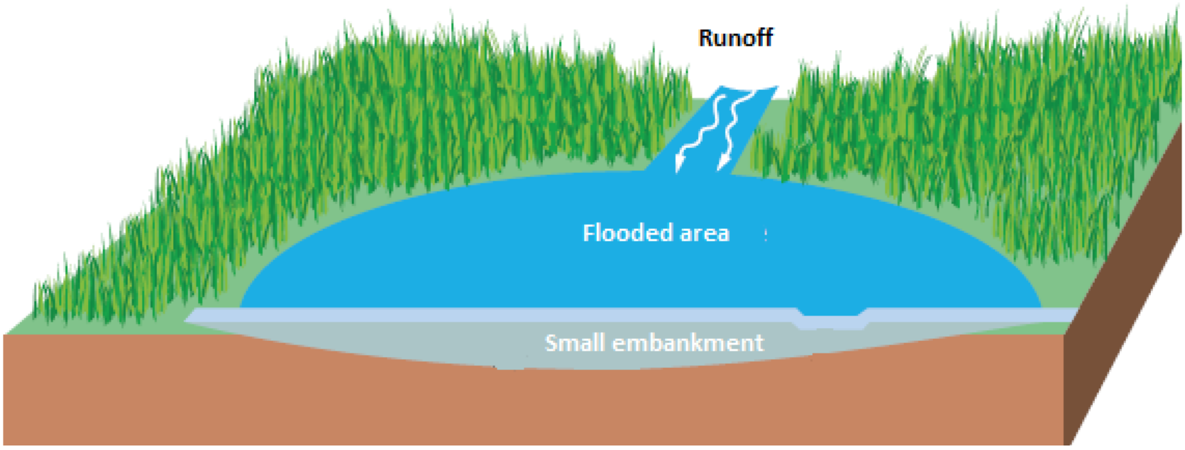


Figure 58: Schematic diagram of a floodplain

- ***Construction and maintenance***

  Construction of floodplains is generally very simple as they exist in nature along streams and on gently sloping ground and plateaus

  For a floodplain to be considered, it should have a certain storage capacity, should not be too sloping and should intercept natural drainage axes. The construction of a small dyke of 30 cm high ensures some water retention during heavy rainfall events.

  Floodplains should be constructed in a thalweg or over a location having an acceptable topography. The filling time is a few hours to a day following a rainfall. Such an area is, however, prone to the proliferation of insects and amphibians. In order to preserve biodiversity which would otherwise sets in when the floodplain is full but will be at peril when it dries up, a permanent marshland can be created by means of a buffer zone as illustrated in the following diagram.

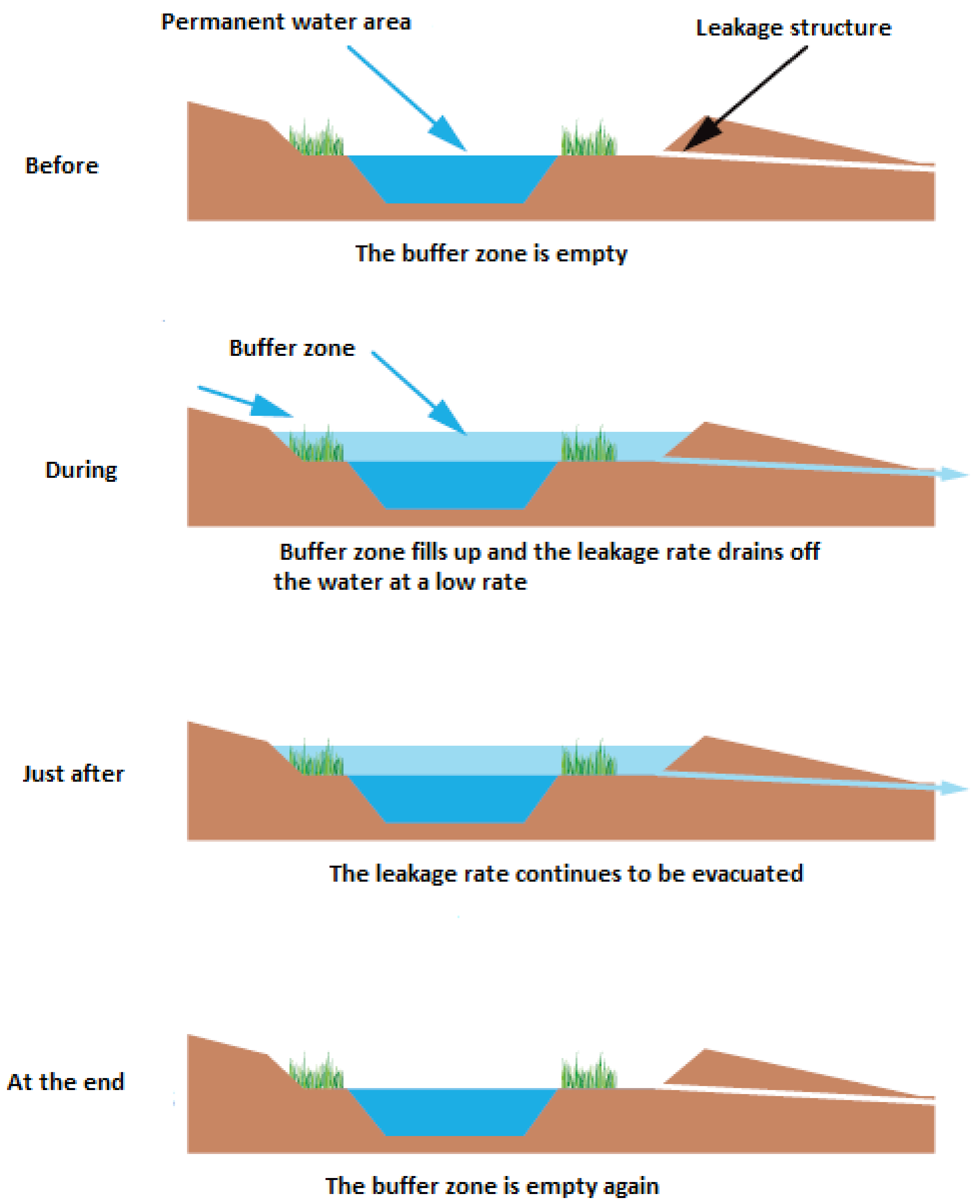


Figure 59: Conversion of floodplain to a wetland

▷ **<u>Embankments and dikes (vegetated and small size)</u>**

- ***<u>General description</u>***

The installations described above can be supplemented by embankments and dikes.

Embankments and dikes are flow diversion works not necessarily requiring a connection to the hydrographic network. Depending on circumstances, they can be combined with ditches or a floodplain.

Embankmens can be constructed using a mechanical loader during the dry period. Typical dimensions of small embankments/ dikes in agricultural zones are: height 0.5 m; crest width 0.5 m; side slope 1/1, giving a base width of 1.5 m.

The embankment should be compacted in layers, each layer being compacted with the bucket of the mechanical loader or by a compactor. This compaction is essential particularly at the core of the embankment to ensure cohesion and stabilization of the structure.

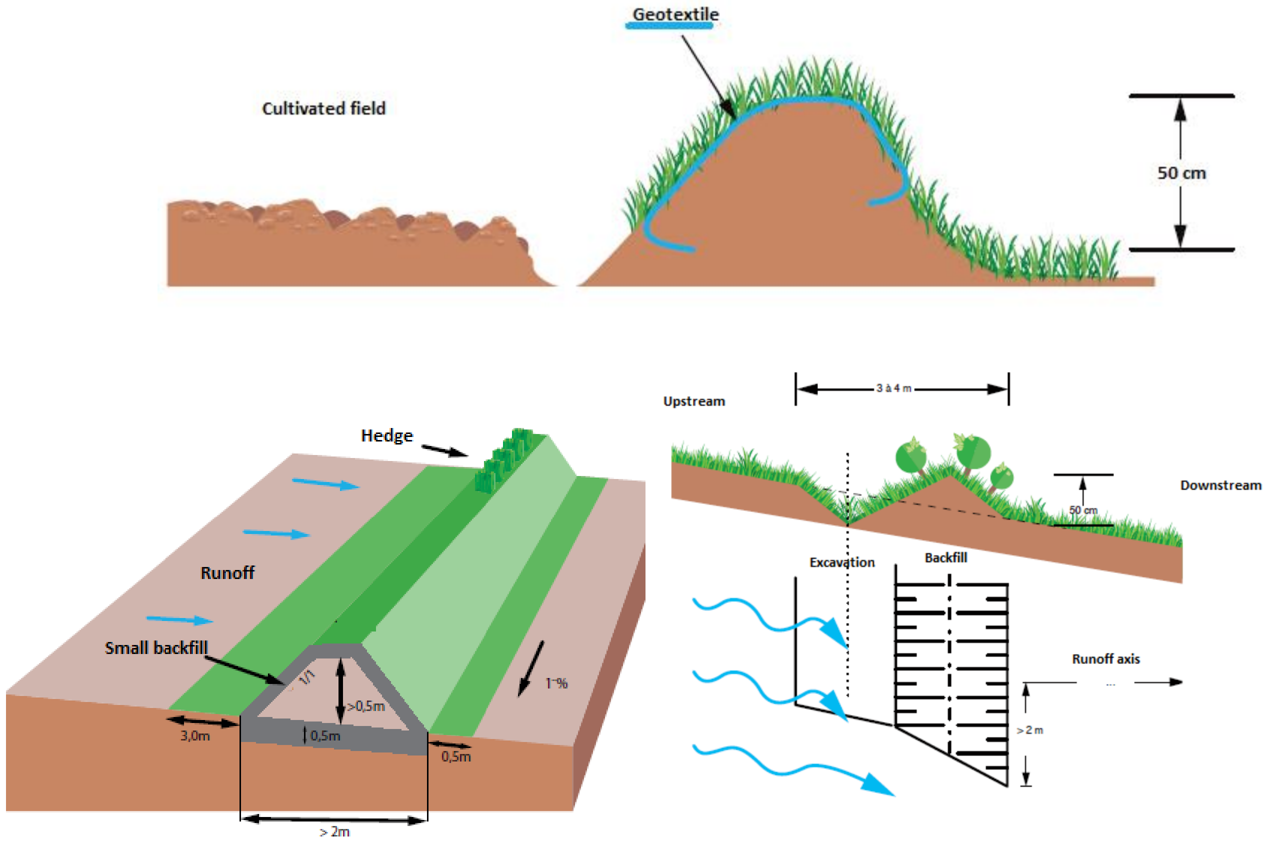


Figure 60: Schematic diagram of dikes

- ***Installation and maintenance***

  It is important to provide for maintenance and monitoring of the stability of the works (scour, erosion of slopes). The embankment is ideally protected by a non-woven drainage geotextile, or by a degradable geotextile during grass seeding, pending its growth. For a wide mesh woven jute geotextile, the slopes should be seeded before placement of the fabric.

  The embankment is constructed upstream of the area to be protected; it must be combined either with a peak flow diversion ditch or a flood zone with leakage flow and overflow threshold.

▷ **Combined hedges, fascine and other buffer zones**

A combination of hedges and fascines can be mustered within the same project. They can also be combined with grassed ditches. The combination can serve multiple purposes within the same site at its thalweg or downstream corner, but it can, if constructed with different sections over a larger length, also fulfil a series of functions.

In site conditions where steep gorges exist upstream of the hedges and fascines there is a risk of rapid sediment build up, sometime during a single event, in which case the inclusion of a grass lined ditch should be envisaged at the very start.

It is important to seek a global solution, failing which new gorges may be formed immediately downstream resulting in no positive impact over the whole area. It may be advantageous either to grass line the ditch over its downstream stretch or to construct a series of fascines at regular intervals over the whole length.

- ***Combined hedges or fascines***

  The functionalities of hedges and fascines, by virtue of their efficiency in reducing the velocity of flow and sediment load in the short and longer term, are such that they can be used jointly. It is thus recommended to construct a densly packed fascine immediately upstream of a hedge in order to protect the younger plants from being inundated by deposits.

- ***Combination of hedge or fascine and grass lined channel on a thalweg***

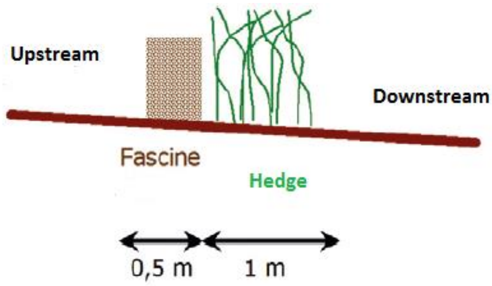


Figure 61: Fascine Hedge Combination

3.3.3.3.3 Decision tree for the implementation of NbS in production areas (on sloping sites).
The following decision tree specifies the conditions for the implementation of these types of NbS for the management of production areas on the slopes.

As a reminder, all these techniques contribute to reducing the time of concentration by slowing down the flows and therefore reducing the peak flows and the flood hazard (roughness and storage).

Table 20: Decision tree for the implementation of NbS in production areas (on sloping sites)

	NbS in production areas (on sloping sites) and optimum upstream Water Catchment size application					
Location	**Fascine**	**Hedges**	**Fascines combined with Hedges and buffer zones**	**Swales or grass ditches as flow slowing mechanism**	**Flood plains**	**Embankments and dikes (vegetated and small size)**
Optimum upstream Water Catchment size application	**1 ha**	**1 ha**	**1 to 5 ha**	**1 to 25 ha**	**1 to 100 ha**	**1 to 10 ha**
1. At the foot of slopes with a gradient > 5 % which suffer from gully erosion (max 1ha for all)	+	+	+	+	/	+
2 Perpendicular to a runoff axis	+	+	+	+	+	+
3 In the corner of the plot	+	+	+	/	+	/
4 At the interface between cultivated plot and meadow	+	+	+	+	/	+
5 - In close protection of an urban area	+	+	+	+	+	+
6- In close protection of a road	+	+	+	+	+	+
7 - In close protection f a reservoir	+	+	+	+	/	+
8 - In close protection of a flood control structure	+	+	+	/	/	+
9 - Reinforcement of a grassed strip along the river	+	+	+	/	/	+
10 - In combination with a talweg grass strip	+	+	+	+	/	+

3.3.3.4 Solutions applicable to urbanisation projects

The following fundamental principles of nature based solutions (NbS) are applicable to urban projects, from the source (the privately owned plot) to the terminal outlet in the natural environment (rivers, water bodies, the ocean):

- ▷ Controlled land levelling;
- ▷ In-field Infiltration devices: Infiltration wells and drainage trenches;
- ▷ Rainwater harvesting;
- ▷ Vegetated filtering strips;
- ▷ Absorption amenities;
- ▷ Soil impermeabilisation attenuation;
- ▷ Bioretention or rain garden;
- ▷ Surface or underground storage
- ▷ Infiltration and retention swales; and
- ▷ Retention basins.

All these principles for optimal management of storm water in relation to nature, are elaborated in chapter 3.4.

3.3.3.5 Nature-based solutions - success factors and main constraints

3.3.3.5.1 Introduction

Constraints abound; so are the unavailability and lack of control of land space, as well as the complex and lengthy administrative and financial procedures.

Emphasis should now be given to nature-based solutions and **must be supported by the implementation of proactive and operational policies** to achieve tangible results islandwide.

Consultative and participative discussions and communication are crucial elements leading to the establishment of Nature-based solution in a country. Any project is bound to succeed if it includes these elements for theimplementation and operation to be well understood and acceptable. Moreover, political and institutional support is often of major advantage.

3.3.3.5.2 Strategic approach and targets

In order to provide an appropriate framework for the development of these practices, the Government of Mauritius will have to adopt a strategic approach of creating the necessary policy frameworks and removing the obstacles to enable the widespread use of nature-based solutions by decision-makers in all situations and territories where it is relevant.

The strategy should meet eight targets. Recommendations for Mauritius are associated with these targets:

Table 21 : NbS - Strategic approach and targets - Recommendations for Mauritius

Targets	Recommendations
Establish an institutional framework to encourage the generalisation of NbS through a national governance system	Action to be taken by the Ministry of Environment, MoH & LUP, LDA and NDU, supported by territorial focal points, such as Local Authorities Within this institutional framework, give priority to NdS in water policies (non-artificialization of soils, low imperviousness, preservation of wetlands, alternative stormwater management)
Dedicate a share of public and private investment to NbS	Creation of government-supported funding and financial aid schemes (tax reduction);
To provide decision-makers with the technical means to respond to their needs, qualified contacts, professionals trained in existing techniques, and the necessary assistance in the design, planning, implementation and sustainability of NbS;	Develop university environmental and hydraulic training, through the creation of university exchanges and interventions by international specialists in island and tropical environments
Adjust knowledge acquisition and transfer to local needs and better inform decision-makers about the	First projects should be carried out by the LDA or the NDU to serve as demonstrators for decision-makers,

Targets	Recommendations
value, effectiveness and relevance of NB	planners and the public.
Improve understanding, generate support, mobilise and involve the public in NbS initiatives	Implement public communication actions, especially for schools, with communication tools such as models and videos.
Reinforce the integration of approaches leading to NbS in territorial planning	Include in the planning (MoH & LUP) and PPG a priority for the implementation of NdS. The project promoter will have to demonstrate the technical impossibility to implement the NdS in order to use more traditional devices. Impose NdS for all Smarcities projects.
Create new frameworks for cross-cutting approaches to develop thematic strategies (for different economic sectors) that address climate change adaptation and ecological restoration together.	Create an inter-ministerial committee between the Ministry of Agro-industry and the Ministry of Environment (among others) in order to implement with the agricultural owners the installation of NdS (hedges and fascines) on the areas of runoff production: control of runoff, land erosion and participation in the creation of a green frame and ecological corridor
Making better use of past and present projects by creating networks to share feedback at different levels (international, regional, Indian Ocean with Reunion Island, national, local) and on different issues and topics.	Create a cooperation with the State departments in Reunion Island to organise visits of installations and share feedback and good practices

3.3.3.5.3 Main constraints and responses to facilitate the implementation of Nds

The following table presents, for the NbS described above, the objectives, constraints and adaptations to facilitate their implementation at the territorial scale.

Table 22 : NbS - Objectives, constraints and adaptations to facilitate their implementation at the territorial scale

Nature based Solution in runoff production areas	Target	Space contraints	Adaptation- integration
Fascines and Hedges	Controlling runoff production	Very limited land constraints, small rights of way at the edge of the plots	Landscape improvement and creation of green spaces - green frame.
Swales or grass ditches as flow slowing mechanism	Controlling runoff transfer	Low land constraints	Integration into the profiles of agricultural paths, roads, parking areas and green spaces
Flood plains	Controlling runoff transfer / Temporary storage by limiting flow rate	Large land areas for good efficiency, temporary impact however	Possibility of using the ponds as a recreational area or landscape park
Embankments and dikes (vegetated and small size)	Controlling runoff transfer / Temporary storage by limiting flow rate	Low land constraints	Integration into the profiles of agricultural paths, roads, parking areas as well as green spaces

3.4 Principles for urban development

3.4.1 Introduction

The main objective of this part of **the Land Drainage Master Plan** is to present **different approaches and techniques** to minimize the hydrological impacts that may be associated with urban development. The document is mainly intended to be a practical tool to guide drainage system designers as well as other stakeholders involved in urban development (urban planners, landscape architects, environmental specialists, developers and municipal decision-makers) in the identification, use and implementation of best practices for the protection of water resources that can be affected by urban runoff. Each particular site requiring a specific approach, these management practice guidelines should be adapted to each situation; hence the reason for the Guide advocating a flexible approach instead of rigid rules which may in some cases be inappropriate.

This Guide should be viewed as a document that will necessarily evolve over time as the design criteria for many management practices progressively get refined with the evolution of construction methods and the availability of performance assessment. Since the Guide brings together elements that are well known and have been incorporated into practice for many years and others which may be considered more innovative, the document should not be viewed as a rigid standard but rather as a manual describing concepts and providing analytical and decision support tools for planning, design and implementation of best practices.

Quantitative assessments are primarily aimed at minimizing impacts for relatively rare events and dictate the sizing of infrastructure for minor and major networks. On the other hand, qualitative assessments, such as erosion control and groundwater recharge are rather part of an ongoing process to be controlled rather than protection against the intensity of disruptive events.

This implies taking into account **the flows and the volumes generated by the more frequent rainfall events** which have a more pronounced impact on these different asessments. One should thus not only consider the exceptional and important rainfall events for the design of these networks but also the more frequent events since the latter are the cause of pollution and erosion in watercourses and influence markedly low water flows and groundwater recharge.

The full range of data should be considered, and particular attention must be given to frequent rainfall events.

Furthermore, contrary to the more traditional approach of addressing only runoff flows, it is now recognized that many aspects can only be managed properly by adopting as closely as possible **a natural hydrological regime which minimises runoff volumes**. This therefore implies maximising infiltration of stormwater as much as possible and using infiltration techniques as control mechanisms. Ground Infiltration will certainly have to be monitored, bearing in mind that this approach may impact groundwater quality. However, infiltration of stormwater should be considered in the development of stormwater management plans as close as possible to the production source, **which is a major shift from the more traditional approach, which favours rapid disposal of stormwater.**

The stormwater management plan should also be structured in an integrated manner, taking into account comprehensive studies which may have been carried out at catchment level, where appropriate, but also using a technological approach that advocates an integrated upstream to downstream visionary approach. Even at the scale of a given project, controlling only a small part of the catchment area, this global approach must be imposed on the designer: in other terms, whatever the size of the urbanisation projects located on a catchment area sensitive to flood risk, the objectives of limitation of imperviousness and compensation by retention volume will be a function of the overall sensitivity of the catchment area, and not of the local capacity of the receiving drain. The logic is therefore a watershed logic.

Instead of considering only controlled devices that are implemented downstream of a drainage network (such as retention basins immediately upstream of the receiving environment), the recommended option would be **control at source** together with the use of other management techniques that can be implemented within the network.

The shematic diagram below and the technique hierarchy is an illustration to encourage the designer to apply different techniques at several levels in the drainage system, from the source to the receiving environment. The integration of these different techniques into the urban grid will enable the different objectives to be achieved.

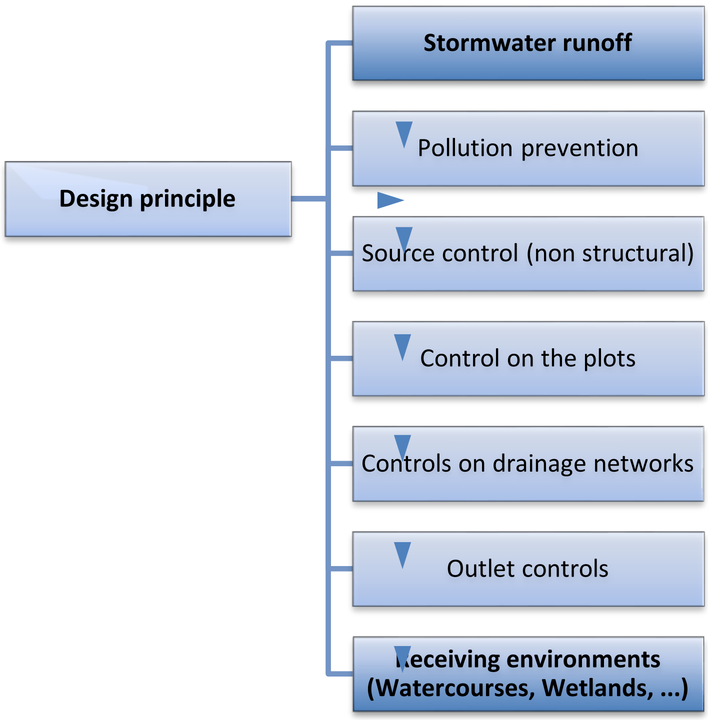


Figure 62: Control Mechanism flow chart for Runoff Control

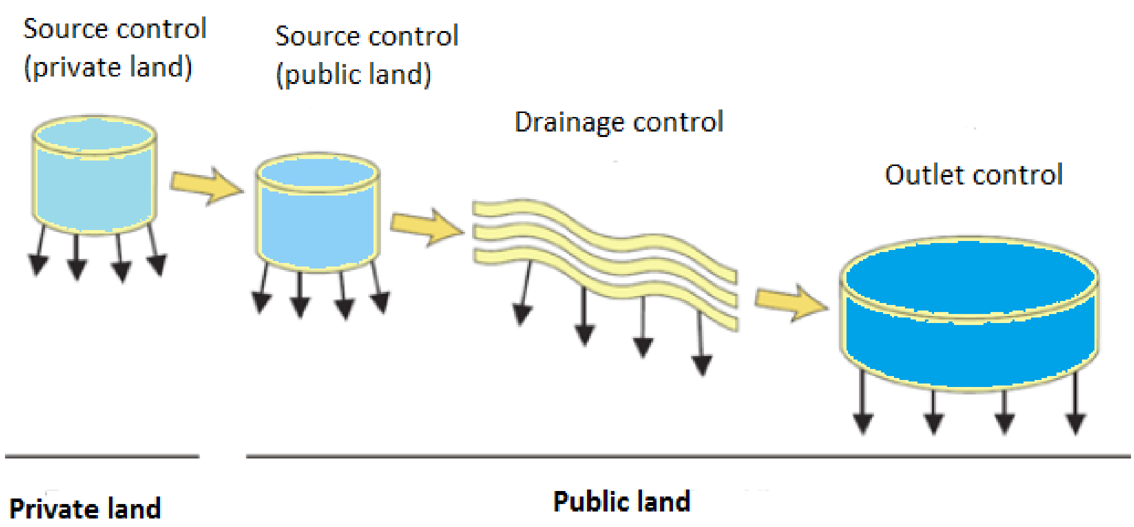


Figure 63: Categorization of stormwater management practices according to their location in drainage networks

The diagram also highlights, upstream of the overall planning process, the need to re-evaluate in some cases the principles of land use planning since these can have a significant impact on the runoff generated following urbanization.

In other terms, the area of an urbanisation project must be reduced (particularly at the natural flow axis level, but also more globally) if the hydraulic impacts of this project are not acceptable for the downstream area, because the effects cannot be compensated. It is not only a question of considering here the new volumes of runoff, but also the effects of works designed to divert runoff upstream of the urbanisation project to make urbanisation possible over the entire initial project area. For example, an urbanisation project at the foot of strong slopes should not be authorised in its entirety if, in order to carry out the entire project, cut-off drains to intercept natural runoff have to be created to the prejudice of the downstream.

In terms of risk management, the logic of building (a drain, a hydraulic structure) to protect (an existing urbanised area) must never give place to a logic aimed at protecting to build (new urbanisations in risk areas).

The percentage of impervious surfaces after urbanization being an important parameter to consider for stormwater management, land **use planning practices can, if necessary, be reviewed, which is not usually the case from a stormwater perspective.**

Interesting opportunities may arise when this reassessment is made, often with the benefit of very low costs compared to other management techniques that would be applied further downstream of an unplanned area based **on a better integrated stormwater management system**.

Within urban and sub-urban areas, in particular, future urbanization projects will have a direct impact on the capacity of the existing networks: it is therefore necessary to set up design criteria to require new projects to show transparency as much as possible with regard to storm water runoff. Moreover, in similar fashion to the slopes upstream of urbanized areas, the following measures are recommended:

- ▷ **Preventive Measures, at source:**
  - Control at source using non-structural measures;
  - Control at source integrating structural measures in the design of the project (from the plot to the project as a whole):
    - Measures to slow down runoff: controlled leveling of the land, vegetative filtering strips;
    - Measures to promote infiltration at source: absorption infrastructure and soil modification, infiltration wells or trenches, bioretention (rain basins) [18];
    - Devices to reduce runoff: Reduction in soil impermeability: use of porous materials;
    - Devices to reduce peak flows and runoff volumes: Surface or underground storage at individual plot level, bioretention or rain garden, storage swales.
- ▷ **Compensating measures downstream of development projects:**
  - Implementation of stormwater retention systems through the application of a new stormwater discharge authorization regulations.

[18] Function of presence of a high-water table and infiltration capacity of the soil. See zoning and recommendation chapter 5.4.3

The table below shows the different techniques for implementation, according to location:

Table 23 : Typical implementation techniques applicable to different locations within the drainage system

Location	Appropriate technique
Source control (private property)	Green roofs Rainwater harvesting and reuse Rain garden (bio-retention) Porous paving Absorbent furnishings Infiltration wells and trenches
Source control (public property)	Dry basin Basin with perrenial water Infiltration into grass land Trench/infiltration basin Filter belt Rain garden (bio-retention) Grassed/lawn ditches and swale Porous paving Retardation basin
Drain control (public property)	Grassed/lawn ditches - swale Ditches with infiltration systems

All of these methodology and techniques should be incorporated at plot, project and water-catchment level, and should integrate Nature-Based concept design solutions (Refer to section 3.2).

3.4.2 Preamble: General code of practice to be observed by applicants for a discharge permit-avoid, reduce, compensate

Environmental considerations must be integrated as early as possible during the conceptual phase of a feasibility planning, implementation programme or individual project (whether in the selection of a project, its siting or its economic feasibility), in order that **the least possible impact is caused to the environment. F**rom the very outset it is crucial to prioritise environment considerations in the following order:

- steps **to avoid** impacts,
- **reduction**, and
- **compensating measures to the residual impacts of the project,** planning, or programme if the previous two steps cannot eradicate them

Any project, planning or programme produces adverse impacts to environmental quality.

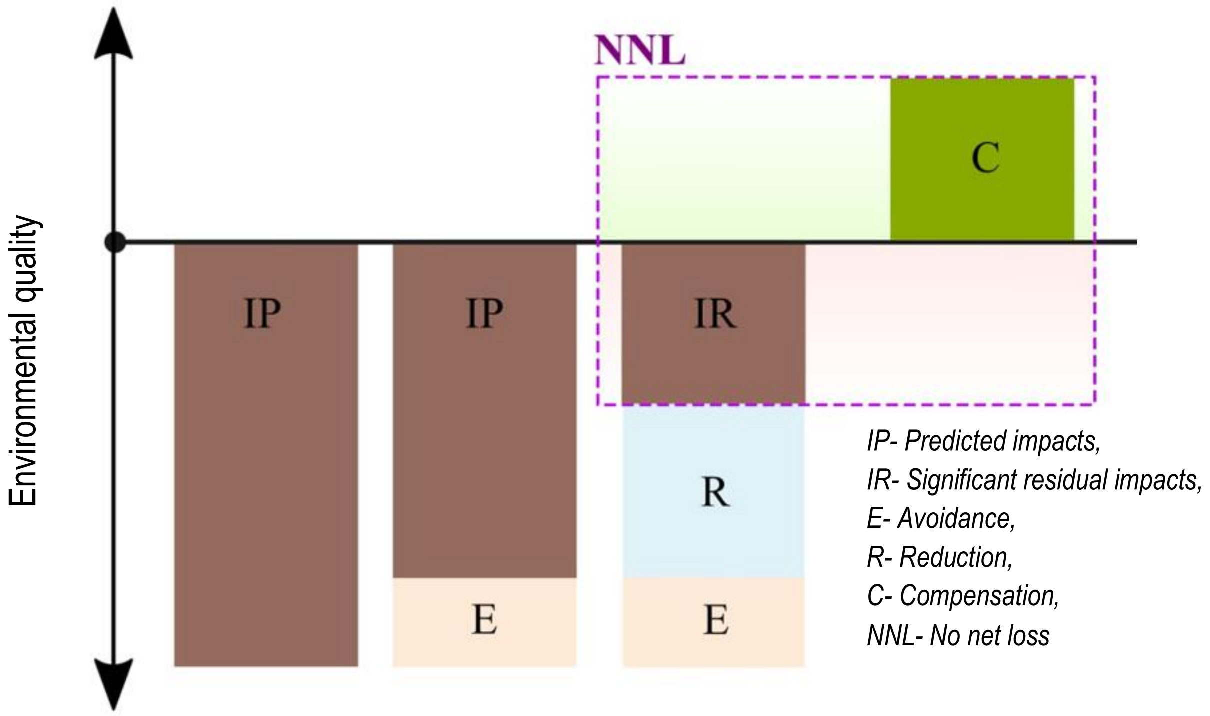


Figure 64: Principle: avoid, reduce, compensate

The best way to preserve the natural environment is to focus **on avoiding these impacts**. To this end, the measures being envisaged may point to the fundamental choices related to the project (geographical or technical avoidance).

If the negative impacts on the environment cannot be fully avoided at a reasonable cost, the residual **impacts to the environment should be mitigated** by technical means as follows:

- specific to the construction phase;
- specific to the work itself, eg construction of swales.

As a last resort, **compensating measures** must be implemented as **a positive counterbalance if the negative impacts persist,** this with the aim of preserving the overall environmental quality. As a matter of fact, the objective of these measures is to prevent a net loss, or even obtain ecological gain: the positive impact of the measures on the biodiversity must be at least equivalent to the damage caused by the project. To this end, they must be sustainable, technically and economically feasible, effective and easily evaluated. For the compensation to be unequivocal, the gain must be felt in proximity to the impacted site. This is the reason why the characterisation of a satisfactory set of compensating measures should be part and parcel of the identification and characterization of the residual impacts of the project, the initial state of the impacted site and the site following compensation measures.

Compensation measures involve rehabilitation, restoration and/or creation of new environments. They should be complemented by management measures to maintain the environmental quality of the region.

3.4.3 Mitigation - stormwater management techniques

3.4.3.1 Design Criteria

The planning and design of stormwater management practices for any particular site should be based on the following principles:

- Restore, as much as possible, the natural hydrological conditions that existed prior to the implementation of the project;
- Provide quality control by maximizing the removal of pollutants associated with urbanization;
- Appropriate techniques must be adopted for the site depending on the physical constraints;
- Maintenance should be an acceptable long-term task and should be considered during the selection of design techniques;
- The techniques should have a positive impact, or at least no negative impact on the natural and human environment.

3.4.3.2 Control at source (non structural)

Control at source using non-structural measures is the most cost-effective way to reduce the impacts of urban runoff.

Overall, the control at source comprises 3 components:

- Need to minimise the negative impacts during project planning, design, and construction;
- Proper maintenance of impermeable and permeable surfaces to minimize resurgence and release of pollutants;
- Education and training to promote awareness of potential problems associated with urban runoff and the available stormwater management measures to help solve or minimize these problems;

This approach includes:

- Public education, awareness and participation;
- Land use planning and management of areas under development;
- Integrated stormwater management planning;
- Control of discharges and removal of chemicals fouling stormwater;
- Formulation and enforcement of regulations on drains;
- Repairs and maintenance practices;
- Supervision and monitoring of construction activities;
- Maintenance of public and private areas.

These non-structural and good governance-related measures are described in Chapter 6.

3.4.3.3 Stormwater Best Management Practices

Stormwater control techniques aim at reducing the volume of stormwater runoff and pre-treat the stormwater before it reaches the drainage network system. They are implemented either on a specific plot or on several lots draining a small area.

The schematic figure below illustrates how many of these techniques could be integrated within a single residential development. Similar techniques could also be integrated within commercial and industrial developments.

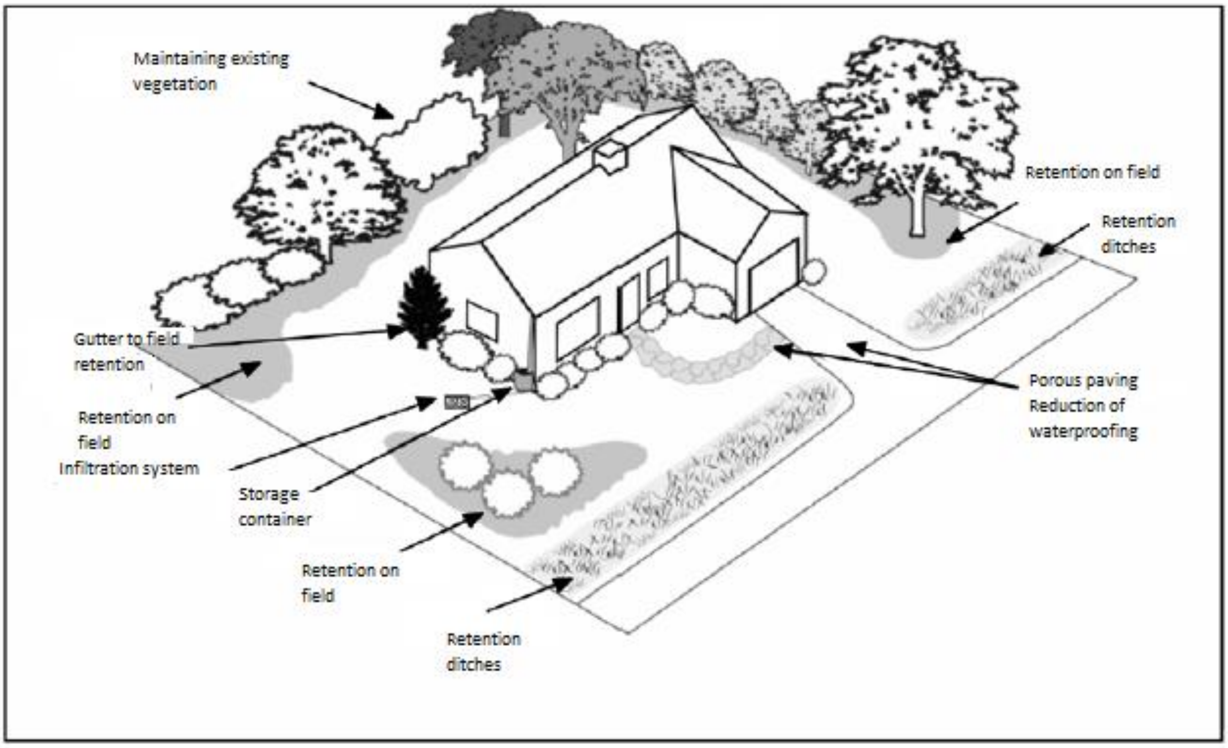


Figure 65: Typical integrated techniques for stormwater control of individual residential plots (adapted from DNR, Ohio, 2006)

In order to compensate for all or part of the effects of urbanisation, the stormwater master plan recommends:

- **Infiltration,** even partial, all the time where possible. The vast majority of the provisions described in this chapter for stormwater management in urban areas can incorporate infiltration when the receiving environment (use), the water table and the infiltration capacity allow it. **These practices should be promoted even though they do not provide enough response on their own**. It contributes to the non-imperviousness of the soil. The global zoning and the infiltration capacity studies to be carried out are detailed in the chapter 5.4.3;

Note: For all systems using infiltration, even partial, runoff from sensitive areas (petrol stations, industries) should be avoided as infiltration can lead to groundwater contamination or damage to vegetation of NbS.

- **Retention**, depending on the rainfall and the level of risk estimated at the scale of the catchment area (see zoning in chapter 5.4.2). In terms of retention, the choice of the application threshold according to the project surface and typology is an important parameter to adapt to make its application effective.

Around the world, current practices are diverse:

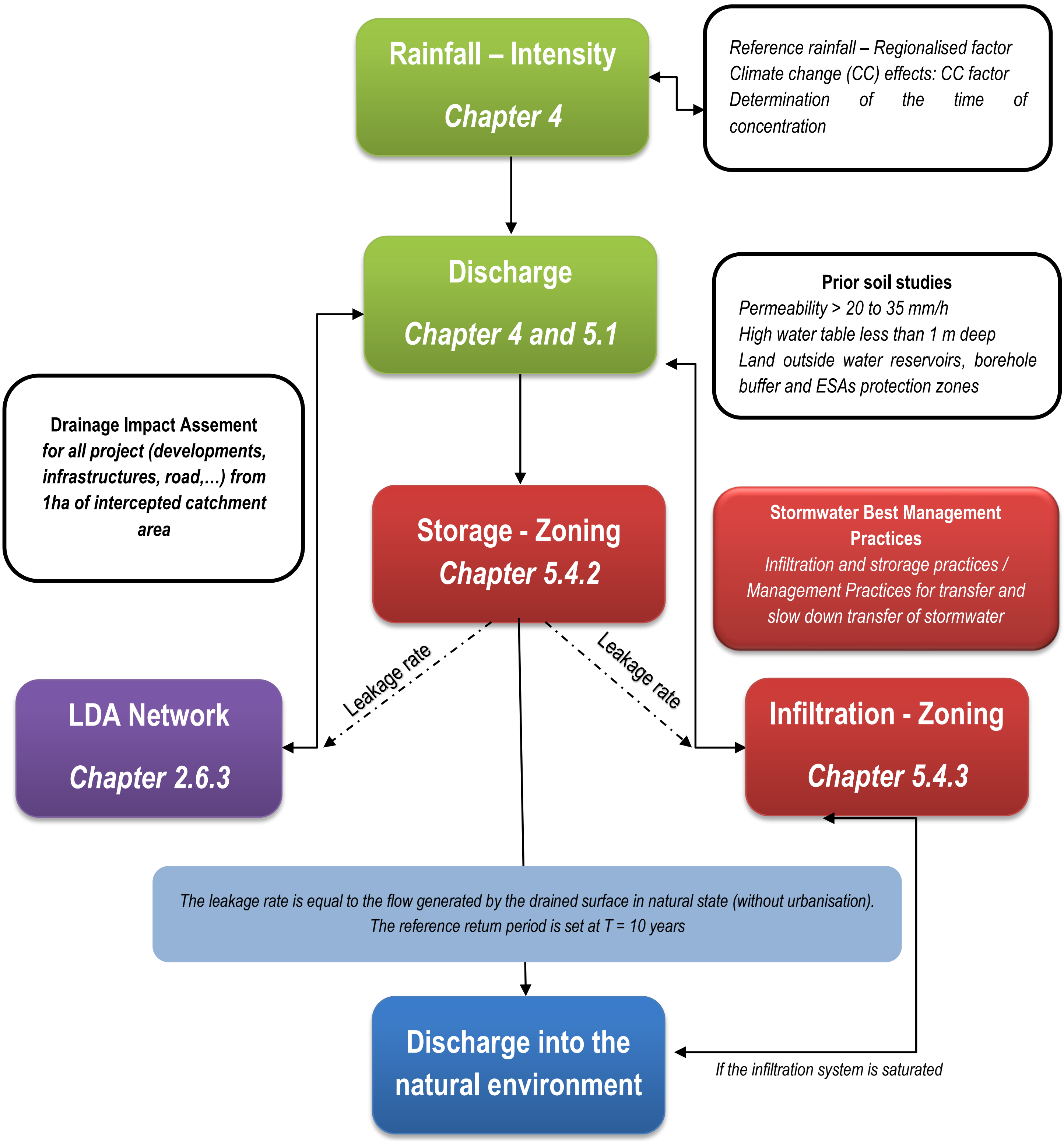
- **Application to all projects,** including at the scale of the single-family dwelling: we speak of management at the plot scale. This is the most effective management, because the sprawling of urbanisation not concerned by this type of plot-based measure (the following case) leads inexorably to an increase in runoff on the scale of the catchment area. However, this measure can be difficult to implement and to control in the context of building authorisations. In order to adapt the feasibility on the territory, simpler and lighter rules are described for plots of less than 1000 m² (example implemented on some municipalities of Reunion Island such as Saint Paul).

- **Application only to projects above a certain size threshold**. As a reference, and on the scale of regions such as Reunion Island or the French West Indies, the French regulations set the following thresholds :
  - 10,000 m² (1ha) of catchment area intercepted by the project (cf 3.2.4°- Project area+ Intercepted upstream catchment area -overland sheet flow) for the implementation of detailed hydraulic studies within the framework of the regulations carried out by the Ministry of the Environment - mandatory compensation
  - Below this threshold, local authorities, as managers of stormwater networks, determine an additional threshold according to their territory within the framework of the stormwater master plan carried out on the scale of their territory. For illustration purposes:
    - Threshold according to the newly waterproofed surface whatever the typology of the buildings: We find threshold values varying from 200 to 500 m².
    - Thresholds depending on the type of building and its foot print area subject to planning permission: housing developments and groups of individual houses with more than two buildings, buildings for commercial, artisanal or industrial use with a surface area of more than 250 m². Single-family houses on a plot of land are not subject to the obligation to install retention devices.

The following diagram describes the path of rainfall to the receiving environment.

It reminds us of the significant elements to be taken into account in the design of structures and specifies the chapters of the LDMP in reference.

Figure 66: Diagram path of rainfall to the receiving environment



3.4.3.3.1 Controlled levelling of properties/ Terracing of sloping terrain and infiltration at source

This measure consists in reducing the natural minimum slope of the land. Outside the foot print area of the building, the slope can be levelled to a slope of 0.5%, in order to promote water retention and natural infiltration in ground depressions. In this endeavour, the soil type and its long-term behaviour must be taken into account, since settlement can, in the long term, considerably reduce the slope. Reducing the slope of the land can be undertaken if the soil has a minimum permeability of not less than 15 mm/hr. This is usually the case with soils coarser than silt; clay soils are not appropriate. In any case, in situ tests must be carried out to determine infiltration rates.

Table 24: Minimum infiltration rate

Soil ype	Infiltration rate (mm/h)
Sand	210
Silty sand	60
Sandy silt	25
Silt	15

With implementation of these measures of limiting slopes during land development, the need for water retention further downstream and prior to discharge into the drain network can be reduced. The only drawback for this type of infrastructure is that the land can be partly waterlogged, albeit for a short duration of time.

3.4.3.3.2 Infiltration Wells or Absorption Trenches within plots

- ***General description***

These types of measures are used to retain stormwater runoff from relatively small water catchment, consisting of single-family dwellings (less than 500 to 1000 m²).

Infiltration wells or absorption trenches not only reduce peak flows but also runoff volumes resuting in a positive impact on water quality.

They can simply be constructed as a pit with a geotextile lining filled with a drainage material, such as stones or complex systems that include sumps and inspection chambers. The figure below illustrates the main components of an infiltration trench.

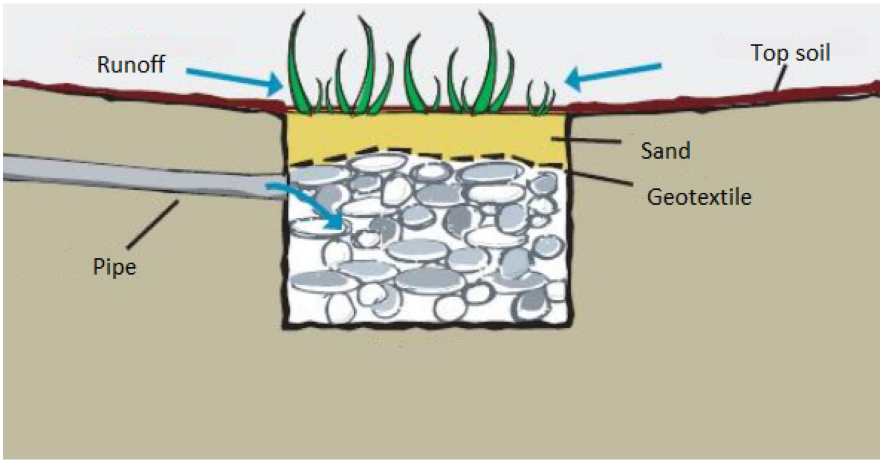


Figure 67: Cross section of a French drain (for a single-family home)

A detailed leterature on the design of such systems can be found in several reference publications (e.g. ASCE/ WEF, 1998).

- ***Advantages***
  - Can reduce the volume of runoff from a site, thereby reducing the need for retention and the costs of downstream structures;
  - Can be used in existing built-up areas where space is limited and where additional stormwater control is required;
  - Can be used on sites where there is no storm drainage network (depending on the infiltration capacity of the existing soils - minimum values of 20 to 35 mm/h);
  - May contribute to groundwater recharge and of pre-development water balance conditions.

- ***Drawbacks***
  - Applies only to small sites (single-family residential lots);
  - During heavy rainfall events, surface water can remain stagnant for several hours, restricting land use;
  - Maintenance is required to ensure proper operation;
  - Not recommended for sites with high sediment loads or runoff that may be contaminated;
  - These systems may not operate properly If the infiltration capacity of the natural soil is inadequate (less than 20 to 35 mm/h). It is recommended that in-situ percolation tests be performed to determine the infiltration capacity of the soil (1 to 3 m deep under the natural ground / a measure every 100 m² minimum depending on the heterogeneity of the soil) (see method chapter 5.4.3);
  - The formation level of the structure should at least 1 m above the water table.

- ***Design criteria and and methodology***
  - The following points should generally be considered when designing a field infiltration system:
  - The distance between the trench formation level and the highest water table level should be a minimum of 1.0 m. Local authorities (WRU) should be consulted or test drilling should be carried out to ensure that this buffer is adequate;
  - The trench should be filled with clean (well washed to minimize the risk of clogging) stones of size 50 mm and be lined with an appropriate geotextile membrane;
  - The void ratio of the trench should be based on the storage that is required following a projected rainfall event and based on the actual porosity of the trench material (generally considered to be between 35 and 40%). The required infiltration area (bottom surface) to drain the system is calculated based on the continuous percolation rate over 24 hours;
  - The trench must be located close to the soil surface;
  - The infiltration trench must be equipped with a filter membrane to limit the entry of solids and debris into the system. If required, an overflow pipe should be installed;
  - As a general rule, infiltration systems should not be constructed over backfill, beneath parking lots or beneath multi-useage areas (for reasons of stability if the drainage is insufficient).

The geometry of a drainage trench depends on the site configuration and the soil infiltration capacity. The length of the trench (in the direction of flow) should be maximized in relation to its width to ensure uniform distribution and to minimize upward movement of the water table. Depths greater than 1 to 1.5 m are generally not recommended.

3.4.3.3.3 Rainwater harvesting

o ***General description***

Runoff from roofs can be collected in barrels or cisterns and then reused for different purposes (irrigation and watering). The barrels are typically installed at the outlet of the roof gutter system and the simplest method for reuse is by gravity. A cistern has a usually larger capacity than a barrel and is installed below ground level.

o ***Application***

This technique can be applied to residential, commercial or industrial sectors, with the correct storage volumes. Re-use can be applied to outdoor uses (watering, irrigation).

o ***Advantages and drawbacks***

The reuse of rainwater can have some effect on runoff volumes and peak discharge rates, especially for light rainfall events. It is, however necessary to properly plan this reuse to ensure that the barrels are emptied after each rainfall. Inclusion of infiltration wells or trenches may also be considered in order to reduce runoff volumes.

3.4.3.3.4 Vegetated Filtering Strips

o ***General description***

A strip of filtering vegetation is a zone with a mild slope (less than 1%) and with vegetation that serve to filter, slow down and partially infiltrate overland sheet runoff flow. In addition to grass, filter strips may include a variety of trees, shrubs and vegetation (Vetiver, Fataque, Hétéropogon, cf. 3.4.4…). An important element in the design of the filter strips is that the flow they receive must be an overland flow with a uniform, well-distributed water level and not a concentrated flow. Flow dividers should therefore be used in some cases, which will allow the runoff to flow over the top of the filter mat. Generally, filter strips treat small drainage basins (less than 0.5 to 1 ha).

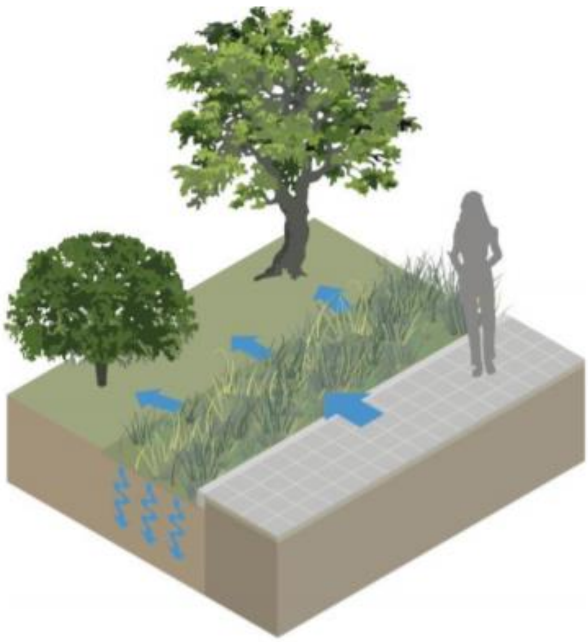


Figure 68: Schematic diagram of a filter strip

- ***Application***

Filter strips are used to control water from roads and highways, rooftops and small parking lots; they are rarely used in isolation and are often found as a pre-treatment technique upstream of other techniques such as infiltration trenches or retention areas. Although filter strips are mainly used to reduce sediment transport, a small reduction in runoff volume can be expected depending on the type of soil, the vegetation cover, the slope and the length of the filter strip. The presence of a permeable surface immediately adjacent to parking areas should encourage the designer to use a filter strip instead of traditional drainage with infiltration trenches.

The cross-section in the following figure shows the main dimensioning rules:

- Slope from 1 to 5% maximum ;
- Variable length (usually 5 to 20 m).

- ***Advantages***
  - Filter strips remove sediments and other associated pollutants;
  - They allow a partial infiltration of storm runoff (reduction of volume and pollution);
  - A filter strip with more abundant and taller vegetation can provide a visual barrier for roads, industries or recreational sites;
  - They are relatively simple and inexpensive to put in place;
  - They do not require much maintenance.

- ***Drawbacks***
  - Filter belts are not suitable for sites with steep slopes or large paved surfaces that generate surface runoff with high velocities;
  - Their use can be difficult in densely urbanized areas where vacant space is scarce or very expensive;
  - Like all devices that use infiltration, even partial, filter strips should not accept runoff from sensitive areas (gas stations, industries) since infiltration may result in groundwater contamination or damage to the vegetation.
  - Filter strips are usually difficult to apply in already built up zones because strips require large areas and they cannot accommodate runoff from large surfaces;
  - Inadequate slope (> 5%) can make this practice ineffective;
  - Because filter strips cannot provide enough storage volume or infiltrate enough water to significantly reduce flows and runoff volumes, they are generally used as one link of a process chain, very often prior to discharging surface runoff to infiltration or storage ponds;
  - The efficiency of filter strips is directly related to the maintaining of stream flow conditions at the surface (thin layer of water).

- ***Design criteria and principles***

The diagram below shows the principle of flow control of a filter belt:

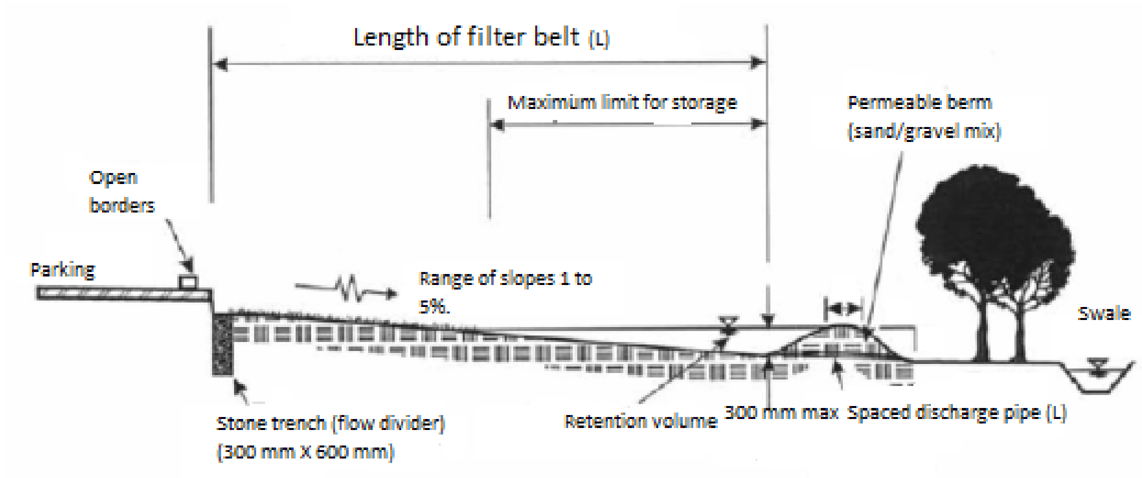


Figure 69: Components of a filter strip (adapted from Claytor and Schueler, 1996)

- **Tributary surface:**

  The extent of secondary (tributary) surfaces whose runoff is directed towards a parent filtering band should be less than 0.5 to 1 ha. The ratio of tributary area to that of the filter strip should not exceed 6:1.

- **Slope and width:**

  Ideally, the slope of the filter strip should be flatter than 5% (the smaller the slope, the easier it will be to maintain an overland flow); the minimum slope should however be 1% or 2% to avoid surface water accumulation. The slope at the top and toe of the embankment should be kept as low as possible to prevent erosion and to maintain an overland flow.

  The width of the filter strip should be between 10 and 20 m in the direction of flow, with a minimum of 5 m. Smaller widths (10-15 m) may be appropriate for milder slopes, while larger widths (15-20 m) are required with slopes of the order of 5%. The length of the strip (perpendicular to the direction of flow) should normally be the same as the tributary surface. The lateral slope of a filter strip should be a maximum of 1%.

- **Flow divider**

  The flow should not be concentrated in one or more places and a flow divider should normally be included in the design. A trench in stone pitching can normally be used, or a small swale with a berm (vegetated or concrete) or concrete kerbs with openings to distribute the flow. In the case of a trench in stone pitching, it is recommended that a small drop of 25-50 mm be provided at the edge of the paving to prevent the formation of deposits that could impede the flow.

- **Storage**

  The storage behind the berm at the toe of the embankment will depend on the desired level of control and the configuration of the filter belt.

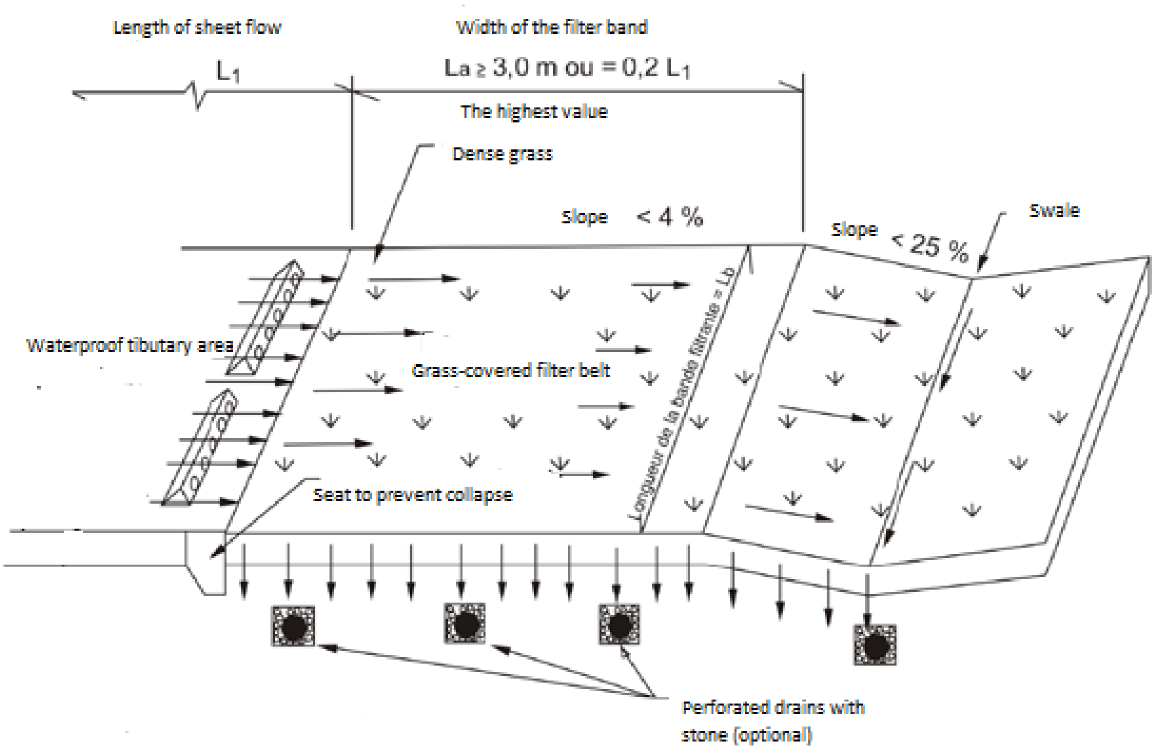


Figure 70: Variants of filter belts (UDFCD, Denver, 2001).

3.4.3.3.5 Absorption infrastructure and soil modification

Since the nature of the soil plays a fundamental role in increasing peak flows and runoff volumes, this relatively recent practice consists in minimising soil imperviousness and the use of landscape areas that maximize the absorption capacity of the soil.

Under natural conditions, with a vegetative cover consisting of a lot of organic matter, the absorption capacity is very important. This type of technique therefore implies the use of a more pervious soil matrix.

- ***Application***

This technique is adapted in the following cases:

- New developments (residential, commercial, industrial). Newly set-up lawns can be mixed with compost and left uncompacted in order to increase the soil porosity;
- Rehabilitation of existing soils. Scarifying soil that had been compacted or that existed since several years (eg, in parks or dry retention basins) can enhance infiltration;
- Maintenance of Landscape areas

- ***Advantages***

- Reduces the runoff coefficient of permeable surfaces;
- Increases infiltration rates for soils with low permeability;
- Contributes to improved filtration and retention of pollutants;
- Increases soil stability, resulting in low incidence of erosion.

3.4.3.3.6 Soil impermeabilisation attenuation: Use of permeable Flooring

This practice reduces the amount of runoff by allowing water to ingress through surfaces that would otherwise be impervious or with a high rate of surface runoff. Water can either infiltrate the soil if permeability permits or be intercepted by a network of perforated drains and directed to a drainage system.

Several categories can be distinguished with respect to the characteristics of the flooring:

- **Porous concrete or porous asphalt mixes**, which are obtained by eliminating or reducing the finer composition (sand and finer particles) and sometime with specific additives to further modify the matrix;
- **Paving stones or blocks**, in different materials, prefabricated or cast in situ.
- **Vegetated paving stones or blocks** (evergreen paving blocks)

Paving stones or blocks

Vegetative paving stones or blocks

PVC mesh overlaid with soil (or grass or gravel)

Figure 71: Different Types of porous flooring

Use of these porous materials will allow developers to reduce the impact of their project and also to limit the need (volume and therefore space) of the detention basins imposed by stormwater zoning (Cf. 5.4.2).

- ***<u>Applications</u>***

The most suitable sites are areas with low traffic that are not exposed to heavy vehicles (vehicle entrances, parking lots, storage yards, bicycle paths, walking paths and playgrounds).

- ***<u>Advantages</u>***
  - Removal of potentially high risk pollutant;
  - Substantial reduction in runoff volume;
  - Lagged hydrological response due to infiltration processes;
  - Aesthetic improvement to the facilities.

- ***<u>Drawbacks</u>***
  - Certain types of porous flooring cost more than traditional materials;
  - Their use depends on the infiltration capacity of the material in place;
  - Maintenance costs may be higher;
  - Not recommended for areas with heavy traffic load.

- ***Design Criteria***

The figure below shows typical cross-sections of porous blocks or flooring systems:

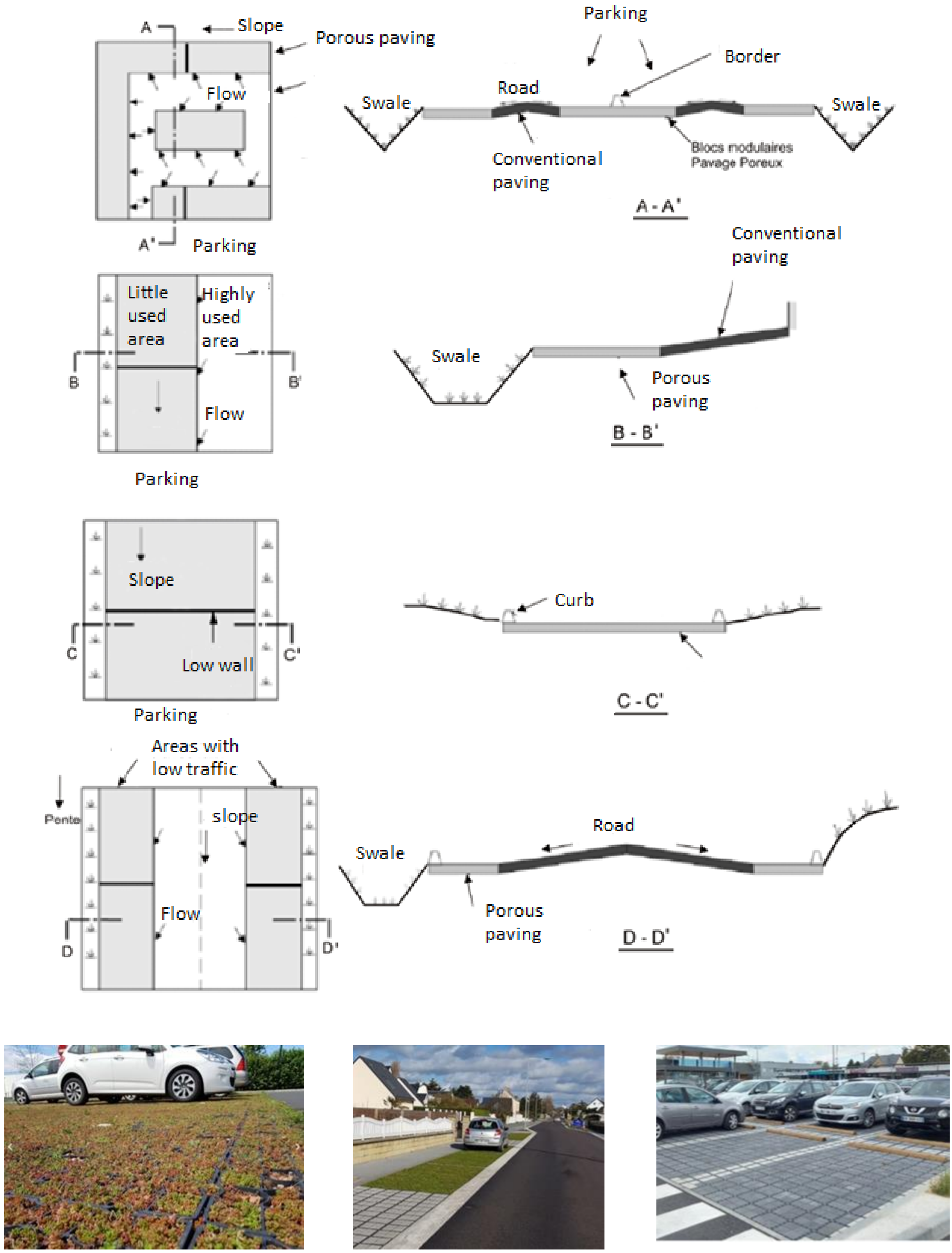


Figure 72: Design concepts with porous floor cladding (adapted from Denver, 2005)

3.4.3.3.7 Bioretention or Rain Garden

The term bioretention describes an integrated management practice that uses the chemical, biological and physical properties of plants and soils to provide quantitative and qualitative control. Several design concepts have been developed over the past 15 years, but the fundamental design criteria remain the same.

Bioretention areas (also called rain gardens) are:

- Shallow depressions with landscaped areas and a mixture of soils and vegetation adapted to the climatic conditions (tropical climate, Cf chapter 3.4.4) to receive rainwater from small tributary areas;
- Structures that are designed to mimic the natural hydrological conditions as close as possible by maximizing infiltration, storage and slow release of runoff;
- Small-scale structures distributed throughout the area.

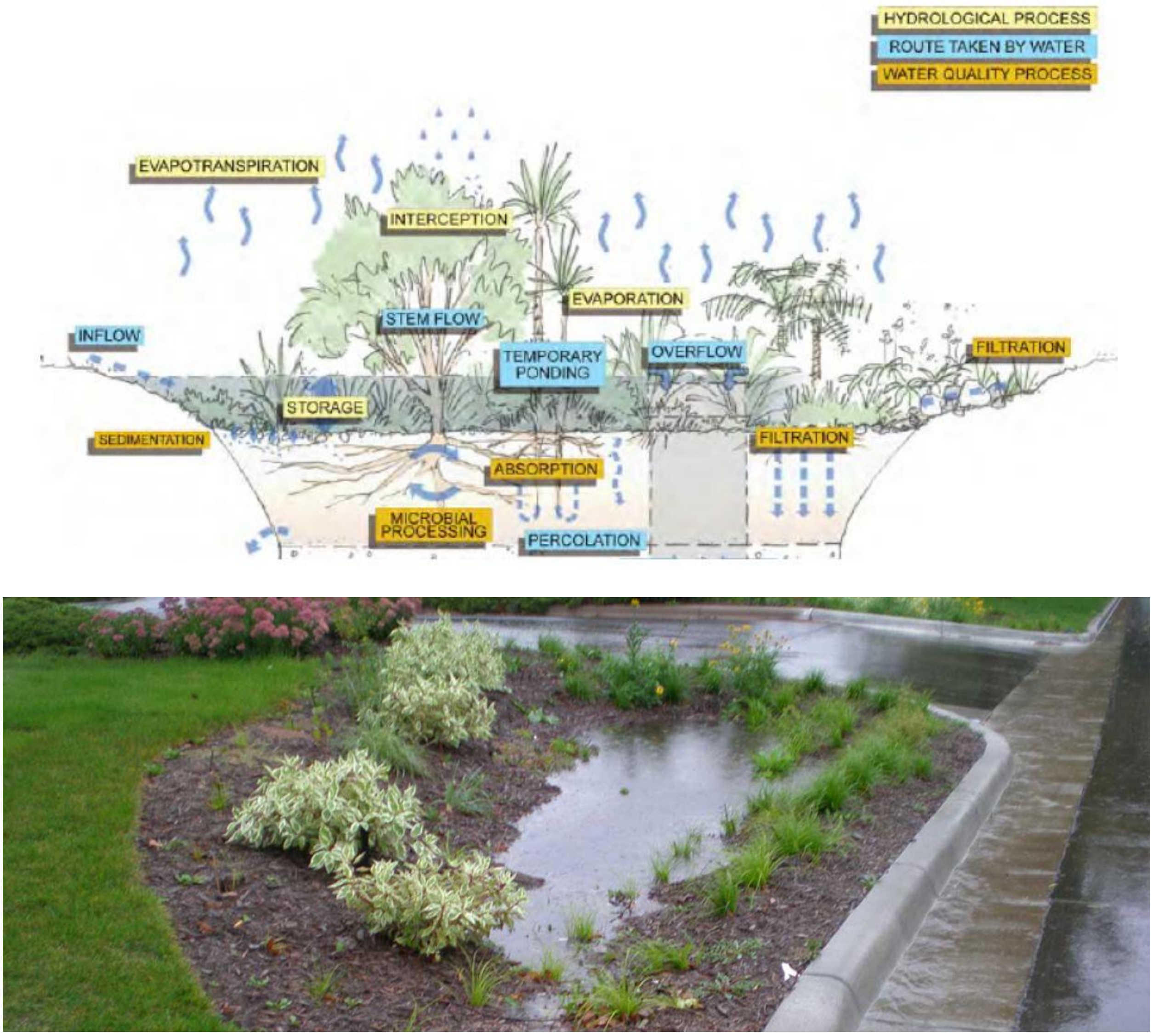


Figure 73: Bioretention Process (New Zealand Bioretention Guidelines)

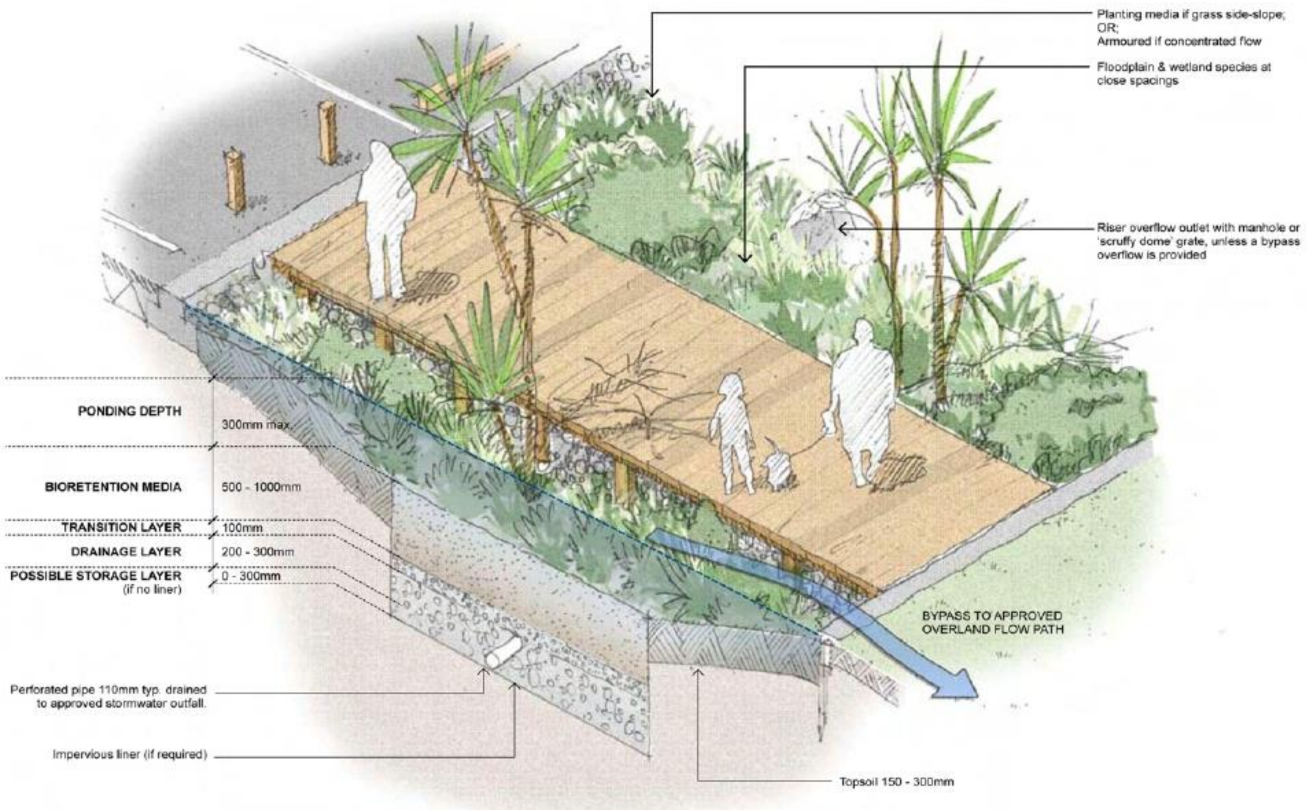


Figure 74: Rain garden - New Zeland Bioretention Guidelines)

Bioretention areas can have a significant impact on the quality of stormwater by removing pollutants through several processes, including adsorption, filtration, and decomposition. The filtered runoff can subsequently either be infiltrated into the surrounding soil (thus functioning as an infiltration basin) or collected by a perforated drain before being returned to the drainage system (functioning as a surface sand filter). Runoff for exceptional rainfall events is normally redirected through an overflow to the drainage system.

- ***Application***

Bioretention concepts can be applied in various instances as shown in the figure below:

- Parking lots islands;
- Peripheral boundaries of parking lots;
- In boulevard or highway medians;
- In commercial or industrial areas;
- In common areas of apartment complexes;
- In front or back yards of single-family dwellings;
- In permeable unoccupied areas of a site;
- At the bottom of dry retention basins;

Figure 75: Various applications of bioretention (source Development Strategies, Design Principles and Best Management Practices for Drainage Systems in Urban Areas - Quebec)

- ***Advantages***
  - When well designed and maintained, bioretention areas are aesthetically more pleasing, incorporating vegetation;
  - Contributes to reducing runoff volumes;
  - Can be very effective for the removal of fine sediments,
  - The infrastructure can be very flexible, and the selection of plant species allows for variation in design;
  - Can be used in a variety of soil conditions and local rainfall conditions, with minor modifications to the design;
  - Perfectly suited for many highly impervious areas, such as parking lots;
  - Contributes to reducing the size and cost of downstream control structures;
  - Reduces downstream system overloads and protects the watercourse;
  - Provides groundwater recharge and base flow for watercourses;
  - Can be used for rehabilitation purposes by modifying existing landscaping areas or where a parking lot is to be paved again.

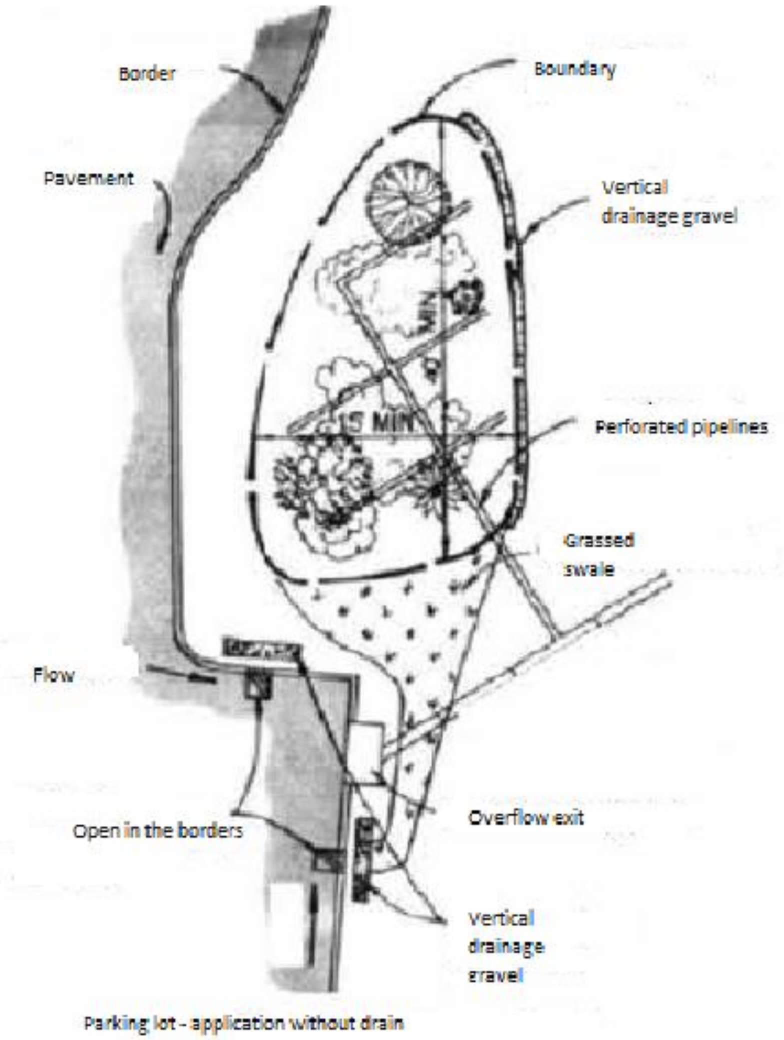


Figure 76: Typical use of Bioretention at Parking perimeter

- ***Drawbacks***
  - Cannot be used for large tributary surfaces, which is a constraint for certain sites;
  - Likely to be clogged by sediment accumulation: **a pre-treatment process is therefore an important process to consider during the design phase;**
  - Tends to occupy a lot of space;
  - Construction costs may be relatively higher than other stormwater management practices (simple retention).

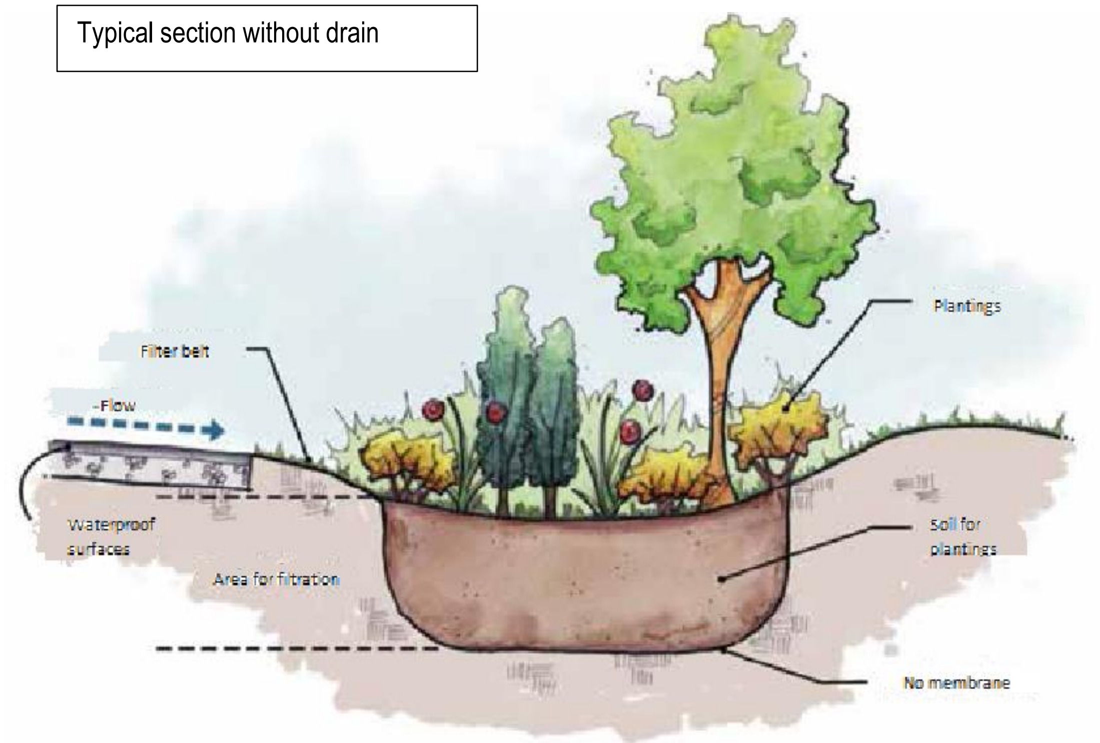
- ***Design Criteria and Principles***

Prior to design, the specific conditions of the site under study should be analyzed to ensure that bio retention is an appropriate choice:

- **Surface area.** Bioretention areas should usually be implemented for small sites (0.5 to 1 ha as a tributary area);
- **Slope**. The slope should ideally be less than 5%;
- **Soil.** Bioretention areas can be applied with most types of soil by modifying the design parameters (e.g. by adding an underdrain that will collect water if the existing soil is not permeable enough to allow infiltration). In all cases, in-situ percolation tests must be done to establish soil characteristics for infiltration capacities;
- **Subsurface layer.** A distance of at least 1.2 m below the bio retention system layer and the water table should be maintained at all times (especially if the system is designed using an infiltration technique).

As illustrated in the figure below, four design types have been developed for biofiltration areas:

- **Complete infiltration**, which is recommended when significant groundwater recharge is desirable. The existing soils must have a high infiltration capacity (25 to 35 mm/h and more);
- **Filtration with partial recharge.** This concept includes a drain that returns part of the filtered water to the drainage network;
- **Filtration with partial recharge and raised drain**. This concept also includes a drain which is located at a higher level in order to create an aerobic/anaerobic intermediate zone under the drain. This concept may be more appropriate for higher nutrient load (especially nitrates);
- **Filtration only**, with a drain coupled with an impervious geotextile (below 25 mm/h).



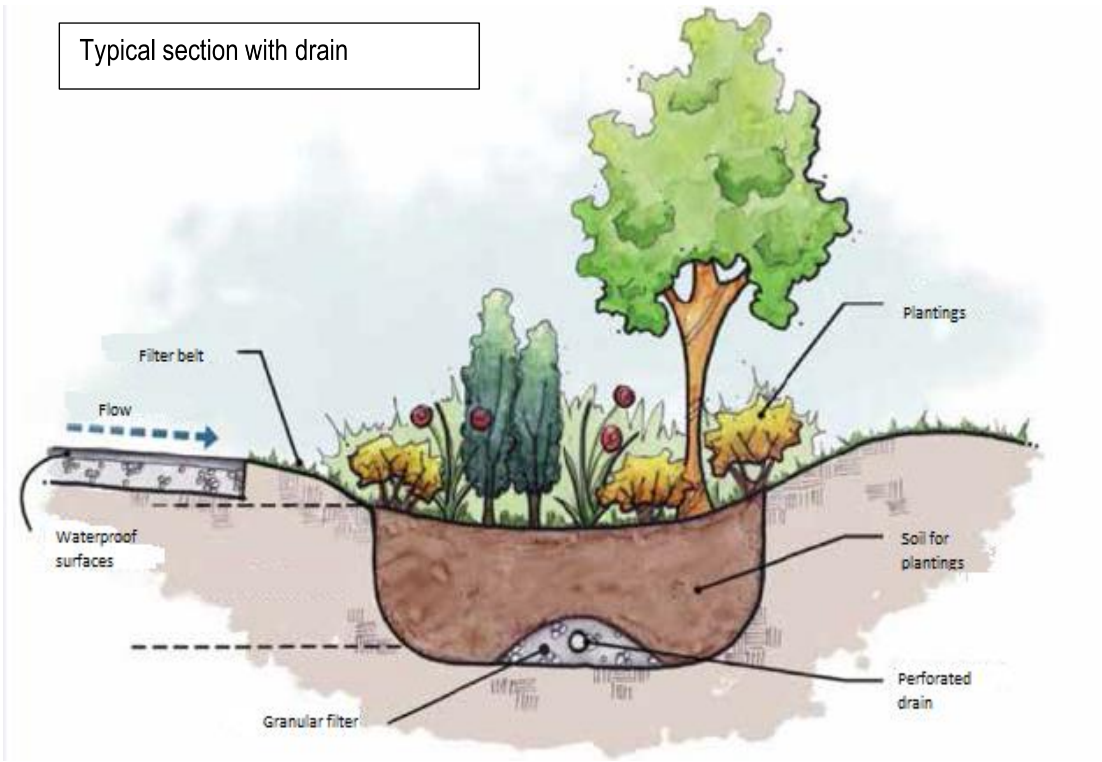
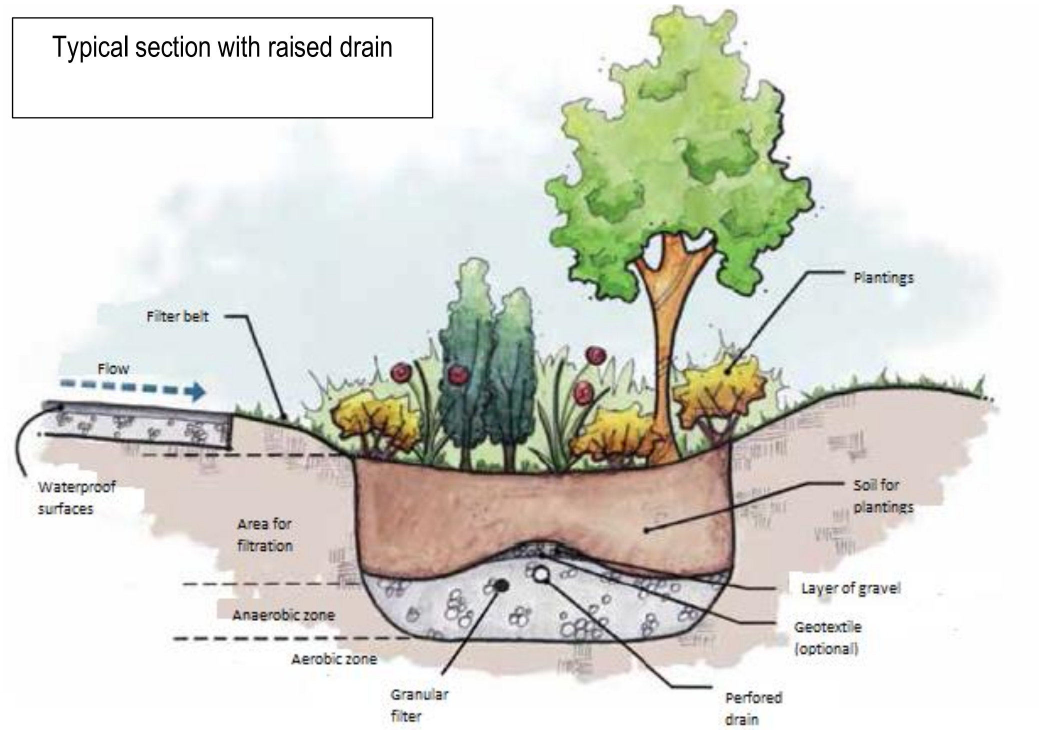


Figure 77: Conceptual variants for bioretention (1/2)



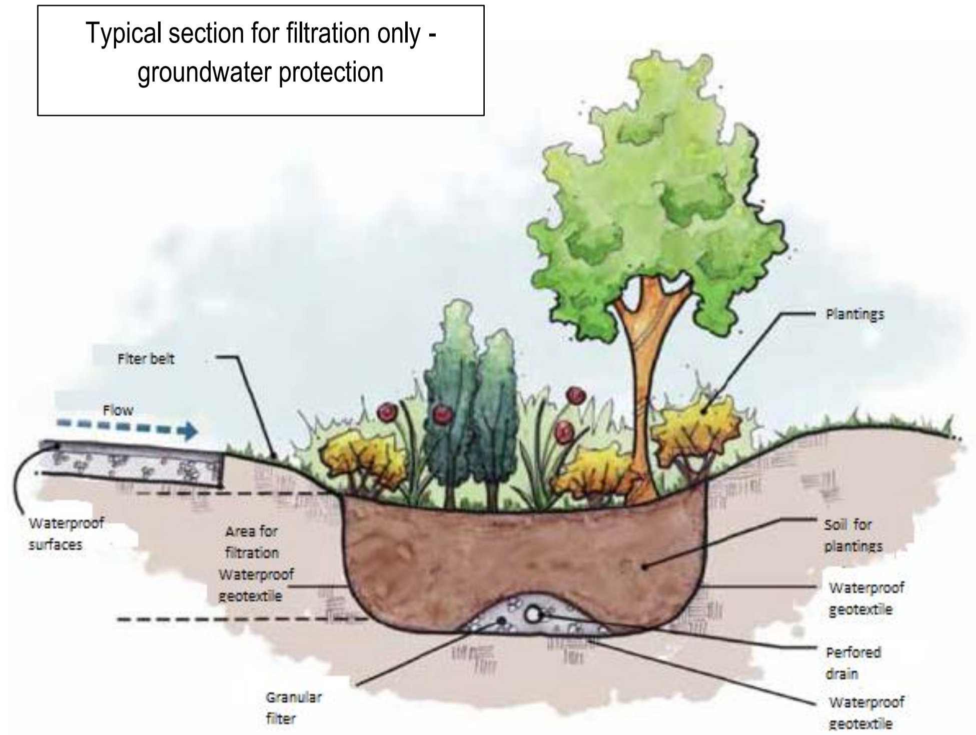


Figure 78: Conceptual variants for bioretention (2/2)

The table below summarises the characteristics of each variant.

Table 25: Characteristics of bioretention variants

Type of bioretention – (raingarden)	Variant	Comment
Infiltration / recharge	Without perforated drain	Highest potential of recharge (emptying in less than 24 hours)
Filtration with recharge	Filtration with recharge	Reduction in recharge potential (emptying takes more than 24 h)
Infiltration / filtration/ recharge	Raised perforated drain	For higher nutrient load and/or quantity control
Filtration	High operating performance of drain with impervious geotextile	Sensitive sector to drain

○ ***Pretreatment***

In view of bioretention units being susceptible to clogging from uncontrolled sediment discharge, it is important **to provide pre-treatment such as a filter belt or other treatment methods.** The most effective method of reducing sediment load is to separate contaminated runoff from the uncontaminated one.

As shown in the figure below, a trench with well-washed coarse gravel is recommended upstream of a filter belt as a flow separator. It is recommended to include as many pre-treatment mechanisms as possible (filter belt, stone trench, etc.).

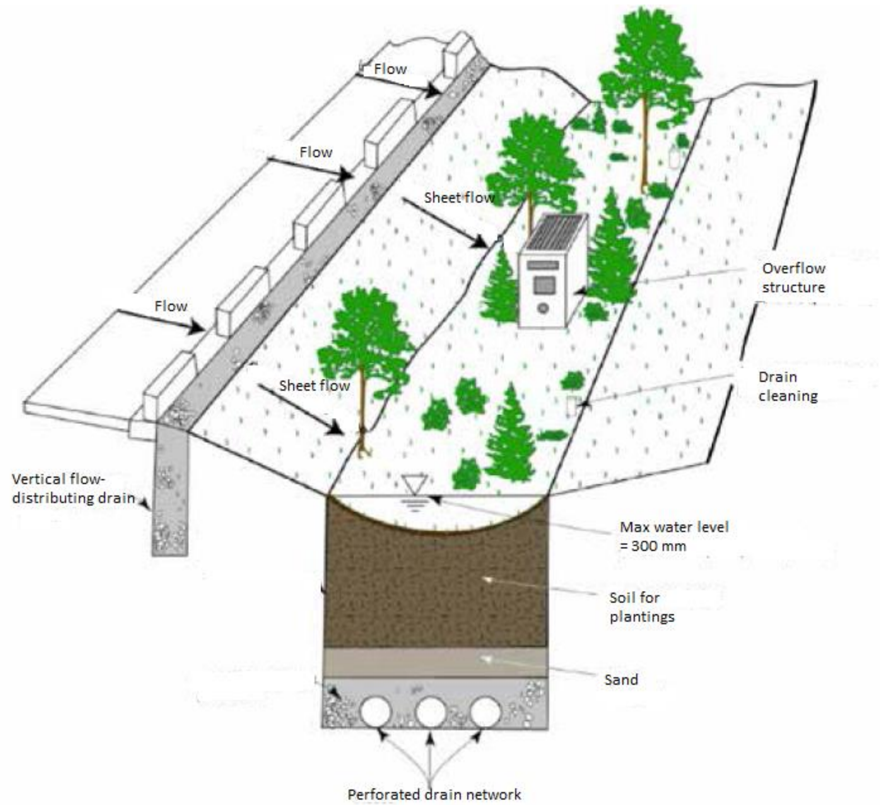


Figure 79 : Components of a bioretention system (adapted from New Jersey (2004) and Claytor and Schueler, 1996).

- ***Storage Surface***

The storage surface area provides an accumulated volume of water before it infiltrates through the ground, while allowing evaporation and sediment deposition.

A maximum height of water of 150 to 300 mm should be provided, beyond which the excess water should be discharged directly into the drainage system.

- ***Drain (where infiltration is not maximized)***

A french drain (a perforated pipe within a gravel bed) can be installed to collect and convey the water to the drainage system after filtration in the soil. Depending on the treatment objectives and site specific constraints (e.g. the risk of groundwater contamination), the bioretention system may or may not include such a drain.

- ***Overflow or bypass system***

The bioretention system must include a mechanism to discharge runoff during rainfall events greater than the design flow rate (which will not be treated by the bioretention unit). In normal practice the design flow corresponds to the flow rate for quality control, and an overflow mechanism should be included in the system to discharge the water to the system. Another option is to provide a bypass system upstream of the bioretention unit to ensure that only the design flow is directed for treatment, with larger flows diverted to the drainage system.

Cf. chapter 3.4.3 and 3.5 for the design of leakage rate and retardation volume.

3.4.3.3.8 Surface or Sub-surface Storage depending on the scale and component of the project

Retention on rooftops, on the surface (parking lots or parks) or in underground chambers or pipes is an efficient and economical way to perform quantitative control.

In general, **retention over parking lots** is economical but results in slightly higher construction costs. It is applicable to commercial or industrial properties. This type of retention is used extensively in vacant lot within development projects in an already built area to minimise the need to increase the size of storm drains downstream. Through retention of parking lots, the volume retained, in combination with the other techniques described, effectively reduces runoff.

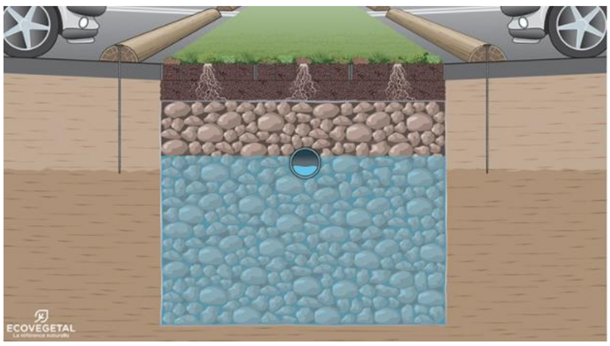


Figure 80: Typical Stormwater storage in a parking lot with drainage through a central filter swale

Water accumulates when the runoff flow rate is greater than the capacity of the discharge flow control structure. Discharge control structures can take the form of perforated drains at the exit of sumps or manholes used for maintenance. The installation of the manhole structure at the property boundary within municipality control will ensure that the device will not be tampered with.

Retention areas should be as far away from buildings as possible and the minimum slope can be 0.5% to 1% (MOE, 2003). In general, the depth of water accumulation should be limited to 300 mm for an acceptable water stagnation duration (normally a few hours, even after a heavy rainfall event). The acceptable retention time varies according to specific regions or sites and is more appropriately defined in a stormwater management master plan (Cf chapter 3.5.2.4).

This implies that in the case of large parking lots and for maximum efficiency, the total area should be subdivided into small lots (cells) of less than 0.5 ha, (each lot draining to a single low point). Provision will need to be made to supplement these over-ground retention structures with other structures such as storage areas at the edge of the parking lots. The lower the flow limit, the smaller should be the surface retention cells; sub-surface retention can of course be used, but at a higher cost.

Large diameter buried pipes can be used to store water and reduce peak flow. The length and cross-section of the structure will obviously be a function of the volume required to control discharge flows. The water outlet must be sized to provide accurate flows that do not exceed the allowable limits (Cf stormwater zoning – Chapter 5.4.2). The length and diameter of the pipe will be a function of the storage volume required;

It is recommended that the pipe be sloped at least 0.5% to facilitate drainage. However, the slope of the pipe should be kept to a minimum; steep slopes will reduce the volume of water stored in the pipe.

Pipes should be provided with access points for cleaning purposes. The design should include overflow mechanisms for emergency situations. A ditch should also be provided to divert overflows in the event of blockages.

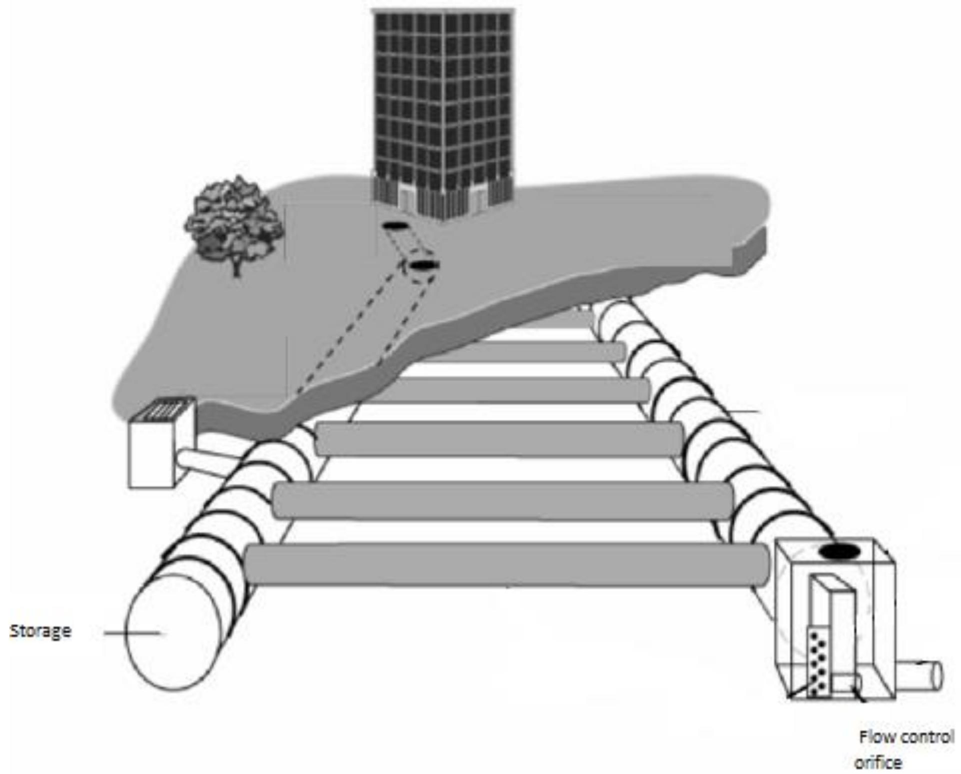


Figure 81: Schematic diagram of stormwater retention using large diameter pipes

3.4.3.3.9 Infiltration and retardation swale

- ***Definition***

A swale is a ground depression or open trench used to collect, retain, drain, evacuate and/or infiltrate rainwater.

The main function of the swale is to store stormwater for a rainfall event (10 or 25 years), but it can also be used to drain stormwater for an exceptional rainfall event (e.g. a 100 years rainfall event). **Storage and water flow is done in the open, within the swale.**

The swale is distinctly shallow and temporarily submerged, with gently sloping banks and is often planted with various adapted grasses or perennials (Cf. 3.4.4). Vegetation over the swale has an additional role of evapotranspiration and phyto-purification. Its form is of elongated shape, usually with parallel banks although not necessarily so, and it can follow the topographical contours and shrink at certain places. A swale can replace a concrete stormwater system with the advantage of a simple design, low cost and easy maintenance.

It is the most widely used technique for the optimal management of stormwater. However, swales require a large surface area, which is not always obvious in urban areas. The surface of the swale can be vegetated, grassed, planted, reinforced (grass slabs), lined (porous or loosely jointed paving slabs).

If the bottom of the swale is lined with concrete, it is more like a dry or storm basin. When it is empty, the swale can, depending on its shape and surface, be used as a playground for children or pathways.

The implementation of the swale can be completed by other stormwater management techniques on the plot.

- ***Swale Types***

There exist several types of swales depending on the soil infiltration characteristics. Comparison is made between the two main types of swales, that is, **infiltration** and **retardation swale** and this is briefly described in the table below

Depending on the environmental conditions, a series of arrangements can be put in place to optimize the operation of the swale, thus creating sub-types of swale which are elaborated in the different sections on the document. Moreover, an intermediate situation may arise where two different types of swales can be integrated, which leads to the implementation of a "mixed swale".

 Source Architecture & Climat - UCLouvain	• **Infiltration swale** This type of swale is used for soil having sufficient infiltration rate. In this option, the water is directed into the structure to be stored before **infiltrating naturally into the soil** thereby restoring the natural water cycle.
	• **Retardation swale** This type of swale is used for soil having a low infiltration rate. In this option, water is channelled into the structure to be stored before being discharged, at a regulated flow rate, **to its outlet.**

Source Architecture & Climat - UCLouvain	

- ***Infiltration swale***

A soil is suitable for infiltration if all of the following conditions are met:

- permeable soil (infiltration capacity > 20 mm/h),
- permeable surface cover (plantation or porous materials, infiltration capacity > 20 mm/h),
- Land outside water reservoirs and environmental protection zones (ESAs in Mauritius),
- uncontaminated soil,
- deep water table (lowest depth > 1 m below the base of the structure).

Under such conditions, drainage by infiltration will be the preferred option over a regulated flow outlet.

When the swale is located in a place with humid soil or when the swale is also reserved for other purposes (eg recreational activities), it may be necessary to provide appropriate facilities to prevent the bottom of the swale being in a wet condition too often and/or for a long period (water puddles which may be incompatible with parallel use of the premises).

The infiltrating swale can thus accommodate, at its low spots, a gutter (or gully) made of solid material (draining concrete, draining paving stones) which allows drainage during small rainy episodes and the start and/or end of exceptional events, this in order to avoid water puddles.

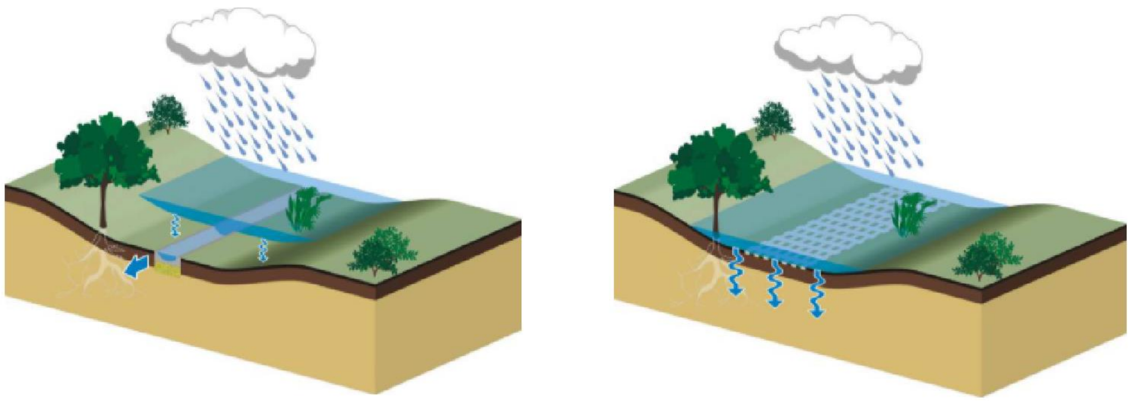


Figure 82: Infiltration swale (left) and base reinforced infiltration swale (right) (Source Architecture & Climat - UCLouvain)

For the same reason, a swale can also be provided with a sub-surface infiltration bed at the lowest point (protected by a geotextile but without a drain). This bed increases the storage capacity.

The infiltration bed is not drained to an outlet but allows temporary storage of part of the runoff water. All water stored within the swale and its bed will then get infiltrated into the soil.

Figure 83: Infiltration swale with a linear infiltration bed at its low point to limit the incidence of puddles and/or increase the storage capacity (Source Architecture & Climat - UCLouvain)

- ***Retardation swale***

A retention swale can be implemented in the following two cases:

- either because of natural soil impermeability (infiltration capacity < 1mm/h); or
- due to environmental considerations (risk of soil or groundwater pollution, risk of transfer of existing contamination, etc.).

In the first case (non-permeable soil), the drainage of the stored water can be carried out:

- Either through surface drainage located at the low point of the swale. In this case, a gully at the bottom of the swale directs the water towards the discharge point; or
- through a drainage system located beneath the swale.

The discharge orifice of the swale can get clogged within a short time and it is therefore very important to ensure maintenance of this orifice.

The retention swale does, however, limit the risk of clogging by filtering suspended solids and other objects through the soil.

Figure 84: Surface drainage swale (Source Architecture & Climat - UCLouvain)

The soil has very low permeability. Stored water is drained at a controlled rate to an outlet via an orifice at the bottom. This orifice must be maintained at regular intervals to avoid obstruction.

Figure 85: Retention swale on very low permeability soil (Source Architecture & Climat - UCLouvain)

Water stored in the swale infiltrates into the superficial substrata and is drained through a stone drain which evacuates the water at a controlled rate to an outlet.

In the case of a permeable soil but through which infiltration is not permitted because of environmental reasons, the structure must first be lined with an impermeable membrane (geo-membrane).

The water percolates through the superficial sub strata and is drained through a stone drain which evacuates the water at a controlled rate to an outlet.

This type of structure, however, slows down flow speed, and therefore peak flows, compared to a conventional concrete drain.

Figure 86: Retention swale with an impervious geo-membrane at the base (Source Architecture & Climat - UCLouvain)

- ***Mixed swale***

With average soil permeability **(infiltration capacity between 10 and 20 mm/h),** the mixed swale can cumulate drainage capacity: drainage can be effected both by **infiltration into the soil and by evacuation at a regulated flow rate**. Infiltration though possible will be slow and the evacuation by means of a regulated discharge rate will empty the structure completely within a fairly reasonable time. Drainage can also evacuate water oozing out from the aquifer if the water table is just beneath thus preserving the emptying capacity of the structure.

Figure 87: Mixed infiltration and buffering swale, on moderately permeable soil (Source Architecture & Climat - UCLouvain)

In addition to the retention and drainage functions of swales, their sizing is elaborated in chapter 3.4.3.4.

3.4.3.3.10 Dry retardation basin

A dry basin resembles hydraulically to a "widened" swale. It is more or less circular in shape and is used rarely for drainage purposes and more for storing water to thereafter infiltrate it into the soil or return it to the outlet at a controlled flow rate. The banks of dry ponds are often provided with a gentle slope although it may sometime be steeper in which case it should be reinforced and the water depth may be greater than that of the gullies.

Temporarily submerged, it is most often landscaped: it can be lined with a vegetative cover or with gravels. A "storm basin" with lined bed and walls (concrete, paving stones, etc.) is a special type of dry basin. The dry basin is most often the penultimate facility after a succession of alternative measures and before the final outlet or it is a complementary facility for exceptionally rare rainfall events (eg 100 years rainfall event).

- ***Hydraulic principle***
  - ***Collection:***

Water is collected, either through pipes, gullies or troughs, eg water draining from roofs or roadway, or direct runoff from adjacent properties. An inlet structure allows runoff flow into the dry basin.

  - ***Dry basin:***

The main function of the dry basin is to store water in the open from a rainy episode (eg 10 to 100 years). Its role is to diffuse and retard stormwater flow.

  - ***Evacuation:***

Stormwater is evacuated towards an outlet (network, well) with regulated flow or by infiltration in the ground and by evaporation. These different evacuation modes can be combined depending on their own merits. In general, when the discharge capacity at the outlet is very limited, infiltration should be the prime treatment.

- ***Types of dry basin structures***

The surface of the dry basin can be vegetated, grassed, planted, reinforced (grass slabs), lined (porous or loosely jointed paving slabs). When it is empty, the dry basin can, depending on its shape, be used as a playground for children, etc.

Semi-aquatic plants, also used in plantations in wastewater treatment, can be chosen and planted due to their capability in the reduction of potentially polluted runoff water (runoff from parking lots, roads, metal roofs containing organic matter, hydrocarbons, heavy metals, etc.).

There exist several types of dry basins depending on the infiltration capacity of the soil:

✓ **Dry infiltration basin (Minimum infiltration capacity : 20 to 35 mm/h)**

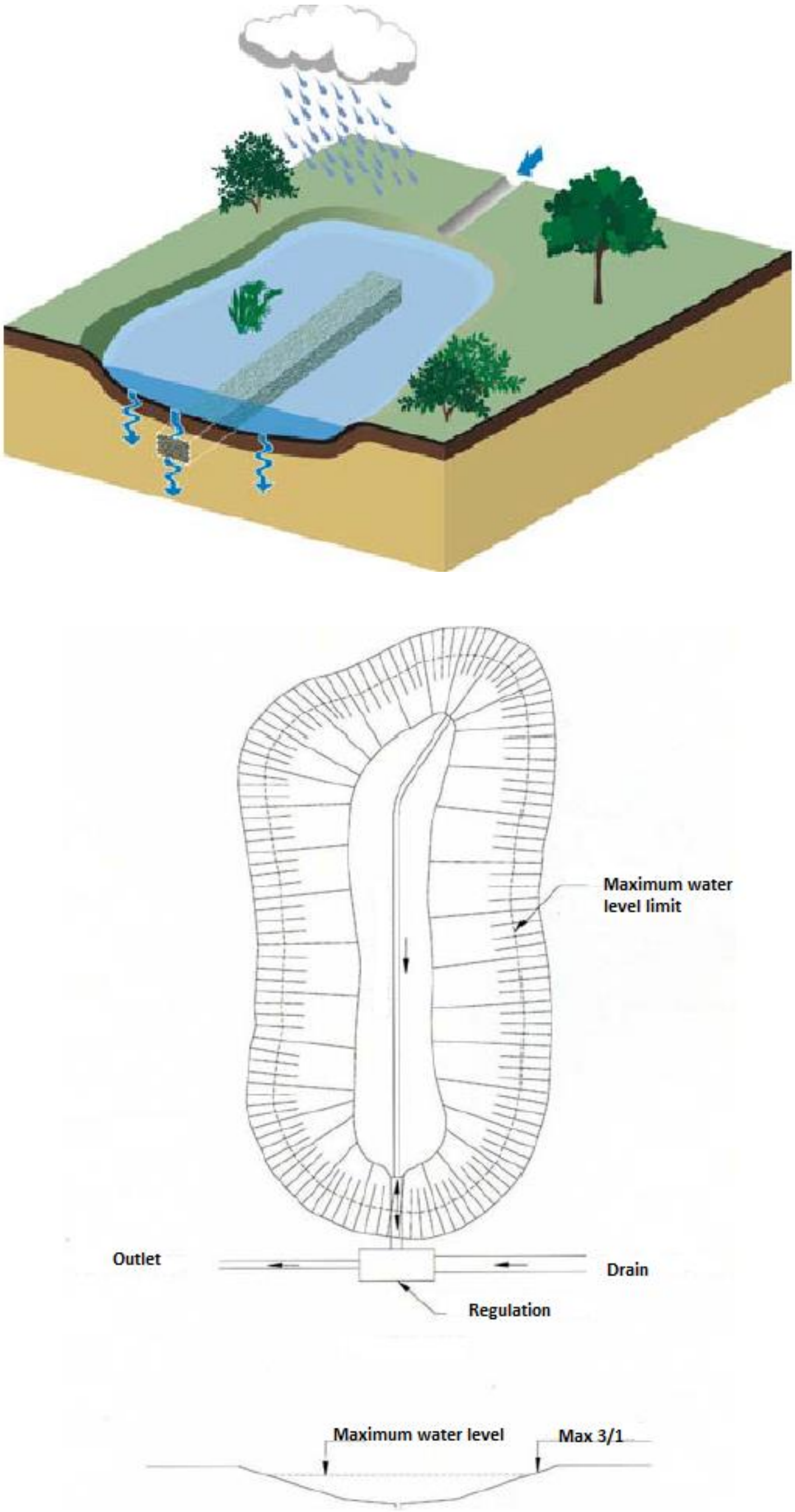


Figure 88: Dry infiltration retention basins (Source Architecture & Climat - UCLouvain)

✓ <u>**Dry superficial evacuation or draining basin**</u>

When the soil has insufficient infiltration capacity (**infiltration capacity < 1 mm/h)** or when infiltration is not recommended, or even prohibited due to environmental reasons (risk of soil or groundwater pollution, risk of displacement of existing contamination, etc.), the dry basin can play an important role of storage with water evacuation at a regulated rate:

- Either by means of a surface evacuation located at the lower point of the dry basin. In this case, a gutter at the bottom of the basin directs the water to the discharge point, or
- Through a system of drains built under the dry basin.

This is termed a "retention basin".

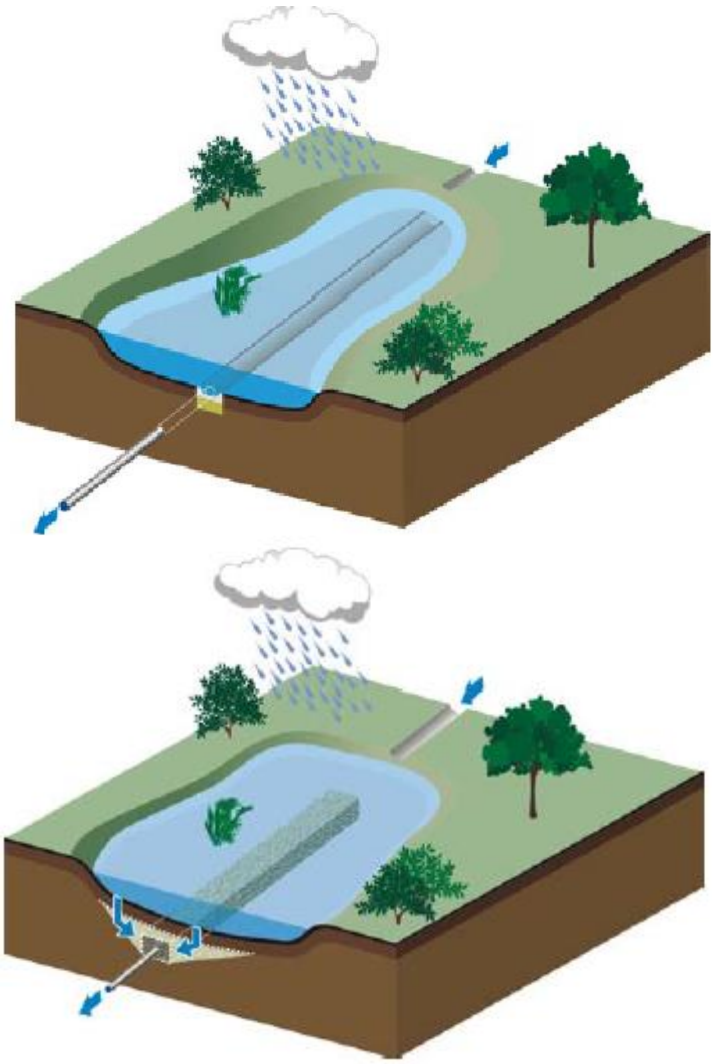


Figure 89: Dry retention basins with surface drainage (with gutter at the top or drain at the bottom) (Source Architecture & Climat - UCLouvain)

The Impermeability of the bed of the structure can be naturally occuring if the existing soil is naturally impermeable, or it can be made impermeable by an impermeable film (geo-membrane). In the presence of this film, bamboo plantations (with a rhizome root system) are strongly discouraged due to the risk of the film getting perforated by the roots. The planting of semi-aquatic plants poses, on the contrary, little risk of perforation.

Impermeability of the surface can also be carried out, if the soil is not sufficiently watertight, by using a layer of clay (or clayey soil) compacted to 20 to 30 cm. This technique is accepted practice in wastewater treatment through natural means (vegetated basins).

Nevertheless, when the subsoil is polluted and in order not to run the risk of displacing this pollution, it is important that the relevance of this technique be discussed with the competent authority (WRU, Ministry of Environment, Solid Waste Management and Climate Change).

The orifice of the dry basin with surface drainage can quickly get clogged. It is therefore important to ensure regular maintenance of this orifice. However, the draining dry basin reduces the risk of clogging by filtering suspended solids and other elements through the soil.

✓ **Mixed dry pond**

When the soil permeability is average **(infiltration capacity between 10 and 20 mm/h),** the mixed dry pond can cumulate drainage capacity: drainage can be effected both by infiltration into the soil and by evacuation at a regulated flow rate.

Infiltration will be possible but slow and evacuation with a regulated discharge rate will empty the structure completely within a fairly reasonable time. Drainage can also evacuate water oozing out from the aquifer if the water table is just beneath thus preserving the emptying capacity of the structure before the next storm.

Figure 90: Mixed retention basins - both infiltration and controlled discharge flow rate to an outlet (Source Architecture & Climat - UCLouvain)

- ***Design***
  - Provide sufficient grassing with a thickness of good quality organic soil (20 cm), to be carried out before operation.
  - If the dry basin is also a playground (eg a soccer field), provide strengthening of the lawn.
  - Provide access to the bed of the dry basin for maintenance purposes (ramp, etc). The bed of the basin must be able to withstand the load exerted by operating equipment.
  - It should be possible to move around the basin for maintenance purposes: sufficient access must be provided between the crest of the bank and the fence or any other obstacle.

- Ensure that the runoff collection surfaces slope towards the dry pond.
- Ensure that the dry pond is designed and constructed so that there is no stagnant water: sufficient slopes, well-constructed, with bed strengthening, gully or riprap at the low point if necessary.
- Plantations (trees, shrubs, etc) will allow a better water infiltration due to their roots aerating the soil and nourishing on water. They will also play a role in water regulation through evapotranspiration. If the retention time of the water in the dry basin is long, it would be preferable to plant species which are adapted to wetlands (cosmopolitan water plants such as *Typha* (cattail) and *Acrostichum* (fern)).
- In general, any planting in or near a structure must be chosen according to its root system and the space available within the impervious area or just outside. Bamboo is not recommended where geo-membranes are used to provide imperviousness. Certain plants should not be planted close to a riprap as their roots may clog.
- Planting in or near an open structure demands more maintenance due to the need for frequent collection of dead leaves.
- Dry ponds can be connected to the stormwater network by a common filling and emptying structure located at the lower point of the pond. This prevents low flows from passing through the pond, as the pond is filled by overflow.

3.4.3.3.11 Wet retardation basins

A water basin always contains a layer of water. Stormwater runoff is discharged into it during rainy episodes. Its level therefore fluctuates and this is beneficial to biodiversity. Its size varies: from a simple garden pond to a lake hosting water sports activities. Irrespective of its size, the water basin always shelters an aquatic ecosystem whose equilibrium depends on variations in the volume and quality of water ensuing from rainfall. The water basin is very sensitive to the quality of the feedwater (stormwater runoff, etc.).

- ***Hydraulic Principle***
    - ***Collection:***

Water is collected, either through pipes, gullies or swales, for example, collection of water from roof and roadway, or direct runoff from adjacent properties. An inlet structure allows the run-off water to be fed into the water basin.

- ***Dry water pond:***

The main function of a water pond is to store water during a rainfall episode (eg a 10 year to 100 years return period) within the limits of its tidal range (the tidal range is the difference between the highest and lowest water levels). Its role is to diffuse and reduce stormwater.

- ***Drainage:***

The water is drained towards an outlet (network, well) and by evaporation, evapotranspiration. In the case of permeable banks above the minimum water level, water can also be drained by lateral infiltration into the soil of these banks.

These different methods of drainage can be integrated according to their own capacity. Often, a discharge at the outlet is needed because the infiltration surface in the soil of the banks is limited.

The wet basin is most often the penultimate facility after a succession of alternative measures and before the final outlet.

- ***Water Structure - Imperviousness of bed surface***

The bed of the structure can be naturally impervious if the existing soil is naturally impermeable. The basin can also be made impervious by laying an impermeable membrane (geomembrane). In the presence of this membrane, bamboo plantations (with a rhizome root system) are strongly discouraged due to the risk of perforation of the membrane by the roots. The planting of semi-aquatic plants presents, on the contrary, little risk of perforation.

Imperviousness of the surface can also be achieved, if the soil is not sufficiently watertight, by using a layer of clay (or clayey soil) compacted over 20 to 30 cm. This technique is accepted practice in wastewater treatment by natural means (planted ponds).

Nevertheless, when the subsoil is polluted and in order not to risk transferring this pollution, it is necessary to discuss the relevance of this technique with the competent authority (WRU, Ministry of Environment, Solid Waste Management and Climate Change).

Semi-aquatic plants, also used for wastewater treatment, can be chosen and planted due to their capability to reduce the pollution load of storm runoff water (runoff from parking lots, roads, metal roofs containing organic matter, hydrocarbons, heavy metals, etc.).

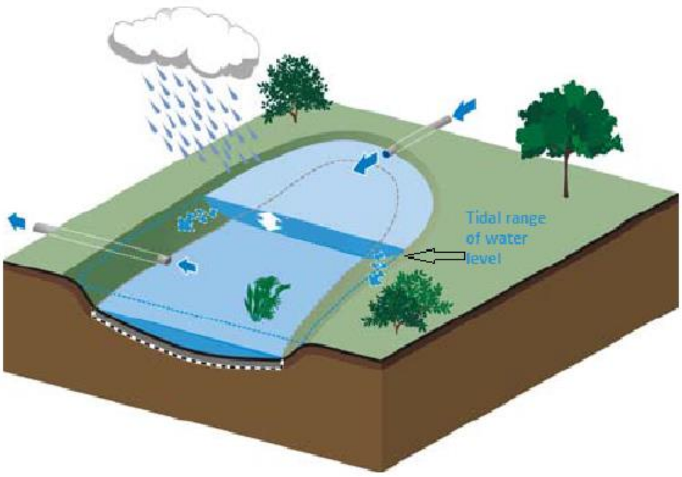


Figure 91: Imperviousness of Water basin by Geo-membrane under a silt bed (Source Architecture & Climat - UCLouvain)

A water inlet floods the basin during storm weather. The water may possibly infiltrate laterally through the banks. Water evacuation at the upper level of the impervious area allows the excess volume to be evacuated at a controlled rate.

- ***Design***
  - It is advised to leave at least 30 cm between the lowest edge of the pool and the maximum water level in the pond. The bank slopes must be gentle,
  - It must be possible to access the pool for maintenance: sufficient access must be provided between the top of the bank and the possible fence or any other obstacle,
  - Ensure that the slope of the runoff collection surfaces is properly directed towards the wet pond,

- Provide a screen upstream of the wet pond to separate the water from large "pollution". Depending on the origin of the stored effluent and water quality objectives, pre-treatment techniques may be considered,
- Design and construct the wet pond so that there is a minimum water depth of 1.5 m to prevent the development and proliferation of aquatic plants,
- The presence of trees and shrubs in the immediate environment of the water pond provides beneficial shade to limit the spread of undesirable aquatic plants but requires additional maintenance when leaves fall,
- Check the compatibility of the plantings with the root resistance of the geomembrane,
- In the case of imperviousness with a geomembrane, attention must be paid to finishing detail, in particular to tidal range: if it is visible, it may be unaesthetic,
- In general, any planting in or near a structure must be chosen according to its rooting system and the available space within the impervious area next to it. Bamboo is prohibited in the case of imperviousness by geomembrane.

o ***Security***

It is necessary to adapt the profile of the pond by providing a shallow area at the periphery (safety berm), coupled with plantation on the bank to restrict access to the water surface. It is also useful to provide cautionary information on the associated danger of the water in order to prevent accidents.

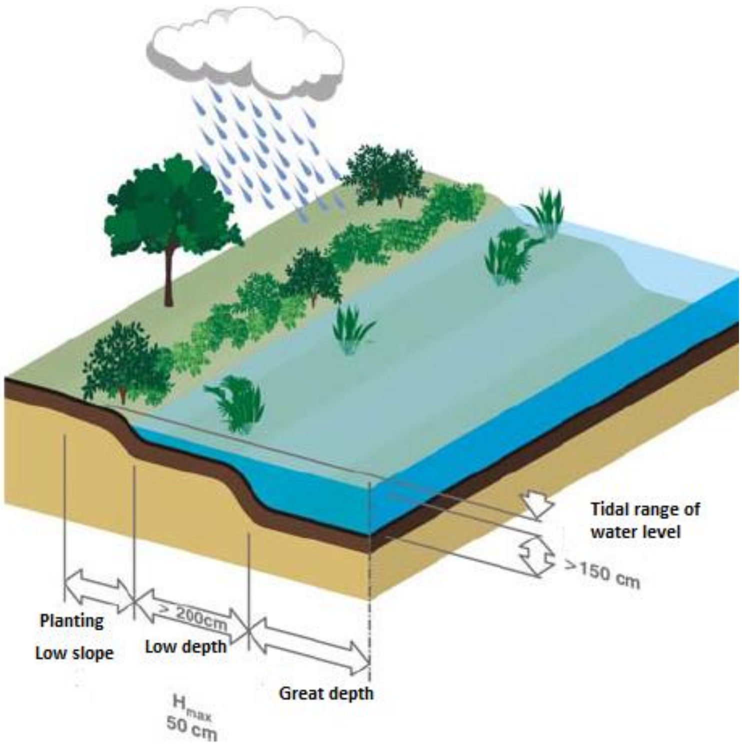


Figure 92: Water pond with embankments designed to prevent accidents: plantations and a shallow water area precede the pond at the deeper end - (Source Architecture & Climat - UCLouvain)

o ***Choice between dry and wet pond***

Apart from the private individual, who may have his own requirements in addition to those on flow and storage imposed during the building permit stage, the designer of the pond will be called upon to strike a balance between the choice of storage volume, morphology, possible surface equipment and the location of the pond.

These choices are made depending on physical constraints (topography, hydrogeology, land use), economic constraints (land use, management, maintenance), technical constraints (levels of protection against accidents involving accidental falls and drowning, maintenance, etc) and environmental constraints (impact on the receiving environment, landscape and quality of life). Useage depends largely on the type of effluent and the frequency of use.

A choice has to be made, according to these multiple criteria, between a wet or dry pond, a retention or infiltration pond, a pond with or without pre-treatment, a single pond or several ponds in parallel or in series.

More specifically, a choice can, for example, be made on:

- Water pond if the soil is impermeable, the water table is not vulnerable,
- Paved pond if the run-off water is heavily polluted, near a freeway or next to a very high-traffic parking lot,
- Water pond if one wishes to embellish an urbanized area with a water surface,
- Dry pond with an upstream water treatment facility if the water is run off from industrial, commercial or parking areas,
- Dry pond set up as a children leisure area, if the pool is not used too often (on hygienic ground).

3.4.3.4 Management Practices for transfer and slow down transfer of stormwater

Certain practices are applicable to transport of stormwater, using approaches that allow both quantitative and qualitative monitoring. Historically, in urban areas, the basic concept has been the rapid and efficient evacuation of stormwater through the implementation of concrete drains with kerbing. Many other solutions are, however, possible through the use of several other types of systems to be considered for an optimum water management plan.

As alternatives to the conventional system of concrete kerb / drain system with no control mechanism, the following solutions can be considered:

- ▷ Ditch or dry grassed swale,
- ▷ Wet swale,
- ▷ Swale or infrastructure with bioretention,
- ▷ Infiltration trench,
- ▷ Street level storage system.

It is worth noting that the concepts involving ditches or swales are different from the traditional road drainage ditch where design criteria are established exclusively for stormwater conveyance rather than for more extensive stormwater control.

The figure below shows typical cross sections for different types of ditches or swales; the term ditch is assigned to traditional drainage ditch and the term swale is used to highlight the fact that such variants perform more functions than simple drainage ditches.

A grass lined ditch can be differentiated from a basic drainage ditch through its wider base, milder slopes and denser vegetation, which offers greater potential for pollution control. Grass lined ditches are used for the storage, infiltration and conveyance of stormwater runoff from roads and land properties. Grass or emergent vegetation in the swale reduces flow velocity, prevents erosion and filters pollutants carried by the stormwater. When properly designed, grass lined ditches are effective devices in terms of the volume of water transported and its quality. The improvement in water quality depends on the contact area between the water and the ditch surface as well as the longitudinal slope.

Deep and narrow channels are less effective than wide and shallow ditches in removing pollutants. Safety issues related to water depth and flow velocity must be considered. Deeper ditches with greater storage capacity can also be used around parking lots to retain a larger volume of water.

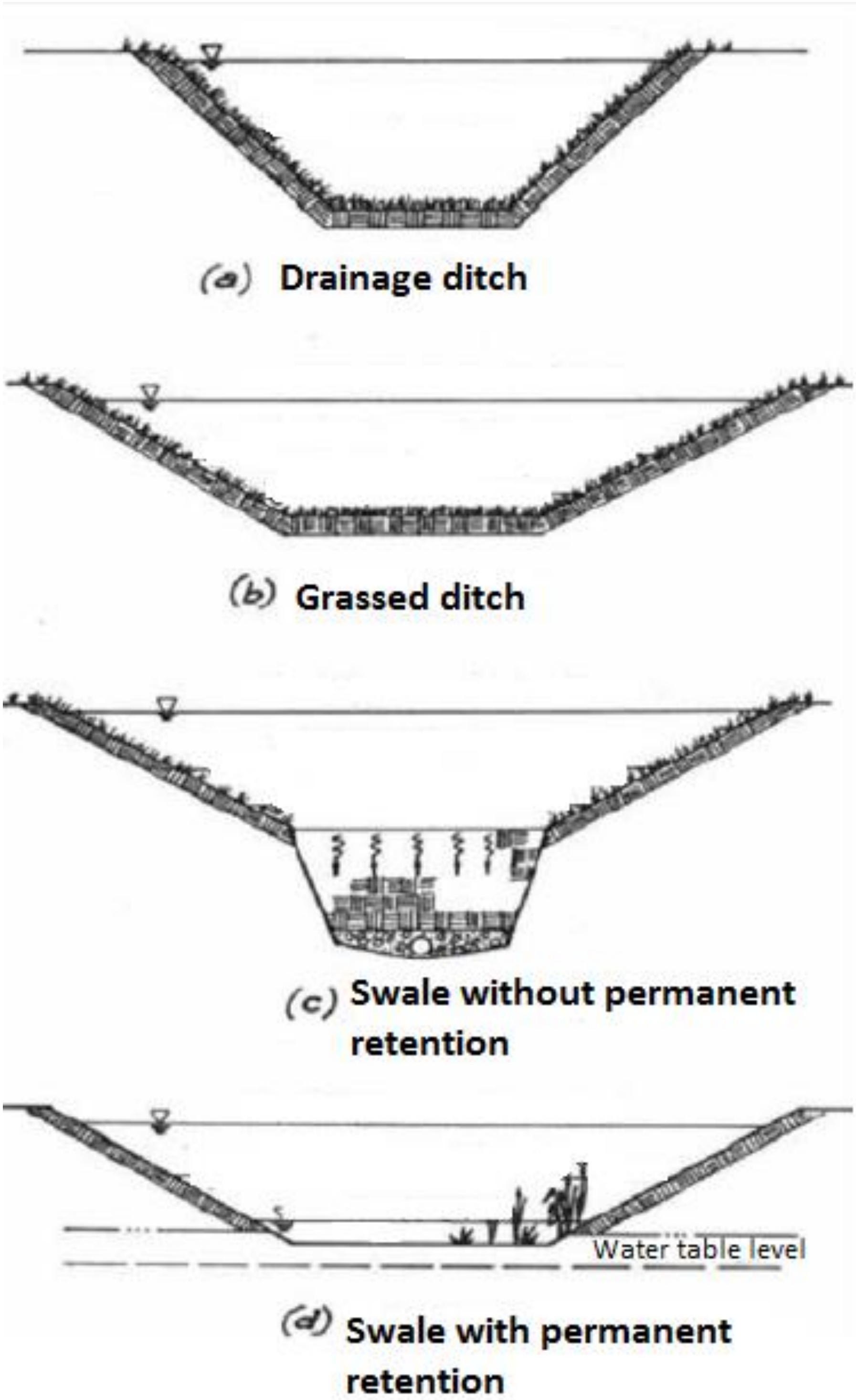


Figure 93: Typology of ditches and swale for rainwater transport (adapted from Claytor and Schueler, 1996).

3.4.3.4.1 Dry and grass lined swales and ditches

Ditches and grass lines swales are trenches designed not only to convey design flows, but also to treat stormwater (qualitative and quantitative).

Unlike the grass lined ditch, which can only be distinguished from a drainage ditch due to its greater width and gentler longitudinal slopes, the dry swale (grass lined swale) includes an infiltration bed, sometime with a perforated drain. The swale is designed to absorb water fairly quickly, retaining it for quality control. In both cases, an energy breaker is included at the inlet with a cell deliniated by a low berm constructed from different types of materials (permeable berm, wood truss or riprap).

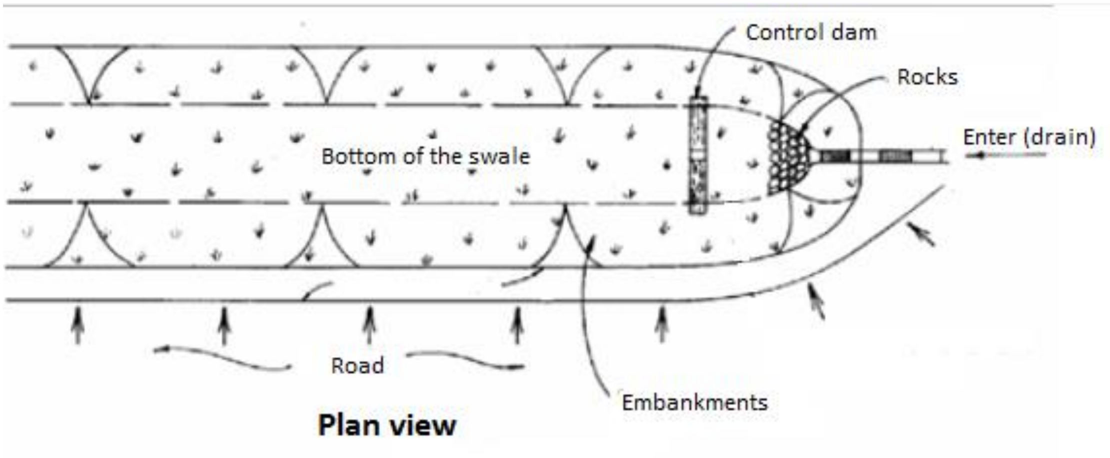


Figure 94: Grass lined swale without retention – energy breakwater device at inlet structure (adapted from Claytor and Schueler, 1996)

Figure 95: Typical grass lined swale without permanent water retention

Grassed swales are particularly well suited to low density residential areas, where the swale, being an extension of the lawn or private ground can be maintained by the individual owner.

- ***<u>Use</u>***

Ditches and swales can be used in various instances:

- Drainage of parking lots,
- Roads and highways and
- Residential developments (on either side of streets or within the central median).

- *__Advantage__*
  - Helps to retain sediment and other pollutants,
  - Allows to some extent control of peak flows by reducing flow velocities and promoting infiltration,
  - Contributes to groundwater recharge when soil conditions and its design concept are appropriate,
  - Good alternative to kerb and drain systems, especially for low-density residential and institutional areas,
  - Can be used in the design of parking lots to reduce the number of impervious surfaces directly connected to the networks,
  - The linear nature of ditches is ideally suited for road and highway runoff,
  - Drains quickly and the gentle slopes and shallow depth facilitate maintenance (Max 3H/1V to 5H/1V),
  - They are generally less expensive to construct than kerb/drain systems.

- *__Drawbacks__*
  - With poor design or inappropriate construction (e.g., if the slopes are inadequate or if the vegetation is not dense enough), gullies will not be effective in settling sediments and pollutants,
  - Swales and ditches can only treat limited tributary surfaces (1 to 25ha, implementation of a network of ditches and swales),
  - May not be easily installed on some sites with multiple vehicle entrances (culvert crossings) or sidewalks,
  - May not be applicable in areas with soils sensitive to erosion or where it is difficult to maintain dense vegetation.

- *__Design Criteria__*

Ditches with a slope of up to 4% can be used to control water quality, but efficiency decreases considerably as the speed increases.

Grass heights should be maintained above 75 mm for better filtration of suspended solids.

- *__Cross section__*

Ditches or swales may have a parabolic or trapezoidal cross section (see following figure). The trapezoidal shape is easier to construct and is more hydraulically efficient. Channels, however, tend to become parabolic over time and it is good practice to ensure this trapezoidal shape.

Deep and narrow ditches are less effective in removing pollutants than wide and shallow ditches.

Ditches or swales should have the widest possible cross-sections to minimize water velocities and heights with flow for quality control.

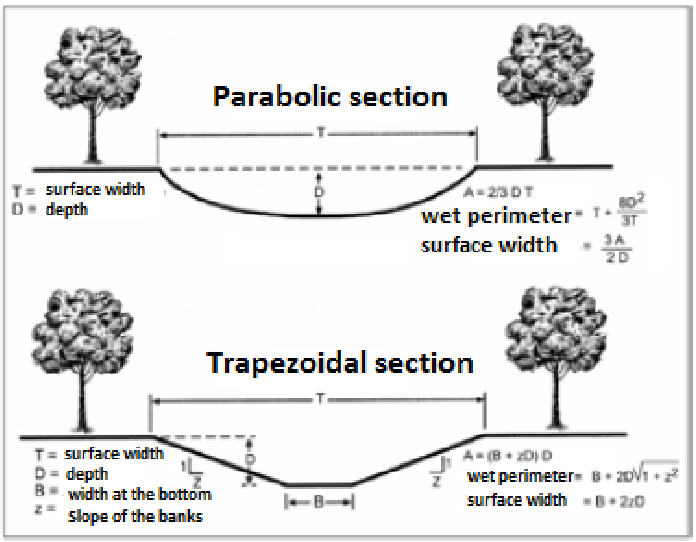


Figure 96: Typical cross sections of dry swale or ditch

- ***Manning n***

This parameter is important to size the swale accurately. Several studies have examined the relationship between Manning's n coefficient and vegetation (Minton, 2005; Wong et al., 2006; FHWA, 1988). As shown in the figure below, the coefficient n varies as a function of water depth and the submerged part of the vegetation. For high water levels, vegetation will be completely submerged, and the coefficient **n tends towards a value of 0.030-0.035. This situation corresponds to the evaluation of the discharge capacity of the drain, e.g. for a flow return period of 10 years or more.**

For small water depths, which correspond to a flow rate conducive for quality control, one should ideally have water depths lower than 2/3 of the height of the vegetation, in order to optimise quality management for this flow rate. The Manning coefficients under these conditions are much higher and **a range of values from 0.25 to 0.35 is recommended for quality control** design.

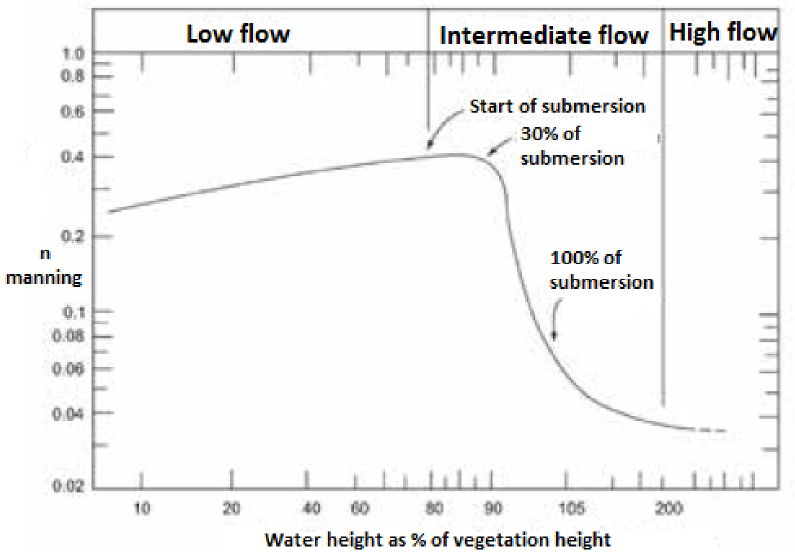


Figure 97: Variation of Manning's coefficient n for channels with vegetative cover (adapted from Wong et al., 2006; Minton, 2005).

- ***Longitudinal Slope***

Optimum efficiency of dry and grass lined swales for stormwater treatment is achieved when the bed slope is kept to a minimum and the bottom is wide (width greater than 1 m). A minimum slope of 1% is recommended, in which case the use of a perforated drain is also recommended.

- ***Side Slopes***

Embankment slopes should be as low as possible for the preliminary treatment of stormwater. A maximum slope of 3H / 1V is recommended with 4H / 1V being the ideal ratio, space permitting.

- ***Flow Velocities***

From a quality control point of view ditches and swales must be designed to convey flow with velocities below 0.5 m/s. This will therefore require wider channels with the lowest possible slopes (minimum 1%). Checks (velocity measurements during the flow period) in order to verify :

- the carrying capacity at the design flow rate (T),
- the control of erosion.

- ***Water depths***

The maximum water depth for the purpose of quality control (design flows less than 6 month to 1 year) should be approximate the vegetation height, aiming at a maximum value of 100 mm. For other design flows (e.g. 2 years for erosion control and 10 years for total capacity), the height will depend on the channel geometry.

- ***Length***

The length will generally be dictated by site constraints (e.g. for entrances). For quality control, a resident time of 10 minutes has been recommended (Claytor and Schueler, 1996; Shaver et al., 2006). The minimum length required for effective treatment can therefore be established by multiplying the velocity (in m/s) by 600 seconds. For a velocity of 0.15 m/s, this represents 90 m. As this length may be difficult to achieve in some cases, the performance of a shorter ditch can be improved by using small check dams to reduce the velocity.

- ***Check dam***

In order to improve performance, small check dams can be installed to increase the resident time and promote infiltration. The dam, made of timber or rockfill, should be 100 to 300 mm high, with a V-shape to minimize erosion. Rip rap can also be used to prevent erosion.

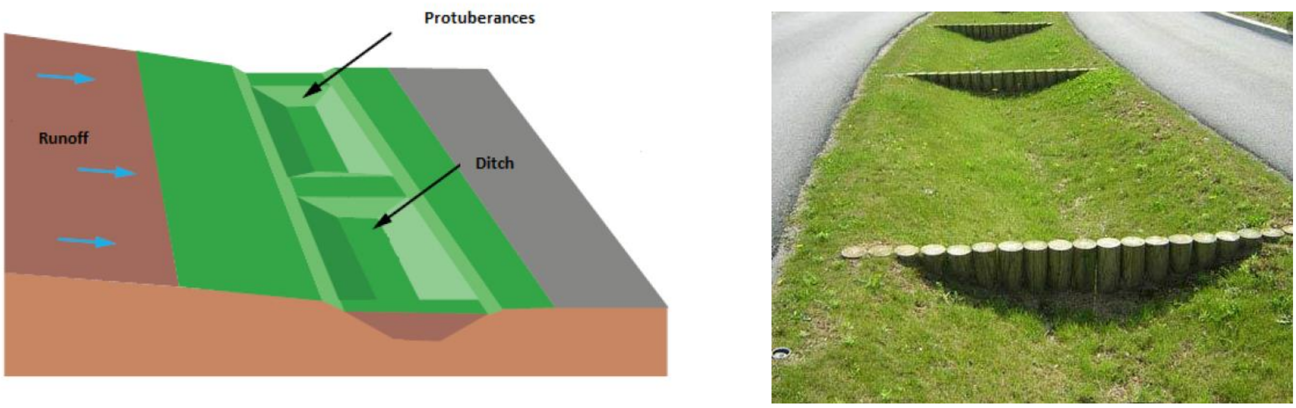


Figure 98: Schematic representation of control dam

- ***Design flow rates***

The design of ditches and swales must be carried out, considering the flow rate for quality control (with the objective of minimizing water heights and flow velocities for these conditions), the flow rates for evaluating likely erosion and carrying capacity (typically 2 years and 10 to 25 years), with a final evaluation of their performance under more severe conditions (50 years or up to 100 years).

Other references can also be consulted for ditches and swales (Azzout et al., 1994; UDFCD, 2003; Geosyntec et al., 2006; Barr, 2001; MPCA, 2005; Georgia, 2001; Connecticut, 2004; Vermont, 2002; Clar et al., 2004; GVSDD, 2005; Claytor et Schueler, 1996; MDE, 2000).

3.4.3.4.2 Wet swale

A swale with permanent water retention is a combination of a swale system and a constructed wetland. Unlike a ditch that is kept dry, the permanently impounded swale has no infiltrated bed and may or may not intercept the water table. This type of swale is typically wider than a dry swale (4 to 6 m) and controlled dams are used to create small water impoundments.

Because of their size, these amenities are more suited for roads and highways rather than for streets in residential areas.

- ***Advantages***
    - Controls peak flows by reducing runoff velocities and promoting infiltration;
    - Provides an effective pre-treatment for amenities in series by capturing, filtering and infiltrating pollutants;
    - Promotes a natural landscape;
    - Costs less than traditional drainage systems;
    - Provides quality treatment through sedimentation and by plants;
    - Enhances biological diversity and creation of habitat.

- ***Drawbacks***
    - Impractical in areas with very gentle or very steep slopes or with poorly drained soils;
    - Large space requirement ;
    - Constraints imposed by entrances (culvert crossings)

- ***Design principles and criteria***

Most of the general principles and recommendations outlined in the section on the dry swales are applicable.

Figure 99: Typical wet swales

3.4.3.4.3 Variant : bioretention swale

Another variant to swales consists in adding bioretention elements (ref 3.3.4.3.3.7) to improve performance in terms of quality control. An interesting variant shown in the figure below involves vegetation, which can be implemented in residential areas such as roadside or road medians. In such cases, a system should be provided to evacuate flows over and above those for quality control (e.g. with retention basins connected to the conventional drainage network).

Figure 100: Typical roadside bioretention swale

This type of development helps to reduce the volume of runoff while controlling quality.

- ***Use***

Bioretention swales can be used in similar fashion to other swale types, with other applications in low-density residential areas.

- ***Design principles and criteria***

The design of this type of amenities should be carried out, considering the features elaborated in the sections dealing with swales and also with bioretention systems.

3.4.4 NbS : Focus on plant species adapted to the Mauritian context

Source : Alternative method to chemical control in the management of grassing in public spaces in Reunion Island: EPL Saint Paul – 2019[19]

Accommodating biodiversity in the urban environment reconnects people to nature (stimulation of the senses, social ties, well-being, etc.), regulates the urban climate and absorbs harmful particles, promote the infiltration and purification of run-off water, preserve sensitive plant species by encouraging their fertilisation (cross-pollination by pollinating insects in particular), preserve wild fauna (small mammals and insects in particular) by providing them with a welcoming environment (installation of refuges, choice of local plants), and regulate invasive species by encouraging the establishment of various plant species. Invasive species must be avoided in view of the challenges posed by the insularity of Mauritius.

The list of suitable plant species (not exhaustive) is as follows:

▷ **Ground cover plants**

This involves planting entire areas with plants forming a thick bottom layer that will quickly colonise the area. Moreover, this low stratum makes it possible to quickly provide plant cover and encourages soil structuring. It is of course necessary to ensure that the hardy species used do not present the risk of being invasive exotic species

Examples:

- *Pouzolzia laevigata*

  Shrub, endemic from Reunion and Mauritius, protected species, semi-dry environment, rocky area, exposure: sun, height: 2 m, fast growing

- *Scaevola taccada*

  Shrub, native to the Mascarene Islands, coastal areas of the island and low altitude, rocky and/or sandy areas, exposure: sun, height: 2 m, fast growing

- *Psiadia arguta*

  Shrub, endemic from Mauritius, protected species, coastal areas: height : 1.5 m, fast growing

- Other exotic ornamental species: *Turnera ulmifolia, Dianella tasmanica, Tradescantia spathacea, Plectranthus neochilus, Ophiopogon jaburan, Evolvulus glomeratus*

[19] Méthode alternative à la lutte chimqiue dans la gestion de l'enherbement des espaces publics à la Réunion - https://formaterra.re/wp-content/uploads/2019/09/livret_1.pdf

Grasslands and meadows

The installation of grass, lawns or meadows is an interesting solution to occupy large spaces.

A distinction is made between:

- **Area lawns and rustic areas :**
  This involves the establishment of a cover composed mainly of turf grasses on sites with little visitor frequency. Maintenance is kept to a minimum to maintain a clean appearance.
  Space maintained at an average height of between 9 and 20 cm, - Intervention initiated at a maximum height of 25 cm, - Minimum height tolerated at 9 cm.
  Species: Cynodon dactylon

- **Grasslands and meadows in natural areas:**
  This involves the establishment of a herbaceous cover, mainly composed of native grass of the heteropogon contortus type and possibly forage plants, the maintenance of which is limited to a few mowings per year (3 to 4 times a year). Intervention just before or during the beginning of the rainy season for sowing.
  Species: Hétéropogon contortus

3.4.5 Management and maintenance of storage facilities

Stormwater retention basins need to be maintained to ensure their longevity and function. This is an important condition for their efficiency and also for their acceptability byft the public.

Maintenance should be adapted to the type of structure. Open basins must be integrated into the urban context, thus the need to maintain a certain esthetic quality and avoid nuisances (bad smells, colour of the water, etc.).

Maintenance must be regular, which requires intervention all year long. Maintenance must be planned from the design stage.

The maintenance and monitoring of stormwater retention basins should be based on a very pragmatic approach, which can be adapted, based on frequent observations of their condition and functioning.

Some operating conditions may vary considerably, and it is not always possible to specify precise general rules on the frequency of interventions or the quantities of residues to be disposed of, for example.

In Mauritius, the problem is important because there is a lot of waste in the networks and the area is subject to a tropical climate. Indeed, the development of mosquito larvae is favoured by tropical climatic conditions. The larval development cycle of the mosquito, from egg-laying to eclosion, requires 8 to 10 days.

As a sanitary rule, the practices on Reunion Island are as follows: "water reserves not intended for drinking, ornamental or irrigation basins, as well as all other receptacles are emptied as often as necessary, in particular to prevent the proliferation of insects. Their cleaning and disinfection is be carried out as often as necessary and at least once a year. ". Therefore, the maintenance of storage facilities in Mauritius will be imperative, if these facilities are at a distance of less than 100m from houses (the distance travelled during the lifetime of an Aedes albopictus mosquito, the vector of chikungunya and other diseases).

3.4.6 Synthesis of Stormwater Best Management Practices in Mauritian context

3.4.6.1 Adaptation to Mauritian context

Mauritius is subject to a particular context in terms of geography and meteorology, like its neighbour the Reunion Island.

These particularities must be taken into account for the implementation of "compensatory techniques for the effect of urbanisation and soil impermeabilisation".

▷ **Rainfall regime:**

Storage and drainage systems may overflow in the event of heavy rainfall in excess of the design rainfall. The impact of these overflows will have to be taken into account to avoid an increase in flood risk. Safety weirs will be designed for a 100-year rainfall for the storage facilities.

It will also need to study the behaviour of the structures for exceptional flooding event set at 1.8 x Q100.

▷ **Steep slopes:**

The installation of these techniques should be adapted in the case of steep slopes, for example by the installation of transverse weirs allowing the delimitation of a succession of reaches with limited slope and falls, in order to optimise the storage volume and reduce the flow velocities..

▷ **A lot of waste:**

Because of the presence of numerous illegal waste deposits in Mauritius, it is recommended that frequent maintenance be carried out, and that importance be attached to the management of this waste when designing the structures. In this respect, vertical comb could complete the arrangement upstream of the storage structures and the swales.

▷ **Presence of agricultural areas 'mixed' with urban areas:**

These areas will have an impact on the storage and infiltration structures (drainage structures), particularly in terms of the contribution of materials (transport or the suspension of materials in the runoff). In this case, it is also recommended that curative maintenance be carried out more frequently, and that the management of these materials be taken into account in the design of the structures.

▷ **Développement potentiel des gîtes larvaires de moustiques:**

Maintenance of storage facilities should be carried out at least every 10 days if they are less than 100m from houses (the distance travelled during the lifetime of an Aedes albopictus mosquito, the vector of chikungunya and other diseases).

3.4.6.2 Decision tree for stormwater best management practices

3.4.6.2.1 General case

The following table presents help to selecting a technique according to the type of town planning.

The following figure also shows the preferential locations for implementation of stormwater best management practices.

Each technique is adapted to the magnitude of the rainfall according to the available space and the suitability of the soil for infiltration, even partial

Table 26: Decision guidance for the choice of stormwater best management practices

		- unsuitable technique / + adapted or conditional technique / ++ adapted technique									
		Dense urban environment		Low-density urban environment		Housing development /Morcellement	Activity area - offices	Industrial area	Commercial area	Public domain (squares, roads, parking)	Reduction of peak runoff flows through :
		Semi-Detached Houses	Residential building	Single-family houses	Residential building						
3	Controlled levelling of properties/ Terracing of sloping terrain and infiltration at source (0)	+	+	++	++	++	+	-	+	+	Increase of concentration times
9	Infiltration Wells or Absorption Trenches within plots (0)	+	+	+	+	+	+	+ (3)	+	+ (2)	Reduction of runoff volumes
2	Rainwater harvesting	++	++	++	++	++	+	+ (3)	+	+	Reduction of runoff volumes
6	Vegetated Filtering Strips	-	-	+	+	++	+	+ (3)	+	++	Increase of concentration times
6	Absorption infrastructure and soil modification	+	++	+	++	++	++	++	++	++	Reduction of runoff volumes
7	Soil impermeabilisation attenuation: Use of permeable Flooring (0)	+	++	+	++	++	++	++	++	++	Reduction of runoff volumes
4	Bioretention or Rain Garden (0)	+ (4)	+ (4)	+ (4)	+ (4)	++	++	+ (3)	++	++	Increase of concentration times and reduction of runoff volumes (0)
1	Surface or Sub-surface Storage depending on the scale and component of the project	-	+ (4)	-	++	++	++	++	++	++	Reduction of runoff volumes
5	Infiltration (0) and retardation swale	-	-	-	+	++	+	+ (1)	+	+	Increase of concentration times and reduction of runoff volumes (0)
1	Dry retardation basin	- (4)	- (4)	- (4)	+	++	+	++	++	++	Reduction of runoff volumes
1	Wet retardation basins	- (4)	- (4)	- (4)	+	++	+	++	++	++	Reduction of runoff volumes
5	Dry and grass lined swales and ditches	-	-	-	+	++	+	+ (1)	+	+	Increase of concentration times
5	Wet swale	- (4)	- (4)	- (4)	+	++	+	++	++	++	Increase of concentration times
5	Variant : bioretention swale (0)	- (4)	- (4)	- (4)	+	++	+	+ (1)	++	++	Increase of concentration times and reduction of runoff volumes (0)

(0): If coupled with infiltration, under condition of permeability > 20 to 35 mm/h
(1): as water is generally charged with pollutants and fines, this technique may not be attractive.
(2): by taking care of maintenance and avoiding practices that could damage the structure
(3): only for water that is not likely to be polluted
(4): problems related to land costs

Figure 101: Stormwater management for new development - range of solutions (Adapted from Ile de France prefecture- France)

3.4.6.2.2 Special cases due to lack of space

Provided that it can be demonstrated that there is not enough space to install retention devices, and for which infiltration conditions are not enough (i.e. only in dense urban areas and for terraced housing projects), rainwater management techniques may be limited to

- Retention tanks for rainwater reuse;
- Reduction of impermeable surfaces - use of permeable flooring techniques (combined with reconstituted and draining soil)

In these cases, it is also recommended that the planning documents include an obligatory proportion of open spaces in order to limit the impermeability coefficient of the land. In this respect, the following values are classically retained:

- Only use of permeable surfaces and tank storage for the historic city centres (continuous buildings);
- 10 to 20% for very dense urban areas;
- 30 to 40% for other urban areas (suburban).

3.4.6.3 Indicative Costs

	These are order prices that do not take into account any particular configurations: rocky terrain, presence of groundwater and, more generally, geotechnical difficulties, need for demolition, cutting of roadways, etc.	Costs			Remarks
		Designation	Unit	Price per unit in MUR	
Vegetative cover and land development planning on sloping sites	Fascine	Installation and planting	ml	500	
	Hedges	Plantings	ml	400	Bamboo, Fatak or Bille
	Fascines combined with Hedges and buffer zones	Installation and planting	ml	600	
	Swales or grass ditches as flow slowing mechanism	Earthworks/excavation/backfil	m3	500	Costs per volume of earthworks, costs per volume of storage vary according to topography
	Flood plains	Earthworks/excavation/backfil	m3	500	Costs per volume of earthworks, costs per volume of storage vary according to topography
	Embankments and dikes (vegetated and small size)	Earthworks/excavation/backfil	m3	500	Costs per volume of earthworks, costs per volume of storage vary according to topography
Stormwater Best Management Practices	Controlled levelling of properties/ Terracing of sloping terrain and infiltration at source	Earthworks/excavation	m3	375	Costs per volume of earthworks, costs per volume of storage vary according to topography
	Infiltration Wells or Absorption Trenches within plots	Earthworks / excavation / hydraulic works.	m3	3500	
		Landscaping	m²	150	
	Rainwater harvesting	Storage tank	m3	10000	Based on a 2000 lts tank with downspout
	Vegetated Filtering Strips	Earthworks/modelling	m3	500	
		Landscaping	m²	150	
	Absorption infrastructure and soil modification	Revegetation of compost, lawns	m²	150	Based on 200 mm of organic top soil
	Soil impermeabilisation attenuation: Use of permeable Flooring	Pervious concrete paving (porous)	m²	800	400x400x100 thick concrete slabs@ 600 mm intervals c/c surrounded by grass for a 1000 mm path with border kerbs
	Bioretention or Rain Garden	Earthworks / excavation / geotextile	m3	700	Costs per volume of earthworks, costs per volume of storage vary according to topography
		Landscaping	m²	150	
	Surface or Sub-surface Storage depending on the scale and component of the project	Open basin without civil engineering: Earthworks / hydraulic engineering	m3	300	Costs per volume of earthworks, costs per volume of storage vary according to topography
		Basin with civil engineering - underground - reinforced concrete / hydraulic engineering	m3	20000	Costs of reinforced concrete
	Infiltration and retardation swale	Earthworks / excavation / geotextile	m3	800	Costs per volume of earthworks, costs per volume of storage vary according to topography
		Waterproofing	m²	900	Inclusive of HDPE liner 1.5mm thick, geotextile underlay and 200 mm thick compacted crusher run 0/20 as support layer
	Dry retardation basin	Earthworks / excavation / hydraulic works.	m3	300	Bulk excavation. Costs per volume of earthworks, costs per volume of storage vary according to topography`
		Landscaping	m²	150	
	Wet retardation basins	Earthworks / excavation / hydraulic works.	m3	300	Bulk excavation. Costs per volume of earthworks, costs per volume of storage vary according to topography
		Waterproofing	m²	900	
		Landscaping	m²	150	
	Dry and grass lined swales and ditches	Earthworks / excavation / geotextile	m3	800	Costs per volume of earthworks, costs per volume of storage vary according to topography
		Landscaping	m²	150	
	Wet swale	Earthworks / excavation / geotextile	m3	800	Costs per volume of earthworks, costs per volume of storage vary according to topography
		Waterproofing	m²	900	Inclusive of HDPE liner 1.5mm thick, geotextile underlay and 200 mm thick compacted crusher run 0/20 as support layer
		Landscaping	m²	150	
	Variant : bioretention swale	Earthworks / excavation / geotextile	m3	800	Costs per volume of earthworks, costs per volume of storage vary according to topography
		Waterproofing	m²	900	Inclusive of HDPE liner 1.5mm thick, geotextile underlay and 200 mm thick compacted crusher run 0/20 as support layer
		Landscaping	m²	150	

Figure 102: Stormwater management for new development – Indicative costs

3.5 Zoning Proposals and main recommendations

3.5.1 General Principle

In terms of stormwater management, the main tool comprises the zoning of stormwater and its associated regulations. The Land Drainage Authority defines and regulates:

- areas where measures must be taken to limit soil imperviousness to ensure control of stormwater flow and runoff
- areas where it is necessary to provide facilities for collection, possible storage and, where necessary, treatment of stormwater and runoff in instances where the pollutants it transfers to the aquatic environment is likely to affect the effectiveness of the wastewater systems.

The stormwater zoning regulations follow from these steps:

- Operational state of the stormwater system,
- Study of the projected functioning of the drainage network with respect to future land development
- Consideration of potential impacts from climate change and responses adapted to the natural functioning of runoff relying on nature-based solutions.

3.5.2 Sizing of retention systems rainfall method principles

3.5.2.1 Principles

In order to determine the retention volumes required at the scale of the project, it is necessary to:

- Provide a method to estimate common runoff coefficients.
- To have a rainfall reference system and finally
- To use a common method for determining the retention volumes: the rainfall method.

The figure below shows the calculation methodology to size the regulation basins. The method and the information necessary for the calculations are elaborated in the following chapters.

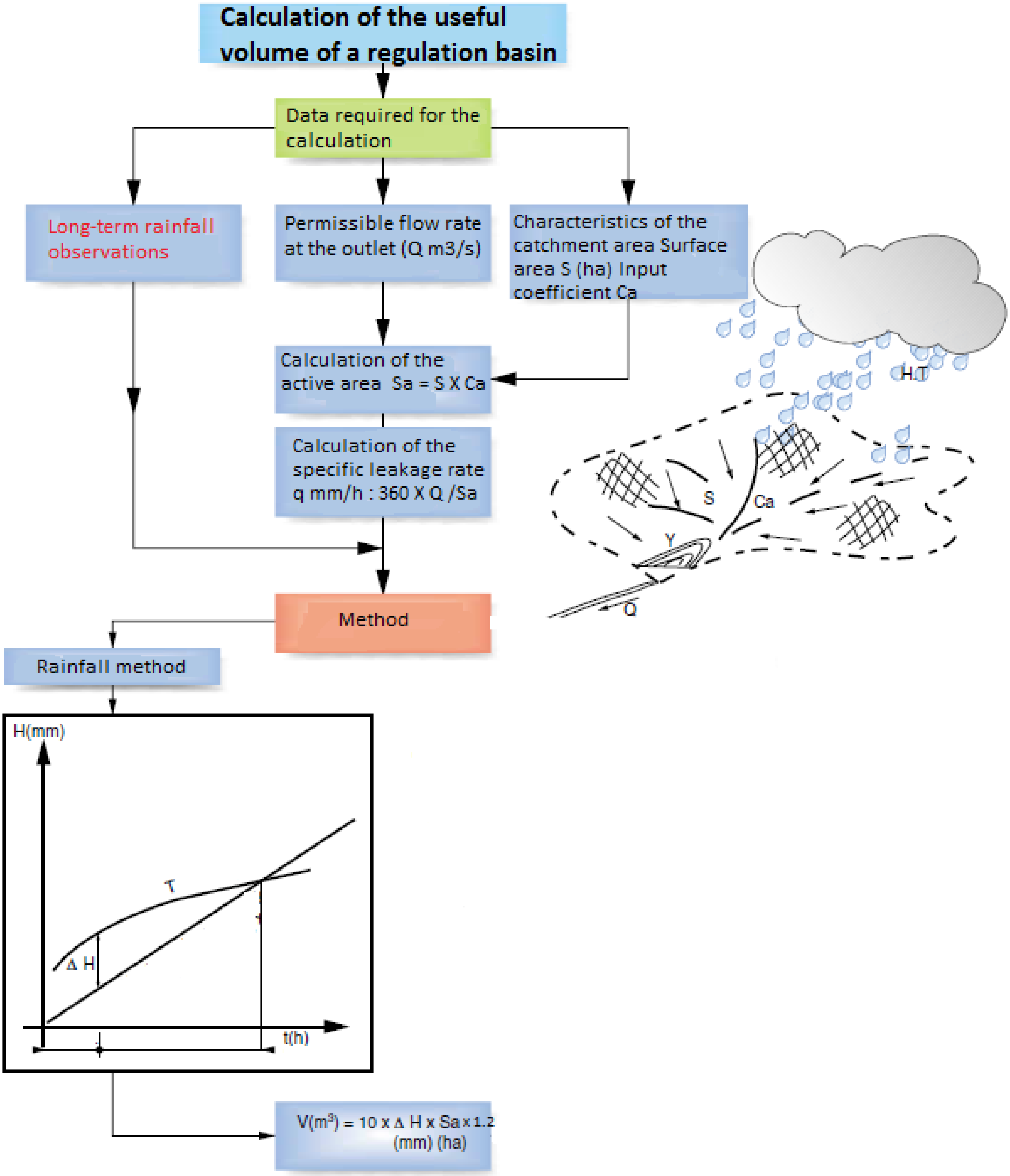


Figure 103: Calculation flow chart for regulation (retardation) basins

3.5.2.2 Runoff coefficient

The runoff coefficient is the most difficult parameter to determine, since its estimation will depend on the flows in an undeveloped (or natural) area that the developer must maintain at all cost, i.e. by not increasing flows downstream of his project.

The runoff coefficient of natural soil depends on its characteristics (sandy, clayey, silty, etc), its cover (meadow, forest, crop, etc), its slope, the intensity of rainfall and its state of saturation related to the past rainfall events

Several concepts need to be defined beforehand:

- **Runoff coefficient:**

$$Cr=\frac{(\text{Runoff volume at time, t})}{(\text{Precipitated Volume at time t})}$$

The runoff coefficient has instantaneous values since it increases progressively as a function of the saturation of the soil during a rainy episode.

- **Input Coefficient :**

$$Ca=\frac{(\text{Total Runoff volume at outlet})}{(\text{Total Volume precipitated})}$$

It is sort of a way to include the runoff coefficient defined above, over the total duration of rainfall.

- And when the project is taken into account, **an impervious coefficient** is defined as follows:

$$Cimp=\frac{(\text{Impervious surface area})}{(\text{Total Surface area})}$$

Note: For the most frequent rainfall, some authors recommend assimilating the impervious coefficient and the runoff coefficient, which leads to neglecting the contribution from natural surfaces. However, for the rare occurrence of rainfall (beyond the annual to biannual occurrence) which has the potential to saturate the soil, the contribution of natural surfaces should be taken into account: coefficients of 0.8 to 0.95 can be retained for 100-years rainfall depending on land use.

3.5.2.3 Determination of Runoff Coefficients and Reference Value

3.5.2.3.1 Detailed approach: spatial consideration of soil saturation for the determination of runoff coefficients

In order to take into account soil saturation, threshold-effect behaviours will be considered: surface runoff occurring after the satisfaction of an initial retention threshold Ia:

The following formula is used to determine the runoff coefficient for non-urban areas for a 100-year return period:

$$Cr(100y) = 0.8\times(1-\frac{Ia}{PJ(100y)})$$

Where :

- PJ (100y) = average daily rainfall for 100 years return period. A simpler approach would be to use the value of 400 mm for the whole island
- Ia = initial abstraction (mm). This parameter is a function of land use and geology.

The following table, resulting from the calibration using the SCS method (Ref D2.2), gives the initial abstraction to be considered depending on the soil type.

Table 27: Ia values per SCS soil group and land use categories

Hydrologic Soil Group	Ia : initial abstraction (mm)			
	Agriculture	Forest	Scrub	Built up area
A	*25*	*42**	*32**	*4*
B	*14*	*42*	*32*	*4*
C	*9*	*22*	*18*	*4*
D	*6*	*15*	*13*	*4*

** Conservative value*

In the formula, "Ia" corresponds to the weighted average of the soil type and the hydrologic Soil Group.

For Cr (10y), a single value of 0.5 is retained. Lastly, for intermediate return periods of 10 to 100 years, a Naperian logarithm adjustment is effected:

$$Cr(Ty)=0.8\times\frac{0.186\times LN(Ty)+0.572^{-33}}{0.186\times LN(100)+0.572^{-33}}$$

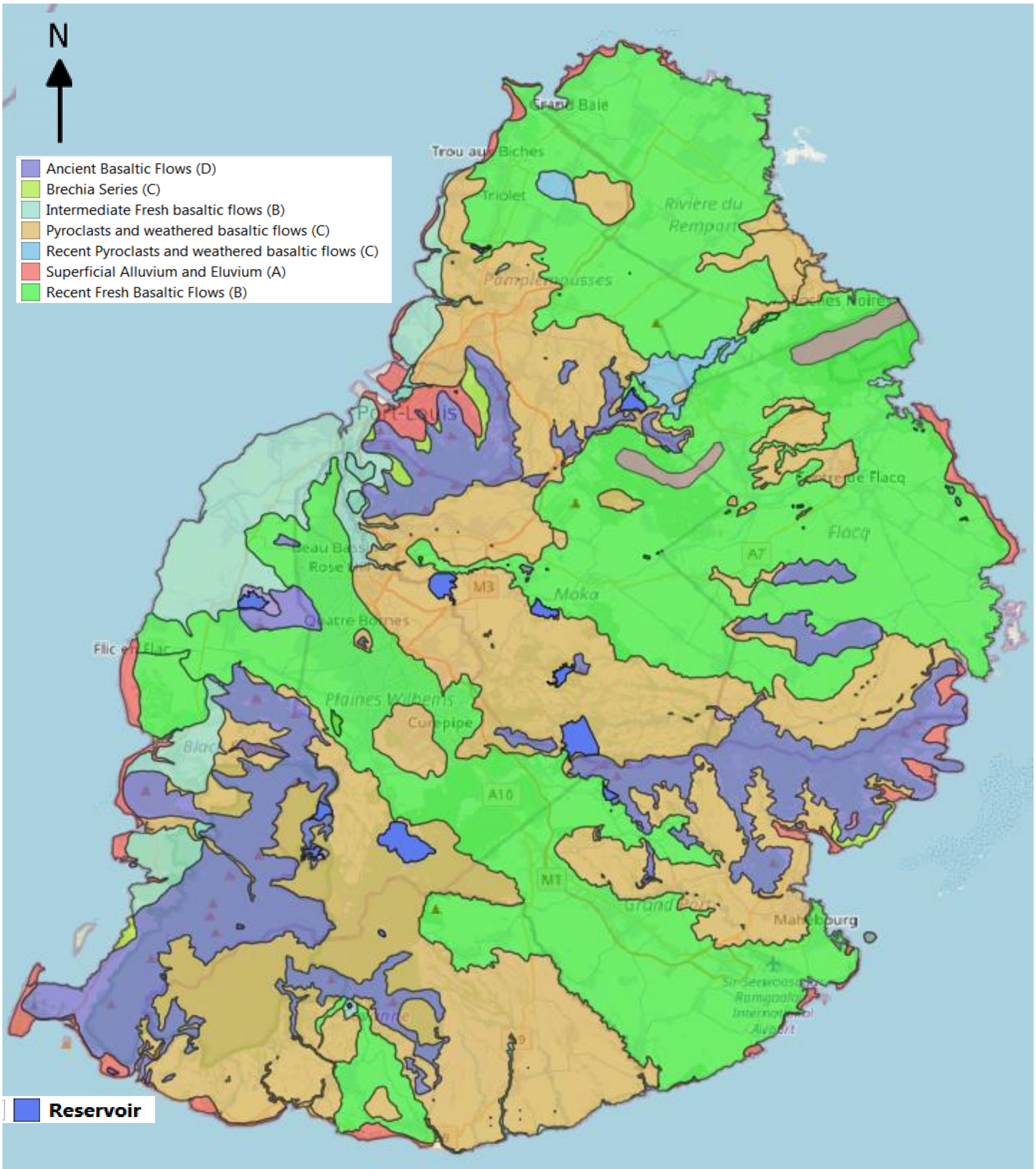


Figure 104: Geology map data GIS ((GIORGI ET ALII, 1999) and SCS soil classification

The following tables show examples of detailed Cr values for different return periods:

Table 28: Example of runoff coefficients - detailed approach

Run off coefficients – Detailed approach for Ia = 42 mm (maximum value)				
Return Period (in years)	**10**	**25**	**50**	**100**
Urban Areas *	0.95	0.95	0.95	0.95
Other Areas(non urban) for Ia max	0.50	0.59	0.65	0.72
Other Areas (non urban) - Conservative values	*0.50*	*0.66*	*0.73*	*0.80*

Run off coefficients – Detailed approach for Ia = 24 mm (average value)				
Return Period (in years)	**10**	**25**	**50**	**100**
Urban Areas *	0.95	0.95	0.95	0.95
Other Areas (non urban) for Ia min	0.50	0.62	0.68	0.75
Other Areas (non urban) - Conservative values	*0.50*	*0.66*	*0.73*	*0.80*

Run off coefficients – Detailed approach for Ia = 6 mm (minimum value)				
Return Period (in years)	**10**	**25**	**50**	**100**
Urban Areas *	0.95	0.95	0.95	0.95
Other Areas (non urban) for Ia min	0.50	0.65	0.72	0.79
Other Areas (non urban) - Conservative values	*0.50*	*0.66*	*0.73*	*0.80*

** As a conservative measure, it is recommended not to differentiate between dense and sparsely urbanized areas.*

It can be observed that conservative estimates of Cr outside urban areas leads to Cr values higher than:

- + 12% for a maximum value of Ia,
- + 6% for an average value of Ia,
- + 2% for a minimum value of Ia.

3.5.2.3.2 Simplified approach: conservative determination of the runoff coefficients

The following table shows values of Cr for different return period:

Table 29: Conservative values of runoff coefficients

Run off table - Conservative values				
Return Period (in years)	**10**	**25**	**50**	**100**
Urban Areas *	0.95	0.95	0.95	0.95
Other Areas (non urban)	0.50	0.66	0.73	0.80

** As a conservative measure, it is recommended not to differentiate between dense and sparsely urbanized areas.*

3.5.2.3.3 Determination of weighted Cr at the catchment level

To calculate the Cr coefficient of a natural or rural catchment prior to any development, an analysis of the land use of the catchment is carried out based on specific criteria. For each particular Iak value, the corresponding area Ak and coefficient Ck are determined. The average runoff coefficient prior to development is calculated by the average weighted area Ak of the runoff coefficients Ck, i.e :

$$Cr = \frac{\sum Ck \times Ak}{A}$$

3.5.2.4 Sizing of the compensation device: Retardation Basin

3.5.2.4.1 Principle of retardation basin

Stormwater management has evolved significantly in recent years, notably through the development of “nature-based techniques”. These techniques can be defined as follows:

Any technique that contributes to maintain the natural water cycle at the scale of the project, both quantitatively and qualitatively.

These are mainly :

- ▷ Delaying runoff flows (controlling runoff flows),
- ▷ Promote infiltration as much as possible (limitation of run-off volumes).

The following drainage works ensue from this "philosophy”:

- Retention and infiltration basins,
- Ditches and swales,
- Drainage trenches,
- Pavements with a water retention structure,
- Terrace/roofs,
- Public Floodable spaces.

The principle of operation remains the same: water is collected, stored in one or more structures, then returned at a controlled flow rate either by an outlet structure (retention / regulation), or by infiltration into the ground (retention / infiltration), or by both.

This principle is described in the figure below:

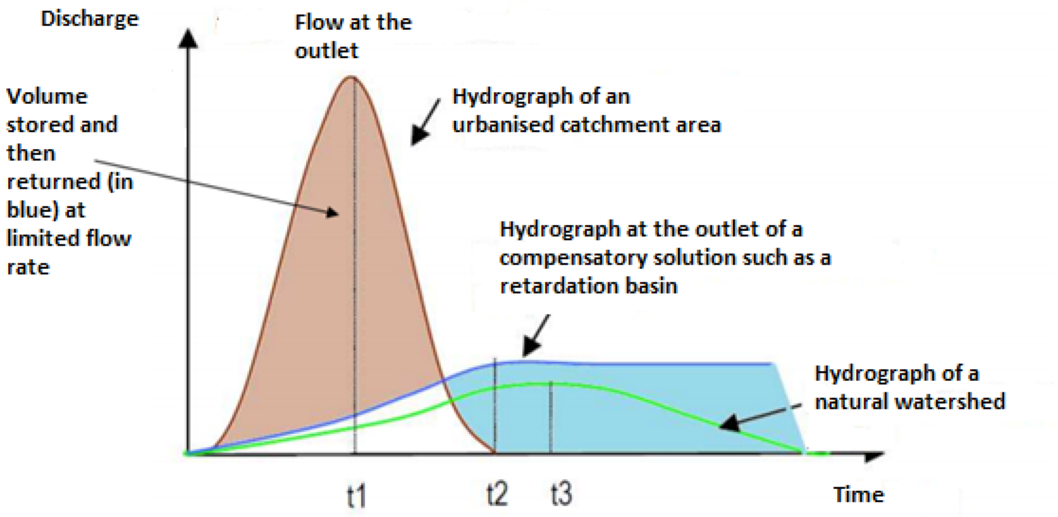


Figure 105: Principle of peak flow regulation by a compensatory device such as a retardation basin

For collection, storage and treatment of water, **preference should be given to open-air systems** such as ditches, swales and grass lined basins to control potential pollution and achieve a partial decontamination of water in particular organic elements.

It should be noted that the retention structures, if properly designed, are clearly adequate to ensure an acceptable level of treatment by **simple sedimentation**. It is recommended to opt for simple structures so that they can maintain their function at the necessary level of maintenance after many years. This is important because it balances the operational means for maintenance and the desired level of maintenance to achieve as near as possible the performance expected.

The sizing of the retention structures must be justified in a calculation note which must highlight the quantitative and qualitative sizing (Ref. below). The sizing is based sequentially on:

- Calculation of the surface area being intercepted by the structure
- Choice of the return period of protection;
- Choice of discharge rate.

3.5.2.4.2 Determination of the active surface area to be compensated

The input coefficient (Ca) measures the overall rainfall yield (the rainfall fraction that actually reaches the outlet of the catchment under consideration).

The following formula can be used to calculate the Ca input coefficient for a catchment:

$$Ca=\frac{\sum Cr\ imp. \times A\ imp. + \sum Cr\ non\ imp. \times A\ non\ imp.}{A\ total}$$

and

$$A\ total=\sum (A\ imp.+A\ non\ imp.)$$

The runoff active surface area (Aa in ha) of an entire development is the product of the total surface area of the catchment (A in ha) and its input coefficient (Ca, without unit):

$$Aa=Ca\ total \times A\ total$$

3.5.2.4.3 Choice of return period of protection (selection of return period of the rainfall envelope curve)

The general trend towards densification of built-up areas can only lead to a high return period of protection for retention structures in a given sector, allowance being made for future upstream waterproofing, while continuing to provide an acceptable level of protection downstream without changing the management guidelines for these structures. **Choosing a high return period in a given sector gives potential adaptive capabilities for this sector.**

Another factor in favour of choosing a high return period for protection relates to uncertainties on precipitation, which are sometimes hastily being considered as extreme, and whose characteristics are, by nature, poorly known. **The return periods resulting from the precipitation count above a given threshold are therefore very sensitive to the duration of data, in particular with changing climate pattern.**

Finally, **hydrological variables do not follow a linear pattern with the return period but rather with their logarithm and therefore a significant increase in security can result in a gradual increase in the volume and the cost of the retention basin.**

Finally, the return period is a variable which requires a minimum knowledge in probability theory. In probability theory, during periods of 20, 30 and 50 years, we have respectively 18.6, 26 and 39.5% of probability to experience an event of return period at least equal to 100 years. These risks are far from being negligible.

The effects of climate change must also be taken into account, especially for the most extreme events (100 years). A detailed analysis and its application are provided in chapter 4.1.

3.5.2.4.4 Discharge rate

▷ **Selection of rainfall event to protect against: Choice based on vulnerability downstream**

The dimensioning of stormwater management system is significantly influenced by the rainfall event taken as a reference, i.e. by the selected rainfall return period. It is **also influenced by the consequences of failure of the drainage infrastructure** (possible flooding).

- **Reference relative to the dimensioning of Stormwater networks**

In general, for dimensioning of stormwater networks, the frequencies of events are based on the verification of two criteria: loading and overflow. These frequencies depend on the location of the project site and the associated assets.

Table 30: Recommended calculation frequencies to be used on the basis of loading and overflow criteria (according to NF EN752, Agence Française de Normalisation)

Place of installation – drainage only *	Frequency of storm calculation for which no loading must not occur		Flooding calculation frequency	
	Return period (1 in "n" years	*Probability of excess for 1 any year*	*Return period (1 in "n" years*	*Probability of excess for 1 any year*
Rural areas	1 in 1	100 %	1 in 10	10 %
Residential areas	1 in 2	50 %	1 in 20	5 %
City centres / areas industrial / commercial	1 in 5	20 %	1 in 30	3 %
Underground / Underpasses	1 in 10	10 %	1 in 50	2 %

* For stormwater drainage, does not apply to natural flows (rivers, streams, rivulet)

It should be noted that network deficiencies (flooding) are accepted for probabilities ranging from 10% per year for rural areas (without stakes) to 2 to 3% for the urban areas most at risk for property and people.

The requirements of the LDA and current practice and guide (PPG) in Mauritius are higher.

Within the framework of the land Drainage Master Plan, the following frequency of events corresponding to the type of infrastructure are retained. Free board values recommended for the passage of floating material are also indicated.

Table 31: Recommended calculation frequencies to be used on the basis of loading and overflow criteria (according to NF EN752, Agence Française de Normalisation)

S.N	Infrastructure	Minimum Rainfall Return Period (years)	Minimum free board required in m
1	Drains (urban area)	25	0.3 m
2	Discharge into watercourses (including Feeders, Rivulets, Rivers)	100	0.5 m
3	Culverts	50	0.5 m
4	Bridges	100	1.0 m

These reference values can also be used for sizing alternative stormwater management techniques for flood protection. Nevertheless, the implementation of retention at source is required to protect or reduce the vulnerability of downstream assets, an objective to which the design and dimensioning of the structure must then be adapted. Thus, a vulnerability downstream (presence of a very busy underground passage, attractive commercial zone, etc) can be used for sizing a retention structure to take into account a larger return period (up to 50 or 100 years).

In all cases, it is also necessary to study the potential consequences of exceptional events (set at 1.8 X Q100), leading to a failure of the structures. The analysis will focus on the amenities themselves and those eventually located downstream: submerged zones, preferential flow axes, flow characteristics. The design of such amenities will seek to minimize these consequences through an adapted integration of stormwater management: submerged public spaces, roadsides, etc., without endangering their users.

- **Determination of outlet capacity: Manning's formula**

Manning's formula is used for sizing drains. The **Manning's formula** is an empirical formula to estimate the average velocity of a liquid flowing over a free surface.

The Manning's coefficient n characterises the frictional forces and permits flow velocities to be estimated. It is estimated for each change in the material of the conveying structure.

The Manning's formula is as follows:

$$Q= \frac{1}{n} \times A \times R^{\frac{2}{3}} \times S\ f^{1/2}$$

Where :

- Q = Flow rate (m^3/s),
- n = Manning's roughness coefficient,
- A = area of flow (m^2),
- R = radius hydraulic (m)
    - $R = \frac{A}{P}$ with P wetted perimeter (m)
- Sf = slope energy grade line, assimiled to bottom slope for normal flow

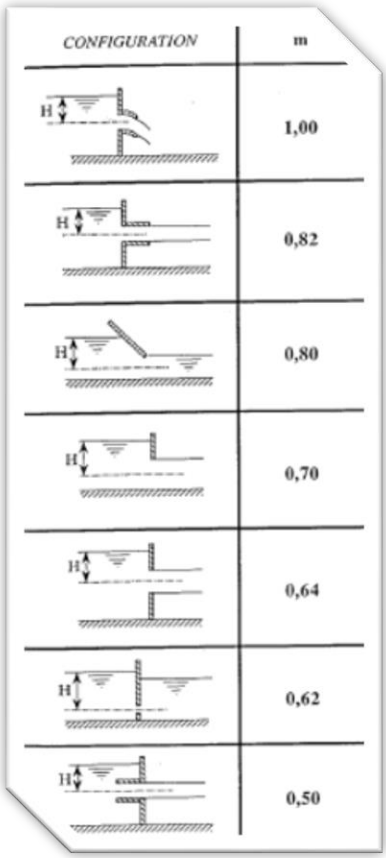
▷ **<u>Orifice sizing principles</u>**

The orifice, used for retention structures with no infiltration, is chosen according to the permissible flow rate downstream. The discharge rate (Ql, in m^3/s) for such structures can be calculated approximately using the following Torricelli's law formula:

$$Ql=m \times S \times \sqrt{2 \times g \times H}$$

Where :

- S: cross sectional area of the orifice (in m²),),
- g: acceleration due to gravity (g = 9.81 m/s²),



- H: Hydraulic head on the orifice (in m) and,
- m: orifice contraction coefficient depending on the orifice shape (for a full small circular orifice m = 0.62)

Orifice contraction coefficient

▷ **Sizing of Spillway: Overflow and fully full**

Sizing of the spillway must be undertaken to discharge a 100-year flow. It will also be pertinent to study the behaviour of the structures for exceptional flooding event set at 1.8 x Q100.

For a weir, the flow rate is determined from the following parameters:

- Length (L),
- Upstream Head H0,
- discharge coeffient depending on its shape, roughness and environment.

For submerged rectangular weir, the discharge flow above a weir is calculated using the following equation:

$$Q=\mu \times L \times H \times \sqrt{2 \times g \times H1}$$

Where,

- Q = discharge flow rate (m^3/s),
- L = weir length (m),
- H_1 = upstream head (m),
- g = acceleration due to gravity (m/s^2),
- μ = discharge coefficient, which depends on the type of structure and having the following range of values:
    - μ = 0.40 to 0.42 for a small rectangular weir with low velocities,
    - μ = 0.35 for a small rectangular weir with medium velocities,

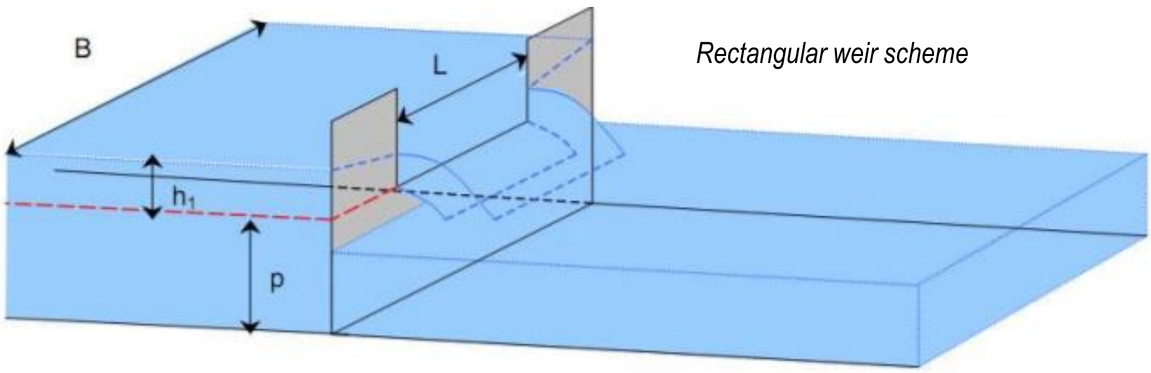


Figure 106: Spillway Sizing

It will be necessary to provide an energy breaker downstream in the form of a depression or chute.

The designer must pay particular attention to anchoring of the weir to resist the strong hydraulic forces.

3.5.2.4.5 Determination of retention volume

Among the methods for calculating the volume of rainwater to be stored, "**the rainfall method**" is the one recommended by the guide "La ville est son assainissement[20] "

This method is based on the use of a graph representing the precipitated height H(t,T) for a given return period (T) and the evolution of the evacuated water heights qs.t as a function of the discharge time (t).

This graph is illustrated as follows:

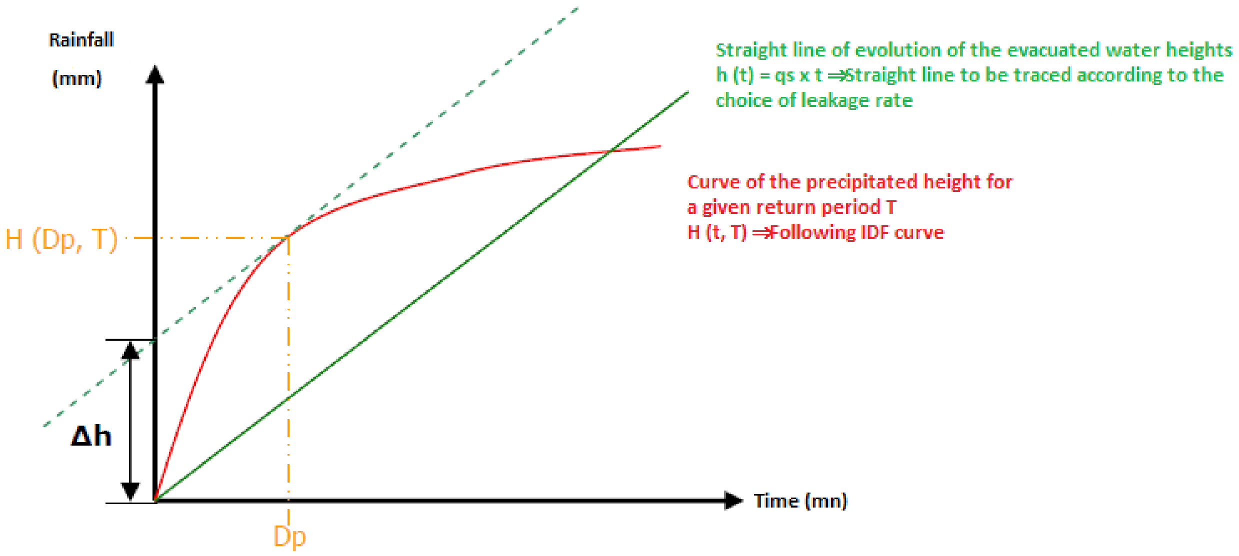


Figure 107: Rainfall method - Rainfall and Evacuated Flow versus Discharge Time

The equations for the precipitation height graph (red curve in the diagram above) corresponding to several return periods (10, 25, 50 and 100 years) and according to different regions of the island are given in Chapter 4.

In order to draw the curve of the evolution of the evacuated water heights as a function of time (green line in the diagram above), it is necessary to determine the gradient of this line (ds). For this, it is assumed that the structure has a constant leakage rate Ql (determined in paragraph 3.5.2.4.4) which is expressed as a specific flow rate ds:

$$qs = 360 \times \frac{Ql}{Aa}$$

Where,

- qs, specific discharge rate (in mm/h),
- Ql, leakage rate of the structure (in m^3/s),
- Aa, surface area (in ha),

[20] Principes, méthodes et outils pour une meilleure intégration dans le cycle de l'eau édité par le CERTU en juin 2003

On the same graph, the straight line graph for emptying the storage structure is drawn based on the following equation

$$h(t) = qs \times t$$

Where,

- h(t), drained height at time t (in mm),
- t, time (in min).

A line is thus drawn parallel to the line h(t)=qs x t passing through the curve H(t, T). The difference Δh between the curve h(t) and H(t, T) corresponds to the maximum storage height to prevent overflow.

Note: The rainfall method is based using a constant leakage rate Ql; it results in underestimating the volume of the compensating structures. In conclusion, it is recommended to apply a factor of 1.2

The volume of water to be stored can be determined by the following equation:

$$V=1.2\times\Delta h \times Aa$$

Where :

- V, Storage volume of water (in m^3),
- Δh, Maximum storage height,
- Sa, Surface Area (en ha).

3.5.2.4.6 Verification on Storage Volumes

From the data provided in the previous chapter, the volume of stormwater to be stored in the retention structure is known (V). This volume does not necessarily correspond to the volume of the retention structure itself. In fact, the useful volume depends on several determining factors:

- Slope of the structure,
- Depth of the structure,
- Porosity of the material constituting the storage structure (presence of a backfill material),
- Maximum storage depth without causing overflow to the upstream networks.

▷ Slope of the structure

If the works to be implemented is located on a sloping site, the loss of storage due to the slope should be considered during the design. In order to improve storage, partitioning of the structure can be carried out (refer to cross profile below).

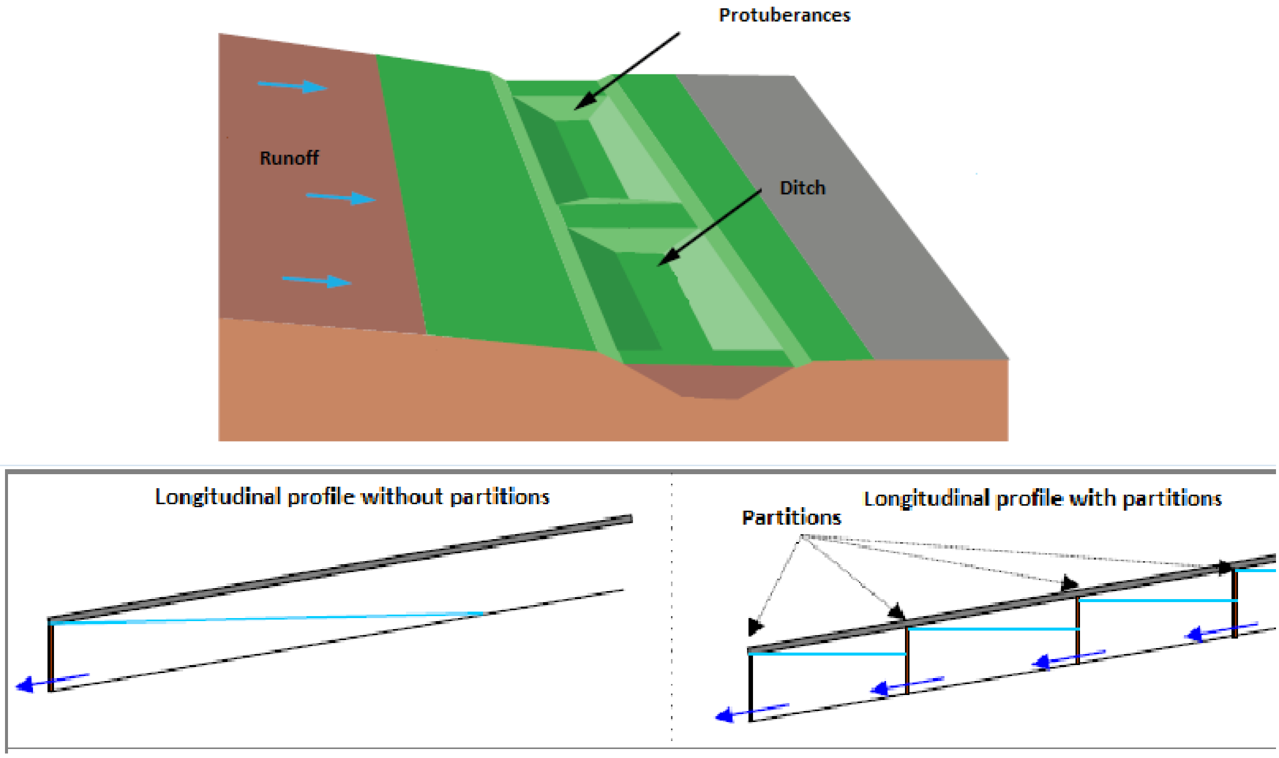


Figure 108: Schematic Diagram of partitioning of retention structures on sloping terrain

▷ Depth of structure

The depth of the structures can sometimes be limited to provide shallow water depths for ease of operation, and also to have manageable water depths for emptying purposes.

For structures with an infiltration mechanism, it is necessary to have a depth of 2 m between the floor of the structure and the highest water level.

For structures discharging into a network or a watercourse, the emptying device must necessarily be located above the invert level of the downstream collector or above the water level of a river, which may limit the depth of the structure or modify the leakage rate accordingly.

▷ **Consideration of consituent material porosity**

To estimate the volume, it is important to include the volume occupied by the materials in the retention structure (gravel, untreated materials of high porosity - 30 to 40%, ballast type 20/60, etc) based on the porosity of each material.

If the constituent material fills the entire storage structure:

$$\text{Total Volume}(m^3) = \frac{\text{Volume to be stored } (m^3)}{\text{Porosity } (\%)}$$

▷ **Maximum height**

When selecting the dimensions of the stormwater retention structure, it is important to check that the maximum allowable height of water in this structure (before overflow) does not result in backflow into the networks upstream, thereby affecting their hydraulic operation.

3.5.3 Application: Rainfall Zoning and Regulations

3.5.3.1.1 Rainfall Zoning - Definition and Objective

Stormwater zoning is a regulatory tool that provides a proactive approach and programming. The rainfall zoning component makes it possible to control runoff and prevent the degradation of aquatic environments during rainy periods in a country.

It sets coherent details at the scale of the study area.

Zoning must be implemented as a matter of priority in highly developing zones.

This zoning can then be used to:

- plan public investments in stormwater management,
- anticipate future impacts of development projects or optimise the benefits of space redevelopment, so as not to worsen the existing situation, or even to improve it.

The relevant authorities generally undertake the zoning exercise as part of a more operational approach, aimed at developing a decision-making tool, the Land Drainage Master Plan.

3.5.3.1.2 Stormwater Zoning Regulations

Stormwater zoning makes it possible to establish regulations (both quantitative and qualitative), such as:

- Control of discharge per plot x l/s/ha or infiltration of a given water mass;
- Technical approach to stormwater management: infiltration, temporary storage, controlled discharge in a separate or combined network, etc ;
- Definition of unit retention volume per new project surface area being made impermeable;
- Possible treatments to be implemented.

The zoning procedure must be the subject of:

- Project Zoning (cartographic feature) and explanatory note including requirements per zone;
- Zoning approval by the relevant legislative bodies which make the zoning effective to third parties.

3.5.3.1.3 Implementation

Builders or developers should be made to implement the following measures for the management of runoff flows:

- For runoff production and transit areas, it relates to **controlling** as much as possible the imperviousness of the soils and counterbalancing the flow rates and volumes emanating from essential impervious surfaces;
- For transit areas, it is necessary that the projects integrate the **free flow from uphill to downhill and the slowing down of flow velocities**;
- For low zones, the development and the building must be designed and built in such a way **considering the local flow conditions** and in particular risks of flooding on the buried parts.

These requirements are addressed in the "No Go Zones" section, where all new urbanisation are prohibited.

As for compensating flows and volumes from newly impervious surfaces, the territory is mapped into stormwater drainage zones.

Each zone is defined, according to the vulnerability of the assets and the drainage infrastructure of the catchment area:

▷ **Maximum permissible discharge rate per catchment surface intercepted: Ql in l/s/ha of catchment intercepted**

The objective is set so that any new impervious surface does not accentuate the actual runoff of the catchment for a 10-year rainfall occurrence. Thus, the maximum permissible discharge rate is fixed as being equal to the natural discharge rate for a 10-year return period for an undeveloped catchment. For this purpose, the results of the rainfall flow model calibrations at the WRU hydrometric station (stations Y01, E12, H02 and M01) were used.

▷ **Compensation volume per active surface area intercepted (including new created active surface areas): V in m^3/ha of active surface area intercepted.**

These unit volumes depend squarly on:

- **Newly urbanized active surfaces:** the more recourse is made to controlling imperviousness (green areas, porous materials, etc) the less will be the useful retention volume.
- **Selection of the return period of rainfall.** Depending on the stakes of the catchment area, and the existing situation pertaining to the risk posed by runoff flow, the following conservative return periods will be retained for the compensation volume:
  - **Zone 1 – Z1:** catchment areas with low to moderate risk (Level 1). The compensation is equal to the volumes generated by a 10-years rainfall.
  - **Zone 2 – Z2:** catchment areas with moderate risk (level 2). The compensation is equal to the volumes generated by a 25-years rainfall.
  - **Zone 3 – Z3:** catchment areas with moderate to high risk (level 3). The compensation is equal to the volumes generated by a 50-years rainfall.

- **Zone 4 – Z4:** catchment areas with high risk to very high risk (levels 4 and 5). The compensation is equal to the volumes generated by a 100-years rainfall.

- **Location of the project** and the corresponding reference rainfall. Projects located upstream of urbanized areas within catchments in the central plateau and receiving most rainfall, will sustain higher needs for compensatory actions.

The graphic and digital applications of this zoning are presented in chapter 5.4.2.

3.5.3.1.4 Regulations for stormwater treatment

▷ **General Planning Principles**

The hydraulic factors aiming to slow down flows downstream and to preserve the natural zones of expansion or infiltration of water, are general rules to be respected for all public or private constructions and new infrastructures. The following main principles are to be respected:

- Water infiltration as close as possible to its source;
- Conservation of natural hydraulic paths;
- Slowing of flow velocities;
- Maintaining free flows rather than channelled flow;
- Reducing slopes and lengthening routes as much as possible;
- Wider cross sections.

▷ **Provisions concerning ditches and thalwegs:**

The covering and channeling of thalwegs and ditches are prohibited, except in specific cases where development is a requirement: providing access structures to the properties and the need to stabilise banks. This measure is intended to upkeep their hydraulic characteristics and to facilitate their monitoring and maintenance. These provisions do not apply to the construction of hydraulic works carried out on the initiative or under the control of LDA.

Responsibility for maintenance of ditches and thalwegs shall, under enacted regulation, rest on riparian owners.

The relevant map enclosed in the appendix shows the Natural Drains to be preserved.

▷ **Respect of the drains flow sections:**

Utility networks (MT, CWA, CEB, etc) and other miscellaneous works should not be installed within or across drains, thalwegs and stormwater ditches.

▷ **Management of stormwater runoff over roads**

Public roads receive free flow of stormwater prior to it being collected through gratings and drainage kerbs into the drainage network. In order to avoid flooding of the dwellings adjacent to roads, the entrance thresholds of these dwellings should be at least at the same elevation as the upper part of the storm drain.

▷ **Source of water**

- **Type of waters permitted**

The stormwater network is intended to collect rainwater and runoff.

- **Waters allowed by way of exemption**

Water drained from swimming pools, fountains, ornamental ponds, etc., exclusively for domestic use, are allowed into the network.

Upon specific arrangement with LDA on a case-to-case basis the following may be discharged into the network:

  - Temporary dewatering during construction phase,
  - Water from construction sites having undergone an appropriate pre-treatment, after authorisation and under control of LDA,
  - Water from an industrial process having undergone an appropriate pre-treatment, after authorization from LDA and under the control of the management department.

- **Water prohibited in the network**
  - All other types of water, and in particular water drained from public swimming pools, untreated wastewater from construction sites and dewatering water are excluded,
  - Likewise, any solid, liquid or gas material liable to endanger the operation personnel in the disposal and treatment works, cause damage to works, or cause obstructions during operation (discharge of toxic products, hydrocarbons, sludge, rubble, tar, grease, plant waste, etc.) are to be excluded,

They must be evacuated by means of appropriate networks and methods.

▷ **Discharge:**

- In the absence of an outlet:

In the absence of an outlet, the water will eventually infiltrate into the land mass. Infiltration devices should be adapted to the soil permeability encountered on the site. The discharge flow rate of the retention structures must be compatible with the infiltration capacities of these devices. If infiltration is not possible, procedures adopted to evacuate the water will be decided on a case-to-case basis with LDA (possible discharge on public road drainage network under certain conditions).

- In the presence of a public outlet:

The water discharge structures must be constructed so as to allow flow in accordance with the flow rate imposed in chapter 5.4.2.

3.5.4 Special case of devices for single-family houses

In the case of single-family developments, the type of retention system must be adapted to the size of the plot and the financial capacity of the owner to ensure the construction and maintenance of the system.

Also, for this type of development, the retention techniques that will be implemented will be simpler and more rustic:

- **by the installation of storage garden;**

A bed of plants or stones located in a depression in the ground and designed to capture rainwater and allow it to be temporarily stored while providing filtration. If the soil is clay, it can be replaced by a mixture of 60% sand, 20% compost and 20% topsoil. Suitable for small retention volumes.

Figure 109: Storage Garden – Individual Residence

- **by the installation of retention tanks -** particularly suitable for the storage of roof water.

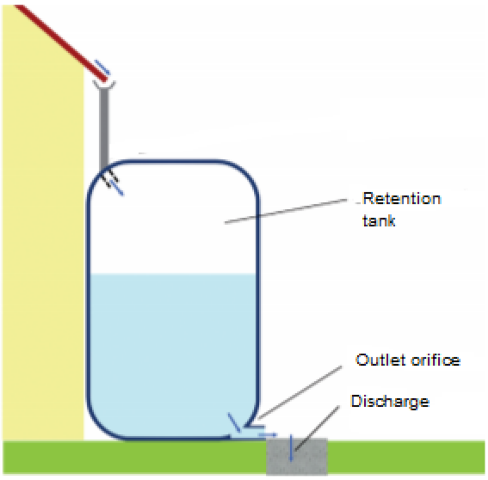


Figure 110 : Retention Tank – Individual Residence

For the sizing of these single-family facilities:

- to ensure island-wide consistency,
- and to make the measure applicable,

a single lump sum compensation will be made according to the following typology: compensation is equal to the volumes generated by a 10-years rainfall as detailed in chapter 5.4.2.2.

3.5.5 Obligations of the Applicant and main verifications by Land Drainage Authority

In order for the rules of stormwater management to be effective, **Land Drainage Authority** will proceed with **essential verifications of the documents submitted by the applicants (project developers).** The verifications will be adapted to local stakes, scope and type of project.

The project submitted for the purpose of autorisation for discharge must be subject to the following verifications:

▷ **<u>Surface Area to be considered:</u>**

The surface area to be considered is not restricted to the impervious surfaces but the total surface area of the project and also the natural watershed upstream being intercepted.

The applicant must support his request with a map or a plan, showing the topography (contours, elevations, etc. extracted from DEM 2019). Where applicable, if the implementation project is phased, the entire project must be submitted for consideration.

▷ **<u>Issues and potential impacts to be considered</u>**

Four main types of issues must be considered by the applicant and then verified by LDA, during the works implementation and operation phase of the project:

- **flood prevention and flow control:** possibility of flooding of the site, hydrographic network, infiltrated/runoff volumes and flows, flood incidence upstream, downstream, and even within the project, during different rainfall conditions from low rainfall to exceptional events;
- **water protection and control of pollutant transfers:** sources of emission, chronic, seasonal or accidental pollutant emissions, transfer mechanisms, potential effects on water and aquatic environments (shock, stress, accumulation);

and optionally:

- **Management of water balance**: reduction of groundwater supply, specific water needs generated by the project with regard to potential rare occurences, risks of restricted use linked to the transfer of pollutants, protection boundary;
- **preservation of ecological areas**: characteristics and achievable mechanisms (ESA).

▷ **<u>Objective and guideline for stormwater management: avoid, reduce or compensate (refer to section 3.4.2)</u>**

To **avoid, reduce or compensate** the impacts of the project, the applicant must define the stormwater management objectives proposed for the different **levels of service**, from low rainfall to exceptional events. They present the guideline of the master plan and the corrective or compensating measures being planned. A description of the proposed infrastructure shall be submitted as early as the preliminary stage (preliminary sizing of structures), or even during the design stage.

This justifies the importance of prevention of the impacts at source:

- preservation of flow axes,
- control of soil impermeabilisation,

- control of runoff and pollutant emissions,
- in situ infiltration for certain levels of service, etc.

The applicant must also list any impacts of the project on the ESAs (exhaustive verification of all the impacts).

▷ **Involvement of development stakeholders**

The submitted document aims at restoring the conditions for integrating stormwater management into the different phases of the project: outline of the master plan, preliminary design, design stage, implementation, handing over and operation. The means of monitoring and intervention in response to the potential risks during the construction and operation phases must be provided. The conditions for a secure access to the facilities and structures should be assured.

Compliance with the guidelines and measures for stormwater management requires identification of the different stakeholders and their roles with respect to the requirements for stormwater management, and the definition of the conditions for coordination, transmission of information and formalisation.

4 DEFINITION OF A REFERENCE HYDROLOGY AT THE SCALE OF EACH SUB-WATERSHED, BASED ON NEW IDF CURVES

4.1 Focus on the effects of climate change on the intensity of extreme precipitation

4.1.1 Ongoing project – BRIO

4.1.1.1 Presentation

L'Agence Française de Développement (AFD) has set up the "Adapt'Action" Facility (2017-2021), which aims to provide technical, methodological and operational support to countries most vulnerable to climate change in order to help implement their commitments made under the Paris Agreement, as a priority in the key area of adaptation. Adapt'Action is intended to benefit, among others, three countries in the Western Indian Ocean (WIO): Comoros, Madagascar and Mauritius. The LDMP is part of the "Adapt'Action" Facility. The program is structured around three axes of parallel and complementary intervention:

- Capacity building and "climate" governance strengthening to ensure implementation and monitoring of contributions determined at national level;
- Support to integrate issues for adaptation into sectoral public policies;
- Support to prepare projects and programs in the field of adaptation.

In this context, AFD supports the initiative of the South West Indian Ocean Climate Outlook Forum (SWIOCOF20), itself part of the ACCLIMATE project (regional strategy for adaptation to climate change) of the IOC (Indian Ocean Commission). The aim is to improve the meteorological equipment and services of the IOC Member States to better cope with the intensification of extreme weather events. In addition, **BRIO**[21] (**Building Resilience in Indian Ocean**) project (2018-2020), in partnership with Météo-France, aims to develop high-resolution climate projections (scale: 12km, Météo France's ALADIN model) to describe the climate in the region up to horizon 2100. It is also a question of training national and regional experts in climatology capable to define and generate climate services adapted to the region, and to provide WIO countries with regional climate simulations which are currently lacking.

Finally, a geoportal must be created to allow the various stakeholders for accessing freely the climate information produced by the BRIO project. For its part, and more generally, the COI ACCLIMATE project aims to improve regional cooperation in the area of adaptation to climate change, and to strengthen the capacities of States in this domain.

[21] https://www.commissionoceanindien.org/portfolio-items/brio

4.1.1.2 Preliminary Findings of Ongoing project – BRIO

Preliminary findings from the project show 3 to 5 °C warming at the end of the 21st century compared to the annual norms (1981-2010) in the catchment, with more pronounced warming on the African continent and Madagascar. This warming is more pronounced within the African continent and less so on the coastal fringes and small islands, such as Réunion and Mauritius.

Region wise, a decrease in precipitation is also expected, with a strong seasonal contrast which suggests a possible increase in the frequency of droughts. Analyses carried out in the framework of the BRIO project are still in progress to qualify the evolution of intense phenomena (extreme precipitation and cyclonic systems) in the catchment and their impact on inhabited territories.

Thus, the detailed studies carried out within the framework of the LDMP, but also within the framework of the BRIO project, have so far not made it possible to conclude on the intensification of significant values of intense precipitation to date.

Changes in rainfall patterns need to be taken into account, both in the design of the flood management system, and in its governance. An approach based on the observed and projected impacts is then adopted: the increase in average temperatures. Recommendations arising from this will then be given in the hydrological chapter and the chapter on general rules (chapter 5).

4.1.2 IPCC – Sixt Assement report - AR6 Climate Change 2021

(Source https://www.ipcc.ch/report/ar6/wg1/#Regional

https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Small_Islands.pdf)

The main lessons to be learned for the geographical area of Mauritius are the following:

- Observed warming (high confidence) in the Small Islands[22] has been attributed to human influence (medium confidence). Warming will continue in the 21st century for all global warming levels and future emissions scenarios, further increasing heat extremes and heat stress (high confidence).
- Ocean acidification has increased globally as have the frequency and intensity of marine heatwaves in some areas of the Indian, Atlantic and Pacific Oceans except for a decrease over the eastern Pacific Ocean. Marine heatwaves and ocean acidification will increase further with 1.5°C of global warming (high confidence) and with larger increases at 2°C and higher.
- Sea levels will very likely continue to rise around Small Islands, more so with higher emissions and over longer time periods (high confidence).
- Sea level rise coupled with storm surges and waves will exacerbate coastal inundation and the potential for increased saltwater intrusion into aquifers (high confidence).
- Sea level rise will cause shorelines to retreat along sandy coasts of most Small Islands.
- **Small Islands will face more intense but generally fewer tropical cyclones** (medium confidence at a global warming level of 2°C and above).
- Speciphic for Western Indian Ocean (WIO) - Declining trends in rainfall are observed in Western Indian Ocean islands over the past 50-60 years.
- Climate information for Small Islands : Though it is clear the climate of Small Islands has and will continue to change in diverse ways, constructing climate information for Small Islands is challenging due to lack of

[22] The WGI AR6 assessment focused primarily on Small Islands in the Caribbean Sea (CAR), Pacific Ocean (PAC) and Western Indian Ocean (WIO).

observations and high-resolution climate projections, as well as the representation and understanding of key modes of variability and their interplay with trends.

One of the findings of the IPCC experts is an increase in the frequency or intensity of intense precipitation. Extreme precipitation events over mid-latitude continents (such as Europe) and in the humid tropics are likely to become more intense and frequent.

4.1.3 Climate change considerations through temperature analysis

4.1.3.1 Observed impacts

(Source: MMS)

Analyses of temperature recorded at Mauritius and its outer islands show a definite warming trend. Average temperature at all stations is rising at the rate of 0.15 °C per decade and has risen by 0.74 – 1.2 °C when compared to the 1961-90 long term mean. At some urban stations the temperature has risen by even greater amounts.

Warming of the atmosphere has also impacted the hydrologic cycle over the southwest Indian Ocean. Long-term time series of rainfall amount over the past century (1905 to 2007) show a decreasing trend in annual rainfall over Mauritius. In fact, the average rate of decrease per decade is around 57 mm. The total decrease during the last ten years is about 8% when compared to the 1950s.

But it is not appropriate to include in a single analysis:

- annual or seasonal rainfall, whose cycle is linked to the global climate at the Indian Ocean scale,
- and short (sub-daily) and intense rainfall, linked to more punctual and short episodes (including heavy rain), such as tropical storms

4.1.3.2 Projection till the end of the century

(Source: Projet BRIO and Météo France)

The maps presented below, produced from global climate models (CMIP5), show more pronounced warming over Madagascar and the African continent than on small islands such as Reunion or Mauritius.

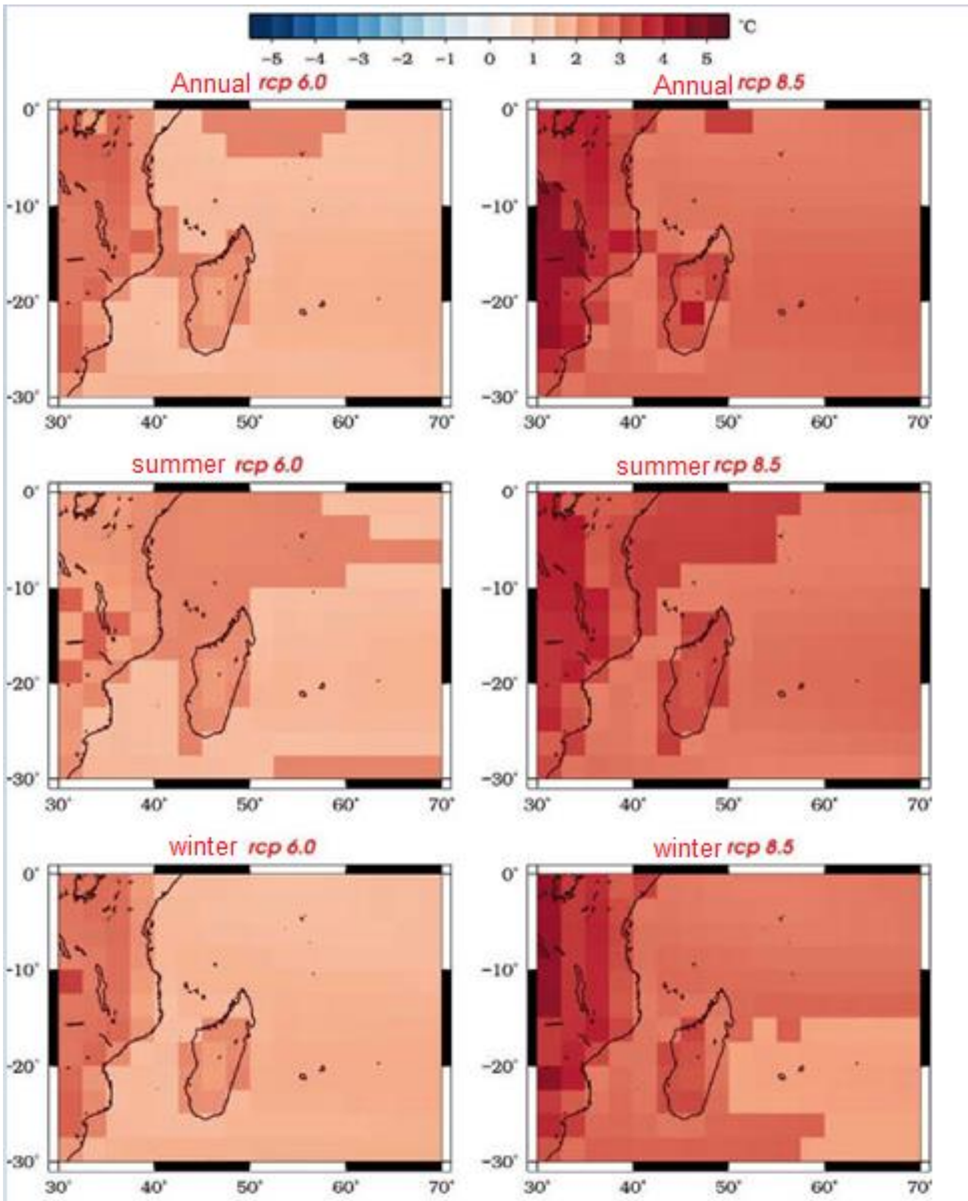


Figure 111: Temperature anomalies for Horizon 2080 (reference period 1971 - 2000)

The rise in temperature is expected to be higher during the warm seasons, auguring more frequent heat waves.

On Reunion Island, the increase in temperatures forecast for the end of the century is set in a range between 1.7 and 2.6 °C according to the 2 scenarios studied (RCP6.0 and RCP8.5):

With:

- RCP8.5: Continuation of demographic growth and uncoordinated development without breach in technological advancement
- RCP6.0: Limiting population growth to 9 billion people, homogeneous development and technological innovations

This value of 2.6 °C increase has therefore been retained for Mauritius.

4.1.3.3 Temperature rise and its effects on the water cycle

(Source : Changement Climatique et Cycle de l'eau - Stephens and Ellis, 2008 (Controls of Global-Mean Precipitation Increases in Global Warming GCM Experiments) / Intergovernemental Panel on Climate Change (IPCC 2013 – Cambridge University Press)[23])

The models strongly simulate global warming for the forthcoming decades, although the magnitude and effect on rainfall remain uncertain, especially at regional level. In all cases, the future evolution is marked by an increase in the global temperature of the planet with a marked contrast according to the adopted socio-economic hypothesis in 2100.

Associated with this temperature increase is an overall increase in atmospheric humidity of about 7% / °C (7% per degree of temperature increase - or even 7% per °K) [24]. **in accordance with the Clausius-Clapeyron law which regulates the amount of water in the atmosphere as a function of temperature.**

The **Clausius-Clapeyron relationship** indicates that the maximum amount of water in vapour form increases with temperature. Observations and models suggest that global warming takes place at almost constant relative humidity, that is, the effective water vapour content increases on average by 7% per °C (or even 7% per °K).

According to the authors of the publication, this growth could be achieved (or even exceeded) for heavy rainfall. On the other hand, the evolution of the average precipitation is also constrained by other factors (energy) and reaches only 2 to 3% per °C (or even 2 to 3% per °K).

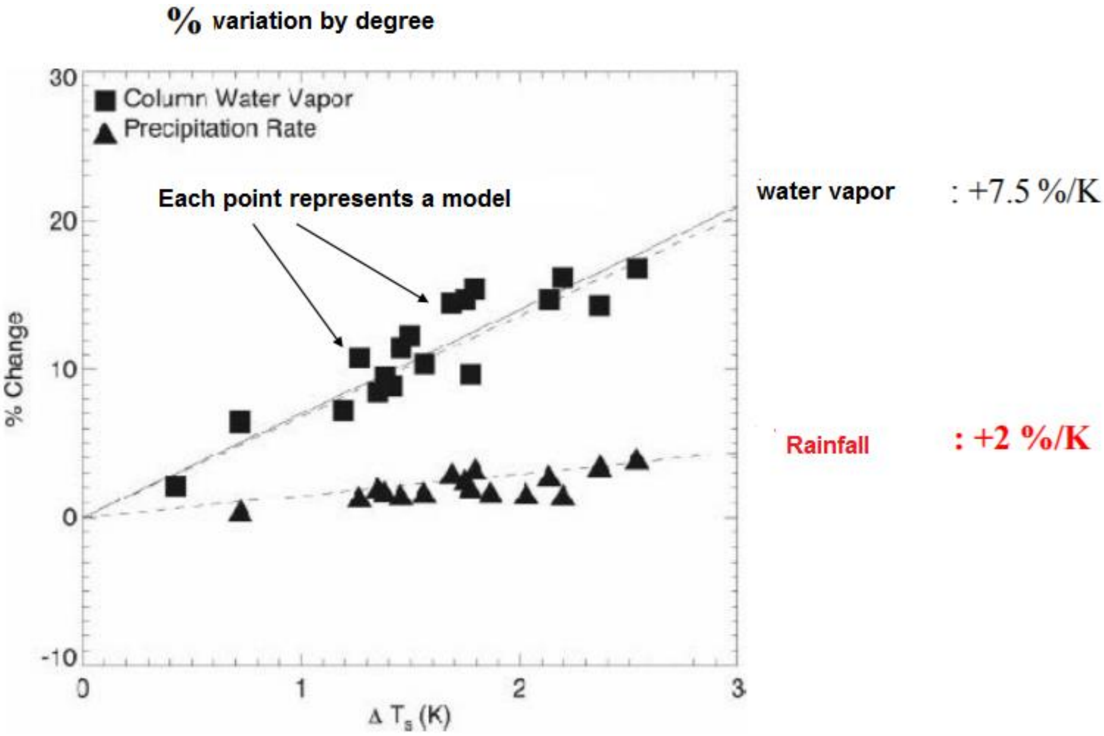


Figure 112: Global Hydrological Cycle Sensitivity- Stephens and Ellis, 2008

[23] https://www.ipcc.ch/report/ar5/wg1
[24] 0 °C + 273,15 = 273,15 K

An analysis of rainfall sensitivity at different time scales was carried out as part of the work of the Intergovernemental Panel on Climate Change (IPCC AR5, 2013).

It shows that, in the models and observations made, Clausius-Clapeyron seems a relevant scale law to represent the sensitivity of extreme precipitation to climate change.

According to the literature in reference:

- climate model predictions of changes in time-averaged global precipitation indicate an expected increase in precipitation of 2 to 3%/°C
- climate model projections for estimates of the increase in local extremes at the 99.9th percentile, for a precipitation duration of 1 hour or less give an expected increase in precipitation of about 7%/°C

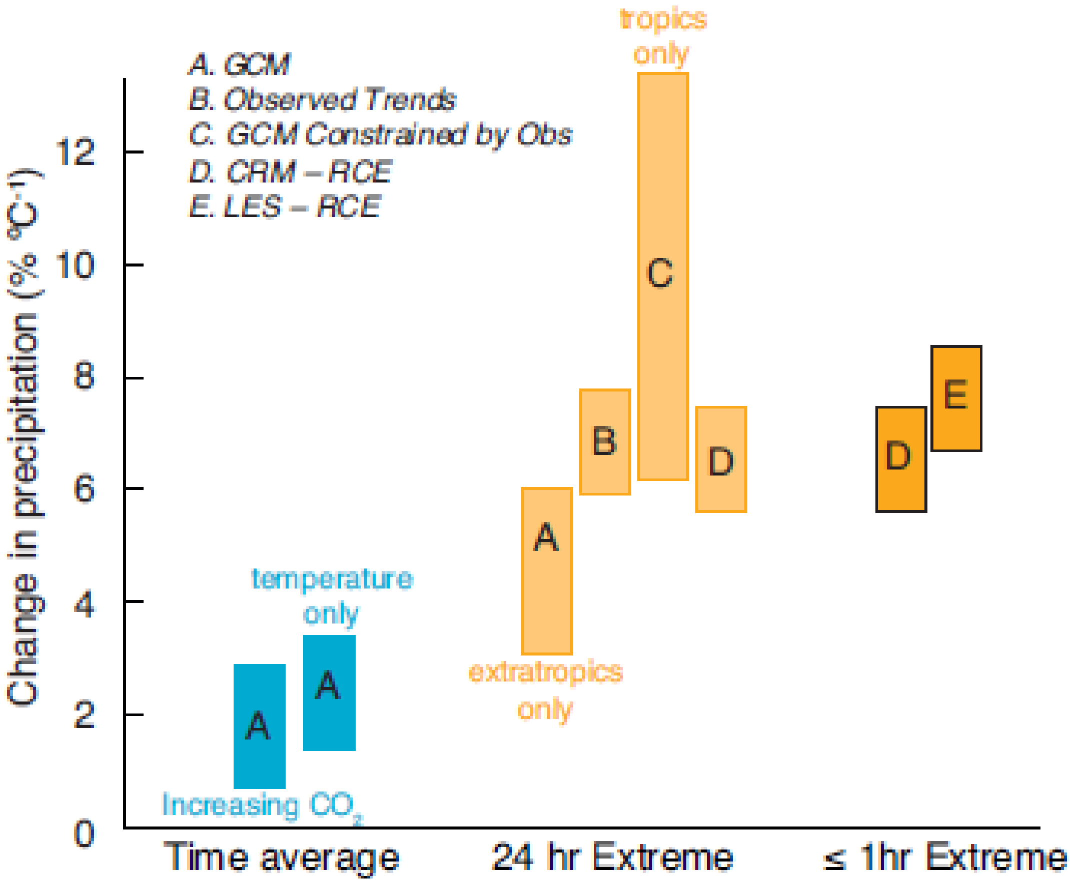


Figure 113: Estimate (5 to 95% range) of the increase in precipitation amount per degree Celsius of global mean surface temperature change - Intergovernemental Panel on Change (IPCC 2013)

On the left of the graph (blue) are climate model predictions of changes in time-averaged global precipitation; at the centre and right (orange) are predictions or estimates of the typical or average increase in local 99.9th percentile extremes, over 24 hours (centre) and over one hour or less (right). Data are adapted from (A) GCM studies (Allen and Ingram, 2002; and Lambert and Webb, 2008, for time average; O'Gorman and Schneider, 2009 for extremes), (B) long-term trends at many sites globally (Westra et al., 2013), (C) GCMs constrained by present day observations of extremes (O'Gorman, 2012), (D, E) cloud-resolving model (CRM) and large-eddy simulation (LES) studies of radiative convective equilibrium (Muller et al., 2011; Romps, 2011).

In conclusion, according to the application of the Clausius-Clapeyron law, which is a relevant scaling law to represent the sensitivity of precipitation extremes to climate change, global warming has an effect on the intensity of extreme precipitation events (frequency greater than 1/98) and of short duration (1 hour).

Thus, rainfall intensities for short periods will tend to be higher, despite the decrease in annual rainfall. On undrained, impermeable soils (effects of urbanisation) or low permeability soils (geological characteristics), these higher rainfall intensities will lead inevitably to higher flash floods (in peak flows).

This conclusion provides an understanding of the recently observed events that generate flash floods in the country. By way of illustration, we mention the following flash floods during the mission:

- **At Plaisance: 375 mm of rainfall was recorded between the early morning of 4 hrs on Friday 16th April 2021 to 14 hrs.**

This rainfall intensities at Plaisance, working back from the new IDF curves, are of the order of :

- **45 mm/hr over a 3 hour period,**
- **46.1 mm/hr over a 4 hour period,**
- **31.8 mm/hr over a 6 hour period**
- **and 37.5 mm/hr over a 10 hour period**

(corresponding to a 50 year, > 100year, 75 year and > 100 year return period respectively).

Ferney

Riviere des Creoles

Courtesy: L'Express, Defi Media, Weekend & Local Inhabitants

Figure 114: Flash flood event – 16 april 2021 – South East region

4.1.3.4 Synthesis: Hypothesis to account for climate change effect on extreme rainfalls

In the context of the assessment of the impacts of climate change on intense rainfall, the studies conducted by the Intergovernemental Panel on Change **(IPCC – 2013- 2019) are a reference.**

These studies allow us to conclude on the following hypotheses to be retained:

- 7% increase in precipitation per °C;
- 2.6˚C increase by 2080;

That is + 18.2% increase in rainfall quantiles (factor of 1.182 to be applied to the IDF).

Note:

It is to be noted that this exclusive hypothesis on precipitation extremes is conservative (safe) with regard to the impact on peak runoff volumes and flows. Global warming will have opposite effects on initial soil moisture (increased evaporation and thus drying of soils) and thus on runoff, both in terms of volume and peak flow.

In addition, this value is applied to all the return periods used in the LDMP, i.e. from 10 to 100 years return period, while effect on the extremes, with a frequency greater than 1 in 98, i.e. close to 100 years is being considered. The conservative (safe) approach of this conclusion therefore affects more frequent events, with a return period of less than 100 years.

4.2 Hydrological Methods

4.2.1 Step 1 : Reference rainfall choice

Rainfall regions are defined on the island as described in task D2.1:

- **Region I: With PJ(10y) > 230 mm** : representative area of the high plateau and the windward coast
- **Region II**: **With PJ(10y) < 230 mm**: representative of the low-altitude and coastal area to the north, and the leeward coast

In order to assess the situation relative to these regions, whether at the level of main watersheds or sub-watersheds, the threshold from following map can be used as a first approach:

Figure 115: Threshold to delimitate Region I and Region II

- **Only for Region II PJ(10y)< 230 mm :**

In the case of an entire region II watershed, the following IDF curve will be applied without modification.

$$H\ (Ty) = a(Ty) \times D^{(1-b(Ty))}$$

Where:

- D = rainfall duration in mn;
- H (Ty) = rainfall in mm for T return period; and
- a(Ty) and b(Ty) are coefficients with the following values:

RII		
Rainfall duration	**6 mn to 2 hrs**	**2 hrs to 24 hrs**
a 10y	7.276	13.206
b 10y	0.457	0.596
a 25y	8.462	14.435
b 25y	0.463	0.587
a 50	9.360	15.391
b 50y	0.466	0.581
a 100y	10.259	16.364
b 100y	0.469	0.577

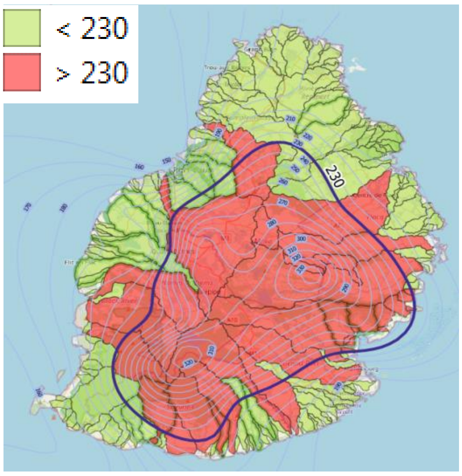


Figure 116: IDF Curve – Region II

- **for Region I PJ(10y)> 230 mm :**

$$H\ (Ty) = Wc\ \times a(Ty) \times D^{(1-b(Ty))}$$

Where:

- D = rainfall duration in mn;
- H (Ty) = rainfall in mm for T return period,
- a(Ty) and b(Ty) are coefficients with the following values:

RI		
Rainfall duration	**6 mn to 2 hrs**	**2 hrs to 24 hrs**
a 10y	9.953	19.741
b 10y	0.455	0.608
a 25y	11.860	22.060
b 25	0.461	0.597
a 50y	13.275	23.789
b 50y	0.464	0.591
a 100y	15.156	25.537
b 100y	0.463	0.587

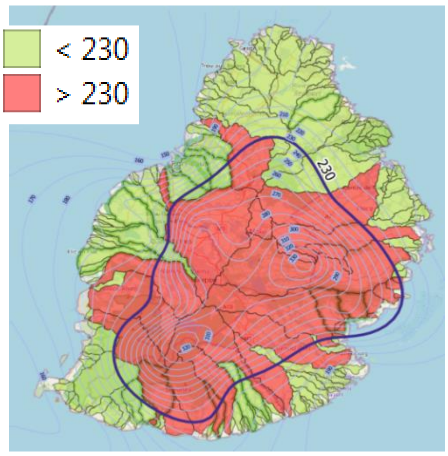


Figure 117: IDF Curve – Region II

• And Wc = watershed geographical localisation factor with the following values:

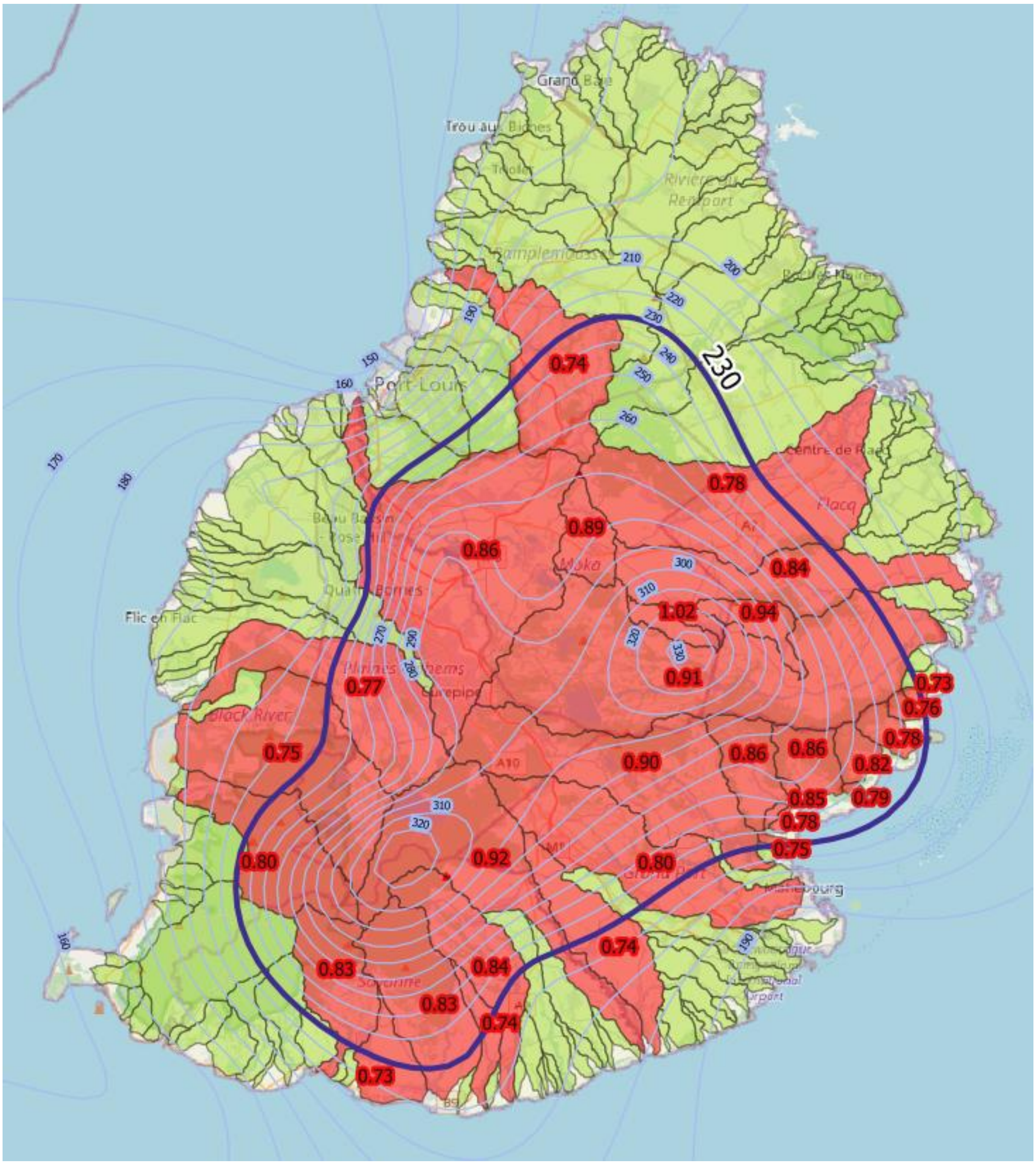
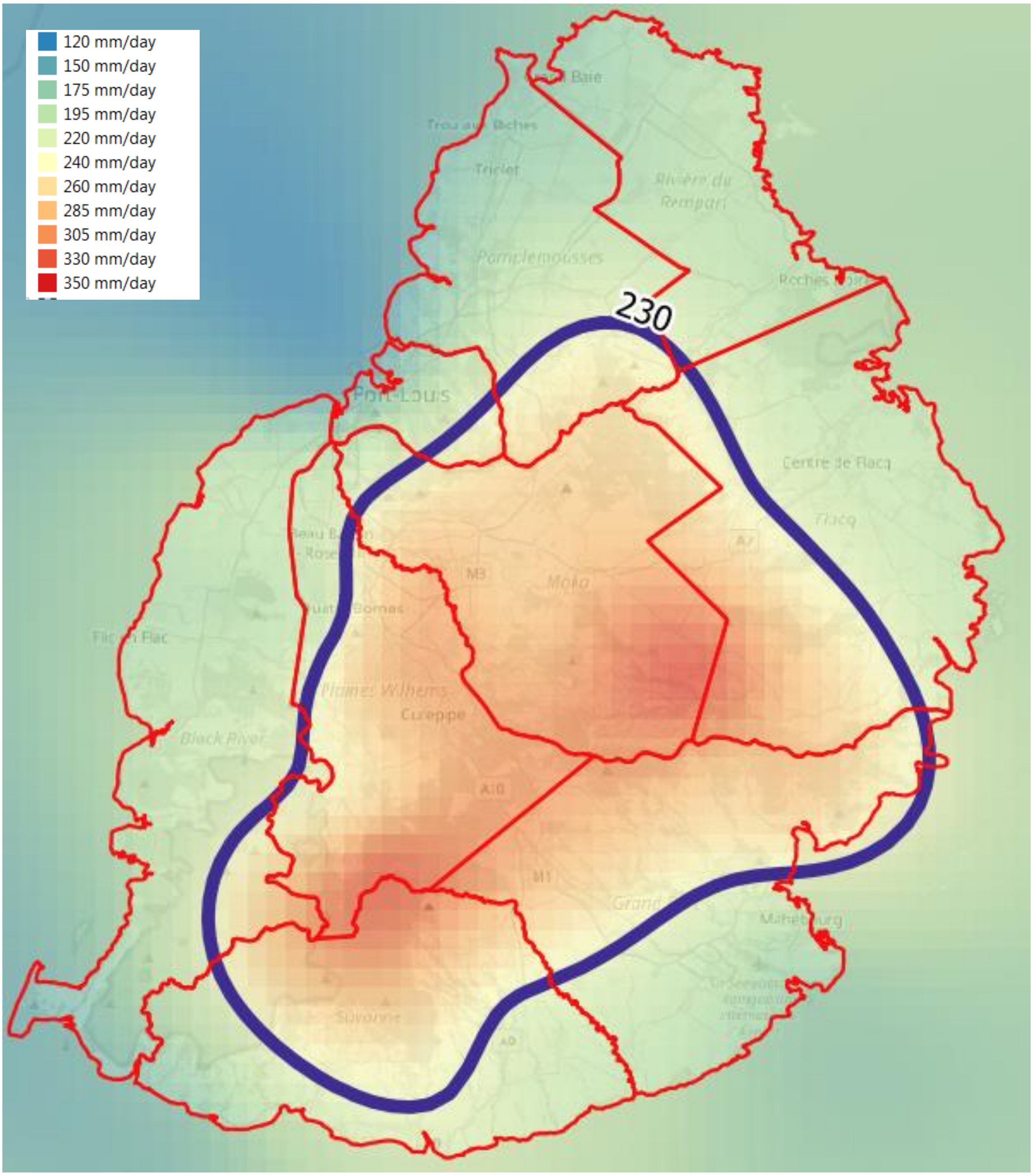


Figure 118: Wc factor values for each main watershed

These Wc factors, applied at the scale of the main catchment areas or even at the scale of the 1 km² grid, represent the regional effect of rainfall for the whole island. This method is the only one which provides a robust estimate of rainfall intensity: these WC factors (at the catchment scale or at the 1 km² grid scale), based on long observation periods (1961 - 2019) instead of only IDF curves based on too short observation periods (2003 - 2019) are valid for all return periods. They have been determined on the most robust statistical estimates, i.e. T10 years, because they have a much longer observation period (58 years) than the calculated return period (10 years).

A more precise Wc factor could be calculated by weighting the PJ 10 quantiles of the 1 km² grid at the scale of the catchment and sub-catchment studied, in which case the raster RP_10y.Tiff (mm) has to be used.



RP_10y.Tiff (mm) – Gridd 1km²

Figure 119: Daily rainfall in mm (1961 – 2018) – RP_10y.Tiff (mm) for Step 1b application

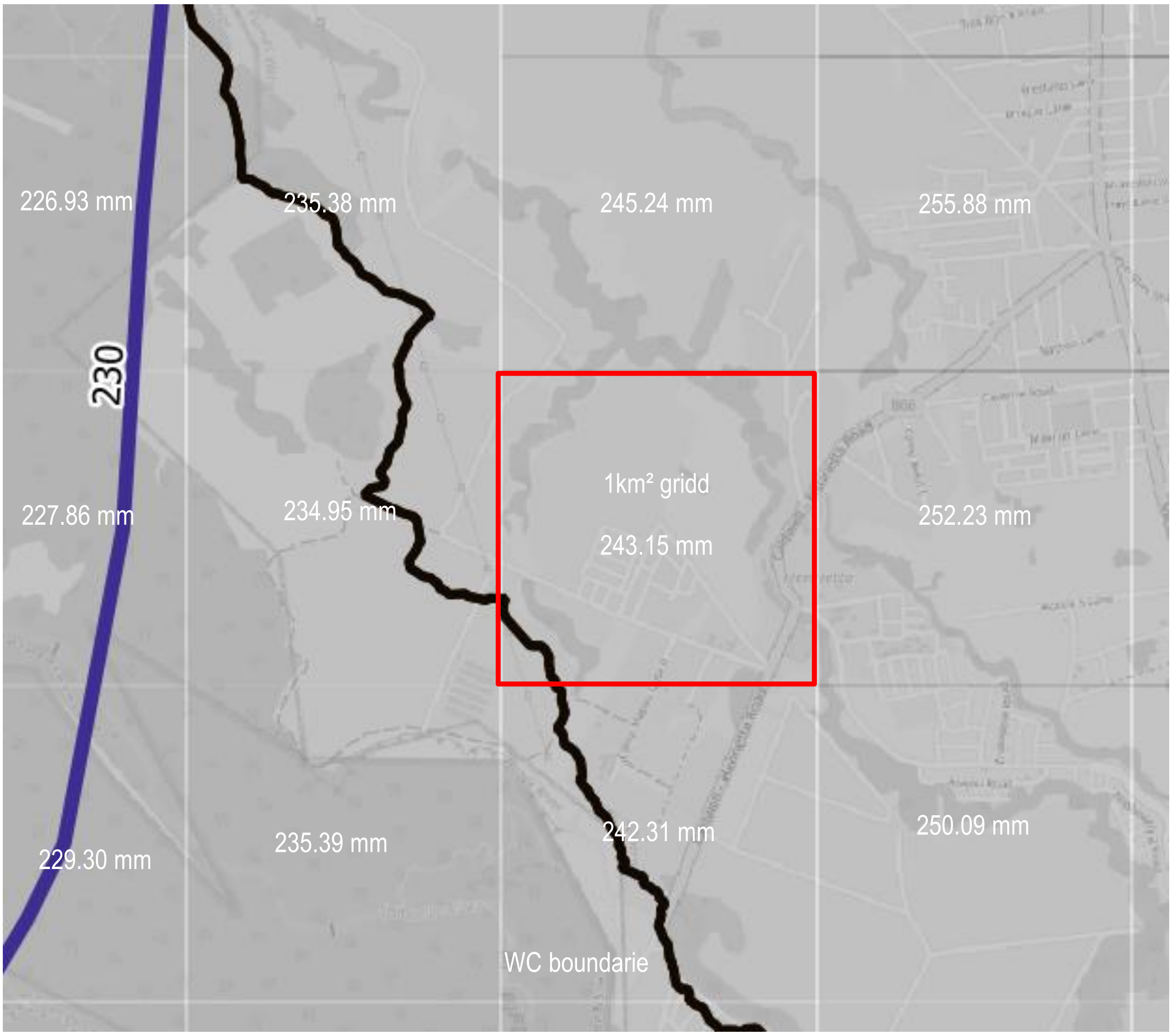


Figure 120: Daily rainfall in mm (1961 – 2018) – RP_10y.Tiff (mm) – local detail of Gridd 1km X 1km

The following maps show the rainfall isohyets for durations of 1 to 3 hours and for return periods of 10 to 100 years established on the basis of 1km² rainfall grid.

- Duration: 1 hour

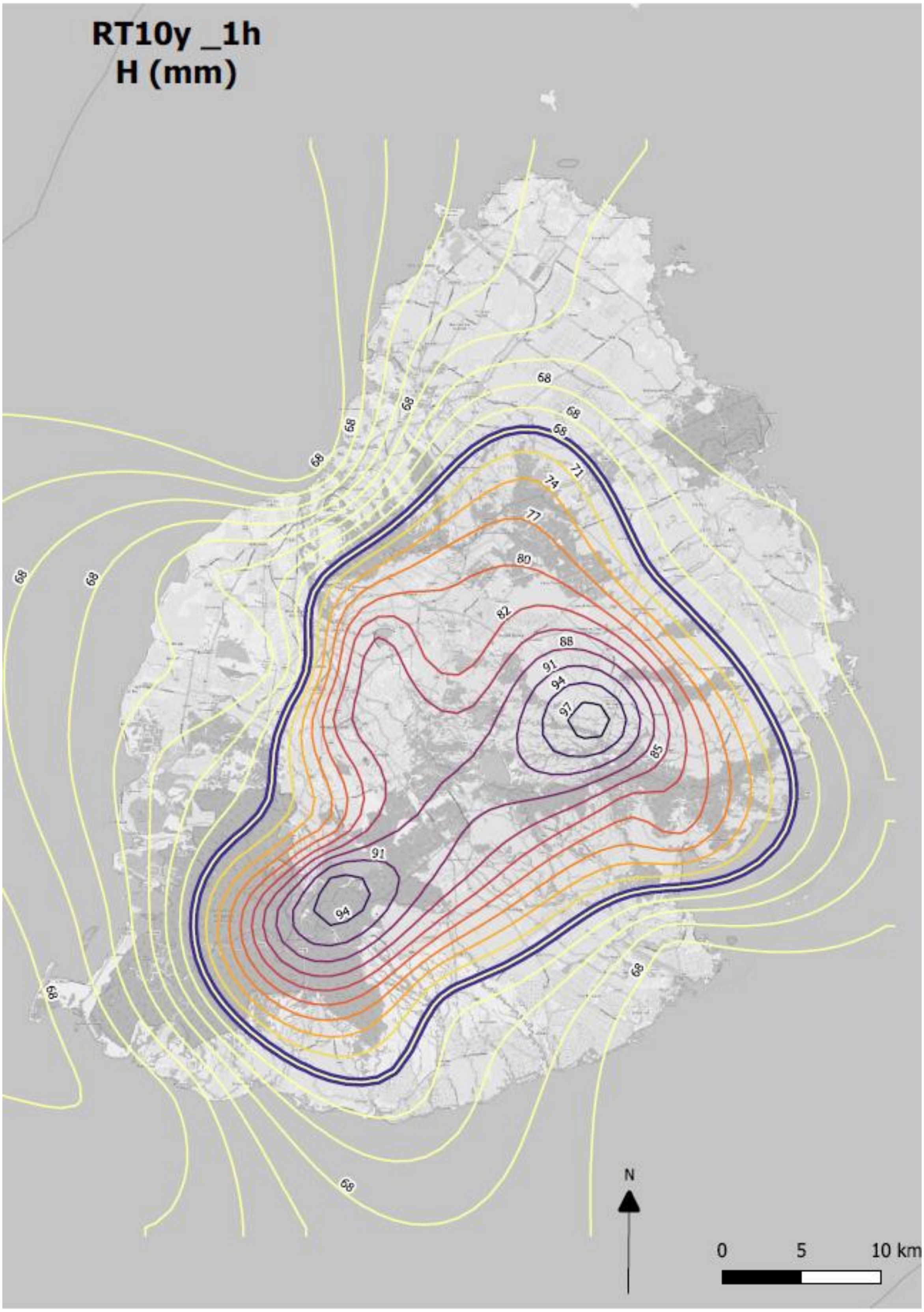


Figure 121: Rainfall isoyets: Duration 1 hour, return period 10 years

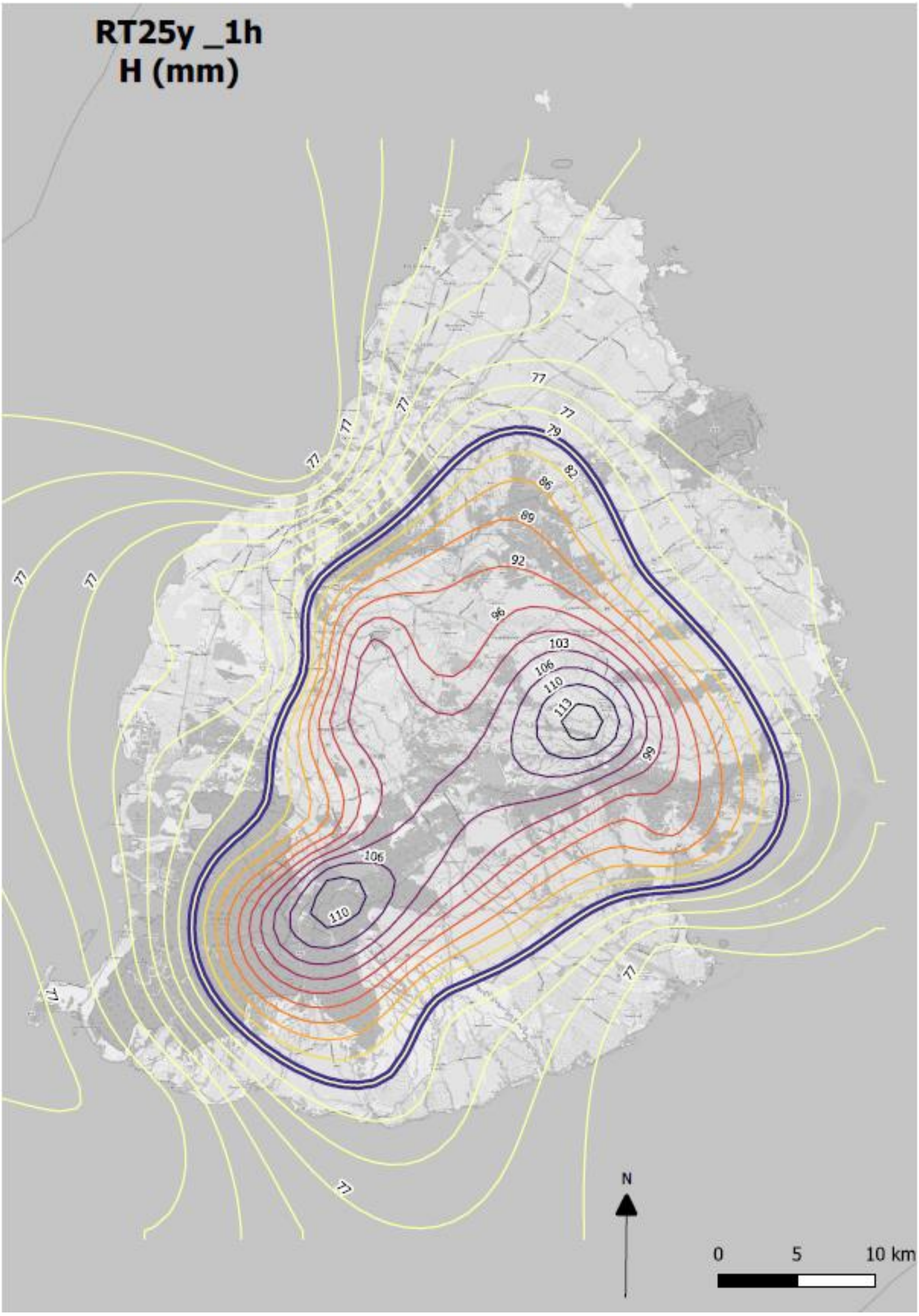


Figure 122: Rainfall isoyets: Duration 1 hour, return period 25 years

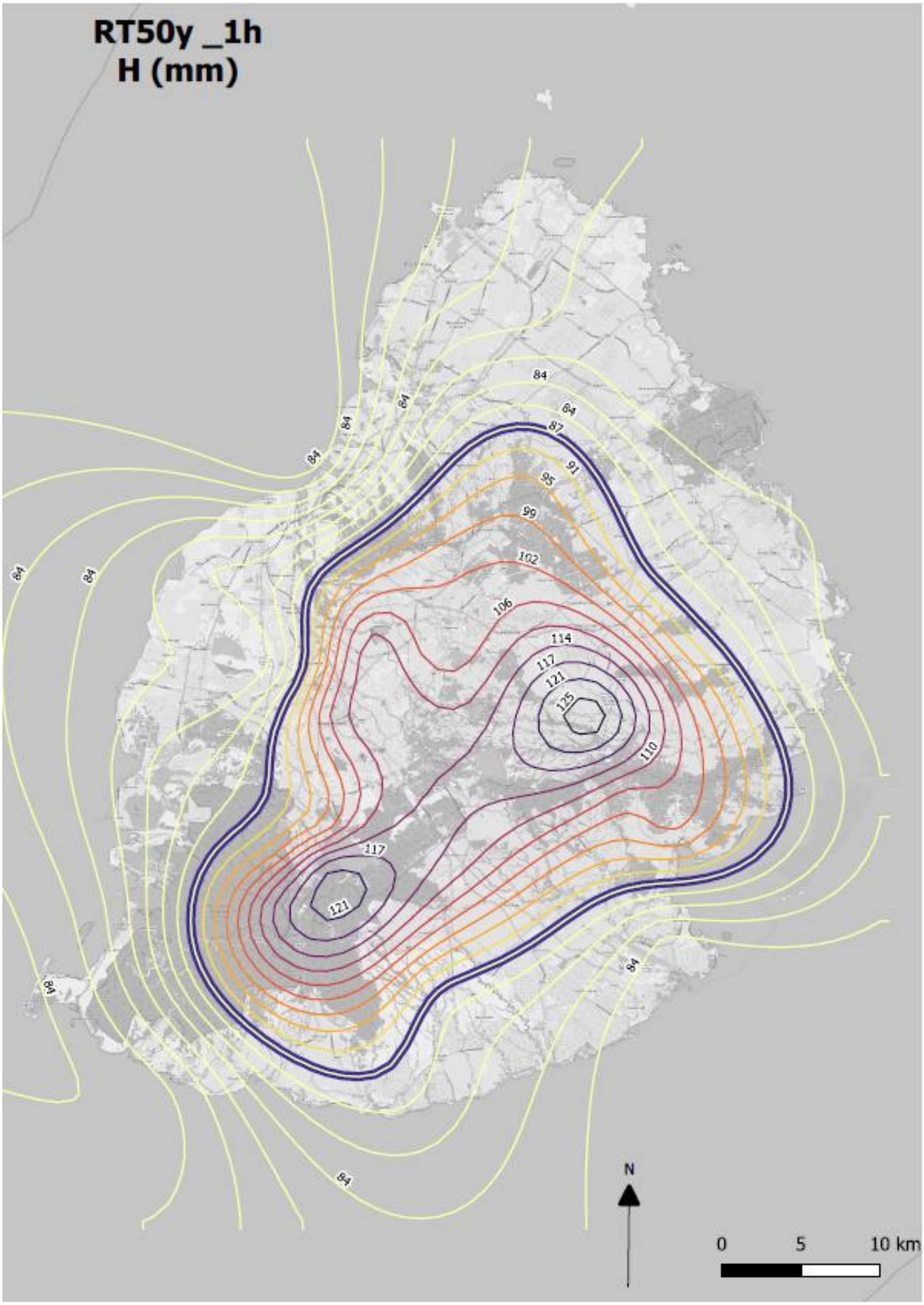


Figure 123: Rainfall isoyets: Duration 1 hour, return period 50 years

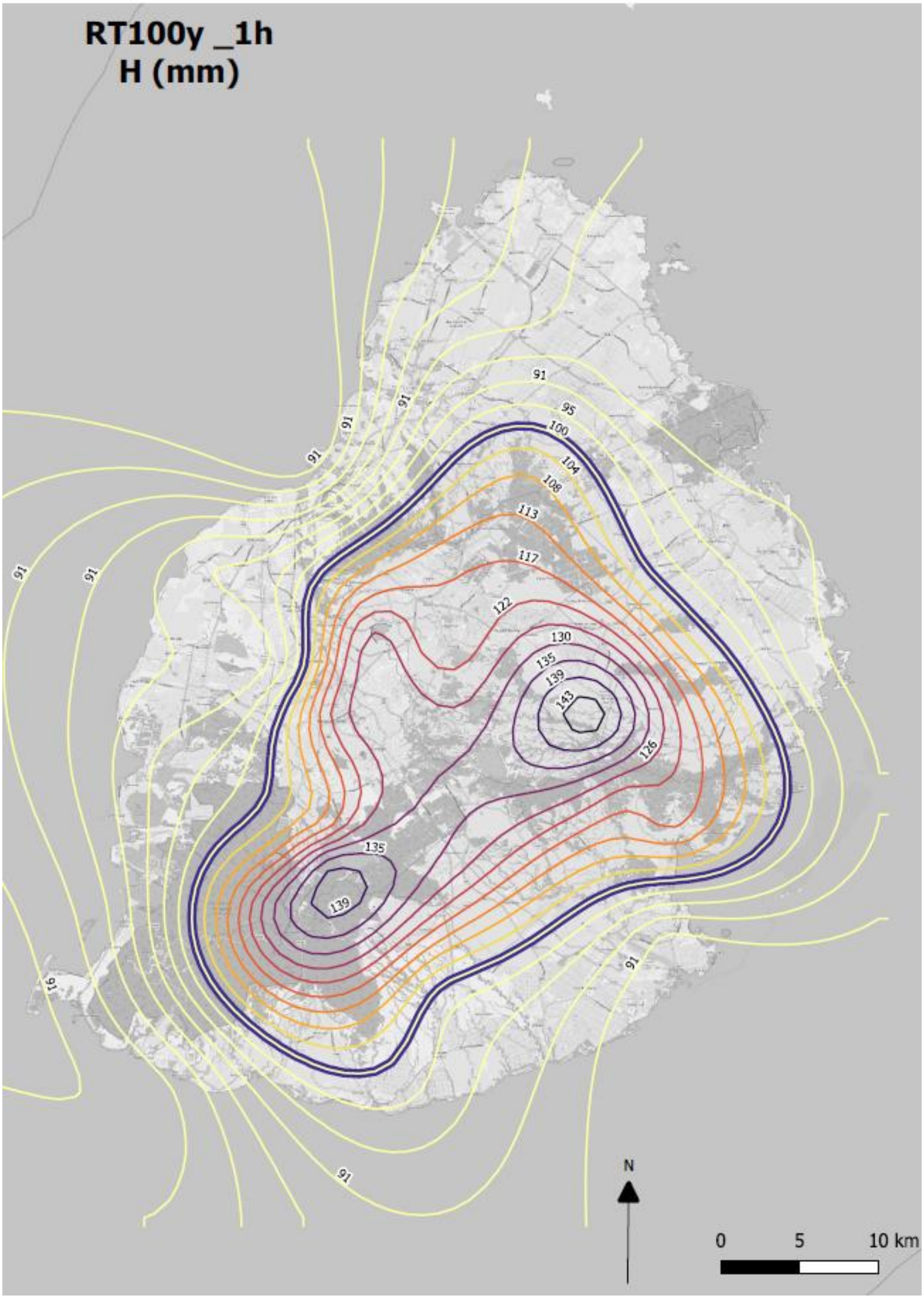


Figure 124: Rainfall isoyets: Duration 1 hour, return period 100 years

- Duration: 2 hours

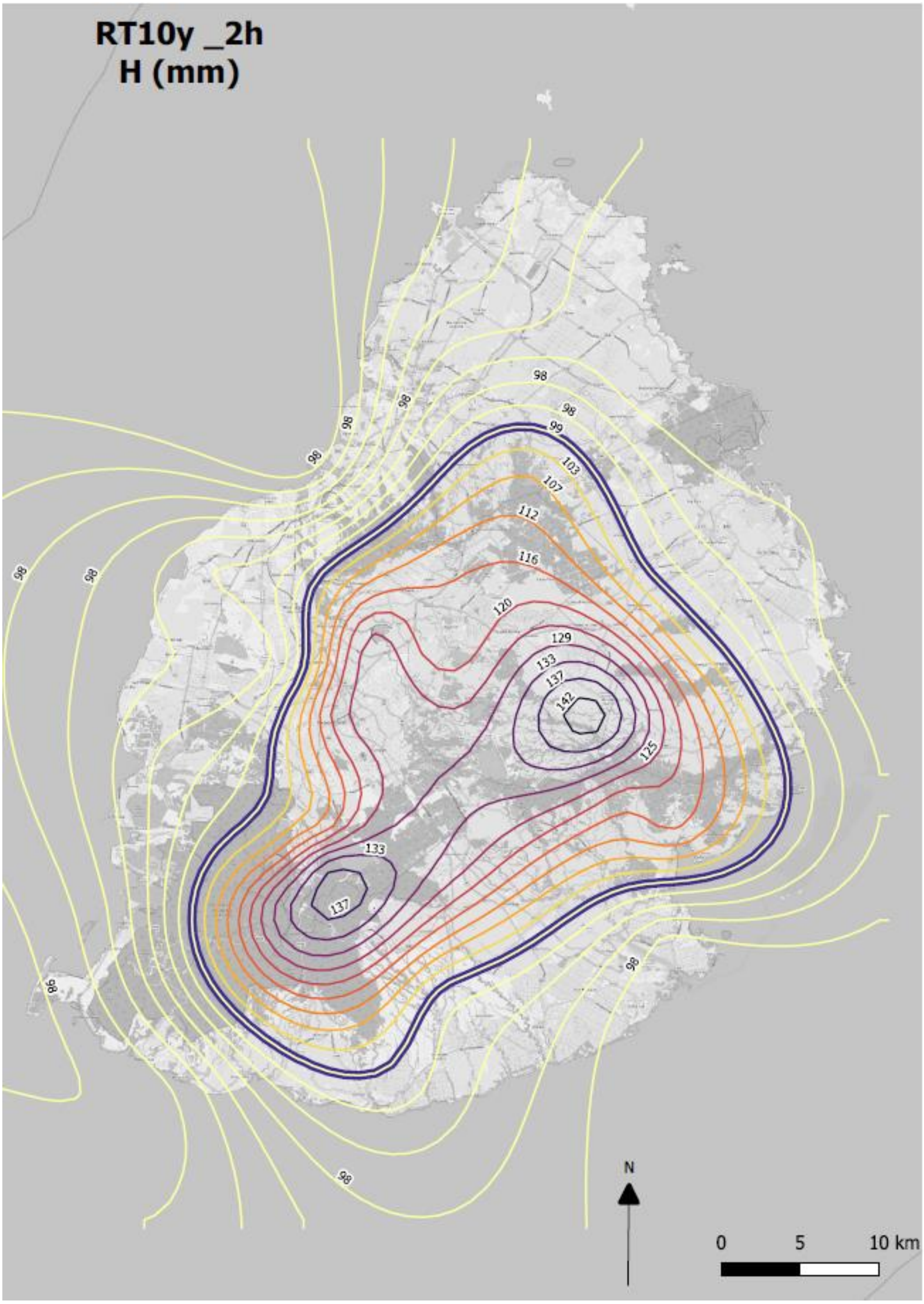


Figure 125: Rainfall isoyets: Duration 2 hours, return period 10 years

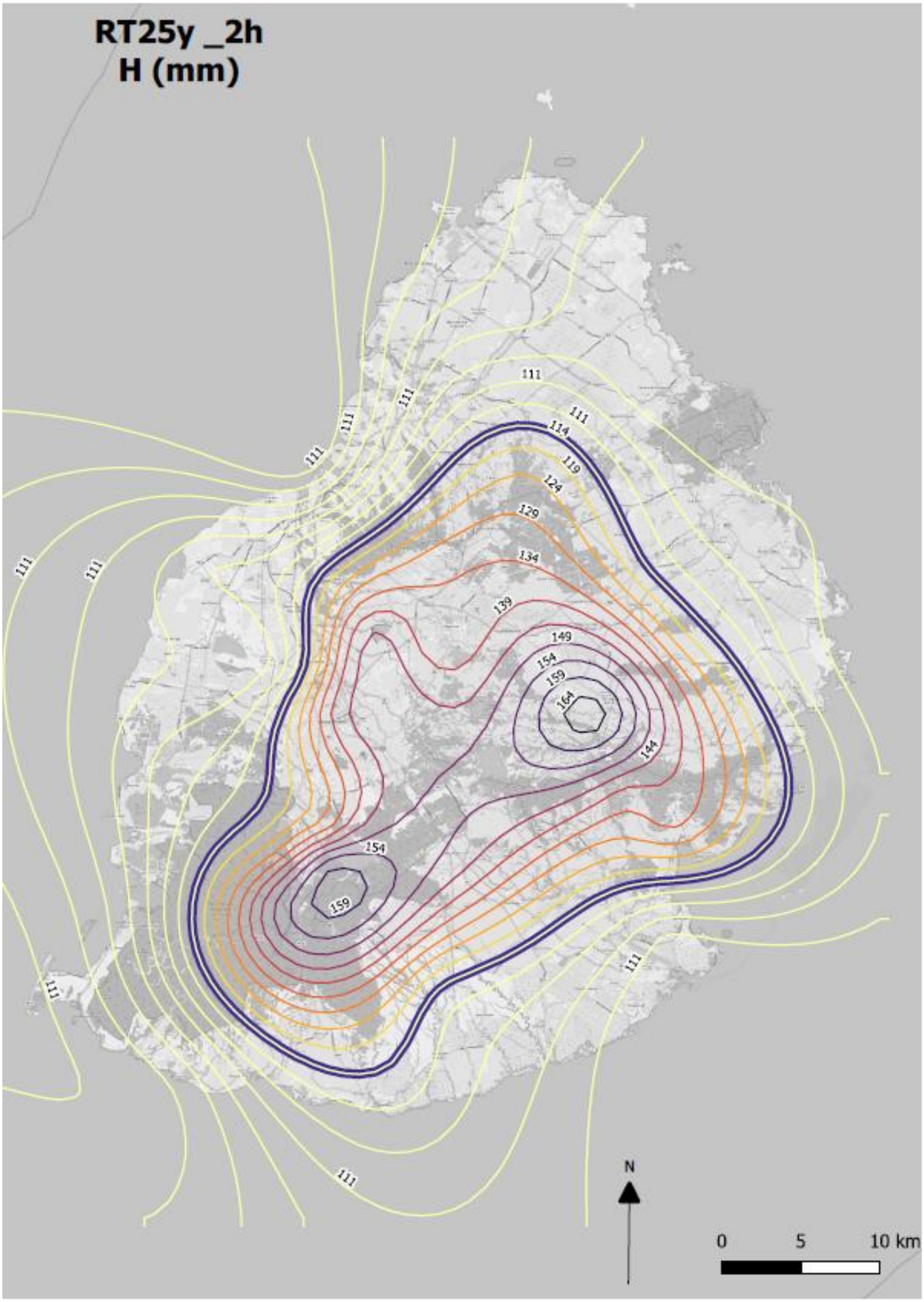


Figure 126: Rainfall isoyets: Duration 2 hours, return period 25 years

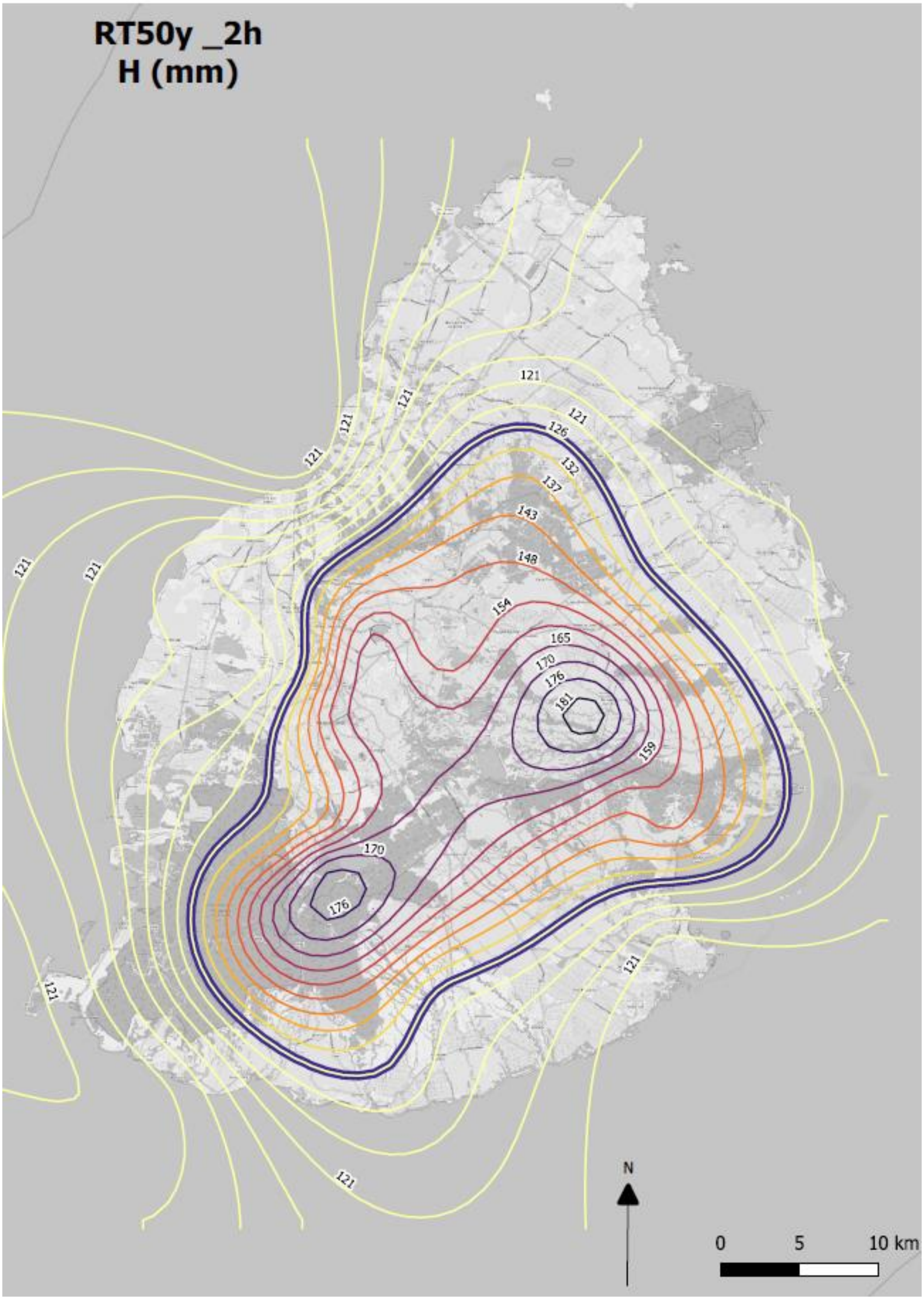


Figure 127: Rainfall isoyets: Duration 2 hours, return period 50 years

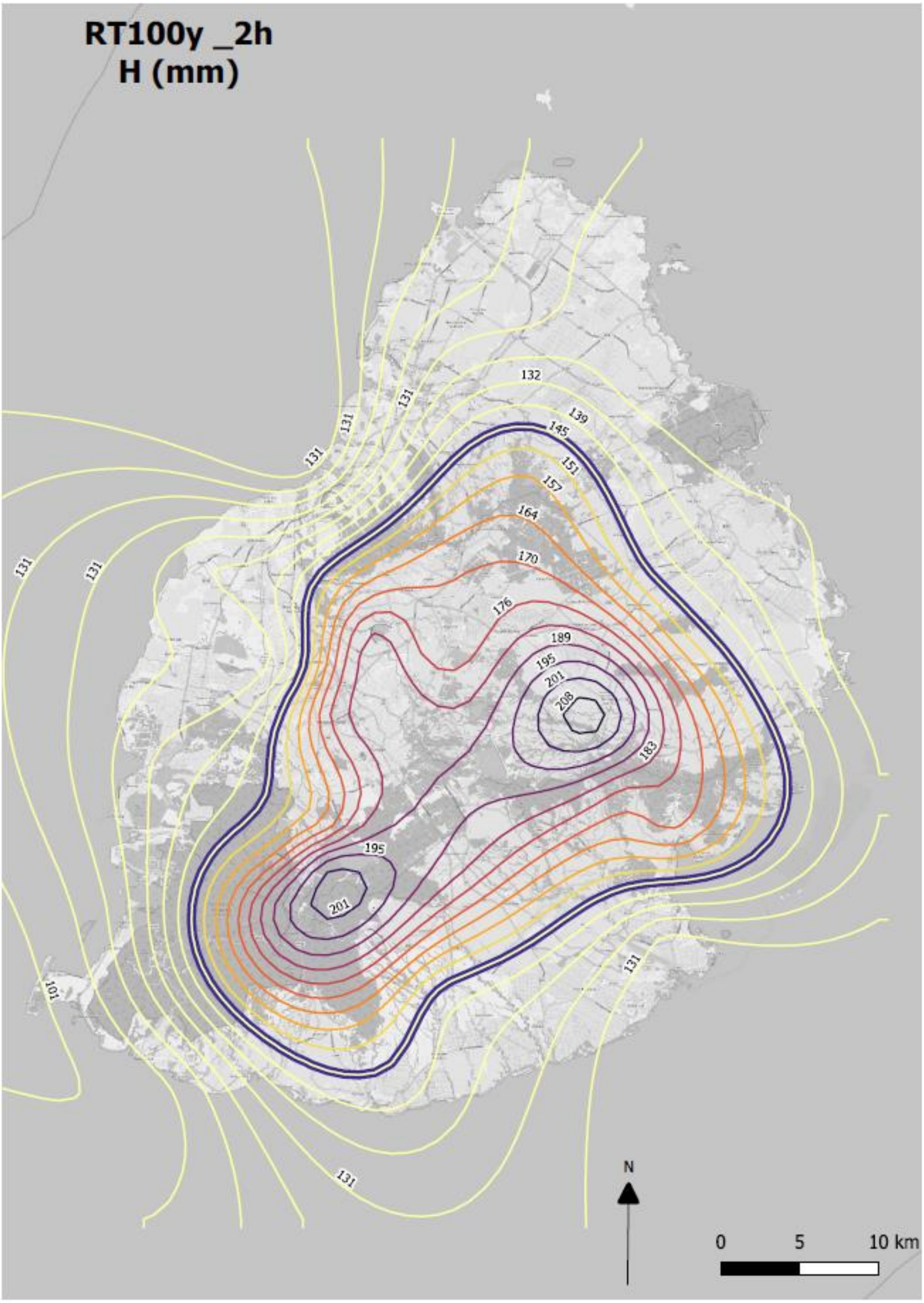


Figure 128: Rainfall isoyets: Duration 2 hours, return period 100 years

- Duration: 3 hours

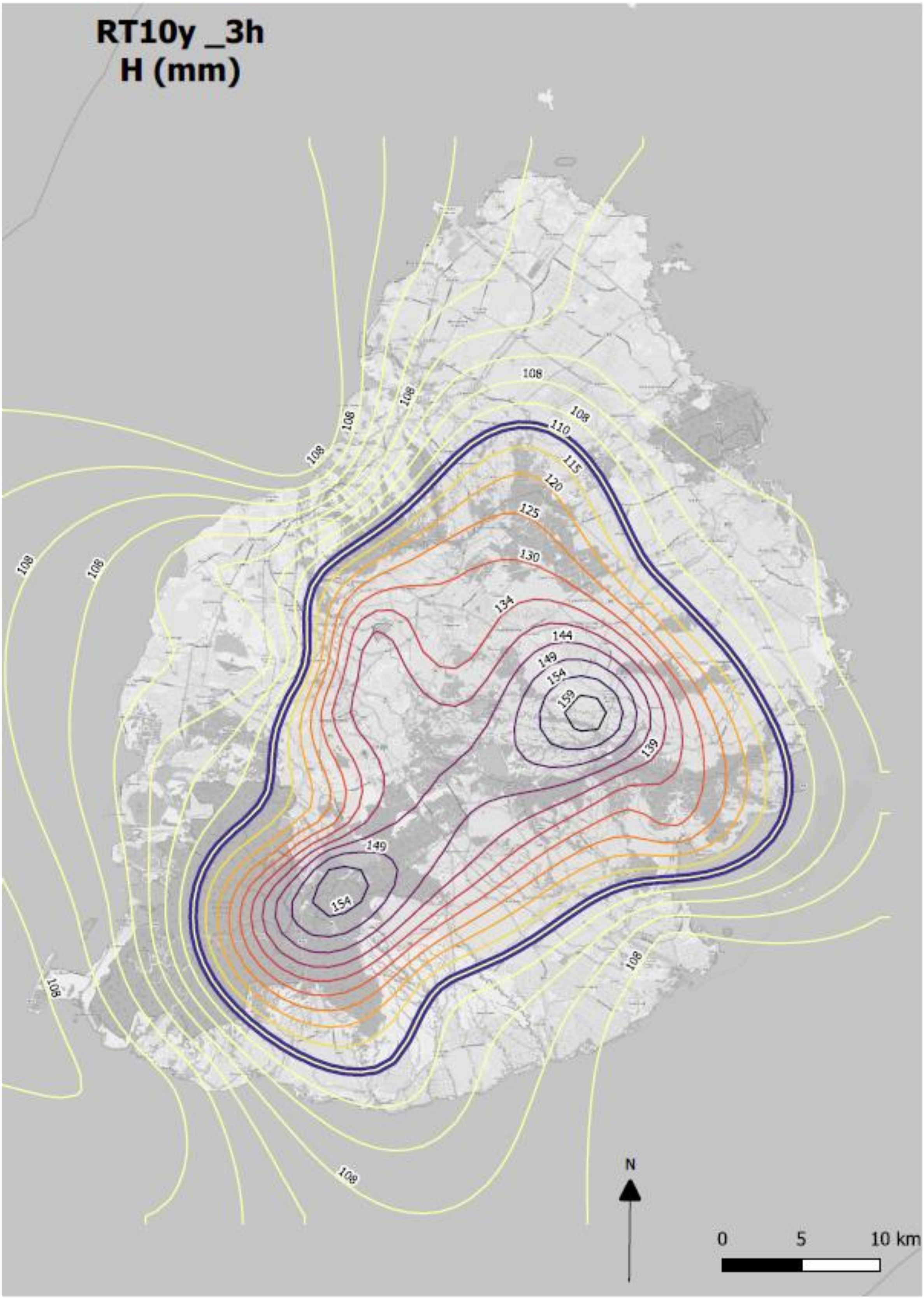


Figure 129: Rainfall isoyets: Duration 3 hours, return period 10 years

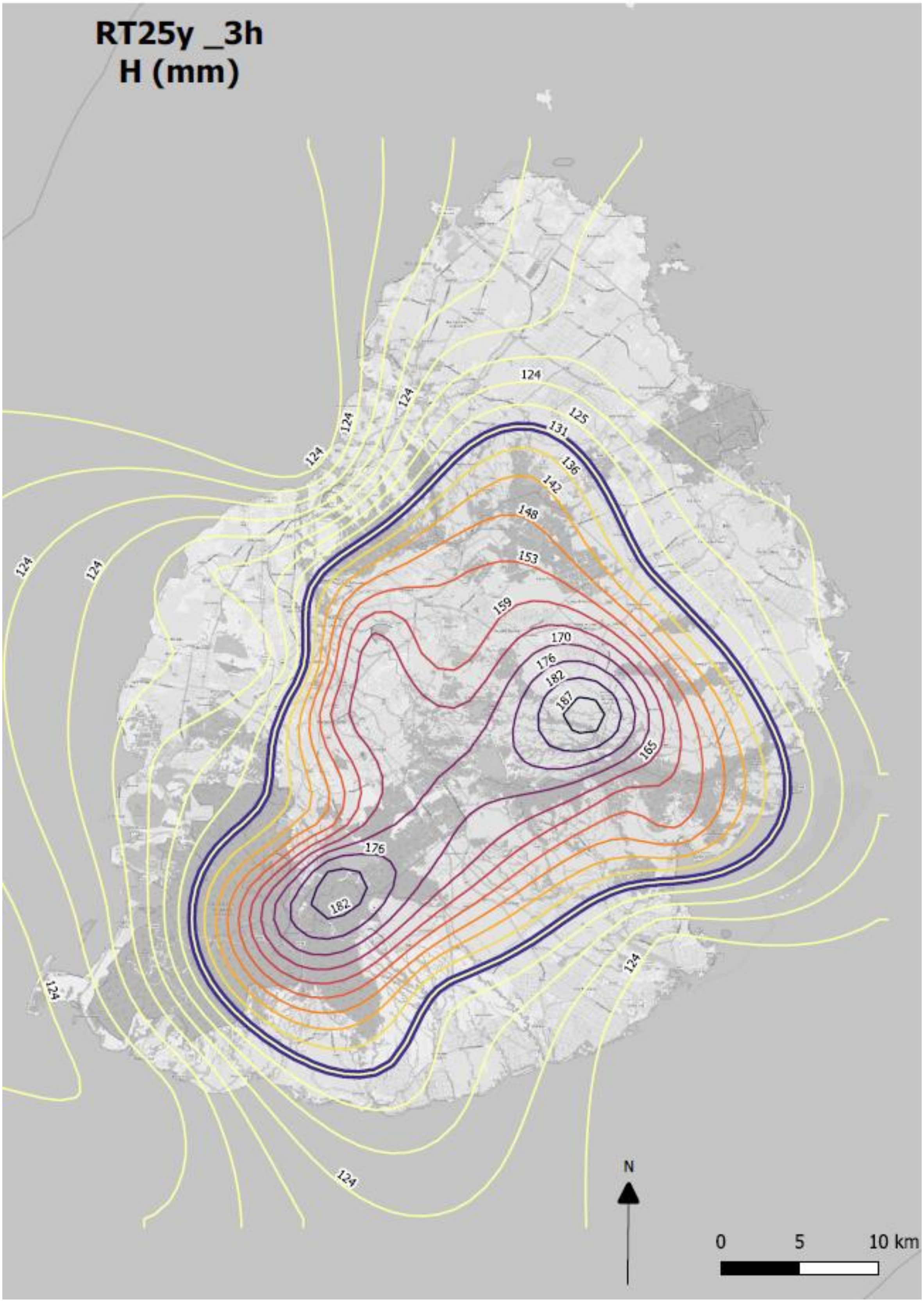


Figure 130: Rainfall isoyets: Duration 3 hours, return period 25 years

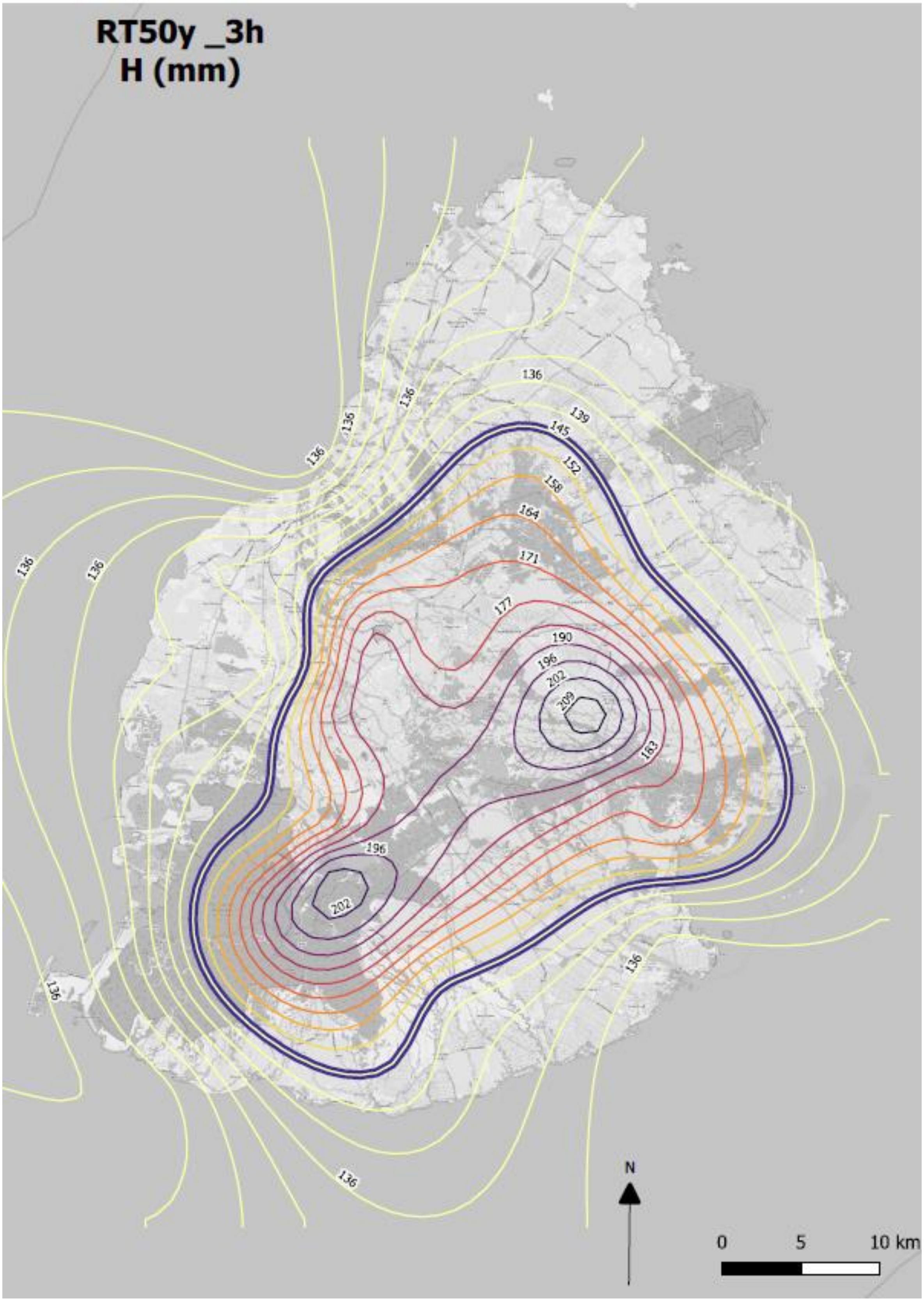


Figure 131: Rainfall isoyets: Duration 3 hours, return period 50 years

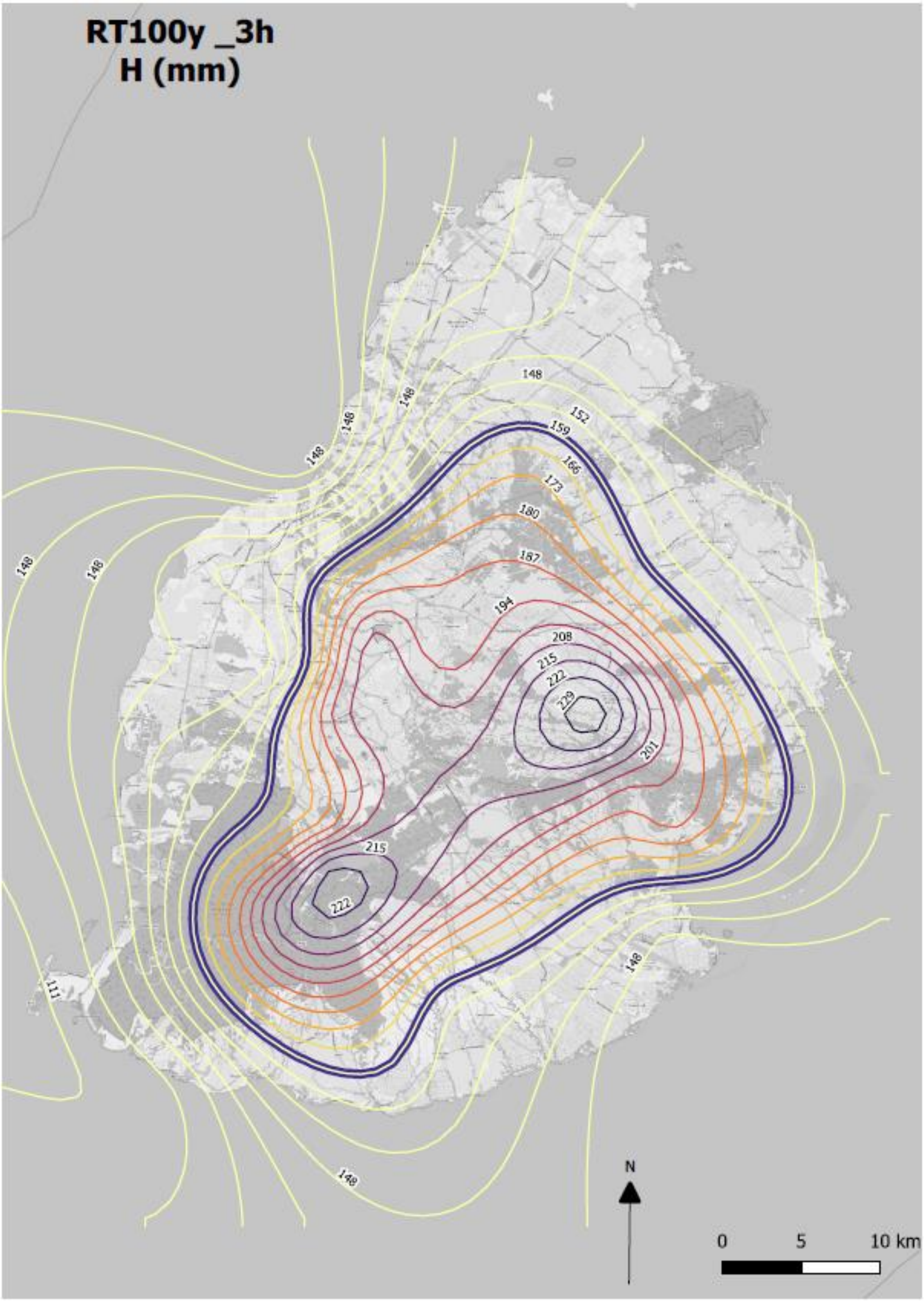


Figure 132: Rainfall isoyets: Duration 3 hours, return period 100 years

These new curves established are specific to the objectives of the LDMP, and more specifically

- They are representative of the evolution of precipitation over the last 58 years, and in particular those observed since 2002 for all available automatic rainfall stations;
- The adjustments are made for 2 duration ranges (6 minutes to 120 minutes and 2 h to 24 h). The curves established for short durations of precipitation (less than 2 hours) allow the entire urban and peri-urban catchment areas and sub-catchment areas to be covered,
- The characteristic curves of short durations allow to characterize the intense episodes generating flash floods.

4.2.2 Step1 Additional: Climate change (CC) effects: CC factor

As part of drainage design studies (drains and retention basins), **it is recommended to integrate the conservative factor which takes into account the effects of global warming** (Refer to section 4.1)

Thus, the rainfall intensities and heights determined under Step 1 will be given a conservative multiplying coefficient.

H with CC = 1.182 * H (IDF)

4.2.3 Step 2: Determination of the time of concentration

4.2.3.1 Definition

An important parameter to be determined when calculating peak flows is the time of concentration for catchments and sub-catchments.

The time of concentration is defined as the time needed for water to flow from the most remote point in a catchment to the catchment outlet.

For catchments selected for the LDMP, which are predominantly urban, sub-urban areas and agricultural areas, the rainfall return period generates a peak flow with the same return period. In fact, when the duration of the rainfall is equal to or exceeds the time of concentration for the catchment, maximum rainfall intensity occurs on the entire catchment, generating the maximum peak flow (the entire area of the catchment receives rainfall of return period T, giving a maximum peak flow corresponding to this same return period T).

4.2.3.2 Determination of the longest hydraulic path

The **longest hydraulic path L** of a catchment is the longest possible path of a drop of water from the ridge of the catchment to the outlet where it is located: this length can never be limited to the course of the watercourse or drain. It is up to the hydrologist to find this path with the help of the DEM contours. Specifically, it is the longest flow path and not the longest metric path between the outlet and the catchment boundaries.

The longest hydraulic path L is measured from the watershed outlet following the main stream course (or drain) extended to the ridgeline, i.e. to the furthest point in the watershed to identify the longest path a drop of water has to travel to the outlet.

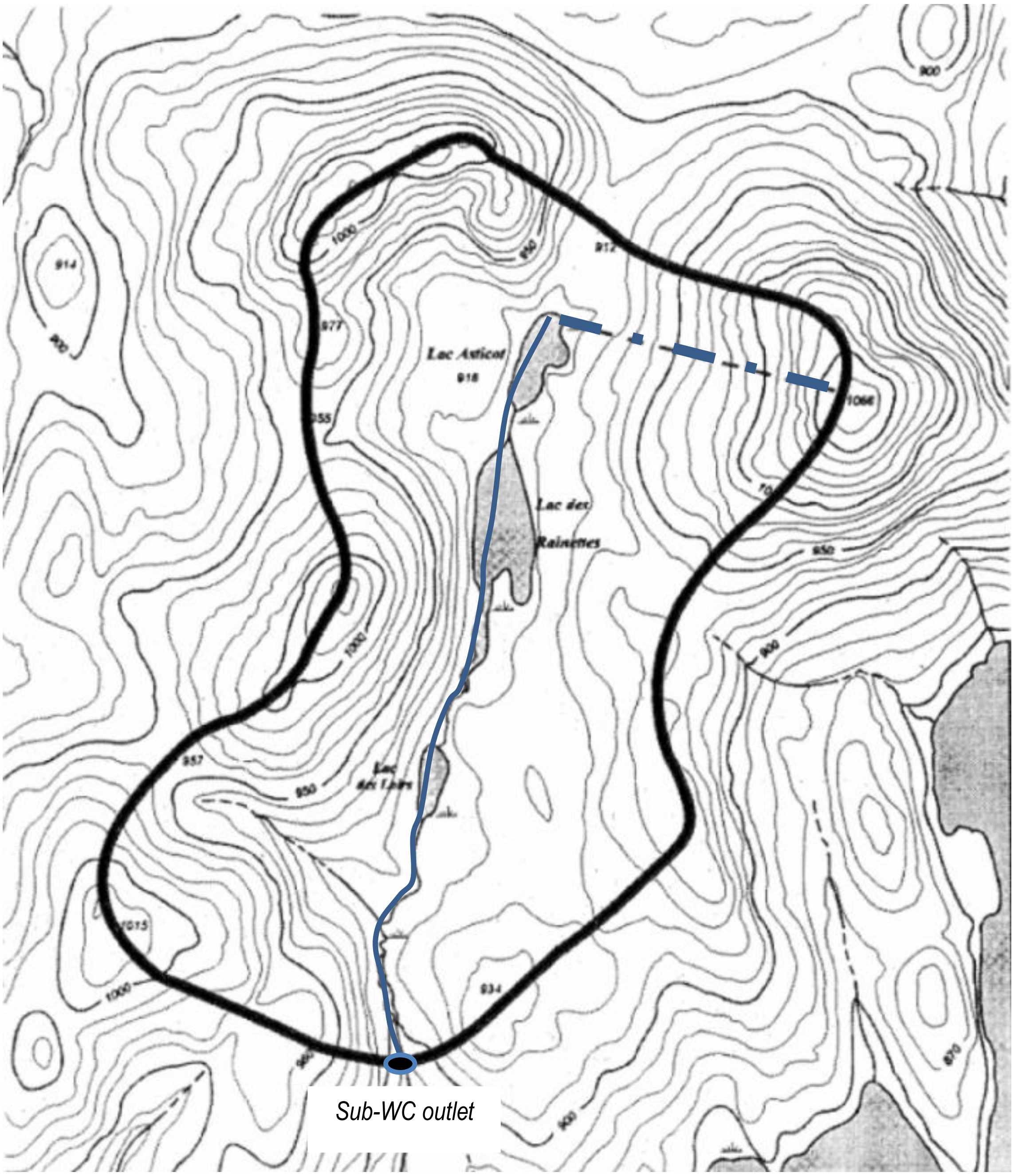


Figure 133: Determination of the longest hydraulic path

4.2.3.3 Methodologies adopted for the LDMP

Several empirical formulae are currently being used to estimate the time of concentration.

As part of the hydrological analysis, applicable to the entire island, a general method has been devised to estimate the peak flows required for sizing the drains; the choice of the methodology is being dictated by the size of the drainage catchment:

- **Case 1: Catchments less than 10 to 20 km²**

The most appropriate method used for small catchments (areas less than 10 to 20 km²) is the Kirpich method.

For this method, the time of concentration is calculated by the following equation:

$$Tc = \frac{0.000325 \times L^{0.77}}{S^{0.385}}$$

Where

- Tc: Time of concentration (in hours);
- L: Maximum water flow length in the catchment (in m);
- S: Average longitudinal slope of the catchment, following the flow path (m/m).

Note:

According to Kirpich (1940), the method can be applied to catchment areas between 0.4 and 81 ha. However, Fang et al. (2007, 2008) [25], has highlighted that the Kirpich equation can also be applied to larger catchments (> 50 km²), giving the results similar to other methods developed for such catchments. According to McCuen et al. (1984), this equation is representative of a typical uniform flow (channel flow equation).

In practice, Kirpich method, like any other empirical method, can be extended to larger catchment areas (up to 20 km² or 2,000 ha). This method, being conservative (by minimizing Tc), can lead to a time of concentration that is representative of the flow velocity characteristics of the catchments being drained. Therefore, it can be used to design the drains.

- **Case No 2 : catchments greater than 20 km²**

The most appropriate methods used for the large catchments (areas greater than 20 km²) are the Kirpich and Passini formulae and the analysis of average flow velocities.

For these methods, the time of concentration is calculated by the following equation:

$$Tc = 0.108 \times \sqrt[3]{(A.L)}/\sqrt{(S)}$$

Provided that $V = \frac{L}{Tc} \geq 1.2\ m/s$

Otherwise, use Tc =Tc Kirpich

Where

- Tc: Time of concentration (in hours);
- A: Catchment areas (in km²) ;
- L: Maximum water flow length in the catchment (in m);
- S: Average longitudinal slope of the catchment, following the flow path (m/m);
- V: Average flow velocity (in m/s)

[25] Time of Concentration Estimated Using Watershed Parameters Determined by Automated and Manual Methods - Xing Fang, Ph.D.; David B. Thompson, Ph.D.; Theodore G. Cleveland, Ph.D.; Pratistha Pradhan, D.E. and Ranjit Malla

The checkings will be done to ensure that this formula does not lead to average flow velocities lower than or equal to 1.2 m/s, so as not to underestimate the peak flows for catchments dictated by drainage systems (agricultural ditches, roadside ditches, man-made drains, etc.). In fact, for the catchments with this type of drains, the catchment reacts more rapidly to the rainfall than the natural rural catchments.

Note: For specific cases, comprising natural watersheds with large watercourses (greater than 40 km²), this analysis may be complemented by:

- *Time of Concentration (Tc) based on other empirical formulae: Turazza, Giandotti and Ventura*

Turazza :

$$Tc = 0{,}277 \times \sqrt{(A)}$$

Ventura :

$$Tc = 0{,}1272 \times \sqrt{(A/S)}$$

Giandotti:

$$Tc = 75/60 \times \frac{4\sqrt{A} + 1.5 \times L}{\sqrt{H}}$$

With

- Tc: Time of concentration (in hours);
- A: Catchment area (in km²);
- L: Maximum water flow length in the catchment (in m);
- S: Average longitudinal slope of the catchment, following the flow path (m/m);
- H: The difference between the mean basin elevation and the outlet elevation (m).

These three empirical formulas are adapted for rural or natural catchment areas.

- Turrazza formula, based only on catchment area, always gives shorter concentration times than the other formulas. It is therefore reserved for catchment areas with high slopes (mountainous), with slopes higher than 15% and limited size (10 km²)
- The Ventura and Giandotti formulas are adapted to watersheds with low to medium slopes.
- Finally, the Giandotti formula is reserved for larger catchment areas, often larger than 100 km².

In practice, if the Ventura and Giandotti formulations converge, an average of these two formulations can be used.

- *On the spread of peak flood data if the catchments are equipped with hydrometric stations*

In the case of a gauged catchment, with a hydrometric station managed by WRU, it is advisable to make an analysis of the flood hydrographs (or the evolution of the level in time) at the station, and to compare this value to the rainfall record on the catchment for a given episode. The time of concentration of the catchment area, given by the duration between the beginning of the rain on the catchment area and the peak of the flood at the station, allows to validate the real functioning of the catchment area, instead of using empirical formulas.

4.2.4 Step 3: Determination of the project rainfall

A project rainfall is a synthetic rainfall defined by a standard hyetogram, unobserved and in a simplified form. This hyetogram is constructed from the statistical characteristics of rainfall, generally described by the IDF curves.

In urban and semi-urban hydrology, the recommendations for determining design rainfall lead to the retention of rain double triangle type.

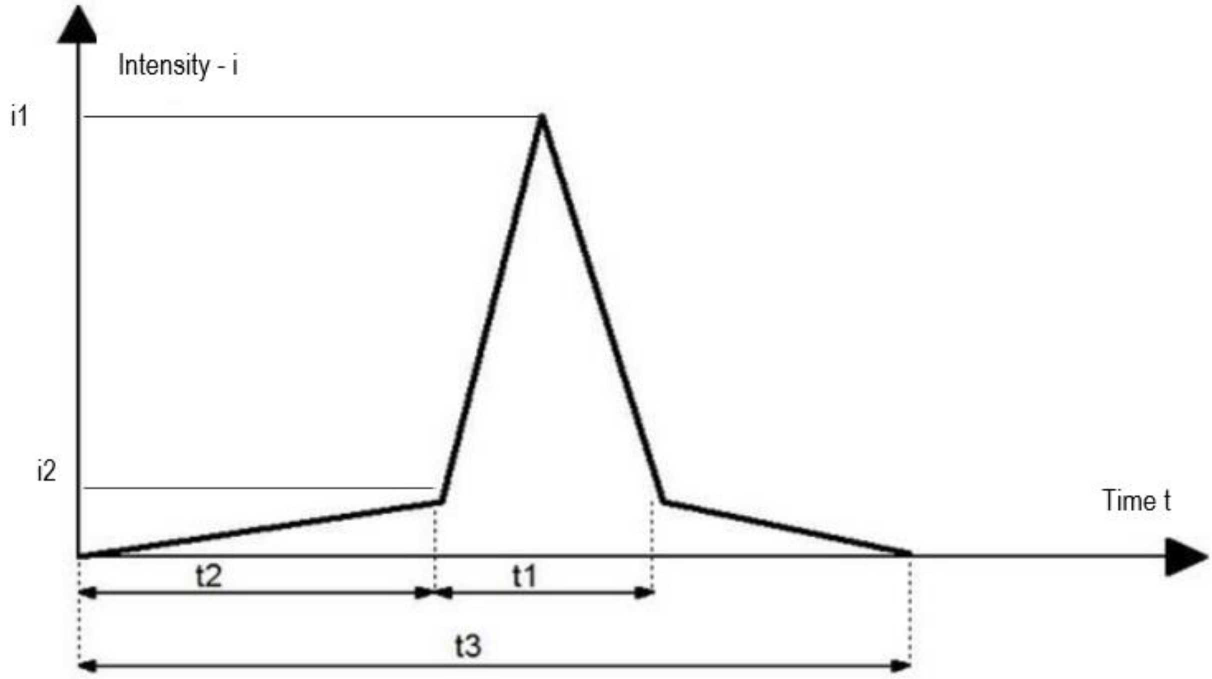


Figure 134: Rain double triangle

The concept of double triangle rain is based on two observations:

- Actual rainfall events, causing surcharge in the storm sewerage networks, generally consist of a relatively intense rainfall for short duration occurring within a few hours' rainfall event;
- Exception being made to the previous provision, no particular temporal intensity distribution has more probability than the other.

Desbordes (1974)[26] proposed to choose a particular project rainfall not dependent on any physical phenomenon but rather on parameters on which the runoff model (used with the rainfall model) was most sensitive. This sensitivity analysis, carried out by using the linear reservoir model, showed that a simple double triangular shape, provided hydrographs and maximum discharge values that were less susceptible to errors on the main parameter of the runoff flow model which is the lag time.

- the total duration t3 (a few hours);
- the duration of high intensity rain: t1 (a few dozen of minutes);
- the location of the peak rainfall intensity relative to the start of the rainfall: ratio t2/t3;

[26] Desbordes, M. & Raous, P. (1980) : Fondements de l'élaboration d'une pluie de projet urbaine : méthodes d'analyse et application à la station de Montpellier Bel Air ; La météorologie ; n°20-21 ; pp. 317- 326 ; juin 1980.

- the average intensity during the highest rain intensity: i1;
- the average intensity outside the highest rain intensity: i2.

The main preferred elements are as follows:

- The total duration t3 can be taken equal to 4 hours. This duration, which is longer than the concentration times of the catchment areas covered by the LDMP, is traditionally used in urban and peri-urban hydrology. Indeed, this duration of 4 hours is sufficient to saturate the soil and " put in water " all the drains before the occurrence of the peak flow. The validity of this total duration has been verified by analysis of hydrographs recorded at WRU gauging stations for peri-urban catchments (see D2.2). Moreover, within the framework of analysis of the needs in retention by the rainfall method (cf. 3.5.2.4), the most penalising rainfall in terms of volume is always lower than this value of 4 h (of the order of 2 h).
- The duration of high intensity rainfall t1 can be between fifteen minutes and one to two hours depending on the nature and surface of the catchment under study. This duration will be taken equal to the time of concentration Tc of the sub-catchment as to get the maximum peak flow;
- The occurrence of the high intensity rainfall within the rainfall spell (θ=t2/t3) has a bearing on the peak flow. Analysis of rainfall events did not show any preferential value of θ (in wet periods, a large part of the soil tends to become saturated relatively quickly in Mauritius). An average value of θ can therefore be taken as 0.5, a case of double triangular rain;
- The magnitude of the total rainfall, during the high rainfall intensity, has the biggest impact on the peak flow. Its value can be taken as an equal to the maximum average intensity corresponding to the same duration on the Intensity-Duration-Frequency curves characterizing the particular rainfall catchment and the return period;
- The magnitude of precipitation outside the period of high rainfall intensity plays a minor role in the value of the peak flow. Its value would correspond to a shorter return period than the one being used for calculating the peak flows;
- The cumulative rainfall over the whole rainfall duration t3 must be equal to the rain drop for the chosen return period (ie the cumulative rainfall over the total duration t3 for any specific return period RT).

4.2.5 Step 4: Rainfall – runoff calculations

Peak flow is the maximum discharge within a catchment for a given rainfall event.

Two rainfall-flow rate methods are recommended:

4.2.5.1 Method 1: Rational Method

A: Formula:

The rational formula is as follows:

$$Qp(T) = \frac{1}{3.6}\, Cr \times I(T) \times A$$

And

$$I(T) = \frac{H\ (T)}{Tc}$$

Where

- Qp(T) = Peak flow rate for T-year return period (in m^3/s);
- Cr = Run-off Coefficient (between 0 et 1);
- I(T) = Rainfall intensity for any specific return period (mm/hour) and for a duration equal to Tc
- H(T) =Rainfall for a duration equal to the time of concentration of the catchment (mm);
- Tc = time of concentration in hours;
  - Method adopted to determine Tc: Kirpich Method
- A: Effective area of catchment (in km^2);

B: Determination of Runoff Coefficient:

The **runoff coefficient**, **C**, is a dimensionless ratio intended to indicate the amount of runoff generated by a watershed, given an average intensity of precipitation for a storm. While it is implied by the rational method that intensity of runoff is proportional to the rainfall intensity, calibration of the runoff coefficient almost always depends on the comparison of the total depth of runoff with the total depth of precipitation; the runoff coefficient thus represents the fraction of rainfall converted into runoff.

The runoff coefficients were determined through analysis of the model calibration of the rainfall- flow rate described in chapter 3.

It is worth noting that both the rainfall intensity and frequency increase the saturated condition of the soil while the runoff coefficient for the same type of land-use increases with the rainfall return period.

Thus, the following two approaches should be retained:

- *Simplified approach: conservative determination of the runoff coefficients:*

The following table indicates Cr values for different return periods:

Table 32: Conservative values of runoff coefficients

Run off table - Conservative values				
Return Period (in years)	**10**	**25**	**50**	**100**
Urban Areas *	0.95	0.95	0.95	0.95
Other Areas (non urban)	0.50	0.66	0.73	0.80

** As a conservative measure, it is recommended not to differentiate between dense and sparsely urbanized areas.*

○ *Detailed approach: spatial consideration of soil saturation for the determination of runoff coefficients:*

The following formula is used to determine the runoff coefficient for non-urban areas for a 100-year return period:

$$Cr(100y) = 0.8 \times (1 - \frac{Ia}{PJ(100y)})$$

Where :

- PJ (100y) = average daily rainfall for 100 years return period. A simpler approach would be to use the value of 400 mm for the whole island.
- Ia = initial abstraction (mm). This parameter is a function of land use and geology.

The following table, resulting from the calibration using the SCS method (Ref next chapter), gives the initial abstraction to be considered depending on the soil type.

Table 33: Ia values per SCS soil group and land use categories

Hydrologic Soil Group	Ia : initial abstraction (mm)			
	Agriculture	Forest	Scrub	Built up area
A	*25*	*42**	*32**	*4*
B	*14*	*42*	*32*	*4*
C	*9*	*22*	*18*	*4*
D	*6*	*15*	*13*	*4*

** Conservative value*

In the formula, "Ia" corresponds to the weighted average of the soil type and the hydrologic Soil Group.

For Cr (10y), a single value of 0.5 is retained. Lastly, for intermediate return periods of 10-100 years, a Naperian logarithm adjustment is affected:

$$Cr(Ty) = 0.8 \times \frac{0.186 \times LN(Ty) + 0.572^{-33}}{0.186 \times LN(100) + 0.572^{-33}}$$

The tables showing examples of detailed Cr values for different return period are presented in chapter 3.5.2.2..

4.2.5.2 Method 2: Soil Conservtaion Service SCS Method and Hydrological Modelling

A: Formula:

Hydrological modelling is based on two transformations, the first one giving the amount of excess rainfall in a catchment that contributes to the runoff process, and the second one giving the runoff production.

Excess rainfall amount can be estimated by a method based on the SCS Curve Number loss model:

Where:

$$Qp(T) = \frac{(P - Ia)^2}{(P - Ia) + S}$$

- Q: Stormflow depth (mm)
- P: daily rainfall depth (mm), usually a one-day design rainfall for a given return period;
- S: potential maximum soil water retention (mm), ≈ Index of the wetness of the catchment's soil prior to a rainfall event;
- Ia: initial abstractions (mm), corresponding to all losses prior to the commencement of runoff. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is highly variable but is generally correlated with soil and cover parameters. Through the studies of many small agricultural watersheds, Ia was approximated by the following empirical equation: Ia = 0.2 S.

Runoff process is estimated by the unit hydrograph method.

B: Determination of CN and Ia:

Each catchment is described by the following parameters:

- The initial abstraction Ia (mm)
- The maximum retention potential after the starting of runoff S
- Data from the experimental tables of soil group, as defined by geology and land use
- The table for the average Curve Number, with a classification limited to the main land use categories, is shown below. It is reproduced from the results of the calibration analysis presented in chapter 3.

Table 34: Average Curve Number (CN) values per SCS soil groups and average land use categories and Ia values

Hydologic Soil Group	CN				Ia : initial abstraction (mm)			
	Agriculture	Forest	Scrub	Built up area	Agriculture	Forest	Scrub	Built up area
A	67	25 - 55	39 - 61	93	*25*	*42**	*32**	*4*
B	78	55	61	93	*14*	*42*	*32*	*4*
C	85	70	74	93	*9*	*22*	*18*	*4*
D	89	77	80	93	*6*	*15*	*13*	*4*

** Conservative value*

Refer to map in chapter 3.5.2.3.1.

- S is derived from the curve number CN (dimensionless unit) by the formula:

$$S = 25.4 \times \left(\frac{1000}{CN} - 10\right),\ \text{with S in mm}$$

- Tc: time of concentration (day), as defined above,
- Td: response time for final drainage (days),
- fo: loss by infiltration into the aquifer (mm/day).

Td and fo are estimated during the calibration phase as the additional loss only in model software.

Urban areas are only partially covered by impervious surfaces: the soil remains an important factor in runoff estimations. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (sands and gravels) than the watershed in silts and clays having low infiltration rates. Any disturbance of a soil profile can significantly change its infiltration characteristics. With urbanization, native soil profiles may be mixed or removed, or backfill material from other sources may have been introduced.

As a conservative measure, it is recommended not to differentiate between dense and sparsely urbanized areas. The coefficient retained for all urbanized areas prescribes low initial losses.

4.2.6 Case Studies

Three cases applicable for the transformation of rainfall into flows are classified according to the Area, A = catchment area:

- <u>**Case No 1 : For A less than 10 km^2 : Application of rational method:**</u>

Rational Method - CIA

STEP 1
- Rainfall Intensity to be considered: intensity over a period equal to the time of concentration of the catchment,

STEP 2
- Estimation of Time of Concentration using Kirpich method,

Cr tables
- Application of runoff coefficients at least by a conservative approach (or additional detailed approach depending on the nature of the catchment).

- <u>**Case No 2 : For A greater than 20 km^2: Application of SCS**</u>

SCS

STEP 1
- Rainfall Intensity to be considered: intensity over a period equal to the time of concentration of the catchment,

STEP 2
- Estimation of Time of Concentration using Kirpich and Passini methods[27] (with the provison for flow velocities greater than or equal to 1.2 m/s),

STEP 3
- Construction of a double triangle project rain.

CN and Ia tables
- Application of the coefficients CN and Ia at least by a conservative approach (or additional detailed approach depending on the nature of the catchment).

- <u>**Case No 3: For A between 10 and 20 km^2: Comparison of values by rational method (case 1) and SCS (case 2) and use of the highest estimated value**</u>

Max Rational Method – CIA and SCS

[27] For larger watersheds (of the order of 40 km^2), the formulas of Turazza, Giandotti and Ventura can also be compared: the shortest value be retained

5 NATIONAL RULES TO ACCOUNT FOR LAND DRAINAGE ISSUES IN TERRITORIAL DEVELOPMENT

5.1 Rules for sizing drainage structures

5.1.1 Return Periods and free board

The estimation of peak flow rates is not sufficient in itself to ensure correct sizing of drainage infrastructure.

Thus, considering the local environment and hydraulic sizing challenges for new drain projects, the following sizing criteria is recommended:

To define the "appropriate event", recommended Return Periods are specified in DIA guideline[28]. However, it is to be noted that those values are applicable **only if the drainage system** (including the water course) downstream of the project area (built area or infrastructure), has sufficient capacity to accommodate the flow rates corresponding to the minimum rainfall return period:

Table 35: Minimum Freeboard for drainage structures

S.N	Infrastructure	Minimum Rainfall Return Period29 (years)	Climate Change factor (to apply to rainfall data)*	Minimum free-board required in m
1	Drains (urban area)	25	+18.2%	0.3 m
2	Discharge into watercourses (including Feeders, Rivulets, Rivers)	100	+18.2%	0.5 m
3	Culverts	50	+18.2%	0.5 m
4	Bridges	100	+18.2%	1.0 m **

** Taking into account climate change on the basis of a global warming of 2.6°C (for scenario RCP8.5) for the end of the century and only application of the Clausius-Clapeyron Law, i.e. +18.2% for cumulative rainfall - +30% on average for unit volumes (cf.4.1).*
***: by ensuring that the free board is greater than $V^2/2g$ (v = flow velocity under the bridge)[30]*

<u>Comment on the maximum freeboard value at 1 m:</u>
The technical rule for determining the freeboard is a function of the energy of flow (proportional to the square of the flow velocity) and on the capacity of the river flow to transport debris without incumbrance. As for the velocity in flood, it is not exceptional for it to reach 4 to 5 m/s. In this case, the energy is about 1 m.
For ease of transport of debris, the energy of the watercourse makes it possible to bring into floatation materials of the order of 1m³ in volume. A free board of 1 m is thus recommended under bridges across watercourses.

As example, the road construction guides (by CEREMA - SETRA in France[31]) impose a freeboard value of :

- 0.6 m for small structures (similar to a culvert)
- 1 m for large structures (bridge)

[28] LDA - Final DIA Guideline 12 Apr 2019.
29 Higher return periods are recommended for regions with known vulnerabilities to flooding.
30 «Wasser Energie Luft» – 105. Jahrgang, 2013, Heft 2, CH-5401 Baden - https://www.swv.ch/fr/wp-content/uploads/sites/2/2018/03/Recommendation-sur-la-revanche_CIPC-2013-1.pdf
31 http://piles.cerema.fr/IMG/pdf/5_-_CETESO_Presentaton_Cours_d_eau_et_ponts_cle0f26ff.pdf

When selecting the return period, the impact downstream of the proposed drain infrastructure should be taken into consideration in order not to aggravate the risks. In general, if resizing of drains is deemed necessary, implementation should always start downstream and then progress upstream in order to protect the downstream assets.

The notion of minimum free board required is important to be taken into account:

- The effects of localised flows, particularly head losses (bends, obstructions etc.)
- Uncertainties in hydrological calculations for determining peak flows, viz:
    - Rainfall estimation,
    - Estimation of time of concentration,
    - Determination of runoff coefficient,
    - Climate change uncertainties, etc

Cumulative uncertainties on the hydrological parameters can be, as much as 10 to 20% depending on the approach, adopted by the designer.

The best approach to address these uncertainties is to abide by a minimum freeboard and regular maintenance of the drains.

As an example, the following graph illustrates the surplus hydraulic capacity of a 1-5 m wide by 1 m high concrete U-drain depending on the freeboard.

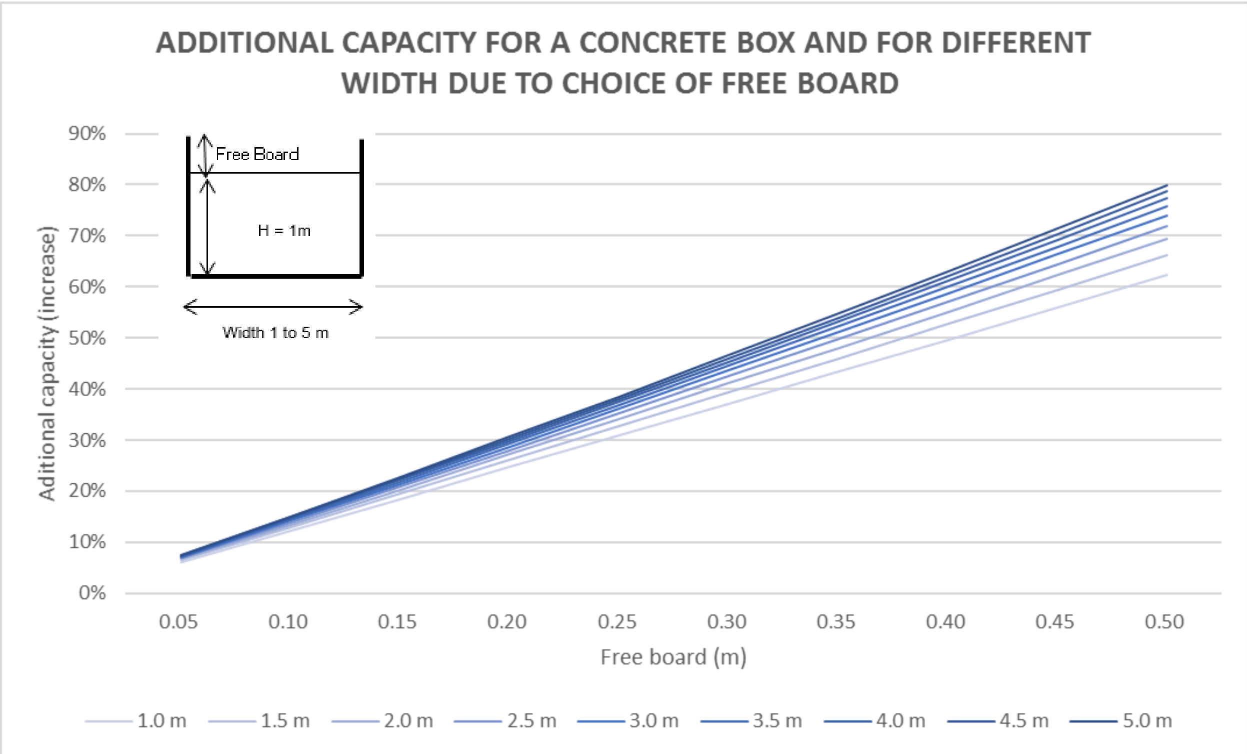


Figure 135: Variation of capacity of a concrete box drain as function of free board value

5.1.2 Peak flow calculation for drain design by rational method

The purpose of this section is to provide a review of the specifications for the application of the rational method in the context of peak flow determination for the design of drains in urban and peri-urban areas.

5.1.2.1 Application conditions for peak flow determination

- Objective: design of storm drains in urban and peri-urban areas
- Catchment area:

Table 36: Methodology for Peak Flow Determination

Catchment area	catchment (Gauged or non gauged)	Method to be used for a global approach
Less than 10 km²	Gauged or non gauged	Rational Method
Between 10 and 20 km²	Non gauged	Comparaison Rational Method and SCS Method / use of the highest estimated value
	Gauged	SCS with calibration
More than 20 km²	Gauged or non gauged	*SCS Method*

5.1.2.2 Rational Method application

5.1.2.2.1 Rational method Formula

The rational formula is as follows:

$$Qp(T) = \frac{1}{3.6}\, Cr \times I(T) \times A$$

And

$$I(T) = \frac{H\,(T)}{Tc}$$

Where

- Qp(T) = Peak flow rate for T-year return period (in m³/s);
- Cr = Run-off Coefficient (between 0 et 1);
- I(T) = Rainfall intensity for any specific return period (mm/hour) and for a duration equal to Tc
- H(T) =Rainfall for a duration equal to the time of concentration of the catchment (mm);
- Tc = time of concentration in hours;
  Method adopted to determine Tc: Kirpich Method
- A: Effective area of catchment (in km²) - less than 10 to 20 km²

5.1.2.2.2 Determination of the time of concentration

Use unic method for small urban and peri-urban areas: **Kirpich method**[32].

$$Tc = \frac{0.000325 \times L^{0.77}}{S^{0.385}}$$

Where

- Tc: Time of concentration (in hours) – minimum value to be retained: 6 mn (lower limit of rainfall recording)
- L: Maximum water flow length in the catchment (in m);
- S: Average longitudinal slope of the catchment, following the flow path (m/m).

5.1.2.2.3 Determination of Runoff Coefficient and consideration of the slope of the catchment area

- **Introduction for the choice of the approach for determining runoff coefficients in urban area** (cf.4.2.5.1).

The approach to be adopted is as follows:

- The simplified approach: conservative determination of the runoff coefficients
- The detailed approach: spatial consideration of soil saturation for the determination of runoff coefficients:

Reminder of the notions of initial losses:

When slopes are steep, surface runoff is greater as a result of the reduced efficiency from initial soil losses: as water runs off the surface more quickly, initial losses are limited.

Three types of losses can be considered for the establishment of the excess rainfall that will contribute to runoff:

- losses by interception,
- losses by storage or surface retention
- losses by infiltration.

In highly urbanised areas, with an appreciable percentage of impermeabilisation, losses by interception and surface retention are generally grouped together for the analyses and are less important than the ones caused by infiltration.

For surface retention, the values presented in the following table, derived from the Denver, Colorado drainage manual in the first case and from various references in the second case, can be used.

[32] According to Kirpich (1940), the method can be applied for catchment areas between 0.4 and 81 ha. However, Fang et al. (2007, 2008), showed that the Kirpich equation could be applied to larger catchments (> 50 km²) and that it gave similar results to other methods developed for large catchments. According to McCuen et al. (1984) this equation could be considered as a flow channel flow equation.

Table 37: Typical values for surface retention losses in urban areas

Type of land use	Loss range (mm)	Recommended values (mm)	Références
Large paved areas	1,25 – 3,8	2,5	UDFCD, 2006[33]
Flat roofs	2,5 – 7,5	2,5	UDFCD, 2006
Roofs with slope	1,25 – 2,5	1,25	UDFCD, 2006
Large paved areas with strong slope	0,5	0,5	Pecher (1969); Viessman et al. (1977)
Large paved areas low slope	1,5 – 3,5	2,5	Pecher (1969); Viessman et al. (1977)

It is important to note that even in an urban context and on a largely paved surfaces, initial losses are effective due to interception and surface retention.
With regards to the infiltration losses, chapter 4.2.5.1 presents details of the calculations required to consider them.

- **Runoff coefficients to be applied – conservative approach**

For the design of drains at the scale of urban or suburban projects, and in order to consider the effects of impermeability and strong slopes, the conservative method will be applied (coefficients without initial losses).

The effect of slopes on peak flows is, therefore, considered on two levels:

- At the level of rain intensity: this value is calculated on the basis of the slope and by determining the time of concentration (shorter duration due to faster runoff, therefore higher rain intensity to be considered via the Kirpich Tc).
- In terms of limited consideration of initial losses: by simplifying the appellation and limiting initial losses

The following table indicates Cr values for different return periods:

Table 38: Runoff coefficients in urban areas

Run off table - Conservative values				
Return Period (in years)	**10**	**25**	**50**	**100**
Urban Areas *	0.95	0.95	0.95	0.95
Other Areas (non urban)	0.50	0.66	0.73	0.80

** As a conservative measure, it is recommended not to differentiate between dense and sparsely urbanized areas.*

It should be noted that the effect of steep slopes on runoff is taken into account by estimating the time of concentration. The conservative coefficients recommended here are therefore global.

[33] UDFCD - Urban Drainage & Flood Control District

5.1.2.2.4 Determination of Rainfall intensity for current situation (without Climate Change)

The intensity is determined:

- For a duration equal to the time of concentration Tc of the catchment area to be drained;
- On the basis of the IDF curves applied with the regional coefficient corresponding to the intercepted catchment area:

- **For Region II PJ (10y) < 230 mm:**

In case of an entire region II watershed, the following IDF curve will be applied without modification.

$$I\ (Ty) = (a(Ty) \times D^{(1-b(Ty))})/Tc$$

Where:

- D = rainfall duration in mn;
- H (Ty) = rainfall in mm for T return period; and
- a(Ty) and b(Ty) are coefficients with the following values:

RII		
Rainfall duration	6 mn to 2 hrs	2 hrs to 24 hrs
a 10y	7.276	13.206
b 10y	0.457	0.596
a 25y	8.462	14.435
b 25y	0.463	0.587
a 50	9.360	15.391
b 50y	0.466	0.581
a 100y	10.259	16.364
b 100y	0.469	0.577

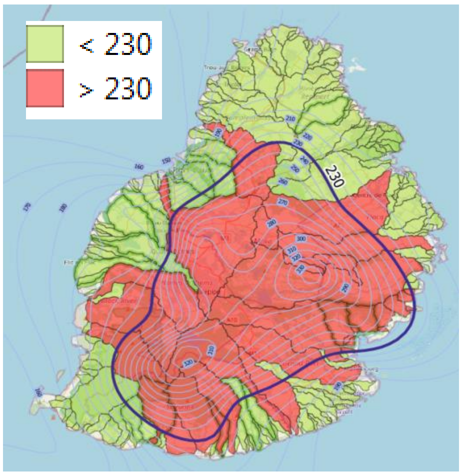


Figure 136: Rainfall coefficients – Region II

- **for Region I PJ (10y)> 230 mm:**

$$I\ (Ty) = \left(Wc\ \times a(Ty) \times D^{(1-b(Ty))}\right)/Tc$$

Where:

- D = rainfall duration in mn;
- H (Ty) = rainfall in mm for T return period,
- a(Ty) and b(Ty) are coefficients with the following values:

RII		
Rainfall duration	**6 mn to 2 hrs**	**2 hrs to 24 hrs**
a 10y	9.953	19.741
b 10y	0.455	0.608
a 25y	11.860	22.060
b 25	0.461	0.597
a 50y	13.275	23.789
b 50y	0.464	0.591
a 100y	15.156	25.537
b 100y	0.463	0.587

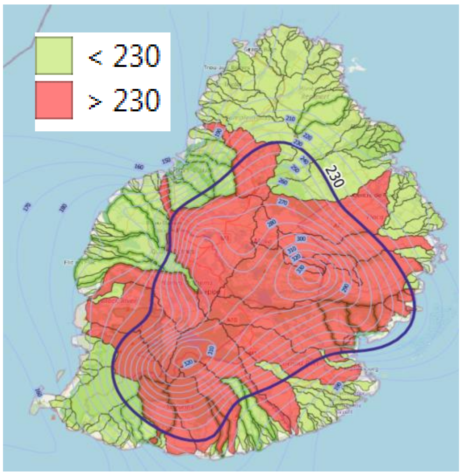
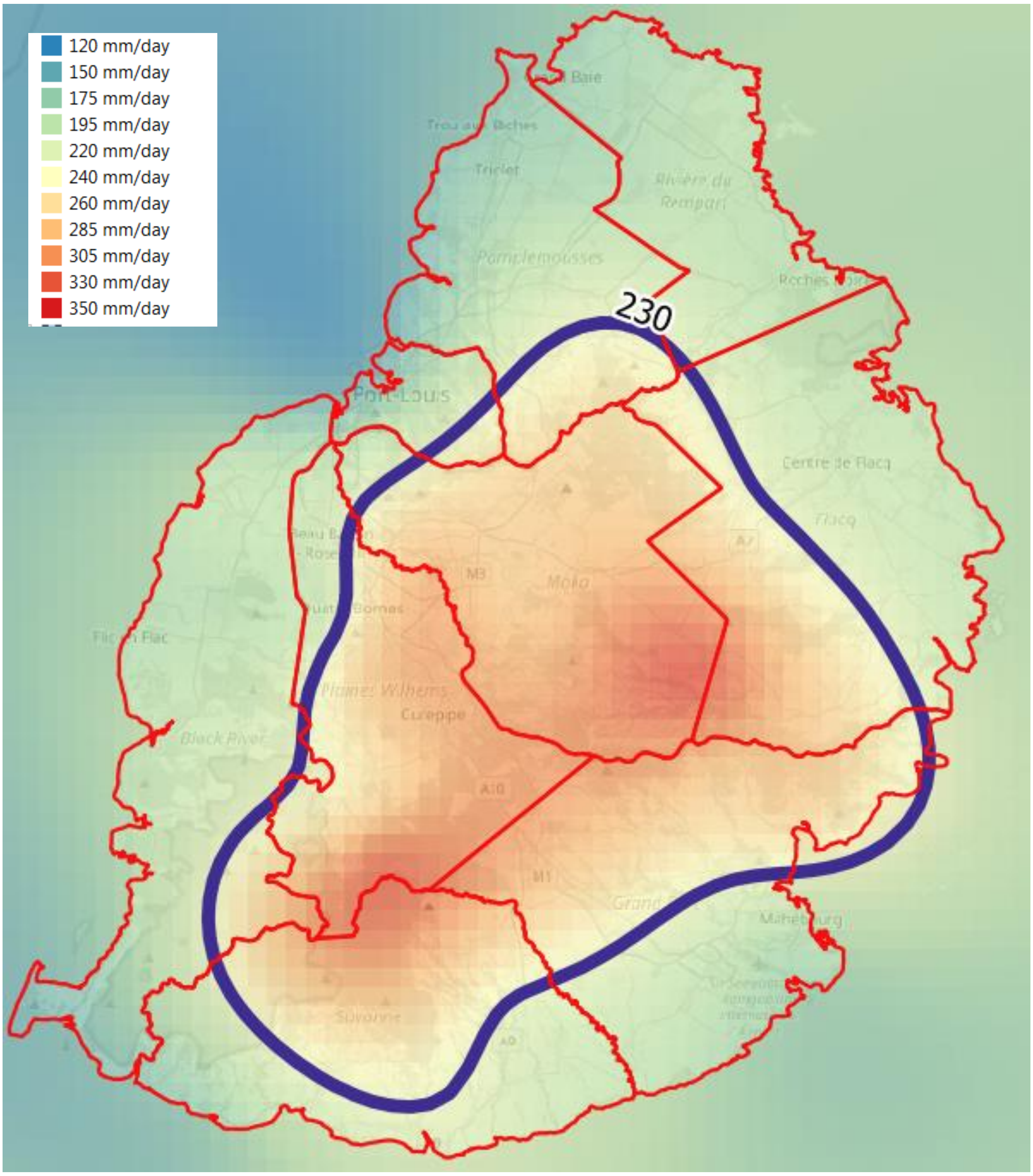


Figure 137: Rainfall coefficients – Region I

Wc factor should be calculated by weighting the PJ 10 quantiles of the 1 km² grid at the scale of the catchment and sub-catchment studied, in such case the raster RP_10y.Tiff (mm) must be used.



RP_10y.Tiff (mm) – Gridd 1km²

Figure 138: Daily rainfall in mm (1961 – 2018) – RP_10y.Tiff (mm)

5.1.2.2.5 Determination of Rainfall intensity with climate change factor

As part of drainage design studies (drains and retention basins), **it is recommended to integrate the conservative factor, which takes into account the effects of global warming** (Refer to section 4.1)

Thus, the rainfall intensities will be given a conservative multiplying coefficient.

$$I(Ty) = 1.182 * \frac{H\ (Ty)}{Tc}$$

5.2 Design of drainage structure: Recommendations

5.2.1 For new development obligations for Sustainable Urban drainage development

5.2.1.1 Managing rainwater at the city scale – Promotion of SUDs

Stormwater management in cities is based on the implementation of a range of complementary solutions, from individual houses to collective facilities.

Rainwater is thus used or infiltrated as closely as possible, and the use of complex structures is limited. The presence of water and vegetation in the city is an asset for the living environment.

Thus, for new development projects, the urban planning regulations of the project should be based on the following recommendations for the use of **Sustainable Drainage Systems** (with reminder of the practice numbers):

- **<u>At the project scale: promote the limitation of soil impermeability</u>**
  - **Obligation of a minimum percentage of green spaces at the scale of the project: 25 to 30% are recommended.** These areas are also used for infiltration functions by levelling, terracing and retention (3, 4, 6);
  - In**tegration of vegetated filtering strips between car parking and green spaces** (6);
  - **Obligatory use of porous pavements**, **at least on all general surfaces outside traffic areas** (7);
  - **Drainage and infiltration** of the remaining impermeable surfaces **by ditches and swales** (5, 9) (cf. chapter 5.2.1.2);
  - **Compensation of urbanisation by the installation of retention basins and according to the zoning of stormwater** (1, 5) (cf chapter 5.4.2).

- **<u>At the plot level, from the house to the building: concept of managing its own water, without discharge, by implementing the following solutions:</u>**
  - **Obligation of a minimum percentage of green spaces at the scale of the project: 25 to 30% are recommended.** These areas are also used for infiltration functions by levelling, terracing and retention (3, 4);
  - **Installation of rainwater reuse tanks** (2);
  - **Levelling of soils for infiltration at the source** (3);
  - **Installation of infiltration and water retention systems: rain gardens** (4), wells and infiltration trenches (9) (cfChpater. 5.4.2)

Each technique is adapted to the magnitude of the rainfall according to the available space and the suitability of the soil for infiltration, even partial.

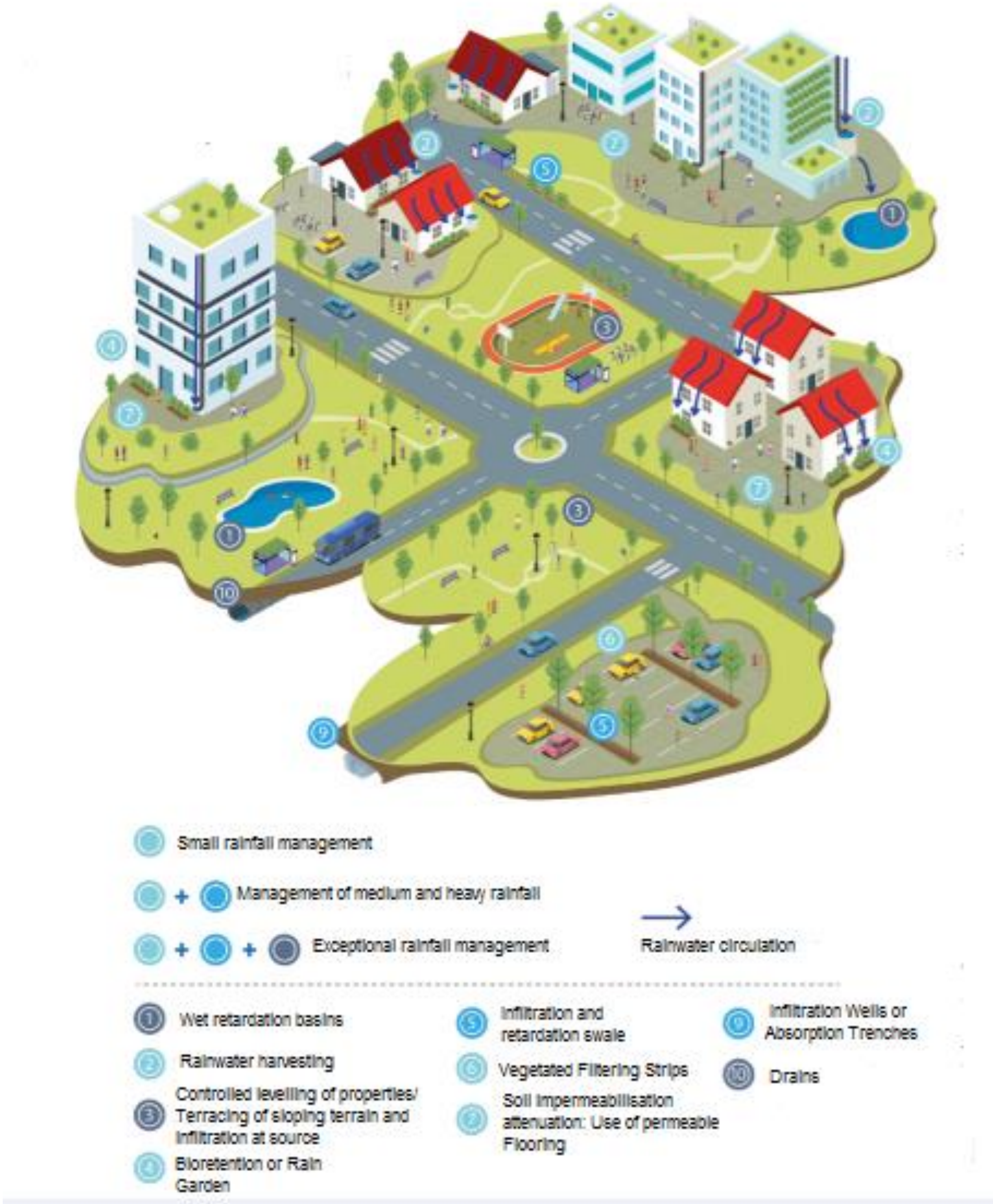


Figure 139: Stormwater management for new development - range of solutions (Adapted from Ile de France prefecture- France)

5.2.1.2 For new development - management practices for transfer and slow down transfer of stormwater and limit of use of traditional drain

For these projects, such as the Smart City, the recommendations for water drainage, to be implemented instead of traditional drains, are as follows:

- **Impose the systematic use of dry and grass lined swales and ditches for drained sites up to 1ha**. These areas will be connected to the drained areas by vegetated filter strips.
- **Impose the systematic use of swales and ditches as transfer systems** (associated with the functions of infiltration and retention according to localised situation - eg French drains) **for intercepted catchment areas up to 25 ha;**

For more details on the design of these types of structures, see chapter 3.4.3.4.

<u>Special case in respect of natural flow paths / limited use of cut-off drains for development:</u>

The use of cut-off drains should be strictly limited to the protection of existing infrastructure and should not be encouraged in the construction of new projects.

With regard to natural flow paths, as stated in chapter 2.6.3.2, for this type of urban development and as called for all other developments, natural flow paths **should be preserved according to the setback margins depending on the catchment area being drained.**

Exception: subject to technical constraints, it may be possible for a developer to create cut-off drains under the following conditions:

- the natural flow path must intercept an area of less than 25 ha
- the developer shall request for special consideration addressed to the LDA together with a comprehensive hydraulic report. This hydraulic report should justify that:
  - the catchment area intercepted by the natural flow path is less than 25 ha
  - the discharge point downstream of the project is unchanged from the current situation
  - the project has no negative impact downstream (no acceleration of flow velocity and peak flow rate)

5.2.1.3 Recommendation for design within the development in lieu of the project area: rain harvesting (Reuse) system and concept to manage and contain stormwater

Thefollowing recommendations are made to promote the re-use of stormwater at the scale of individual parcels, while ensuring that peak flow control measures are respected by the retardation principle:

(Cf; principle 3.5.4).

- **: Upstream structure: storage function for re-use of rainwater**
  - **by the installation of retention tanks -** particularly suitable for the storage of roof water (preferred option).

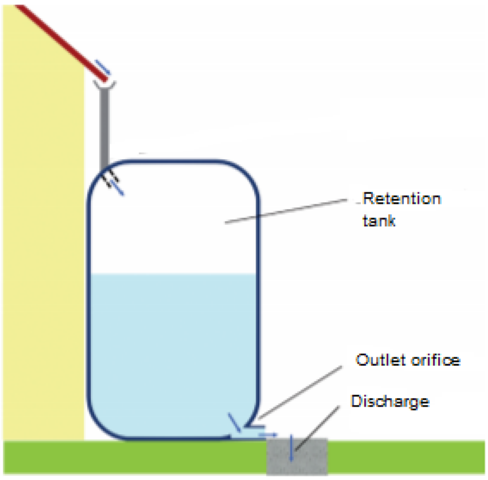


Figure 140 : Rain Harvesting

  - **direct storage on the roof**
- **:Dowstream structures: installation of storage garden (retardation function)**

A bed of plants or stones located in a depression in the ground and designed to capture rainwater and allow it to be temporarily stored while promoting infiltration. If the soil is clayey, it can be replaced by a mixture of 60% sand, 20% compost and 20% topsoil. This measure is suitable for small retention volumes.

Figure 141: Rain storage garden

The final discharge will end up into the drainage system managed by the LDA after a discharge permit has been granted.

5.2.2 Open drains / covered drains with concrete slabs / Gullies

In the assessment of the effectiveness of storm drains in Mauritius, it was generally found that concrete slabs placed on drains, particularly cross drains, hinder the inflow of runoff water.

The guideline recommends the use of metal gratings in lieu of concrete slabs.

Therefore, in order to improve the efficiency of the drains and particularly the collection of water towards the drains, the following provisions must be respected:

Figure 142 : Concrete slabs with openings

- Without cover, either directly into the drain for drains outside the right of way of roads or footpaths;
- Through a wide mesh grating (more than 60% opening), in the case of drains outside the roadway which need to be protected (for example for pedestrian crossings and light traffic).
- Through gratings with wide openings (minimum 20 mm by 20 mm) reinforced for vehicular traffic.

Figure 143: Metal gratings

The useful surfaces will depend on the percentage of opening (generally 40 to 60%).

The absorption capacity of a gutter grate is calculated by the Manning Strickler formula:

$$Q = ks \times S \times \sqrt{}(2 \times g \times h)$$

With:

- ks depends on the geometry of the grate = $0.6 \times n \times S \times k$
  - n : numbers of openings in the grid
  - k: blocking coefficient (0.8 < k <1)
  - s: cross-sectional area of each of the n openings in the grid
- h: height of water considered (h < 0.10 m in practice)
- g: acceleration of gravity g = 9.81 m/s².

If we take a stormwater grate with a surface area of 1 m^2 with 40% opening and 20% closing (k = 0.8), then the maximum flow that can be engulfed would be 270 l/s.

In the case of slopes > 1%, it is recommended to place these gratings immediately upstream of a raised pedestrian crossing in such a way as to allow the water to run off the road and to reduce the speed of flow over the road surface.

In case of a longitudinal slope of the road between 0.5 and 1%, the distance between the gratings is set at a maximum of 10 m interval. In case of longitudinal slope =< 0.5%, the distance between the gratings is 2 to 5 m maximum.

Size of gullies:

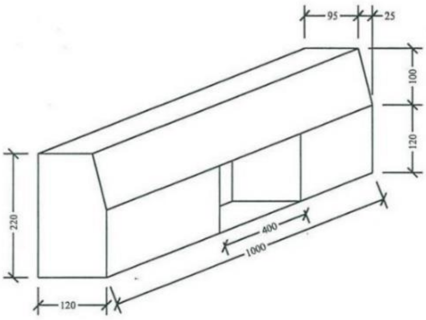
Generally, and especially in Mauritius, gullies easily and quickly get clogged, partly attributed to resurfacing work being carried out without raising the gully kerb. A minimum size for the gully inlet should be defined.

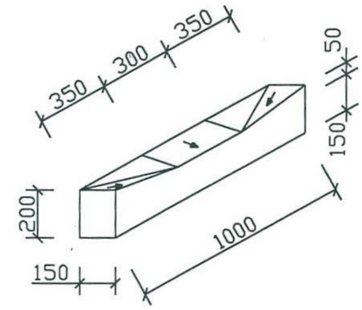
The following recommendations must be respected:

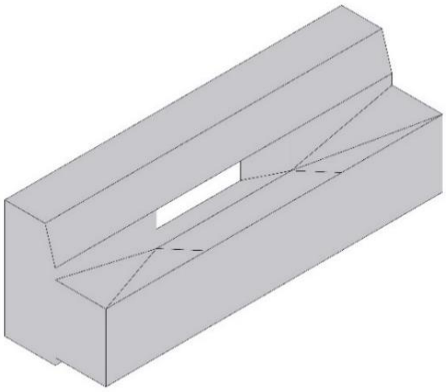
- A two-piece open side concrete gully with a sloping receptacle for stormwater entry.
- Minimum cross section: 0.1 m^2 and minimum height of 15 cm.

For optimum efficiency, it is recommended to have one gully kerb for every 5 to 6 m^2 surface of road, i.e. for a 5 m wide road, a gully every 2 to 2.5 meters (on either side of the road).

To make up for possible contraction of the aperture through resurfacing work, the gully should be provided with a wider opening and galvanised mild steel (gms) rods or flats incorporated in the kerb casting to serve the dual purpose of reinforcement against vertical loading and as a grating to prevent the entry of large objects.







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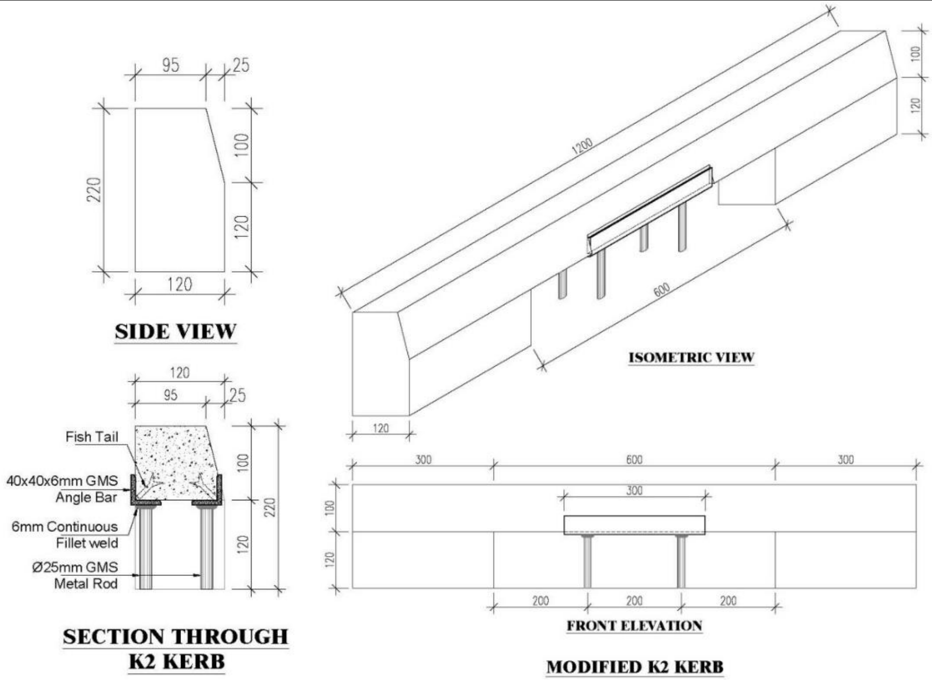


Alternatively, ductile iron kerb gratings should be used in preference as they also provide easy access for maintenance of the covered drain (trottoir) in lieu of heavy concrete slabs



Figure 144: Gully kerbs

5.2.3 Covered drains: standard sizes for manholes for cleaning and maintenance

For covered drains, manholes allow access to the drain network, if it is large enough to be visited, or simply to inspect it and ensure its maintenance and service.

Manholes can thus be listed as:

- access manholes for inspection,
- maintenance manholes for cleaning or equipment access.

Main characteristics / Standard manhole sizes for maintenance:

Access manholes should be **1000 mm in diameter or an equivalent size for drains in general** and **1200 mm equivalent diameter for manifolds on primary drains**. **Manhole covers should respectively be 600mm and 800mm.**

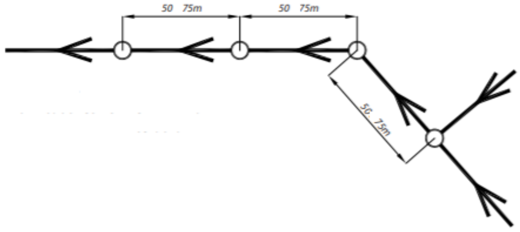
These standard sizes allow access for cleaning and maintenance purposes.

Access manholes must have safety equipment if the depth is greater than 2.0m and a ladder is mandatory.

Design rules: accessible and semi-accessible systems:

Design of manholes for inspection purposes:

- every 50m, and at most every 75m in a straight line,
- at each change of direction, slope or section, or in the event of a fall or weir on the network;
- at each network intersection
  Access and cleaning manholes should be positioned off the road wherever possible, and where appropriate, should cause minimum obstruction to traffic.



5.2.4 Slot drains and RC pipes

The effectiveness of slot drains for flood control, given the inherent difficulty of maintenance, requires that their use be limited to only a few specific applications:

- In landscaping works in public or private spaces subject to regular maintenance control;
- For drainage at the foot of buildings.

Similar maintenance problems are recurrent for RC pipes.

It is therefore recommended not to use slot drains and RC pipes for all future developments, except for exceptional cases mentioned above.

Figure 145: Slotted Drains

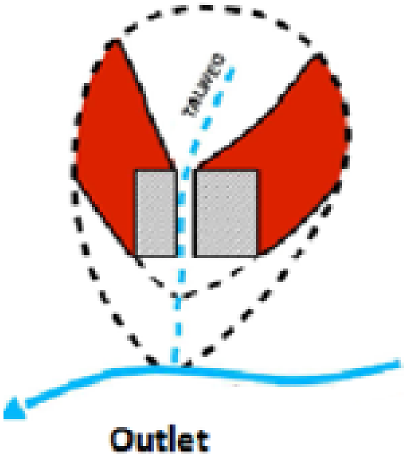
5.2.5 Roadside recommendations

As a preliminary point, it is important to indicate that stormwater must be taken into account in the design of the road:

- The longitudinal and cross-sectional profiles of roads should be designed to allow for stormwater runoff and drainage of the roadway surface;
- The stormwater management guarantees the proper use of the road, under the responsibility of the public person in charge of its maintenance in case of damage due to the absence or malfunctioning of the networks (design or maintenance failure);
- The design and maintenance of networks is a mandatory expense for the competent authorities in charge of stormwater management.

For the consideration of road projects, the following recommendations are based, as for any project, on the concept of intercepted catchment area (see Table 17: Representation of project area within a watershed).

Table 39: Representation of the road project area within the watershed

Geographichal Configuration	
Analysis	***c :*** *The road project area intercepts upstream natural sheet flows but allows concentrated throughflow in the valley (thalweg..):* • *Project on a preserved thalweg*
Total Surface area to consider	Project Area+ Intercepted upstream catchment areas (overland sheet flow)

The authority in charge of the road project must then:

- **Consider all-natural flow and stream axes to be recovered**, i.e. make the road hydraulically transparent at the intersections of all talweg. The size of the hydraulic structure will be :
  - for a return period of 100 years with 1m of free board in the case of rivers and streams
  - o for a return period of 50 years with 0.5 m of free board in the case of a drain
- **Define the catchment area intercepted by the road project:**
  - **For an intercepted catchment area of less than 1ha, the roadside stormwater system can be used both for road drainage and for collecting water from the intercepted catchment area (single drain)**. In this case, the volume of water to be collected must take into account the total amount of water in the intercepted catchment area.
  - **Above 1ha of intercepted catchment area, and in accordance with the recommendation relating to hydraulic recovery, the road drain must be separate from the catchment area**: it will only drain the road surface concerned. It will be provided with retention basins before discharge of road stormwater at a regulated rate into the natural talweg.

As the project will generate new impermeabilisation, the road projects will be subject to impermeabilisation compensation measures. In this context, the rainwater drainage network dedicated to the road will be built with a retardation basin before discharge into the natural talweg. The volumes and discharge rates of these basins will comply with the zoning rules (5.4.2). These measures require the project developer to have a larger land area than the road's lane.

Finally, the following recommendations incorporating sustainable stormwater management techniques should be implemented:

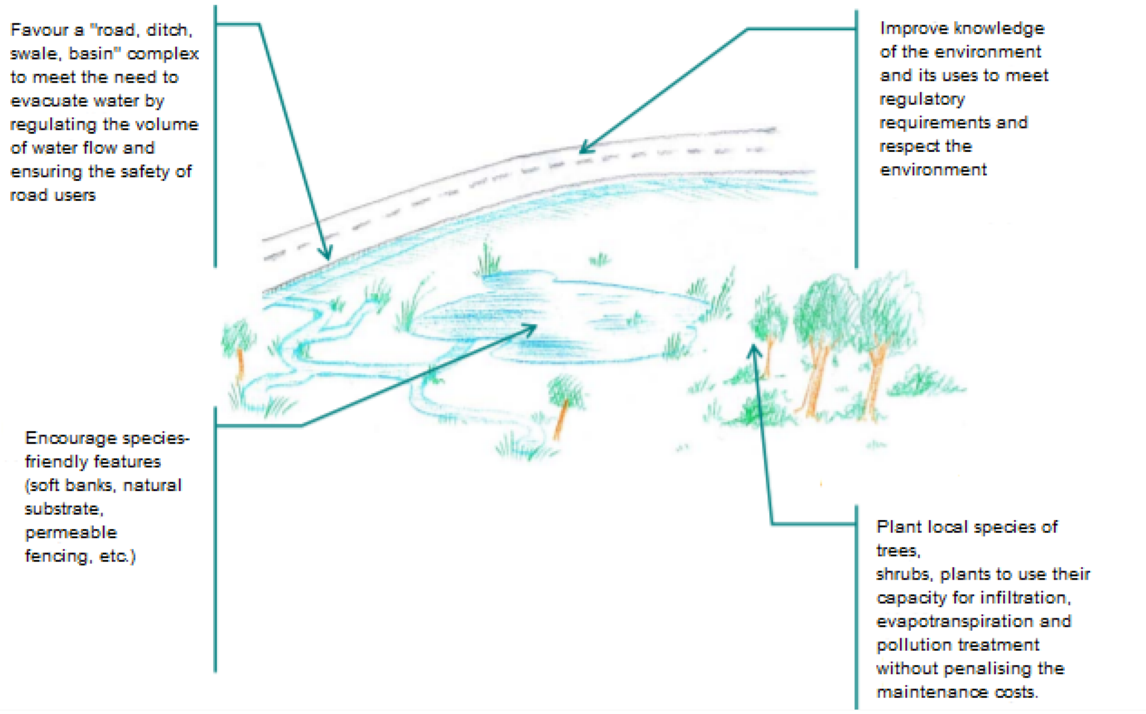


Figure 146: Recommendations for the implementation of nature-based sustainable solutions – case of road structures

5.2.6 *Swales specifications*

Swale stormwater controls may be used to model a range of stormwater controls including, but not limited to, wet swales, vegetated, dry swales, French drains, filter trenches, infiltration trenches, trench soakaways, all with and without under additional French drain.

5.2.6.1 Typical section for swales

The following figure shows a typical swale without French drains.

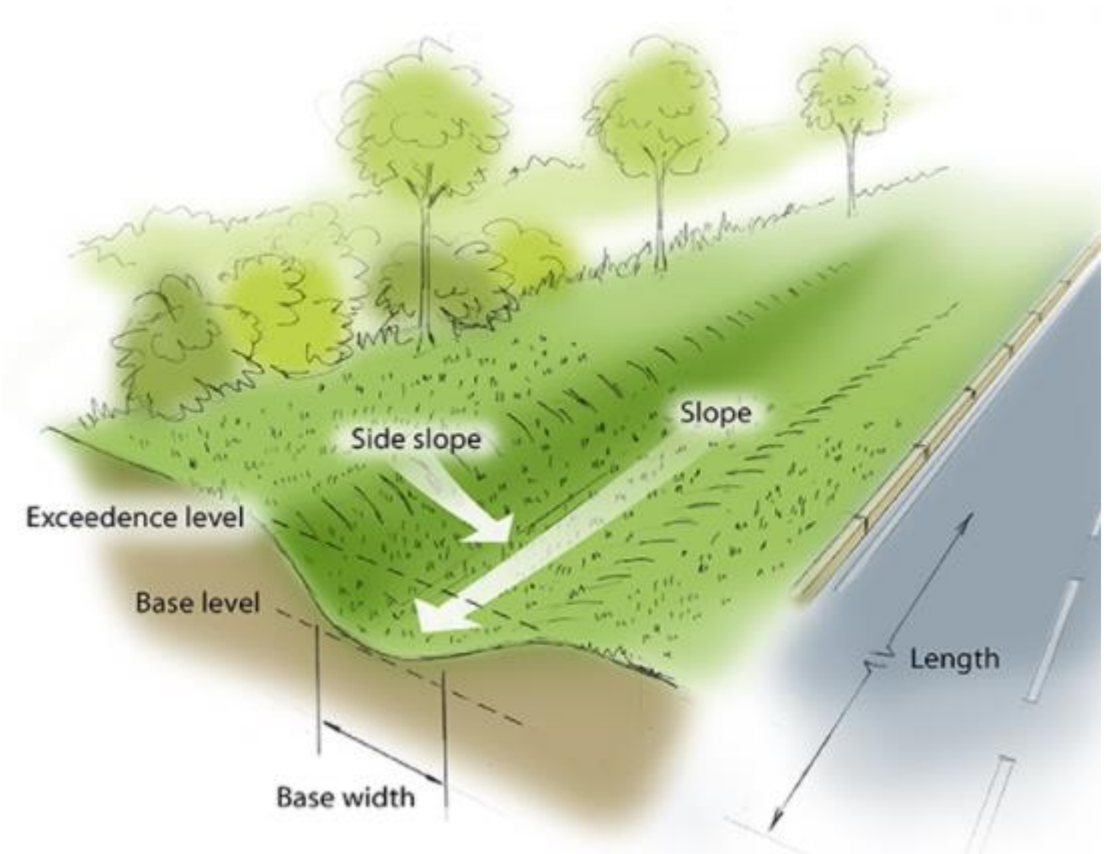


Figure 147: Typical section for swale (source Innovyze drainage)

- ***<u>Cross section</u>***

Ditches or swales may have a parabolic or trapezoidal cross section (see following figure). The trapezoidal shape is easier to construct and is more hydraulically efficient. Channels, however, tend to become parabolic over time and it is good practice to ensure this trapezoidal shape.

Deep and narrow ditches are less effective in removing pollutants than wide and shallow ditches.

Ditches or swales should have the widest possible cross-sections to minimize water velocities and heights with flow for quality control.

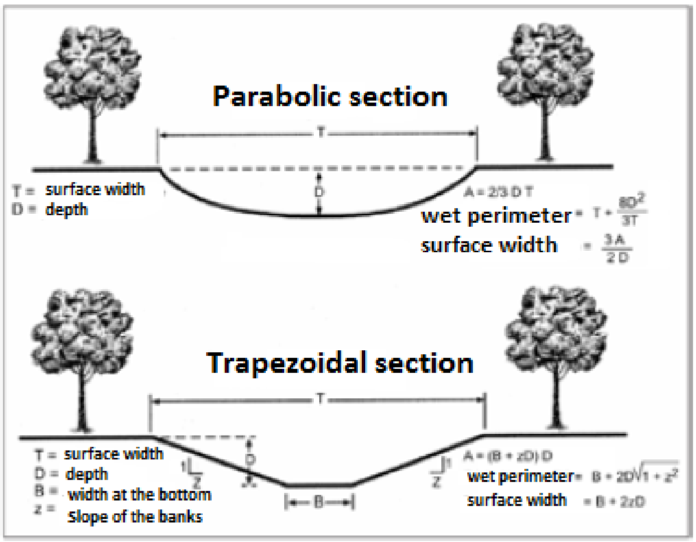


Figure 148: Typical cross sections of dry swale

- ***Longitudinal Slope***

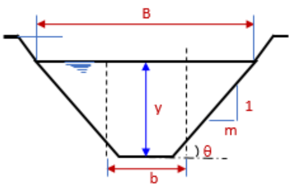
Optimum efficiency of dry and grass lined swales for stormwater treatment is achieved when the bed slope is kept to a minimum and the bottom is wide (width greater than 1 m). A minimum slope of 1% is recommended, in which case the use of a perforated drain is also recommended.

- ***Side Slopes (m)***

Embankment slopes should be as low as possible for the preliminary treatment of stormwater. A maximum slope of 3H / 1V is recommended with 4H / 1V being the ideal ratio, space permitting.

- ***Capacity***

- $Longitudinal\ slope\ I\ (m/m)$
- $Wetted\ cross\text{-}sectional \rightarrow A(m^2) = by + my^2$
- $Wetted\ perimeter \rightarrow P_m\ (m) = b + 2y\sqrt{1+m^2}$
- $Hydraulic\ radius \rightarrow R_h(\ m) = \frac{S}{P_m}$



$$\boldsymbol{Discharge\ capacity\ in\ m3/s \rightarrow Q = \frac{1}{n} S {R_h}^{2/3} \sqrt{I}}$$

Surface Material	Manning's Roughness Coefficient - *n* -
Asphalt	0.016
Brick and cement mortar	0.015
Clay tile	0.014
Concrete - steel forms	0.011
Concrete (Cement) - finished	0.012
Earth, smooth	0.018
Earth channel - clean	0.022
Earth channel - gravelly	0.025
Earth channel - weedy	0.03
Earth channel - stony, cobbles	0.035
Floodplains - pasture, farmland	0.035
Floodplains - light brush	0.05
Floodplains - heavy brush	0.075
Floodplains - trees	0.15
Gravel, firm	0.023
Masonry	0.025
Natural channels, very poor condition	0.06
Rubble Masonry	0.017 - 0.022
Steel - smooth	0.012

5.2.6.2 Additional french drains beneath the swales

If the longitudinal slope is small (less than 1%), then it will be possible in edition to add a French drain beneath the swale.

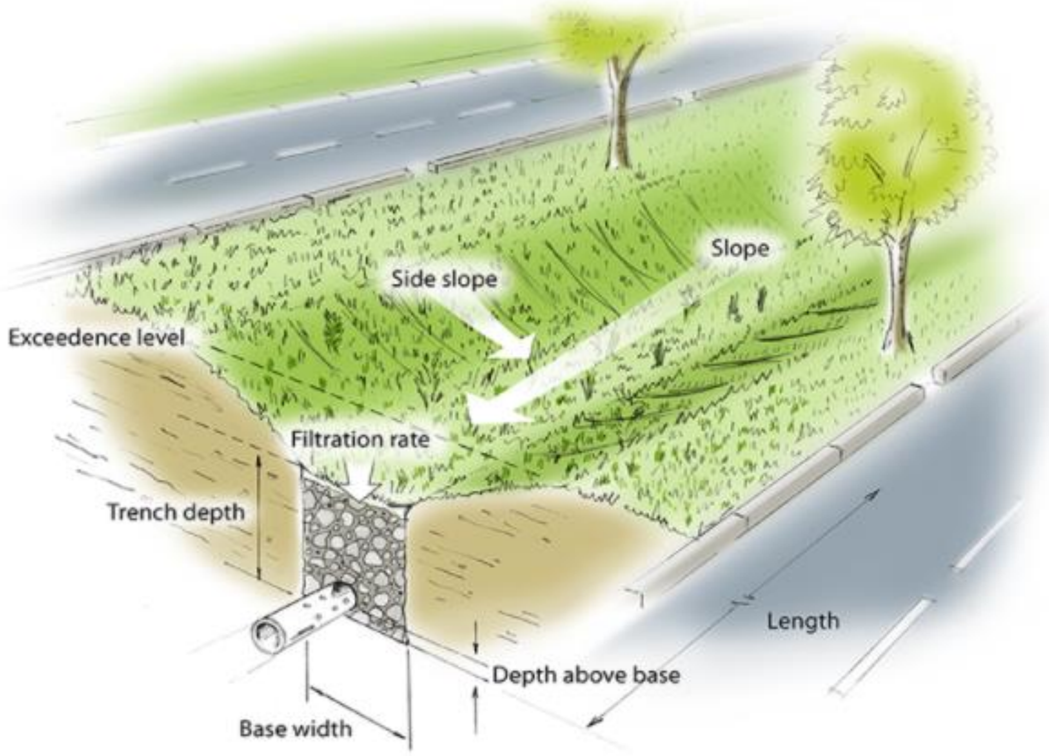


Figure 149: Typical section for swale with French drains beneath (source Innovyze drainage)

The following section shows the specifications for French drains.

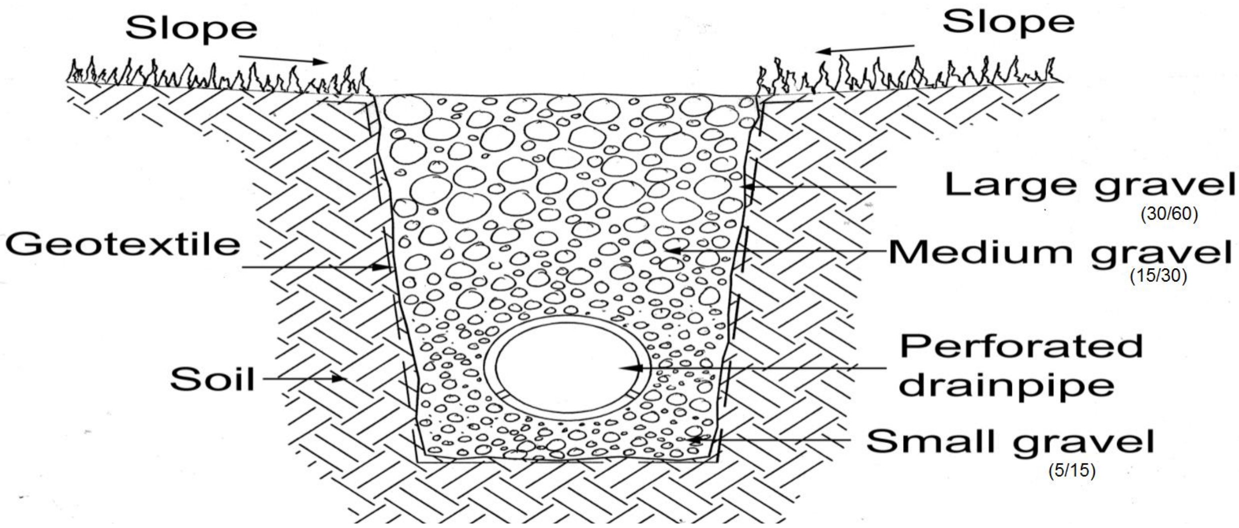


Figure 150: Typical section for French drains lined wth a geotextile liner (source LDHP Cynthia J Steward)

Recommendations for french drains beneath swale:

Although this measure enhances drainage and infiltration to an extent, many similar situations of this type of installation on the island (eg absoption drains) illustrate the limit on their effectiveness, in particular in the absence of regular maintenance due to fine sediment transport clogging the drains.

The following recommendations are therefore made for this type of design:

- Do not implement if the infiltration capacity of the soil is too low (less than 20 mm/h)
- For catchment areas subject to erosion where fine soil particles can be entrained in stormwater, systematically use a sedimenattion basin upstream of the swale. Regular maintenance of this basin after each rainfall will then be necessary to remove the fine sediments.

5.2.7 Hydraulic design specifications

5.2.7.1 Use of energy dissipation structures

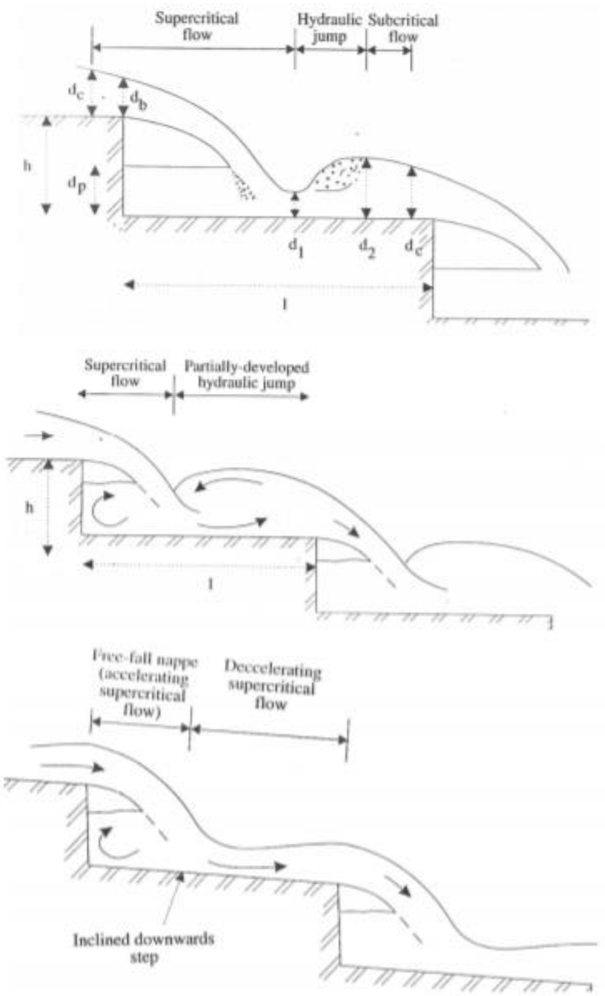
- **For drain flows on steep slopes**
  - **General provisions**

For steep flows (from about 1.5 to 2% and above), ditches should be provided with regular weirs (velocity > 2.5 to 3 m/s and above for swale).

Downstream of the weir and/or the outlet, it is essential to provide for the dissipation of the energy of the overflow. A structure covered with a geotextile filter will in most cases allow the waterfall to be absorbed.

A classic length of 5 m is required, with a downstream weir if possible. For large structures, a specific dimensioning study is necessary.

Energy dissipation ditches: these are used on the steepest slopes. They are reinforced by a succession of small waterfalls and basins to dissipate energy.



Top illustration: groundwater flow with full development of hydraulic jump. Middle illustration: groundwater flow with partial development of hydraulic jump. bottom illustration: groundwater flow without hydraulic overflow - (Chanson, 1994a, pages 46 & 47)

Figure 151: Energy dissipation structures

- **Simple Vertical Drop Falls**

Simple vertical drop fall or sarda fall consists, single vertical drop which allows the upstream water to fall with sudden impact on downstream. The downstream acts like cushion for the

upstream water and dissipate extra energy.

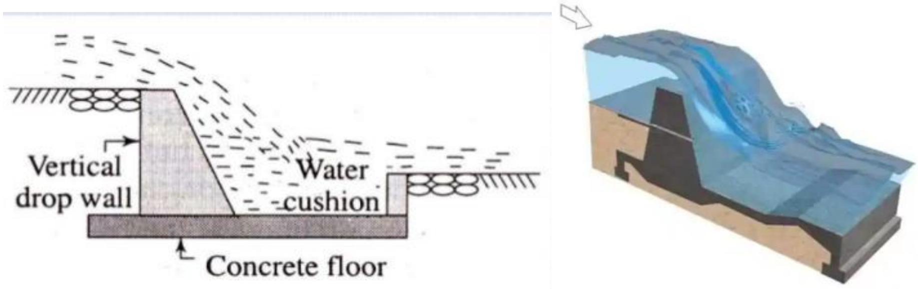


Figure 152: Vertical Drop Falls

- **Stepped Canal Falls**

As in the name itself, stepped fall consists in vertical steps at gradual intervals. Stepped fall is the modification of rapid fall. It is suitable for the canal which has its upstream at very high level as compared to downstream. These two levels are connected by providing vertical steps or drops as shown in figure.

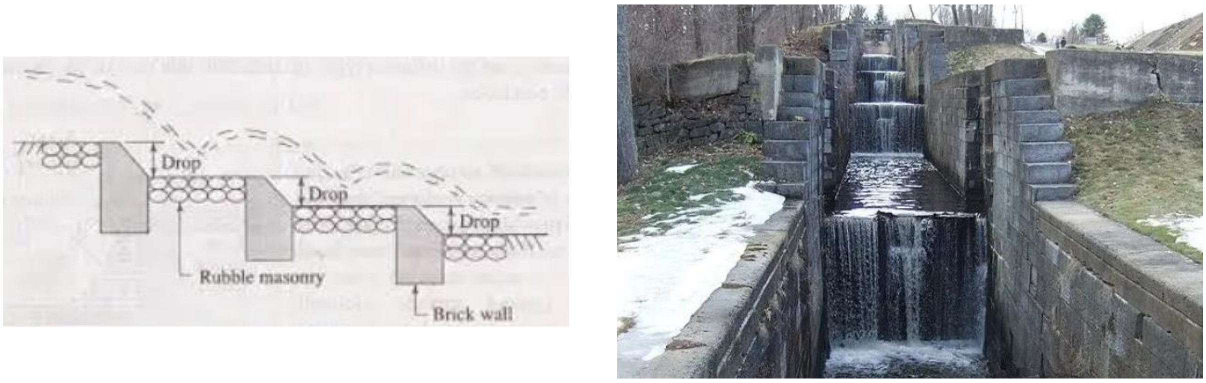


Figure 153: Stepped Canal Falls

- **Rapid Canal Falls**

Rapid fall consists in a long sloping glacis. It is constructed if the available natural ground surface is plane and long. For this, a bed of rubble masonry is provided, and it is finished with cement mortar of 1:3 ratio. To maintain the slope a bed of curtain walls is provided at both upstream and downstream.

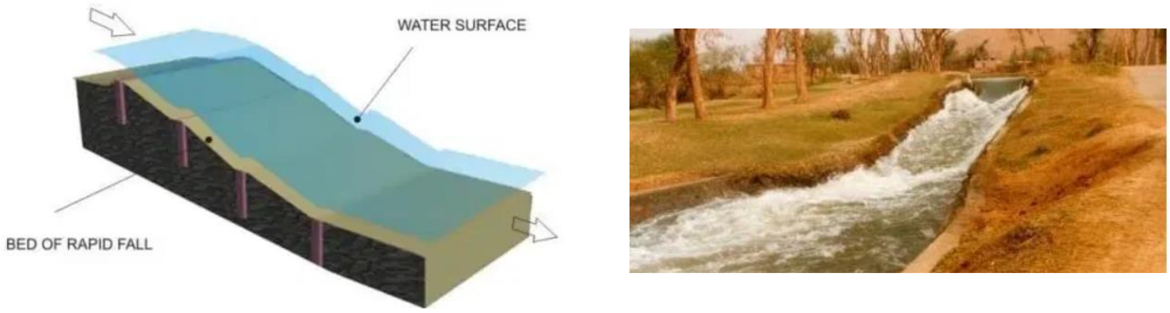


Figure 154: Rapid Canal Falls

- **Specific provisions**

Figure 155: Staircase drainage on road embankment

Figure 156: Cascading overflow structures in a ditch (view from donwstream)

- **For discharges into natural path**

The objective of these structures is to dissipate the energy of the flow discharged into the natural environment in order to reduce its erosive power. The use of this type of structure is particularly important when the substrate of the receiving environment is erodible (clay matrix, etc.) and when the discharge is made with a particularly high head or speed. The structures can be dissipation ditches, concrete or rockfill structures, perpendicular to the direction of flow of the discharge.

A 2 meters long energy dissipation ditch (1 metre on either side of the discharge axis) must be formed in accordance with the following scheme:

The bottom of the ditch should be lowered by 30 to 50 centimetres from the original water level to create a wet ditch during rainy periods to mitigate the effect of the waterfall. A soft 2 meters long slope connection should be made to the bottom of the ditch at the upstream and downstream ends of the structure.

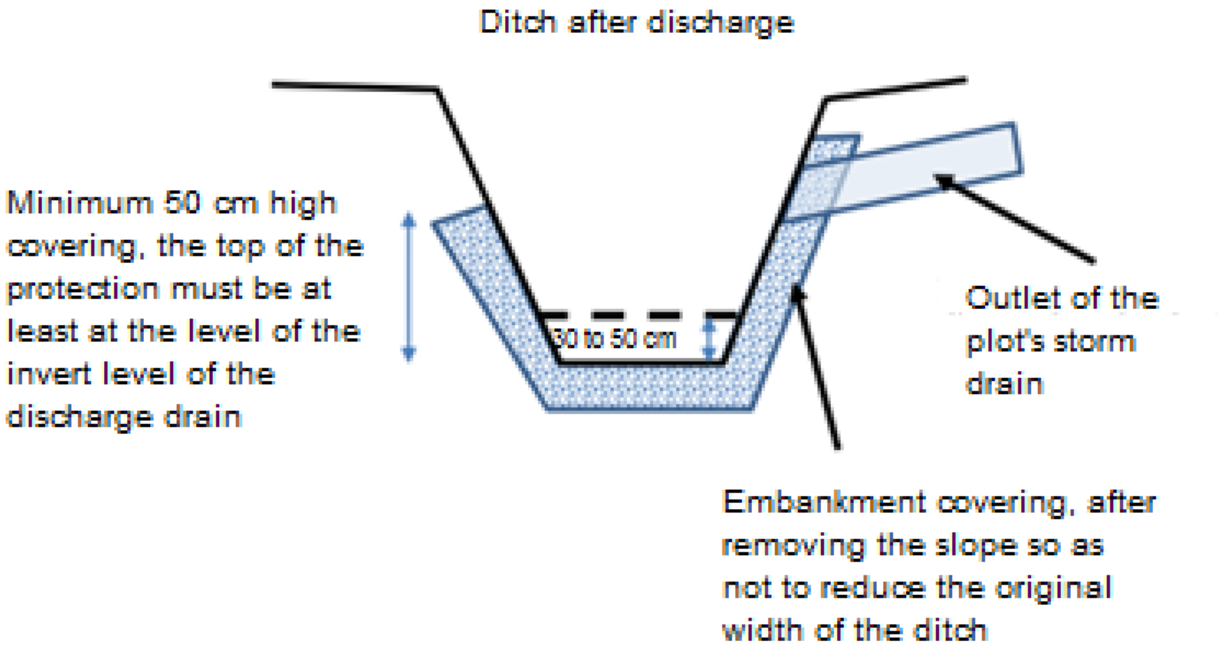


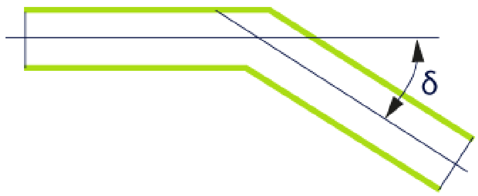
Figure 157: Schematic diagram of energy dissipation from discharge into a ditch

5.2.7.2 Angle of curvature and setbacks

5.2.7.2.1 Angle of curvature

It is recommended to limit the curves of the changes of direction of the drains according to the flow speed

The following formula applies :



$$\Delta h = K \frac{V^2}{2g}$$

	δ (°)	22.5	30	45	60	75	90
	K	0.17	0.2	0.4	0.7	1	1.5
V m/s	Δh (m)						
1.0		0.01	0.01	0.02	0.04	0.05	0.08
2.0		0.03	0.04	0.08	0.14	0.20	0.31
3.0		0.08	0.09	0.18	0.32	0.46	0.69
4.0		0.14	0.16	0.33	0.57	0.82	1.22
5.0		0.22	0.25	0.51	0.89	1.27	1.91

Figure 158 : Head loss by curvature angle (source https://www.suezwaterhandbook.com) and application examples

In practice, in order to limit head losses to half of the freeboard, it is necessary to limit the maximum velocities in the drains:

- The maximum velocities in the drains should be limited to 4 m/s. Beyond that, it will be useful to provide for larger free boards, especially on the extrados of curves
- At an angle of 45° maximum, 30° ideally.

The water level inclination due to the centrifugal force in a curve can also be evaluated according to the following simplified formula:

$$\Delta Z = \frac{V^2 \times B}{2g \times r}$$

With :

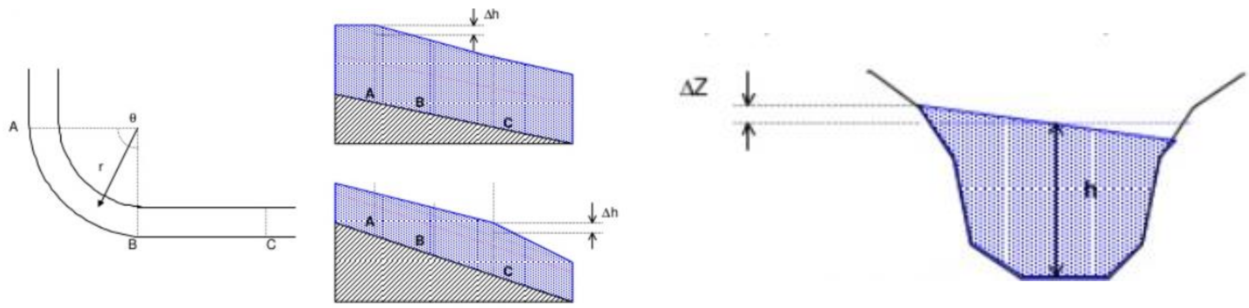
ΔZ : water level increase (m)

V : flow velocity (m/s)

B : width at the mirror (m)

r : rayon moyen de la courbe (m)

Thus, the following table allows to validate the radius of curvature for drains of different widths and for different speeds in order to limit the inclination to the minimum free board (30 cm).



	B (m)	1	1	1	1	1	1	1
	r (m)	2	4	6	8	10	15	20
V m/s								
1.0	ΔZ (m)	0.03	0.01	0.01	0.01	0.01	0.00	0.00
2.0		0.10	0.05	0.03	0.03	0.02	0.01	0.01
3.0		0.23	0.11	0.08	0.06	0.05	0.03	0.02
4.0		0.41	0.20	0.14	0.10	0.08	0.05	0.04
5.0		0.64	0.32	0.21	0.16	0.13	0.08	0.06

	B (m)	2	2	2	2	2	2	2
	r (m)	2	4	6	8	10	15	20
V m/s								
1.0	ΔZ (m)	0.05	0.03	0.02	0.01	0.01	0.01	0.01
2.0		0.20	0.10	0.07	0.05	0.04	0.03	0.02
3.0		0.46	0.23	0.15	0.11	0.09	0.06	0.05
4.0		0.82	0.41	0.27	0.20	0.16	0.11	0.08
5.0		1.27	0.64	0.42	0.32	0.25	0.17	0.13

	B (m)	3	3	3	3	3	3	3
	r (m)	2	4	6	8	10	15	20
V m/s								
1.0	ΔZ (m)	0.08	0.04	0.03	0.02	0.02	0.01	0.01
2.0		0.31	0.15	0.10	0.08	0.06	0.04	0.03
3.0		0.69	0.34	0.23	0.17	0.14	0.09	0.07
4.0		1.22	0.61	0.41	0.31	0.24	0.16	0.12
5.0		1.91	0.96	0.64	0.48	0.38	0.25	0.19

	B (m)	4	4	4	4	4	4	4
	r (m)	2	4	6	8	10	15	20
V m/s								
1.0	ΔZ (m)	0.10	0.05	0.03	0.03	0.02	0.01	0.01
2.0		0.41	0.20	0.14	0.10	0.08	0.05	0.04
3.0		0.92	0.46	0.31	0.23	0.18	0.12	0.09
4.0		1.63	0.82	0.54	0.41	0.33	0.22	0.16
5.0		2.55	1.27	0.85	0.64	0.51	0.34	0.25

	B (m)	5	5	5	5	5	5	5
	r (m)	2	4	6	8	10	15	20
V m/s								
1.0	ΔZ (m)	0.13	0.06	0.04	0.03	0.03	0.02	0.01
2.0		0.51	0.25	0.17	0.13	0.10	0.07	0.05
3.0		1.15	0.57	0.38	0.29	0.23	0.15	0.11
4.0		2.04	1.02	0.68	0.51	0.41	0.27	0.20
5.0		3.19	1.59	1.06	0.80	0.64	0.42	0.32

Figure 159: Level inclination due to the centrifugal force and application examples

5.2.7.2.2 Setbacks of drainage structures

It is often problematic to have setbacks on drains in urban areas.

Therefore, while respecting the buffers on the axes of natural flow intercepted by a drain (chapter 2.6.3.2), it is recommended to maintain **a setback of 1.5 m on both sides of the outside walls of the drains** in order to protect against the first spills, but also to facilitate maintenance

5.2.8 Special case for projects on hilly and sloping sites

5.2.8.1 Introduction

Sloping land is very prone to erosion whereby vegetative cover gets washed away by surface run-off or where intensive land use bares the soil. It is therefore important to prevent stormwater flows from rushing down slopes in an uncontrolled manner as to undermine houses and turn paths and streets into inaccessible gulleys. **As a rule of thumb, slopes of more than 5% can be considered as steep slopes.**

On steep terrain, the only way to retain water within the soil mass is through terracing as a way to reduce the slope. Various methods are used to control erosion on agricultural land. However, these methods can be replicated in an urban area only if the neighbourhood is not fully built up.

5.2.8.2 Stormwater management on steep slopes

Source: Surface Water Drainage for Low-Income Communities (World Health Organisation)

Different methods used to direct stormwater gradually down steep slopes and in manageable quantities are described below:

(a) Diverting stormwater almost horizontally by means of a bank built along contour lines or by turnout drains, thus reducing the flow velocity and avoiding accumulation of stormwater from the whole slope into a single drain.

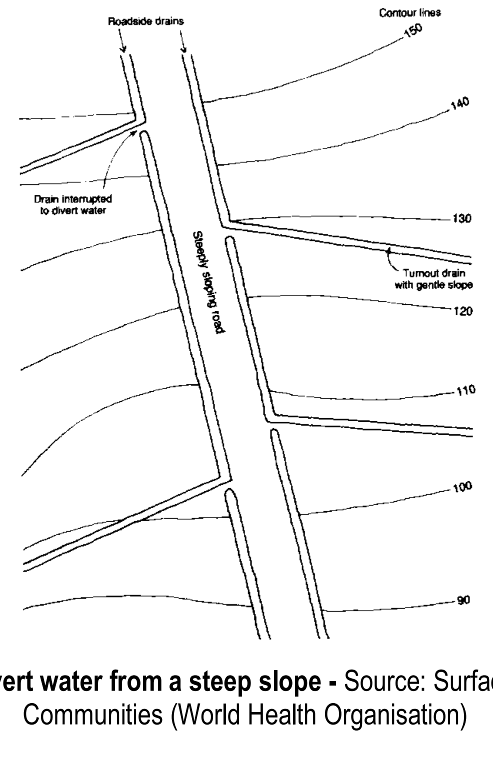


Figure 160: Turnout drains to divert water from a steep slope - Source: Surface Water Drainage for Low-Income Communities (World Health Organisation)

(b) Directing water flow in a controlled zigzag fashion by means of baffles built into the drain to slow down the flow;

As described in chapter 3.2.7, theses action leading to reduce runoff, increasing time of concentration and reducing peak flow, especially for projects located at the upper reach and midway of the catchment area.

(c) Building steps into the drain - The area on to which the water falls from each step is designed to resist the force of the falling water. Step drains are practical if the slope exceeds 30%, but otherwise they are not economical.

(d) Checkwalls offer a less expensive solution to the problem, and can be used in unlined drains. Stormwater deposits silt behind each checkwall, gradually building up a stepped drain. The checkwalls should be seated well into the ground on either side and below to ensure that water does not flow past them. In particular, the foundation of any checkwall should not be higher than the crest of the one downstream.

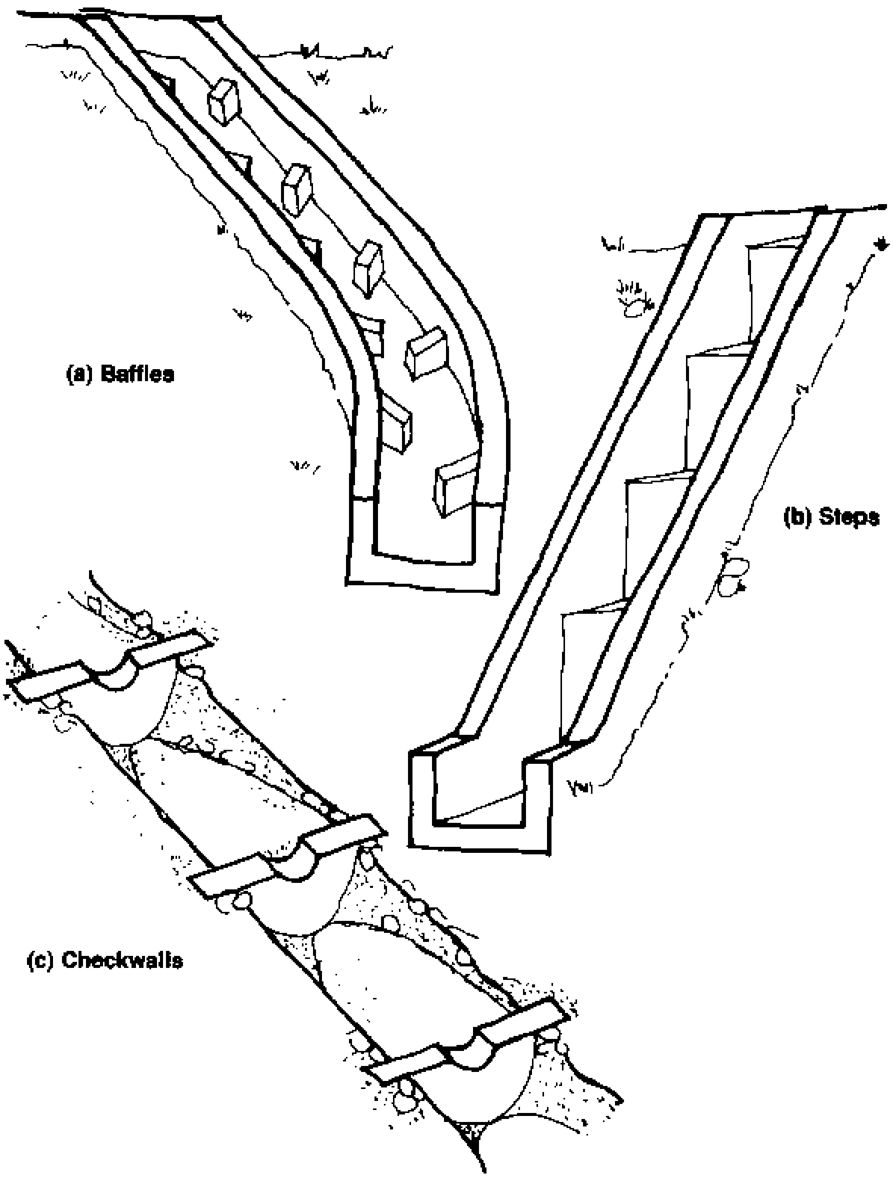


Figure 161: Drain types on steep terrain - Source: Surface Water Drainage for Low-Income Communities (World Health Organisation)

Checkwalls can be built from various materials besides concrete or masonry. Stockpiling large stones help to dissipate the energy of water as it flows through the tortuous voids between the stones. The stones must be of sucha size to resist being carried downstream by the water flow.

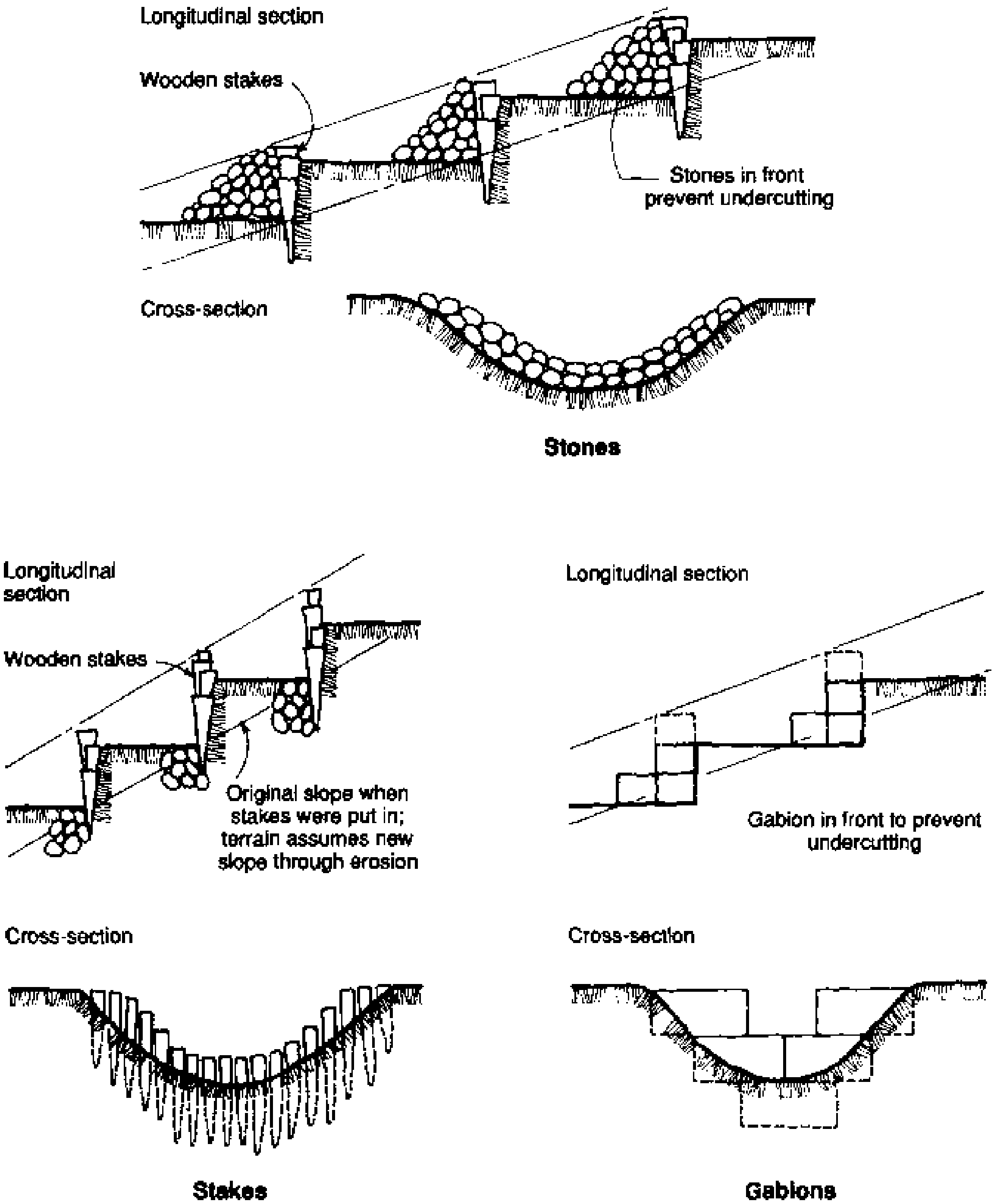


Figure 162: Types of checkwall or dissipator - Source: Surface Water Drainage for Low-Income Communities (World Health Organisation)

(refer to chapter 5.2.7.1 for hydraulics specifications).

In areas where rocks of adequate size are not readily available, rocks of smaller size may be assembled within gabion baskets.

A gabion is made by filling a large basket of galvanized wire mesh with stones, to make a large rectangular bundle of about 0.5-1.0 m³. These can be built up into a wall; however, it is advisable to fill them only after putting them in position.

In areas with a moderate ground slope of about 4-10%, drainage channels may be lined with concrete, masonry or vegetation to prevent scouring of the channel bed.

These provisions on steep slopes, by reducing the velocity and therefore the hydraulic head of the runoff, will help to control erosion of the land located downstream of these facilities, and thus contribute to the reduction of the effects of flash floods on rural and peri-urban areas.

Figure 163: Typical erosion due to slope: 16th April 2021 – Ferney and Providence (Source Tele plus and L'Express)

5.2.8.3 Sizing parameters

The hydraulic sizing of a steep drain must be carried out using dual control:

- first, with the peak flow
- secondly on the calculation of the energy line, i.e. by adding to the elevation of the water surface (capacity flow) the term $V^2/2g$ (i.e. the energy).

The freeboard is then added to the height of the structure to define the final size of the drain

5.2.9 Recommendations on Flap valves

It is not recommended to use flap valves for stormwater outlets since debris and insufficient hydraulic head render these facilities non-operational.

The developer should design his project to ensure free discharge flow above the receiving water level (see 5.2.7).

Should this not be feasible:

- hand operated or actuated sluice gate equipped with sensors may be a final recourse. The sensors are able to detect differential heads between the upstream and downstream faces of the gate and promt the gate to open or close accordingly.
- Lightweight flap valves with counter balancing weight will be accepted to limit charge losses.

The developer must demonstrate the use of flap valves as a last resort.

5.2.10 Additional design for bridges – Debris prevention

Any acceptable degree of blockage conditions should reflect both the likehood of occurrence and the consequences of such a blockage.

Typical blockage allowance of 10 % to 20% of the culvert flow area, but if the height < 3 m or with < 5m, the risk of 100% blockage increases.

Typical 100 % blockage of handrails and traffics barriers

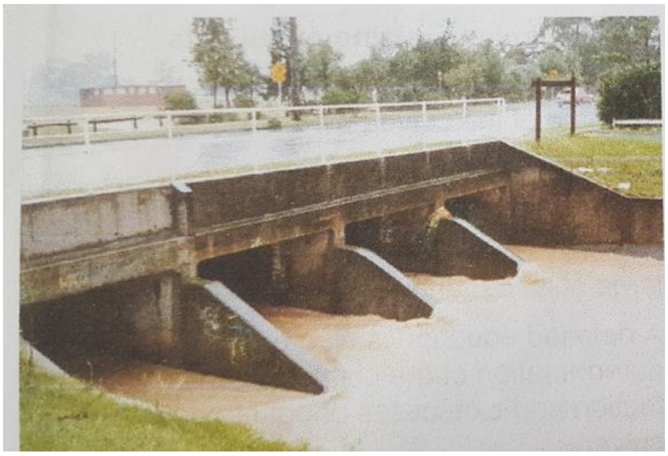
5.2.10.1 Single span cuvert

The implementation of single cell culverts, where technically possible, are favoured to twin or multiple spans.

in view of preventing obstruction to flow from the accumulation of debris and floating materials.

5.2.10.2 **Additional provisions**

- Multi-span culverts may be provided with **debris deflectors** on the upstream side of the culvert to reduce the risk of blockage.
- Debris deflectors are inclined extensions to the upstream centre walls to force floating objects up and out of the water way instead preventing them being forced into the culvert.



- Trash rails (*Peignes à Embacles) fixed into* the river bed upstream of bridges/culverts sre recommended

to prevent large floating debris from blocking the entrance of the bridge/culvert.

Trash rails *(Peignes à Embacles)* () are structures placed at the entrance of bridges or culverts to trap the majority of large debris while smaller floating objects get deflected and are guided through the openings. They are usually V-shaped with the crest pointing upstream to divert floating objects towards the banks. The reverse configuration is also used

Figure 164: Inverted V Trash Rails « Peigne à embâcle »

The rails are usually driven piles designed to resist high speed impacts (5 to 8 m/s).

Trash rails should be provided with an access ramp for maintenance of the structure. Any major obstruction to flow will lead to a rise in the water stage upstream and failure of the rails may be cause of damage downstream.

Regular maintenance of this structure is therefore essential.

5.2.11 Backflow prevention in low lying areas

In flat low-lying areas subject to flooding, a major problem often results from the relatively high level of the receiving water body. This limits the slope to which drains can be laid, resulting in water flowing along them quite slowly. Coupled with the difficulty of digging deep drainage channels where the groundwater level is high, drains have to be relatively wide in order to provide sufficient capacity.

The water level in the receiving water body often fluctuates, owing to tidal effects or the flows from other catchment areas. The variations in level should be analysed in terms of their frequency (return period), following which a decision can be made on possible solutions.

Possible solutions include:

- **Landfill**

Short of relocating houses located in isolated low lying areas the whole neighbourhood could be raised through backfilling including the floor levels of buildings. Only raising the levels of streets prone to inundation will cause increased flooding of the residential plots.

- **Polder system**

The need for backfilling can be avoided by building an embankment or dike along the bank of a river liable to flood, or right around the residential area creating a "polder"(initiated in the Netherlands for developing techniques to drain wetlands and make them usable for agriculture and other development). Of course, some installation such as a sluice gate is needed to allow a way out for water to drain from the area.

- **sluice gate**

Tidal or outlet variations in level can be addressed by installing a **sluice gate** at the outlet of the drainage system which is closed at high tide or high water level in the receiving body and opened when the level subsides.This operation can be performed either manually or remotely through an actuator. Level sensors placed on either side of the sluice gate can detect the variation in levels and activate the actuator to operate automatically.

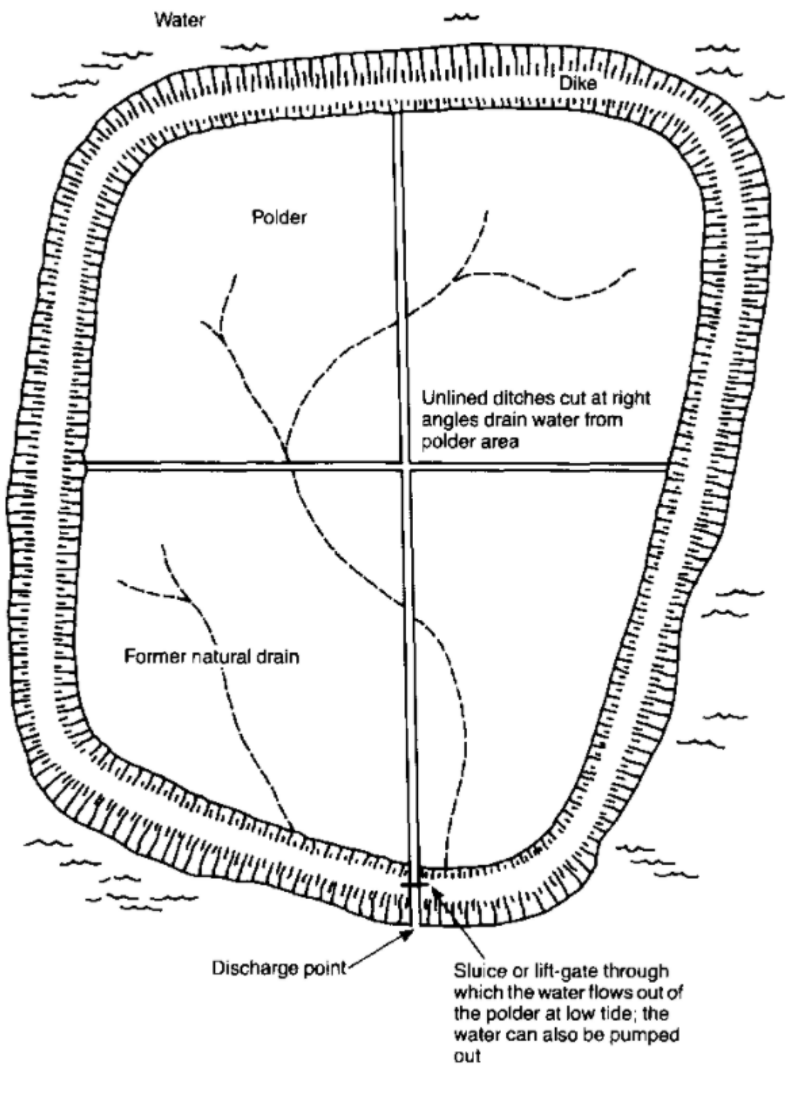


Figure 108: The polder system – Outlet equipped with a sluice gate (Source: Surface Water Drainage for Low-Income Communities (World Health Organisation)

- **Pumping**

As a last option it's possible to resort to pumping for disposal of stormwater, either using submersible pumps or archimedes screw pumps.

The archimedes screw pump is a positive displacement pump consisting of a rotating axial tube, inclined at an angle of 30° to 38° to the horizontal, around which are fixed one to three helicoidal spirals, rotating within an enveloping cylinder with the same axis, and along which the water or sludge rises. Archimedes screw pumps are frequently used in sewage treatment works for raising of urban wastewater or sludge but are also used in lieu of submersible pumps for transferring soil laden stormwater to small heights.

Compared to conventional pumps, the archimedes screw pumps has two major advantages:

- It can pump sediment loaded water and even coarse solids with little risk of clogging, as it has a larger flow area;
- It works at constant speed for a wide range of pumped flows with high efficiencies of between 65% and 85% depending on the operating conditions in relation to the maximum capacity.

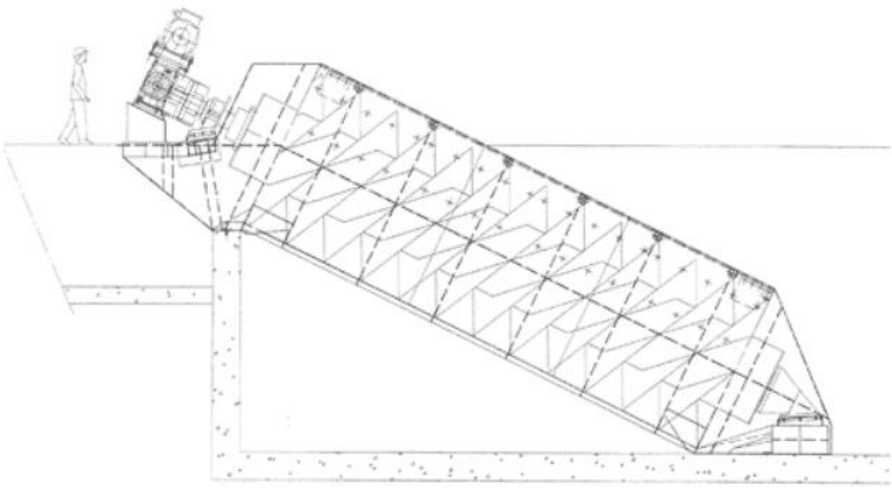


Figure 108: Pumping - Compact Archimedes screw pumps

5.3 Levels of protection of new buildings or structures when their construction is authorized in flood risk areas

5.3.1 Main objectives

The management and construction policy in flood-prone areas sets the following objectives:

- Preserve the storage and flow capacities of floods so as not to aggravate the risks for areas located upstream or downstream;
- Prohibit new human settlements in the most dangerous areas, where, safety of people cannot be fully guaranteed and limit them in other flood-prone areas;
- Avoid any embankment or backfilling, unless justifications are provided to protect the highly urbanized areas;
- Safeguard the quality of natural environments, which are often noticeable due to the proximity of water.

The regulations to be put in place set rules which mainly concern new projects but also projects on existing properties and more generally land use.

The defined measures are intended to preserve the areas of expansion from flooding, to promote free flow and to limit damage to existing or future properties and activities.

5.3.2 Construction in already urbanized areas subject to flood risks

In areas with dense settlements and subject to flood risks, it is possible to build infill sites. Infills are unbuilt land units, which are characterized as a discontinuity in the surrounding urban morphology. This notion does not apply to a loosely built area. It borders on several built plots (or roads) existing on the date of approval of the LDMP.

The objectives are as follows:

- Non-aggravation or even a reduction in the vulnerability of assets and activities. In order to ensure the safety of people and limit damage to property, it is necessary not to increase the assets at risk.
- Preservation of existing overflow zones and restriction on obstructions to flow in order not to accentuate floods.

The basic principles of construction are common sense: all new constructions should be designed to withstand flood (water depth and velocity).

Their siting, as well as other amenities within the plot, such as fences, landforms, crawl spaces or piling must not hinder the flow. Ground floors (underside of the living floor) should be in excess of 0.50m* above the natural ground level to avoid inundation during rising floods.

Vulnerable floor (and especially the place to sleep) level must be above the highest 100 years flood water mark, accessible from the inside and provided with an access permitting evacuation of the occupants from outside under all circumstances, be it flood or not. The European flood directives impose the construction of the first vulnerable floors above the highest 100 years flood water mark with a safety margin of 20 to 50 cm. The choice of 50 cm is generally applied everywhere where the definition of the 100 years flood mark is difficult (local effects due to runoff velocities), especially in urban areas.

This objective to ensure the safety of people can also translate into prohibiting living space (bedroom, living room, and kitchen) on the ground floor, unless the building is sufficiently raised or the living space is located at a section of the ground floor where the adjoining exterior is at a higher elevation than the rest of the building. Likewise, consideration should be given to positioning of the main openings and stairs and any basements to allow people to move upstairs rapidly.

*** Choice of 50 cm threshold:**

Based on the French guidance for flood risk prevention "Plan de Prévention des Risques (PPR)", a flood water depth of 50 cm has been adopted as the threshold, above which there is risk for a person to be carried away by water current.

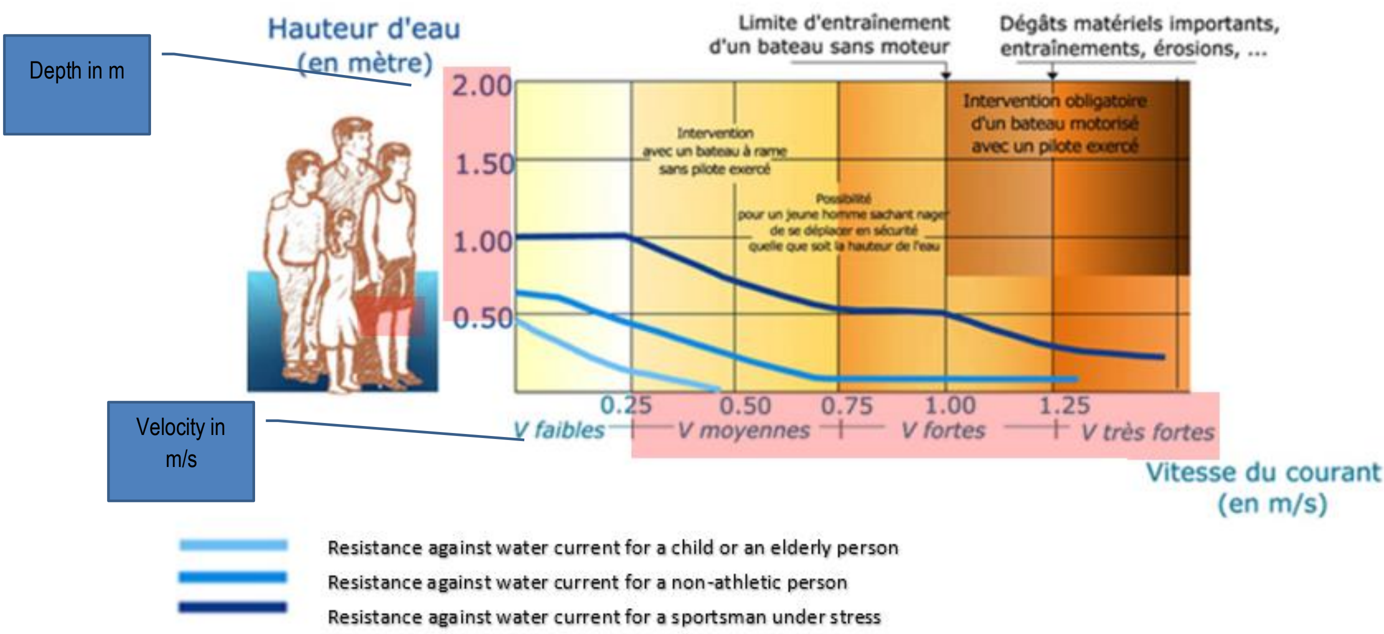


Figure 165: Vulnerability to human life in relation to water depth and flow velocity (source: Ministére de l'Environnement et du developpement Durable MEDD – France)

The following are then authorized under conditions:

- ▷ New construction: Authorized, provided that construction cannot be effected on the parcel elsewhere than outside the flood zone;
- ▷ Raising (addition of one or more storey) / adaptable to water rise: Authorised;
- ▷ Reconstruction / refurbishment: Authorized ;
- ▷ Extension: Authorized, provided that flow obstruction is avoided as much as possible;
- ▷ Usage Conversion: Authorised, unless the proposal is to convert into a sensitive institution and / or dwellings for vulnerable persons;
- ▷ Extension of an existing building for residential use (or garden shed): Authorized. Garages may be located at natural ground level ;
- ▷ Demolition: Autorised, provided that it does not increase the vulnerability of surrounding buildings.

5.4 Urban Planning policy recommendations

5.4.1 No Go Zones and No Expansion Zone

5.4.1.1 Principle

The aim of No Go Zones and No Expansion Zone is to prohibit and reduce all new urbanisation in high-risk areas, whether sparsely or non urbanised to date. In addition, this policy will preserve river reserves and floodplain expansion during flood events.

The following table summarises the principles of regulations related to No Go Zones and No Expansion Zones.

Table 40: Applications for No Go Zones and No Expansion Zones

Prescriptions for urban planning	No Go Zones	No Expansion Zones
Objectives	- Preservation of natural flood expansion areas / - Preserve the flow and flood expansion capacities so as not to aggravate the risks for upstream and downstream areas.	- Limit human settlements in the most dangerous areas where, regardless of the facilities, the safety of people cannot be fully guaranteed and limit them in other flood-prone areas Building under condition
Where	Mainly in non-urbanized areas or in areas with isolated building	Mainly in already urbanised areas
Fundamental principles of zone delimitation	- Flood zones mapped by hydraulic modelling integrating the reference flood, i.e. the 100-year return period flood - Outside the modelling areas, mapping according to the hydrogeomorphological approach established by the EXZECO method - functionality threshold - starting from 100 ha of catchment area, in order to allow new urbanisations consistent with the risks of flooding and runoff.	
Urban planning policy recommendations	**All new urbanisations are prohibited**	**All new urbanizations are subject to conditions and restrictions**
	For public utility works are authorized on condition that they do not increase the risks	*Extensions of existing buildings up to a % of the floor area* *For public utility works are authorized on condition that they do not increase the risks*

Strict control on urbanization of these particular area is necessary.

- **<u>Within non-urbanised areas (Natural or scattered habitable areas or with isolated buldings)</u>:**
  - Preserve flood expansion fields (overflow zones) by prohibiting any occupation or use of the land likely to obstruct the flow of water, or restrict the volume of flood storage. These overflow zones reduce flooding downstream (lower water depth).
  - Preserve and maintain the equilibrium of the environment depending on floods, or on the proximity of water bodies and the natural characteristics of the valleys.

Table 41: Justifications for NGZ and NEZ in non-urban areas

Within non-urbanised area (Natural or with isolated buldings): *All public utility works are authorized on condition that they do not increase the risks (2)*		
Where	**What**	**Main justification and *conditions***
In the lowlands, i.e. the accumulation zones (whatever the depth of the lowlands)	**NO GO ZONE**	Building and backfilling ban: lowlands participate in the reduction of the hazard by retention
In areas of flooding by run-off or overflow - Reference flood T= 100 years		
If Depth > 50 cm	**NO GO ZONE**	Need to preserve flood and runoff expansion fields
If Depth < 50 cm	**NO EXPANSION ZONE**	Need to allow moderate and adapted urbanisation *Construction limited in size (limited to 20% of the plot or 20% of the extension (1) if existing) + Build a living floor (underside of the floor) minimum 50 cm above the highest point of the ground level*
In areas where only the hydrogeomorphological extent is known (EXZECO)		
If the upstream catchment area is less than 100 ha (1km²),	**NO GO ZONE** (*) **only for buffer axis**	Preservation of natural flow paths - limit any obstructions to flows in order not to worsen the effects of the flood *Outside the buffer on axes, no restriction, but it is recommended that the first habitable floor be built if possible minimum 50 cm above the highest point of the ground level*
If the upstream catchment area is larger than 100 ha (1km²),	**NO GO ZONE**	Do not increase the risks downstream Non-aggravation or even reduction in the vulnerability of the assets and activities at risk. In order to ensure the safety of people and limit damage to property, it is necessary not to increase the number of assets already at risk.
Additional condition: In accordance with wetland buffers and other environmental regulations		

- **(1) Extension:** extension being defined as the construction of an additional surface adjoining an existing surfac). These extensions must not encroach on the existing setback from a watercourse.
- **(2) For public utility works, justifying the need for immediate proximity to the watercourse** (civil engineering works requiring backfill, technical room for raising alarm in the event of impending floods, or water abstraction works) will be authorized with the proviso that these will not aggravate risks.

(*): European legislation (Flood Directive and Flood Risk Prevention Plan) in order to manage flood risk and preserve flood expansion zones and non-urbanised areas regulates according to the hazard and land use. In non-urbanised areas, the regulation imposes that any new construction is forbidden whatever the hazard degree. This application participates in the protection and preservation of:

- flood expansion zones, essential for the dynamic slowing down of floods and streams
- already urbanised areas located downstream of non-urbanised areas

This principle is often applied by maps established by hydrogeomorphological methodology, whatever the surface area of the watershed concerned.

The recommendation made here, for a catchment area of 1km², is an adaptation to the insularity of the Mauritius territory. It is however recommended to be particularly vigilant on these zones which can then be urbanized. The evaluation and analysis of the drainage impact assessment on these zones (EXZECO between 25 and 100 ha) will have to be particularly analysed in order to respect the requirements of the stormwater zoning.

Focus on public utility works :

- Example of a list of public utility works:
    - Equipment of general interest = infrastructure or superstructure of collective interest intended for a public service:
        - drinking water supply, including boreholes,
        - sewerage, waste water treatment,
        - waste disposal centres,
        - networks,
        - infrastructure,
        - public transport equipment,
        - dykes to protect densely populated areas
        - ...
    - Work on sports facilities and light equipment for entertainment and outdoor recreation
    - Recreational park

- Details and requirement:

They are allowed subject to a prior hydraulic study, which must define the upstream and downstream consequences and determine their impact on flood flow, the compensatory measures to be adopted to cancel out their effects on floods and the conditions for making them safe. It also concerns works or developments on existing structures and dykes of interest to public safety, including the creation of embankments to protect densely populated areas, as demonstrated by a hydraulic study, and after obtaining the necessary regulatory authorisations.

Sensitive equipment, especially electrical equipment, should be placed above the water level

- **<u>Within already urbanised areas</u>**
    - Allow urban development to take account of the risk of flooding,
    - Preservation of flow paths - limit any obstructions to flows in order not to worsen the effects of the flood
    - Non-aggravation or even reduction in the vulnerability of the assets and activities at risk. In order to ensure the safety of people and limit damage to property, it is necessary not to increase the number of assets already at high risk.

Table 42: Justifications for NGZ and NEZ in non-urban areas

In urbanised area (or spread habitable areas) *All public utility works are authorized everywhere on condition that they do not increase the risks (2)*		
Where	**What**	**Main justification and *conditions***
In the lowlands, i.e. the accumulation zones		
Only if lowland deeper than 50 cm (*)	**NO GO ZONE**	Building and backfilling ban: lowlands participate in the reduction of the hazard by retention
In areas of flooding by run-off or overflow - Reference flood T= 100 years		
If water depth > 50 cm	**NO GO ZONE**	Principle of safety of property and persons Need to preserve flood and runoff expansion fields
If water depth < 50 cm	**NO EXPANSION ZONE**	Need to allow moderate and adapted urbanisation *Construction limited in size (limited to 50% of the plot or 50% of the extension (1) if existing) + Build a living floor (underside of the floor) minimum 50 cm above the highest point of the ground level*
In areas where only the hydrogeomorphological extent is known (EXZECO)		
If the upstream catchment area is less than 100 ha (1km²),	**NO GO ZONE only for buffer axis**	Preservation of natural flow paths - limit any obstructions to flows in order not to worsen the effects of the flood *Outside the buffer on axes, no restriction, but it is recommended that the first habitable floor be built if possible minimum 50 cm above the highest point of the ground level*
If the upstream catchment area is larger than 100 ha (1km²),	**NO GO ZONE only for buffer axis / NO EXPANSION ZONE elsewhere**	**Without hydraulic studies**. Principle of safety of property and persons *Construction limited in size (limited to 20% of the plot or 20% of the extension (1) if existing) + Build a living floor (underside of the floor) minimum 100 cm above the highest point of the ground level*
	NO EXPANSION ZONE	**Possibility to carry out a hydraulic study** with modelling of the 100-year return period flood if water depth < 50 cm *Construction limited in size (limited to 50% of the plot or 50% of the extension (1) if existing) + Build a living floor (underside of the floor) minimum 50 cm above the highest point of the ground level* 100-year return period flood if water depth >50 cm and < 100 cm *Construction limited in size (limited to 20% of the plot or 20% of the extension (1) if existing) + Build a living floor (underside of the floor) minimum 100 cm above the highest point of the ground level.*
Additional condition: In accordance with wetland buffers and other environmental regulations		

(*): this recommendation leads to allow new constructions on lowlands of less than 50 cm in depth, in order to meet the housing needs of the populations.

As a reminder, the buffer values to be considered on the natural axes are the following:

All constructions or obstacles to the flows are prohibited (buildings, embankments, walls, etc.) except for drainage works and infrastructure installations (roads, etc.), on condition of being hydraulically unobstructive (without any constraint) for the T=100 years flood.

Table 43: Buffer zone along watercourses

Type	Source	*Curent value of "River reserve"*	New buffer value for watercourses	Comments
River	Fourth Schedule	**16 m**	**16 m and NGZ or NEZ**	The land extending from the edge of a watercourse to a distance measured on the horizontal plane
Rivulet	Fourth Schedule	**8 m**	**8 m and NGZ or NEZ**	
Feeder = affluent of a river or rivulet	Fourth Schedule	**3 m**	**5 m (*) and NGZ or NEZ**	
Natural path : 1 to 50 ha	LDMP	/	**7 m**	From the axis
Natural path : 50 to 100 ha	LDMP	/	**10 m**	From the axis
Natural path > 100 ha	LDMP	/	**10 m and NGZ or NEZ**	From the axis

(*) : equivalent to 5+5 = 10 m minimum buffer as for natural path for WC > 100 ha

Following the 2021 Finance Bill Act, section 32 - Forests and Reserves Act – the "river reserve" in the case of a natural water path or natural drainage path is fixed at 2 metres.

Important:

In terms of risk management policy, the following doctrine should be respected:

"Build to protect, not protect to build".

Therefrom, risk mapping, i.e. NO GO ZONE, NO EXPANSION ZONE and BUFFERS on natural axes must be included in cartographic documents as public utility easements. These are therefore graphic documents known as "SUPRA", in the same way as other cartographies and buffers aimed at protecting the ESA.

Thus, risk and environmental protection maps are given priority over all other documents, particularly planning.

5.4.1.2 Mapping No Go Zone and No Expansion Zone, including Lowlands

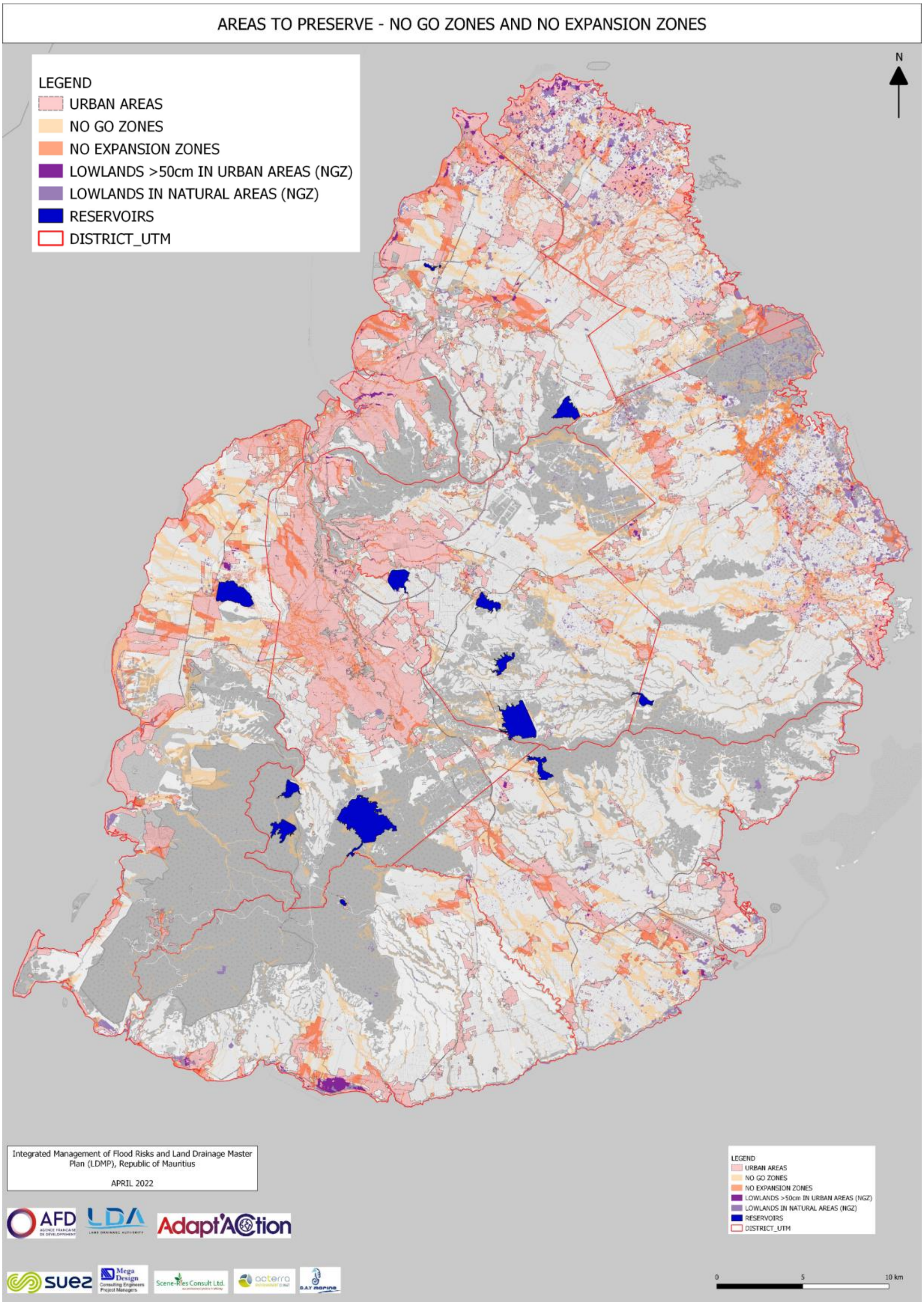


Figure 166: Areas to preserve: No Go Zone and No Expansion Zone including lowlands

5.4.1.3 Synthesis table, No Go Zone and No Expansion Zone

Table 44: No Go Zone and No Expansion Zone – location and extent by district

SN	DC	District	Extent of NGZ (Area in km²)	Extent of NEZ (Area in km²)	Extent of NGZ and NEZ (Area in km²)
1	**PL**	**PORT LOUIS**	1.68	1.79	3.47
2	**PA**	**PAMPLEMOUSSES**	16.24	15.42	31.66
3	**RR**	**RIVIERE DU RAMPART**	18.82	17.00	35.82
4	**FL**	**FLACQ**	50.58	18.05	68.63
5	**GP**	**GRAND PORT**	32.91	6.53	39.44
6	**SA**	**SAVANNE**	15.31	5.70	21.01
7	**PW**	**PLAINE WILHEMS**	16.06	11.70	27.76
8	**MK**	**MOKA**	30.12	3.89	34.01
9	**BR**	**BLACK RIVER**	36.61	13.93	50.54
TOTAL			**218.33**	**94.01**	**312.34**

5.4.2 Stormwater zoning for retention - Digital Applications

5.4.2.1 Development project situation

Compensation volume per active surface area intercepted (including new created active surface areas):

V in m^3/ha of active surface area intercepted.

These unit volumes depend directly on:

- **Newly urbanized active surfaces:** the more recourse is made to controlling imperviousness (green areas, porous materials, etc) the less will be the useful retention volume.

  Note: The use of porous materials will allow developers to reduce the adverse impact of their project and also to limit the need (volume and therefore space) for retardation basins imposed by the stormwater zoning management.
- **Selection of the return period of rainfall.** Depending on the stakes of the catchment area, and the existing situation pertaining to the risk posed by runoff flow, the following conservative return periods will be retained for the compensation volume:
  - **Zone 1 – Z1:** catchment areas with low to moderate risk (Level 1). The compensation is equal to the volumes generated by a 10-years rainfall – retention of 69 to 113 mm depending on location (local Rainfall).
  - **Zone 2 – Z2:** catchment areas with moderate risk (level 2). The compensation is equal to the volumes generated by a 25-years rainfall - retention of 84 to 144 mm depending on location (local Rainfall).
  - **Zone 3 – Z3:** catchment areas with moderate to high risk (level 3). The compensation is equal to the volumes generated by a 50-years rainfall - retention of 96 to 173 mm depending on location (local Rainfall).
  - **Zone 4 – Z4:** catchment areas with high risk to very high risk (levels 4 and 5). The compensation is equal to the volumes generated by a 100-years rainfall; - retention of 107 to 203 mm depending on location (local Rainfall).
- **Location of the project** and the corresponding reference rainfall. Projects located upstream of urbanized areas within catchments in the central plateau and receiving most rainfall, will sustain higher needs for compensatory actions.

The following table summarises **the rainfall – stormwater zoning**, making it possible to define the ratio of controlled discharge and compensation volume by zone and by spatial location (Region II, average for the whole island and region I without spatial correction).

These values define the minimum and maximum volumes and means of compensation to be put in place. They include the effects of climate change based on the Clavius-Clapeyron law and approach.

Table 45: Rainfall - stormwater zonal compensation

<table>
<tr><th colspan="2">Rainfall zones</th><th>Minimum value : Rainfall Region RII</th><th>Average value for the territory (Rainfall region RI with spatial correction)</th><th>Maximum value : Rainfall Region RI without spatial correction</th></tr>
<tr><th>Zones</th><th>QI = Maximum unit controlled discharge rate (l/s/ha of intercepted catchment area)</th><th colspan="3">V = Unit Compensation Volume (m^3/ ha of intercepted active surface area)</th></tr>
<tr><td>Zone 1</td><td rowspan="4">65</td><td>830</td><td>1 110</td><td>1 360</td></tr>
<tr><td>Zone 2</td><td>1010</td><td>1 370</td><td>1 730</td></tr>
<tr><td>Zone 3</td><td>1 150</td><td>1 630</td><td>2 080</td></tr>
<tr><td>Zone 4</td><td>1 290</td><td>1 910</td><td>2 440</td></tr>
<tr><td rowspan="2">N.B :Basic Sizing</td><td>Natural controlled discharge flow with a 10-year return period for a natural catchment</td><td colspan="3">Zone 1: compensation is equal to the volumes generated by a 10-year rainfall
Zone 2: compensation is equal to the volumes generated by a 25-year rainfall
Zone 3: compensation is equal to the volumes generated by a 50-year rainfall
Zone 4: compensation is equal to the volumes generated by a 100-year rainfall</td></tr>
<tr><td></td><td colspan="3">Taking into account climate change on the basis of a global warming of 2.6 °C (For scenario RCP8.5) over the period and application of Clavius-Clapeyron Law only i.e. + 18.2% on the accumulated precipitation - + 30 % average on unit volumes (ref 4.1)</td></tr>
</table>

For these dimensions, the retention time varies from 2 to 8 hours depending on the return period of protection, the configuration of the works (discharge device) and the rate of soil imperviousness. This time remains compatible in the local context, subject to ensuring good maintenance of the leakage structures.

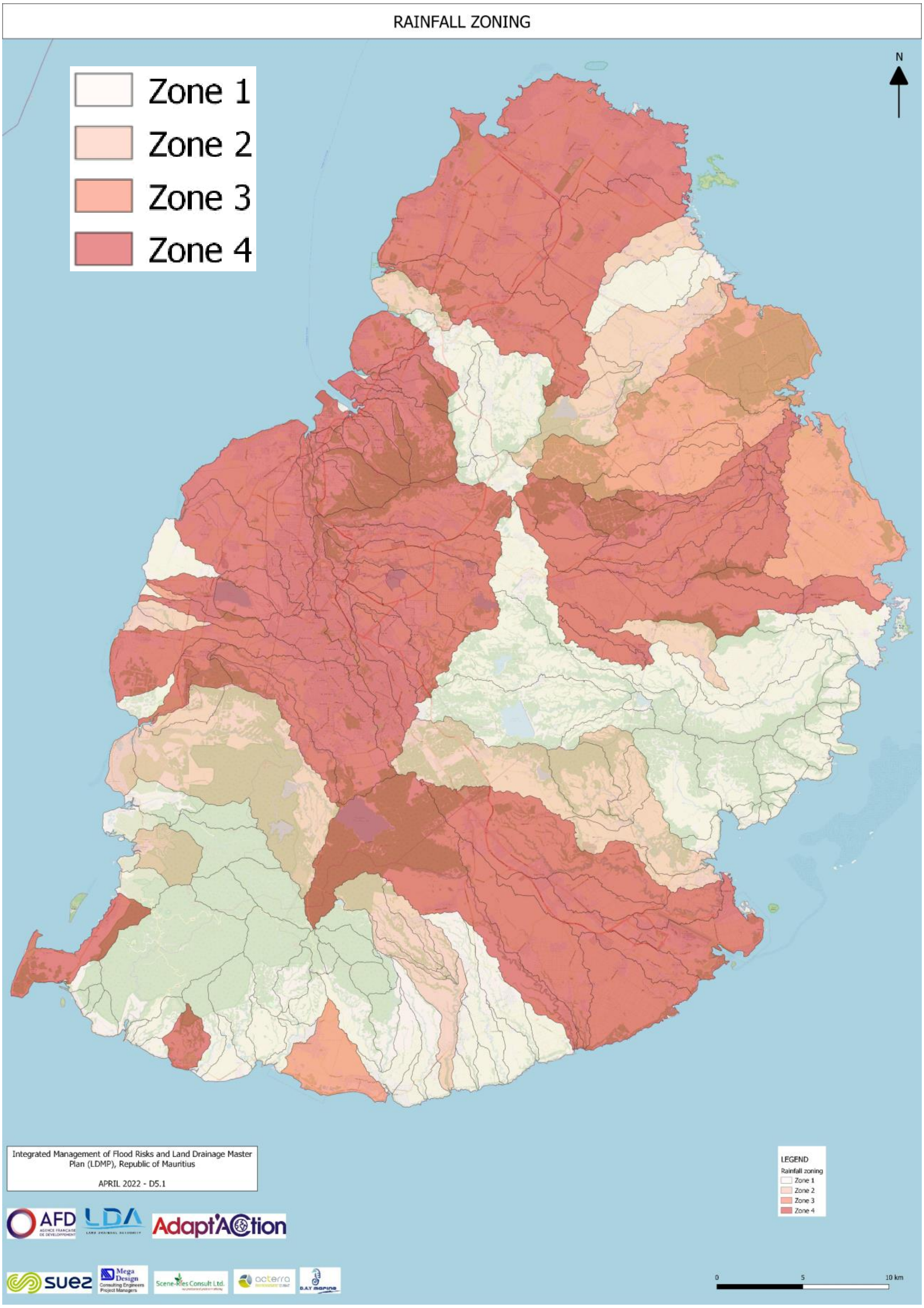


Figure 167: Stormwater zoning for retention

5.4.2.2 Devices for single-family houses

A single-family house is defined as any development with a plot size of less than 1000 m².

The following table presents the type of system to be implemented, valid for the whole island.

Table 46: Compensation - single value for single-family houses

Application single value for single-family houses Unic value for whole island			
Zones	**QI = Maximum unit-controlled discharge rate (l/s/ha of intercepted catchment area)**	**V = Unit Compensation Volume (m³/ ha of intercepted active surface area)**	**Orifice diameter in mm**
For whole island	**130**	**280**	**80**
N.B :Basic Sizing		*Compensation is equal to the volumes generated by a 10-year rainfall*	*Calculation established for a hole under 1 metre of hydraulic head*
		Calculation Without climate change factor	

Example of application:

Table 47: Compensation - single-family houses – application

Plot size in m²	**500**		**750**		**1 000**	
Covered floor area (m²)	150	250	200	300	300	400
% impermeability	0.30	0.50	0.27	0.3	0.30	0.40
Retardation volume (m³)	4.2	7.0	5.6	8.4	8.4	11.2

5.4.3 Soil infiltration capacity, global mapping and in situ measures

5.4.3.1 Implementation of rainwater infiltration

As presented previously, the use of infiltration should be promoted even if it has to be complemented by retention devices.

However, infiltration will not be used in the following cases:

- protection of boreholes for drinking water (within the limits of the recommended buffer zones)
- in presence of a high-water table (high water table less than 1 m deep);
- if the infiltration capacity of the soil is too low. In practice, minimum values of 20 to 35 mm/h are to be taken into account.

Therefore, with regard to the infiltration capacity, the following studies are to be carried out:

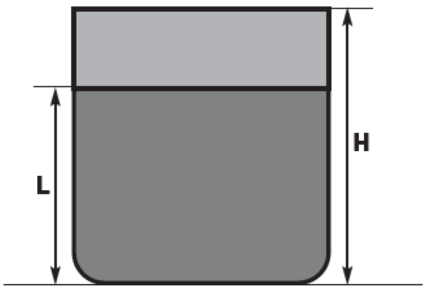
- **Preliminary infiltration study**: The purpose of this study is to define the nature of the surface layers of the soil in the area of the project with a view to prescribing rainwater treatment and infiltration systems adapted to the terrain (infiltration basin, infiltration on the plot).
- **Plot infiltration study**: The purpose of this study will be to define the infiltration capacity of the soil in the area of the project in order to size the stormwater treatment and infiltration system

5.4.3.2 Infiltration study

The study of the permeability of superficial soils (from 1 to 3 m deep under the natural ground) which constitute the bottoms and walls of infiltration works requires a particular approach for two essential reasons: the low depth and the reduced thickness of the horizon to study. Thus, given the very high variability of permeability on the same site, it is required to carry out measurements of permeability.

In the case of a storage structure designed to allow infiltration, the infiltration leakage rate is provided by the Darcy formula:

$$Qs = Ks \times S \times H/L$$



Where

- Qs:the infiltrated flow (m^3/s);
- Ks: the hydraulic conductivity or coefficient of permeability (m/s);
- S: the section area of the column, (m^2);
- H: the hydraulic head (m);
- L: the height of the saturated soil column (m).

The value of Ks can be determined simply by the design office via a permeability test permeability test (**Porchet method). In order to ensure the effectiveness of the device, the conductivity should be between 10^{-2}m/s and about 10^{-5} m/s (20 to 35 mm/h**).

It is recommended to correct the infiltration capacity measured on site by a safety factor of 50%.

For information, the literature gives the following order of magnitude:

Table 48: Hydraulic Conductivity of Different Soils (Musy & Soutter, 1991)

Ks (m/s)	10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10}			
Ks (mm/h)	1000 100 10			
Type of soil	Gravel without sand and fines	Sand with gravel, coarse to fine sand	Very fine sand, coarse silt to clayey silt	Silty clay to homogeneous clay
Infiltration possibilities	Excellent	Good	Medium to low	Low

In soils with permeability > 10^{-2}, consideration should be given to include devices to prevent leaching of the soil.

5.4.3.3 Preliminary Zoning: Global maping of potential permeability

In order to classify the soils as a function of their permeability, in addition to a basic approach based on geology, the analysis was based on their pedology.

This island-wide approach should not be used as substitute where local permeability measurements are available.

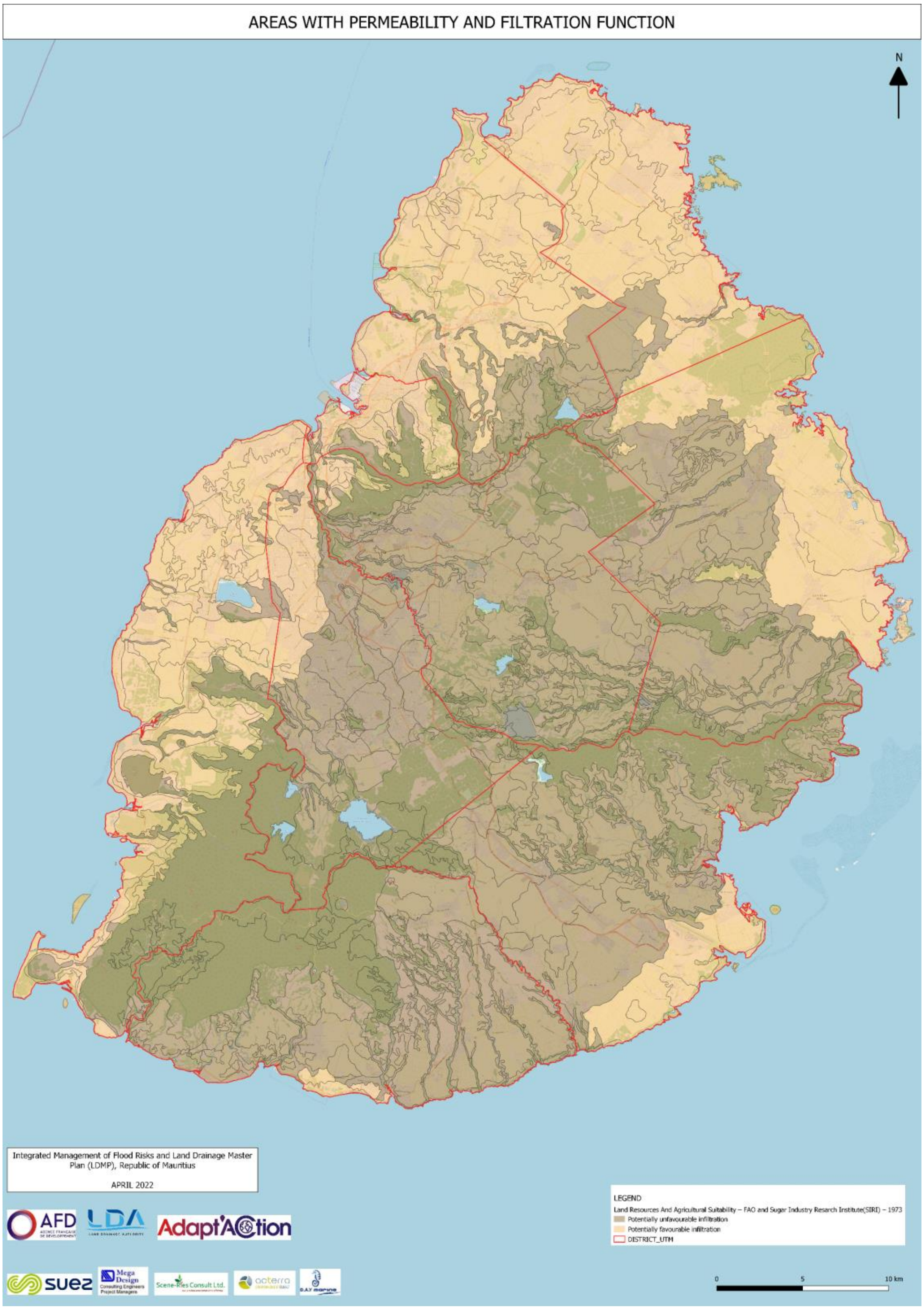


Figure 168: Areas with permeability and filtration function (bases on climate diagram pedology)

The areas favourable to infiltration are also compared here with the modelling of sensitivity to rising groundwater for Grand Baie Pereybere and Flic en Flac Areas.

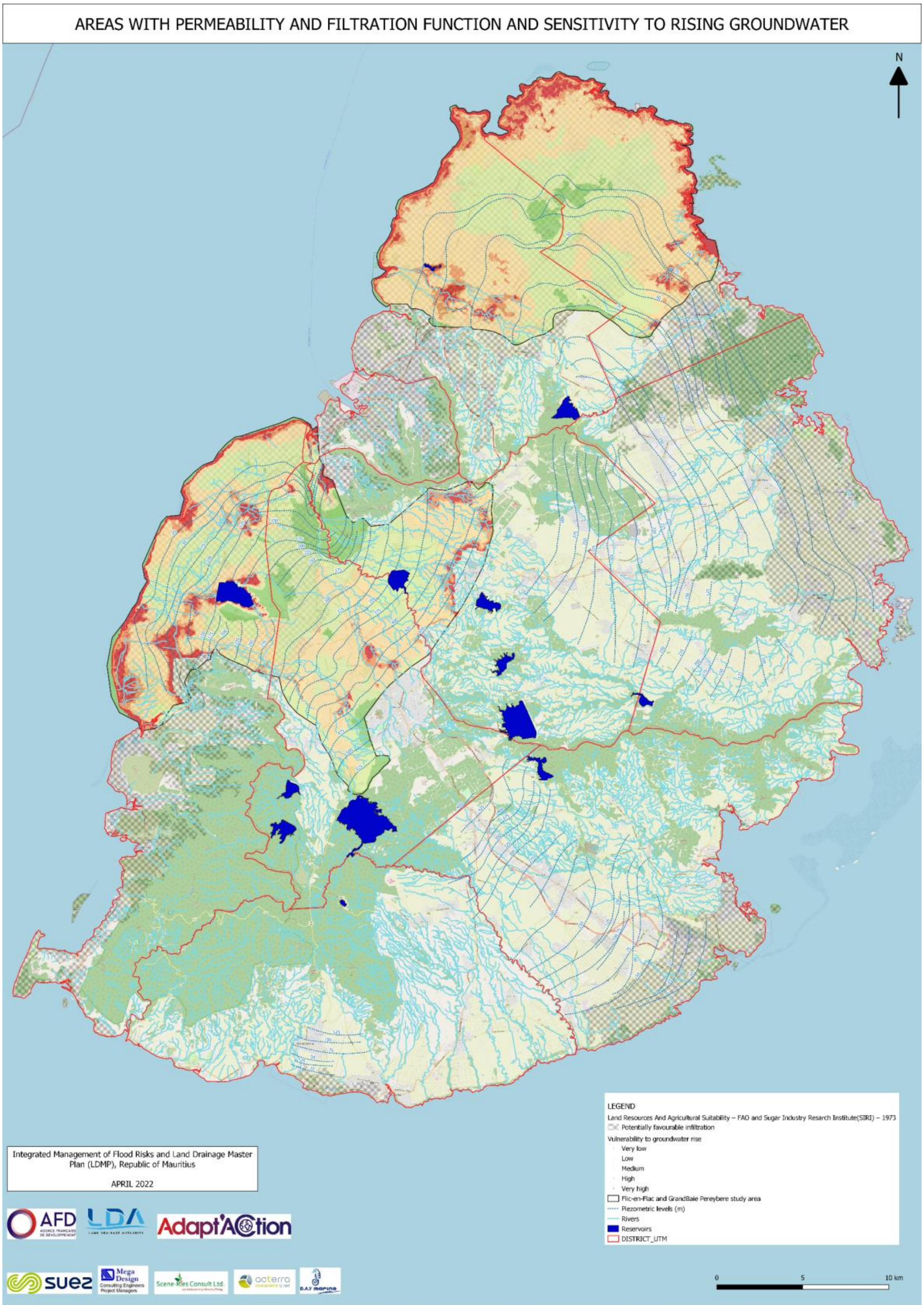


Figure 169: Areas with permeability and filtration function - sensitivity to rising groundwater

6 STORMWATER MANAGEMENT PLAN AND GOVERNANCE RECOMMENDATIONS

6.1 Stormwater Management Plan

6.1.1 Stormwater management (SWM) Strategy and Objectives

6.1.1.1 SWM Strategy

A SWM strategy may be used to:

- Assist in the development of Stormwater Quality Management plans
- Guide authorities in planning, designing, and operating stormwater infrastructure,
- Guide authorities in the integration of stormwater issues into other planning schemes.

6.1.1.2 SWM Objectives

The objectives of a SWM plan are to:

- Protect/enhance receiving water
- Limit flooding to acceptable levels
- Acceptable social and economic cost
- Enhanced community awareness
- Engage the community in the development of parameters for the design and evaluation of stormwater management solutions. Community participation helps to identify strategies that are responsive to community concerns,
- Minimise the quantity of directly connected impervious surface area where practical, surround impervious surfaces with porous surfaces such as gravel beds, lawns and gardens.
- Explore problems, issues and strategies openly
- Increase public ownership and acceptance of proposed solutions

In the absence of adequate controls, urban development can increase peak discharge rates and runoff volumes, causing damage to properties and harm to people.

Nature based sustainable solutions no longer seek the quickest way of channelling stormwater into a river or watercourse as these require a large infrastructure. They consist nowadays in finding ways and means of controlling flows at source and breaking the peak flows as much as possible prior to releasing them in a controlled manner into the drainage infrastructure.

Different methods are used to control stormwater peak discharge and volume at source or upstream of a catchment area, including but not limited to:

- Detention systems which delay the release and control stormwater flows, but do not reduce the volume.
- Retention systems which alter the volume of stormwater runoff by retaining a portion of the flow for a secondary use.
- Infiltration systems which reduce both the volume and flow rate by absorbing a portion of the flows into the ground.

Variations of detention systems are:

- Dry ponds,
- Wet ponds,
- Constructed wetlands, and
- Bioretention basins

Flood expansion zones can also be created along water courses to retard peak flows.

6.1.2 Stormwater Management Policies & Principes

The conversion of pervious land to impervious surfaces following land development leads to an increased rate and volume of stormwater runoff as a result of reductions in groundwater recharge as well as evapotranspiration. Uncontrolled, the impacts of development on stormwater runoff lead to flooding, water quality degradation, soil erosion, modification to the water balance within a catchment and harm to landscape and sensitive habitat.

The objective of a Stormwater Management Policy is to set the guidelines necessary to comply with the LDA's requirements and design standards to achieve a robust and efficient drainage infrastructure.

The guidelines which follow make recommendations to assist a designer or a proponent in complying with the Authority's requirements, without for that matter relieving them of their responsibility for the integrity and design of the various facilities proposed, inclusive of a monitoring and an operation and maintenance plan.

6.1.3 Stormwater Drainage System Criteria

Well-designed stormwater conveyance systems are critical for ensuring that stormwater is safely conveyed away from roads and residential areas to appropriate drainage outlets. The objective of the Land Drainage Masterplan (LDMP) is to ensure that the existing drainage systems are characterised and upgraded and those for new developments are robust and designed to the highest standards of performance.

- All proposed developments or expansion of existing developments must assess their potential impacts on both local and regional flooding and mitigate accordingly.
- Proposals and mitigation measures shall consider the entire drainage area and the external flows.
- The minor drainage system typically includes roof leaders of individual lots and gutters, kerbs and roadside drains. Minor drainage systems shall be sized to capture and convey the 10 year storm..
- The major drainage system includes natural streams, swales, artificial drains, roadways and ponds. Major drainage systems shall be sized to capture and convey flows from a minor system as well as overland flows not captured by the minor system without flooding adjacent properties.
- For infill/redevelopment sites the proponent should demonstrate through a drainage system analysis that the downstream drainage system has sufficient capacity to safely accommodate design flows from the development site to a secondary drain or an existing outfall.

This section discusses the policies and design guidelines applicable to the storm drainage system.

6.1.3.1 Stormwater Drain Design

6.1.3.1.1 Design Flow

Flows for sizing stormwater drains shall be determined using the Rational Method, IDF data, runoff coefficients and Manning's equation for urban catchments smaller than 10 km^2 and rural catchments smaller than 20 km^2 provided that the outlet is not submerged by the receiving system.

For bigger areas, the SCS Curve Number Method is recommended.

6.1.3.1.2 Drain Capacities

Drain capacities shall be computed using the Manning's Equation. Piped drains shall be designed to convey the design flow at 80% capacity flowing in a subcritical condition.

6.1.3.1.3 Minimum Velocity

The minimum average flow velocity shall be 0.6 m/s to prevent sedimentation and vegetative growth.

6.1.3.1.4 Maximum Velocity

The maximum average flow velocity shall be 4 m/s. For flow velocities in excess of 2 m/s, drains will be provided with a 1.2 m high handrail or covered with solid or grated covers along its entire length for public safety.

Where velocities in excess of 3 m/s are proposed, additional design factors shall be taken to protect against scouring, erosion, and hydraulic jumps.

6.1.3.1.5 Minimum Grades

The minimum grade on stormwater drains shall be half a percent (0.5% or 1 in 200 to minimise the likelihood of ponding and siltation within the drain.

6.1.3.1.6 Maximum Grades

The maximum grade shall be such that the average flow velocity in the drain under all operating conditions does not exceed 2 m/s for unlined drains and 4 m/s for lined drains.

6.1.3.1.7 Changes in Drain Alignment

The maximum change in direction is 45 degrees. At right angle junctions, the change in direction shall be effected in sections to produce the permitted deflection.

6.1.3.1.8 Catchbasins

Catchbasins shall be provided to collect drainage from both pervious and impervious areas.

6.1.3.1.9 Minor System Outlet Structures

New outfalls discharging to watercourses shall be designed to prevent erosion. They should be blended into the natural surroundings, in an aesthetically pleasing manner to the greatest extent possible. Exit velocities shall not impart additional erosion potential to the streambed and banks. In addition, the outfall shall be adequately protected from erosive forces in the receiving watercourse to prevent scouring and undermining. Outfalls shall not discharge at the top of embankments.

The designer should position the outlet to minimize the angle at which flow from the outfall ties into the watercourse. Outfall channels should join a watercourse at no more than 90 degrees, with angles less than 45 degrees preferred.

Outfalls to natural watercourses should discharge at or above the average water elevation of the watercourse. If high water levels cause the submergence of the outlet, the impact of the submergence on the system must be assessed in the hydraulic design. The invert of the outlet shall be above the 25 year flood elevation of the receiving channel.

Storm sewer outfalls discharging directly into the sea will need to consider the potential problem of dynamic beaches and the potential obstruction of the outlet. The outfall's invert should be located above the swash line. Appropriate mitigation measures should be taken if this condition cannot be met.

Grates shall be installed with means for locking. Provisions must be made for opening or removing the grate for cleaning purposes. Grates should be designed to break away or swing open under extreme hydraulic loads due to blockage.

Outfalls should be made as safe as possible by utilizing fencing along the headwalls and wingwalls to prevent accidental falls.

6.1.3.2 Roadway crossings

The minimum hydraulic capacity of culverts and bridges is summarized in the table below.

Table 49: Design capacity of culverts and bridges

Road Class	Design Capacity Return Period	
	Culverts	Bridges
Local Roads	50	100
Rural Roads	50	100
Arterial Roads	50	100
Main A Roads	50	100
Main B Roads	50	100

Culverts and bridges should also be provided with a minimum freeboard of 500 mm to 1000 mm to have sufficient capacity to avoid adverse backwater effects due to waves.

6.1.3.3 Volume and Peak Flow Control

All developing or re-developing areas must assess their potential impacts on local and regional flooding and implement mitigation measures to prevent impacts. These include, but not limited to volume and peak flow control.

Post-development peak flows should be controlled to pre-development levels for the 10 year return period. The level of protection (sizing of imperviousness compensation basins) varies according to the location of the projects (see Stormwater Zoning Cf. 5.4.2).

Any design of stormwater infrastructure involving the determination of peak flows or runoff volume must be supported with acceptable hydrologic calculations signed by a Registered Professional Engineer experience in Water Resources Engineering.

6.1.4 Stormwater Management Design Guidelines

A treatment train approach to Storm Water Management is advocated, whereby the following sequence of multiple stormwater processes are adopted to control volume and peak flows, as well as pollutant load:

- Source Control
- Conveyance Control
- End-of-Pipe Control

The design of source, conveyance and outlet controls shall be in accordance with the policy of **Low Impact Development (LID)**, a stormwater management strategy that makes use of best management practices to reduce the impervious area associated with a development, while using lot level and conveyance controls to store stormwater for infiltration, re-use, evaporation etc. LID practices reduce runoff volume and improve water quality and include inter-alia, infiltration trenches, green roofs and permeable pavements.

The following figure also shows the preferential locations for implementation of stormwater best management practices, based on **Low Impact Development (LID)** in urban areas (Cf. 3.4.6).

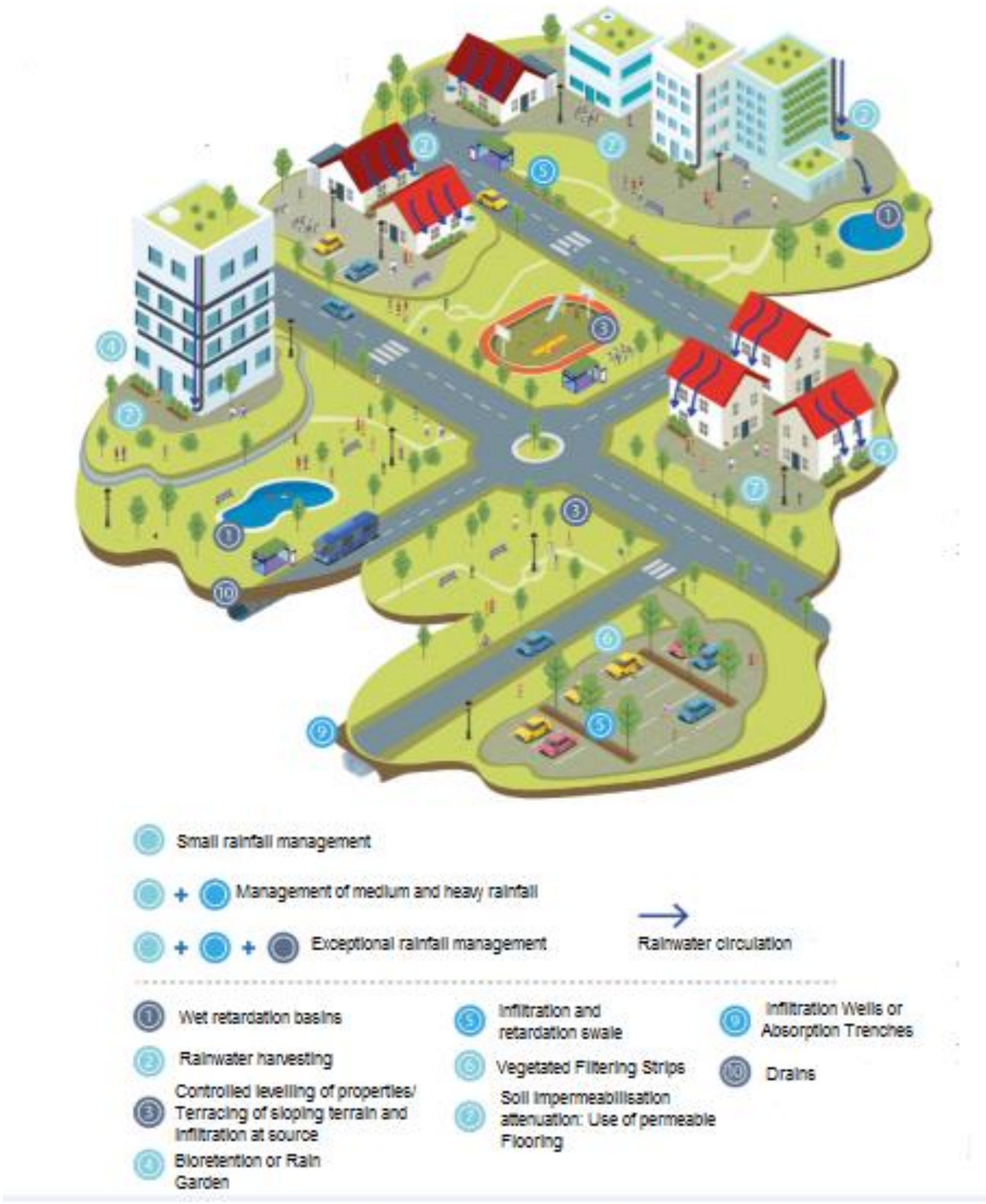


Figure 170: Stormwater management for new development - range of solutions (Adapted from Ile de France prefecture- France)

6.1.4.1 Main Source Controls devices in urban areas

6.1.4.1.1 Special applications for roofs

- **Roof Discharge to Surface**

All lots must have their downspouts connected to the storm drainage system via a pervious (grassed) area or a soakage pit provided with an overflow. The downspouts shall not discharge to impervious areas directly connected to the storm network (e.g., sidewalks, driveways, parking areas).

Figure 171: Roof discharge onto impervious surface

- **Greenroofs**

Greenroofs are encouraged subject to them being properly designed as not to cause extended local ponding.

- **Rooftop Storage**

Rooftop storage for water quantity control is not encouraged due to the risk of it being breeding grounds for mosquitoes. Their use as a temporary detention basin when provided with a perimeter upstand and a control outlet would be acceptable.

6.1.4.1.2 Surface Storage

Commercial, industrial, institutional and infill residential developments may use parking lots and/or ground storage to control post-development flows to the receiving storm water network systems.

The connection from the site into the receiving storm water system shall be through an orifice tube which restricts the flow to the required rate.

All stormwater detention tank designs shall be included as part of the application for Building and Land Use Permits.

6.1.4.1.3 Porous and Pervious Pavement

Porous and permeable pavement installations shall be encouraged, provided that they are not receiving runoff from high traffic areas or from source areas where land uses or activities have the potential to generate highly contaminated runoff (e.g., vehicle refuelling, handling areas for hazardous materials etc.).

Figure 172: Pervious pavement

6.1.4.1.4 Bioretention

Bioretention areas are designed to store and infiltrate stormwater runoff. Water quality is improved through the use of bioretention, as particles are filtered out as water passes through the filter bed. If the underlying soil has a low infiltration rate, an underdrain may be required to prevent standing water.

6.1.4.1.5 Soil Amendments

Soil amendments are used to improve the quality of existing soils, where compaction and a reduction in available organic material have degraded the soil. Improvements in the soil through the addition of compost and organic material will result in increased infiltration for LID practices, reduction in runoff volumes, and increased plant survival and growth.

6.1.4.2 Conveyance Controls in urban areas

6.1.4.2.1 Swales and Enhanced Grassed Swales

Swales and enhanced grassed swales promote infiltration and provides flow control.

6.1.4.2.2 Oversized Channels

Oversized channels serve as both detention and conveyance structures and can be used to provide quantity control for re-development and infill areas. The stormwater channel connection from the site into the receiving municipal drain is to be controlled by an orifice designed to restrict the inflow to the required rate.

Oversized channels offer a feasible alternative to detention basins when a site has limited space; however, oversized pipes do not provide volume control through infiltration or water quality improvements.

6.1.4.3 End of Conveyance Controls

6.1.4.3.1 Infiltration Trenches

Infiltration trenches are encouraged to promote infiltration of runoff. End of conveyance control is located at the end of a flow conveyance route and is not limited to wet ponds, constructed wetlands and other similar systems. Infiltration trenches shall not be located adjacent to valley land slopes. Measures to prevent sediment and debris from entering these systems should be provided. (The maximum draw down time should be less than 72 hours, soils permitting; longer drawdown times may be permitted where soils exhibit lower percolation rates provided that it has been accounted for in the design.) The bottom elevation of infiltration trenches shall be a minimum of 1.0 metre above seasonal high ground water table.

6.1.4.3.2 Vegetated Filter Strips

Vegetated filter strips are vegetated areas adjacent impervious areas that improve the quality of and reduce the velocity of stormwater with gradual slopes and vegetation such as grasses. They are frequently used to pre-treat stormwater runoff prior to other LID practices such as infiltration trenches.

Figure 173: Grassed strips adjoining impervious areas

6.1.4.3.3 Oil/Grit Separators

Oil/grit separators should be installed at places where there is high incidence of stormwater contamination by spent or spilled oil/fuel.

Oil/fuel spill hotspots include:

- Fueling stations
- Mechanical workshops/vehicle repair centres
- Restaurants
- Hotels

When completing sizing calculations for oil/grit separators, the following guidelines shall apply:

- The total suspended solids (TSS) removal efficiency for oil/grit separator devices is 50% removal of the 1 to 1000 microns particle size distribution.
- Oil/grit separator devices must be sized to capture and treat at least 90% of the runoff volume.
- Additional measures and supporting calculations shall be provided to demonstrate that the quality control treatment is achieved.

Operation and maintenance requirements for oil/grit separators shall be identified for the site and shall be implemented by the owner to ensure that the continued performance of the device as designed is achieved as per the Environmental Protection Act.

6.1.4.3.4 Extended Detention Wet Ponds

Wet ponds shall be designed in accordance with standard practice with a forebay to trap sediments.

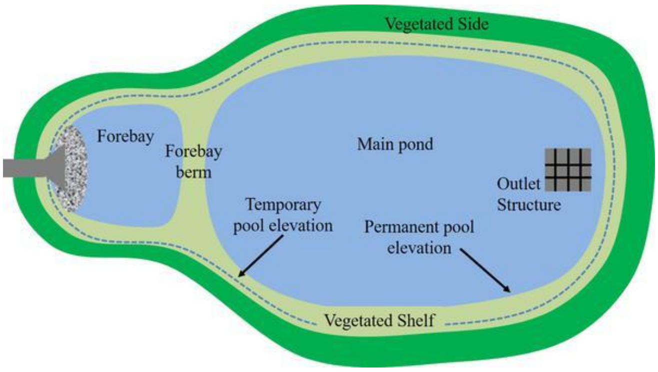


Figure 174: Wet ponds design

6.1.4.3.5 Dry Ponds

Dry ponds may be used as a part of a treatment train approach within parks.

6.1.4.4 Stormwater management facilities (Wet Ponds and Wetlands)

An Operation and Maintenance Manual for the SWM facility shall be submitted to the Authority for the site and shall be implemented by the owner to ensure that the continued performance of the facility as designed is achieved.

6.1.4.4.1 General Siting Guidelines

Generally, a SWM facility will need to be located near the lowest point of the site, so that it will be possible to convey both the major and minor system flow to the facility from the entire site.

6.1.4.4.2 Length-to-Width Ratio

The length-to-width ratio of a SWM facility is extremely important for the SWM facility's removal efficiency. The minimum length-to-width ratio shall be 4:1. Baffles and berms should be used to maximize the length-to-width ratio.

6.1.4.4.3 Water Levels

Water levels within SWM facilities shall be designed in accordance with standard practice.

A permanent marker/monument (e.g., pole or marked permanent landscape feature) shall be included in the design of the SWM facility to identify the elevation of the permanent pool, extended detention and 100 year water levels for visual verification of facility water elevations by operations staff.

6.1.4.4.4 Forebay

A de-watering sump shall be installed in the forebay to enable the drawdown of the permanent pool for maintenance and sediment removal.

6.1.4.4.5 Berming

Berms around wetlands and wet ponds shall be designed with a minimum top width of 2.0 m with a 3:1 maximum side slope on the outside. The core of the berms shall be constructed with engineered fill on the basis of the recommendations of a Registered Professional Engineer. Topsoil is not permitted for berm construction except as a dressing to support vegetation on the top of the core.

The berm's design must be in accordance with the recommendations of the United States Bureau of Reclamation, "Design of small dams, 1987". Furthermore, the construction of the berm must be supervised and certified by a Registered Professional Engineer.

6.1.4.4.6 Sediment Drying Area

A sediment drying area shall be provided immediately adjacent to the sediment forebay to facilitate sediment removal from the forebay, sediment storage and disposal.

6.1.4.4.7 Maintenance Access Roadway

Maintenance access roads are required to all inlets, outlet structures, spillways, sediment forebays, sediment drying areas and outfall channels associated with SWM facilities.

6.1.4.4.8 Fencing

Fencing shall be installed around the perimeter of all SWM facilities.

Fencing shall be:

- 1.8 m high
- Secure
- Anti-climb
- Anti-cut
- Vandal-proof
- Highly transparent
- Attractive
- Durable

6.1.4.4.9 Warning Signage

Warning signs shall be clearly visible and erected at all access points to the SWM facility. Warning signs shall be supplied and installed by the developer and designed in accordance with current legislations.

6.1.4.4.10 Inlet Structures

Inlet structures shall be installed with the invert set to the Normal Water Level (NWL) or higher.

Suitable erosion control and energy dissipation treatment shall be provided at all inlets to the SWM facility. The sizing of rip rap or spalls shall be based on appropriate erosive velocity calculations.

Headwalls and safety grating shall be installed at all inlets.

6.1.4.4.11 Outlet Control Structures

Outlet control structures shall be designed with flow regulating devices (e.g., orifice) to control the flow and drawdown time.

Suitable erosion control and energy dissipation treatment shall be provided at the facility outfall where it discharges to the outfall channel.

6.1.4.4.12 Emergency Spillway and Outfall Channels

All SWM facilities shall be designed with an emergency spillway. The emergency spillway shall be designed to convey the larger of the uncontrolled 100 year or the uncontrolled regional storm peak flow with the invert of the spillway set, as a minimum, at the 100 year controlled water level. A minimum freeboard of 300 mm shall be provided above the maximum water level of the uncontrolled 100 year or uncontrolled regional storm flow, whichever is greater.

It will also be pertinent to study the behaviour of the structures for exceptional flooding event set at 1.8 x Q100 in order to be sure that the freeboard selected allows this exceptional flow to pass through the spillway only.

The location of transitions from supercritical to subcritical flow regimes (i.e., hydraulic jumps) on the spillway and in the outfall channel shall be determined and erosion protection measures shall be designed accordingly.

Spillway side slopes shall not be steeper than 3:1. The spillway shall not be located directly above the outlet control structure and a minimum clearance of 3.0 m shall be provided.

The emergency spillway shall have an outfall channel which safely conveys the uncontrolled regulatory storm flow, defined as the larger of the 100 year or regional storm, from the emergency spillway to the basin's main outfall channel or directly to the watercourse.

6.1.4.4.13 Existing Groundwater Elevation

The bottom of the SWM facility shall be a minimum of 1.0 m above the seasonal high groundwater level unless it can be demonstrated to the satisfaction of the Authority that there will be no impact to groundwater elevation and groundwater quality.

6.1.4.4.14 Liners

Liners shall be installed so that they can be covered with a maximum of 300 mm of top dressing which will act as a "reminder layer". Top dressing shall consist of 50 mm of rocksand (0-4 mm) overlaid with 100 mm of crushed rock (0-

20) and covered with 150 mm of native organic soil. The crushed rock layer is to indicate the location of the liner for future maintenance operations.

6.1.4.4.15 Mosquito Proliferation
Measures shall be incorporated in the design of wet ponds and wetlands to minimise the proliferation of mosquitoes. Such measures will focus on creating habitat less suitable for mosquito breeding, such as

- Plant dominant environment as opposed to algae dominant environment
- Predators such as snails, frogs which feed on mosquito eggs and larvae and birds which feed on flying insects.
- Maximise water depths to 1.0 m or greater

6.1.4.4.16 Maintenance and Inspections
An Operational Maintenance Manual shall be prepared to identify ongoing operation procedures including inspection and maintenance protocol.

6.1.4.4.17 Stormwater Management Facility Planting Guidelines
The Landscape design and planting requirements for SWM facilities shall be consistent with popular preference for endemic plants.

6.1.5 Guidelines for Hydrologic and Hydraulic Analysis

The analytical methods presented herewith represent well established techniques acceptable to the Authority. The designer is not limited to the methods herein. However, approval from the Authority and other Government Authorities is required prior to using alternative hydrologic and hydraulic analytical techniques.

6.1.5.1 Guidance on the Use of Computer Programs by Professional Engineers

All practitioners who plan to use computer models or programs in their designs shall familiarise themselves with the following guidelines:

- The practice of professional engineering has become increasingly reliant on computers, and engineers use many computer programs that incorporate engineering principles and matters. Many of these programs are based upon or include assumptions, limitations, interpretations and judgments on engineering matters that were made by or on behalf of an engineer when the program was first developed. Therefore, it is often difficult to determine, just by using a program or by being given a description of its function how the software deals with the engineering principles and matters it incorporates.
- Professional engineers are responsible for all aspects of the design or analysis they incorporate into their work, whether it is done by an engineering intern, a technician or a computer programmer. Therefore, practitioners are advised always to use the data obtained from engineering software judiciously and only after submitting results to a vigorous checking process to ensure the practitioner's due diligence obligations are fulfilled.
- Due diligence is the effort expected to be made by an prudent or reasonable party to avoid harm to another party. A practitioner's due diligence is best demonstrated by taking an organized approach to ensuring all potential sources of error and omission are assessed and, if necessary, corrected before any action is taken.

- Engineers should become familiar with the engineering principles, equations, models, algorithms and assumptions used in the software.

6.1.5.2 Hydrology

6.1.5.2.1 Event Based Hydrologic Models

Sound hydrologic modelling standards of practice should be followed in developing an event based hydrologic model. The following standards of practice are intended as a guide for hydrologic modelling:

1. The modeller should provide the purpose for developing the hydrologic model (e.g., determining flow rates, runoff volumes, etc.).
2. The modeller should provide the study objectives and how they relate to the hydrologic modelling.
3. The modeller should provide the model selection criteria and how the model matches the criteria.
4. The modeller should outline how the design storm has been selected.
5. The modeller should provide drainage area plans outlining both internal and external catchments, modelling schematics and tables providing drainage area parameters.
6. Background information on the drainage area parameters should be provided and all assumptions shall be appropriately justified.
7. Background data on major and minor systems should be provided with plans clearly presenting and labeling both systems.
8. Detailed plans and calculations should be provided outlining how the stage/discharge relationship for storage systems has been determined.
9. Sensitivity analysis should be completed on critical parameters to assess the model's uncertainty.
10. Verification or validation of results should be provided through various methods such as calibration to recorded stream flow, unit flow rates and runoff volume comparisons. The application of the validation technique will depend on the availability of data and the sensitivity of the analysis.
11. The modeller should provide all input and output details in a logical manner. Any errors shall be appropriately explained

6.1.5.2.2 Rational Method

Flows for sizing storm drains shall be determined using the Rational Method and the new set of IDF data for water catchment areas less than 20 km^2.

The assumptions in the Rational Method are as follows:

1. The drainage area should be smaller than 20 km^2.
2. The peak discharge occurs when the entire watershed is contributing flow.
3. A storm that has a duration equal to the time of concentration produces the highest peak discharge for this frequency.
4. The rainfall intensity is uniform over a storm time duration equal to the time of concentration. The time of concentration is the time required for water to travel from the hydrologically most remote point of the basin to the outlet or point of interest.
5. The frequency of the computed peak flow is equal to the frequency of the rainfall intensity. In other words, the 10 year rainfall intensity, i, is assumed to produce the 10 year peak discharge.

Table 44: Runoff Coefficient Adjustment for 10-100 Year Storms

Run off coefficients (Conservative values)				
Return Period (in years)	**10**	**25**	**50**	**100**
Urban Areas *	0.95	0.95	0.95	0.95

Other Areas (non urban)	0.50	0.66	0.73	0.80

6.1.5.2.3 SCS Curve Number Method

The SCS curve number method is a simple, widely used and efficient method for determining the approximate amount for runoff from a rainfall event in a particular area. The curve number CN, is based on the area's hydrologic soil group, land use treatment and hydrologic condition.

Whereas the rational method uses a constant intensity storm for its model, the SCS method uses a storm that is initially gentle but that has a period of much greater intensity at some time during the event.

6.1.5.2.4 Rainfall - Intensity-Duration-Frequency (IDF)

IDF curves shall be used to determine the appropriate rainfall intensity for use with the Rational and SCS Method.

Rainfall intensities adopted for design storms should incorporate an appropriate allowance for expected climate change. (Cf. chapter 4).

6.1.5.2.5 Time of Concentration

The time of concentration is the travel time of water from the most hydraulically remote point in the contributing area to the outlet or point of interest. It can be considered to be the sum of the overland flow travel time and times of travel in street gutters, drainage channels, small streams and other conveyance systems (ASCE Code of Practice 77, 1993).

One of the most significant effects of urban development on flow velocity is less retardance to flow. That is, undeveloped areas with very slow and shallow overland flow through vegetation become modified by urban development: the flow is then delivered to streets, gutters, and storm drains that transport runoff downstream more rapidly.

There is rarely streamflow data available for engineers to use to derive an accurate representation of the catchment's time of concentration. In the absence of data, engineers must exercise sound engineering judgment in the determination of this parameter as peak flow calculations are sensitive to the time of concentration.

Time of concentration varies with the size and shape of the drainage area, the land slope, the type of surface and land uses within the catchment, the intensity of rainfall, and whether flow is overland or channelised. (Cf. chapter 4).

6.1.6 Hydraulics

The hydraulic capacity of the storm drainage system can be determined through hydraulic modelling and for certain applications through the use of standard "hand calculations".

When analyzing the capacity of an existing system, a dynamic computer model will provide more realistic results since it can account for effects of limited catchbasin capture, depression storage, times of concentrations and so on. When designing large collector storm drainage systems with drainage areas greater than 40 hectares, computer models or similar hydrograph based simulation methods may be used.

The following standards of practice should be used as a guide for hydraulic modelling:

1. The designer should clearly identify the study objectives and how they relate to the hydraulic modelling.

2. The designer should provide the purpose for the hydraulic modelling.

3. The modeller should provide the model selection criteria and how the model matches the criteria.

4. The designer should provide plans clearly presenting the closed and/or open hydraulic system.

5. For plans describing the major system, the designer should note the cross-sections, study limits, land use, crossing details, spill areas, ineffective flow areas, and flooding limits and elevations for the appropriate design event(s).

6. For plans describing closed systems such as storm drains, the designer should note the storm drain network details including study limits, land use, node numbers, ground elevation, storm drain sizes, inverts, length and slope.

7. For combined hydrologic/hydraulic models, the proponent should provide plans that describe the minor and major system and the respective drainage areas of each.

8. For all hydraulic models, the designer should provide the downstream and, if applicable, upstream boundary conditions for each storm modeled and the assumptions used to define the boundary condition (e.g., water level in the rivulet/pond/receiving watercourse, etc.).

9. For all hydraulic models, the designer should document the parameters used for hydraulic losses such as Manning's "n", inlet and outlet losses, bend losses and other appropriate losses.

10. The designer should summarize the selection of procedures for determining the computed energy grade line and water surface elevations.

11. The designer should document the hydraulic results in summary form for the relevant storm events.

12. The designer should model the major system such that it fully contains the modeled flows without exceeding the hydraulic cross-section. Should it not be possible to contain the flows within the defined geometry of the major system, the designer should provide details on the spill characteristics.

13. The designer should document potential impacts on existing infrastructure and possible mitigation measures.

14. Sensitivity analysis should be conducted on a limited number of parameters depending on the model type and complexity.

15. The designer should, if possible, verify hydraulic results for the existing major/minor system by documenting historical flood elevations for specific storm events and comparing the hydraulic modelling results to the historical data.

16. The designer should provide the input and output data in a logical manner.

Bridge and culvert hydraulic calculations may be carried out using computer programs and these include capacity and headwater elevation calculations for culverts, and hydraulic calculations associated with bridges.

6.1.7 Engeneering Submission Reporting Requirements

A complete submission package must be delivered to the LDA for detailed engineering review of SWM Plans for both the conceptual/preliminary design stage and the detailed design stage. Submissions at the conceptual/preliminary design stage will consist of a Preliminary SWM Report. Submissions at the detailed design stage will consist of a SWM Report and an Operation and Maintenance Manual.

In general, printed and digital copies of the SWM Plan and Operation and Maintenance Manual must be submitted with each development proposal. Digital copies are to be submitted in original format, and include report text, drawings and appendices, as well as the full set of engineering drawings (for detailed design). Reports must be signed by a Registered Professional Engineer or the legal representative of a firm of Engineers registered at the Construction Industry Development Board (CIDB), and include, as a minimum, the items outlined below.

6.1.7.1 Reporting Requirements for Conceptual/preliminary SWM Plans (Prelimenary Report)

6.1.7.1.1 Primary Figures and Drawings

- Site Location Plan
- Draft Plan
- Hazard Area Mapping (if applicable)
  - Pre-development internal and external catchment areas and catchment I.D.'s on a topographic base showing existing land use and drainage patterns.
  - Post-development internal and external catchment areas and catchment I.D.'s on a topographic base showing future land use, and major and minor flow routes.
- Conceptual drawings and siting of any proposed SWM facilities, including location of inlet, outlet and spillway. Normal Water Level (NWL) and High Water Level (HWL) must be indicated on the conceptual drawings.
- Conceptual siting and details for any proposed infiltration measures.
- Full set of Engineering Conceptual/Preliminary Design Drawings.

6.1.7.1.2 Supporting Hydrology and Hydraulics Calculations and Modelling Details and Output

- Copies of the calculations or model schematics and hydrologic modelling, including input and detailed output files for the 2-yr through 100-yr return period events (i.e., must look at 1 and 12 hour MMS distributions), or subcatchment specific erosion control criteria for existing and future land uses as required.

- Relevant Storm Design Parameters - Identifying the design storm duration and distribution used.

- Details should be provided comparing the pre and post development peak flows for different storm distributions and durations for the site and required storage volumes to determine the critical storm to be used.
  - Soil Characteristics - Listing the areal distribution of each soil type (expressed as a %) within every subcatchment.
  - Model Input Parameters - Summarizing key input parameters for existing and future land use for each catchment including subcatchment I.D., drainage area, CN, IA, Tp, Slope, % impervious, pervious and impervious Manning's roughness, etc.

- Model input parameters, i.e., CN, IA, Tc, % imperviousness, etc., calculations.

- Incremental and cumulative volume calculations for the SWM facility.

- Drawdown time calculations for SWM facility (if applicable).

- Water balance calculations showing pre-development, unmitigated post-development and mitigated post-development infiltration volume analysis.
  - Pre and post-development watershed modelling schematics reflecting the model subcatchment I.D.'s and catchment areas.

6.1.7.2 Reporting Requirements for Detailled SWM Plans (Detailled Design)

SWM plans typically submitted to the LDA in support of site plan and plan of subdivision applications at the detailed design stage should include a SWM Report. The specific requirements that must be included in a SWM Report shall include, as a minimum, the items outlined below:

6.1.7.2.1 Background Information

- Introductory sheets describing the property location and legal descriptions, the proposed development scheme, the construction phasing plan, the intent of the report, the existing/historical land use and reference for the topographic information using the Ministry of Housing Control Points.

6.1.7.2.2 Storm Drainage Areas

- Pre-development conditions must be indicated including: internal and external catchment areas and catchment I.D.s with drainage patterns.

- Post-development conditions must be provided including: internal and external catchment areas and catchment I.D.s, and major and minor flow routes for the site, and relevant external lands.

6.1.7.2.3 SWM Targets/Objectives and Design Criteria

- SWM reports should identify how applicable recommendations from the Land Drainage Masterplan have been incorporated into the design.

- Outline the SWM design criteria being applied in the report. This should include criteria for water quality, erosion and quantity control as well as infiltration.

6.1.7.2.4 Storm Drainage System Design

- o It must be shown that the site provides safe conveyance of both the minor storm and event flows from both the subject site and any external lands, through the development to a sufficient outlet, with no adverse impact to either the upstream or downstream landowners. A sufficient outlet constitutes: a permanently flowing watercourse or the ocean.

6.1.7.2.5 SWM Facility Design

- o Pre-development conditions must be indicated including: hydrologic parameters used for modelling, and pre-development peak flow rates for the 2 year, 5 year, 10 year, 25 year, 50 year, and 100 year design storms for the critical storm distribution and duration.

- o Post-development conditions must be provided including: hydrologic parameters used for modelling, and post-development peak flow rates for the 2 year, 5 year, 10 year, 25 year, 50 year, and 100 year design storms for the critical storm distribution and duration for each sub catchment. A table summarizing the critical storm analysis must be included in support of the storm selected for the SWM facility.

- o The Water Surface elevations adjacent the site and downstream of the SWM facility outlet structure must be indicated to ensure the appropriate hydraulic calculations should backwater conditions exist.

- o It must be demonstrated that sufficient measures are provided to meet the required level of water quality control as per the Environmental Protection Act.

- o It must be demonstrated that sufficient measures are provided to achieve the required level of erosion control.

6.1.7.2.6 SWM Facility Inspection and Maintenance Requirements

- o Description of proposed inspection and maintenance requirements to ensure that the SWM facilities will continue to operate as designed must be included in an Operation and Maintenance Manual. A schedule and frequency of maintenance activities is required.

6.1.7.2.7 Primary Tables

- o Existing and proposed runoff coefficients for each catchment.

- o SWM Facility Operation Characteristics and Summary of Significant SWM Features - These include type of facility, contributing drainage area, lumped catchment imperviousness ratio, extended detention and quantity control volumes, as well as elevations for base of pond, base of forebay, normal water level, and active storage design high water level, 100 year design storm high water levels, and top of berm, inlet and outlet structure design details, such as: pipe or channel size, orifice size, weir length, and invert elevation, and total draw down time required for the extended detention volume.
  - ▪ A comparison of pre-development, uncontrolled post-development and controlled post- development flows table – showing peak flows for the 2 year through 100 year design storm events at significant points of interest throughout the catchment area.

6.1.7.2.8 Primary Figures and Drawings

- o Site Location Plan
  - ▪ Pre-development internal and external catchment areas and catchment I.D.'s on a topographic base showing existing land use and drainage patterns.
  - ▪ Post-development internal and external catchment areas and catchment I.D.'s on a topographic base showing future land use, and major and minor flow routes.

- o Siting and details for any proposed infiltration measures and SWM facilities.

- Full set of Engineering Detailed Design Drawings.

6.1.7.2.9 Supporting Hydrology and Hydraulics Calculations and Modelling Details and Output

- Calculations demonstrating that all minor and major system storm outlets have sufficient energy dissipation and/or erosion protection based on calculated erosive velocities at each outlet, supported by calculation sheets.

- Copies of the model schematics and hydrologic modelling, including input and detailed output files for the 2 year through 100 year return period events.

- Relevant Storm Design Parameters Table - Identifying the design storm duration and distribution used.

- Table should be provided comparing the pre and post-development peak flows for different storm distributions and durations for the site and required storage volumes.
  - Soil Characteristics Table – Listing the areal distribution of each soil type (expressed as a %) within every subcatchment.
  - Model Input Parameters Table - Summarizing key input parameters for existing and future land use for each catchment including subcatchment I.D., drainage area, CN, IA, Tp, Slope, % impervious, modelling time step, pervious and impervious Manning's roughness, etc.

- Conveyance capacity calculations for the major system flow path.

- Stage-Storage-Discharge spreadsheet with hydraulic calculations for any proposed outlet control structure. (Calculation equations, coefficients, and design values for all hydraulic structures should be clearly identified).

- Incremental and cumulative volume calculations for the stormwater management facility.

- Sizing of emergency spillway for the regulatory Storm flow.

- Drawdown time calculations for the SWM facilities.

- Sizing of erosion control structures.

- Calculations demonstrating that any proposed infiltration measures will provide the required infiltration volumes for the site.

- Drainage calculations in hard copy and digital format.

- Tailwater elevations must be indicated for the outlet of any storm drain and/or proposed SWM facility to demonstrate that any backwater conditions have been properly accounted for in the hydraulic design of the conveyance structures.

- Operation and Maintenance Manual including a monitoring program plan for SWM facilities indicating how the facility will be monitored including water quality on a periodic basis.

6.1.7.3 Reporting requirements for operation and maintenance of SWM Facility

6.1.7.3.1 Background Information

The operation and maintenance manual shall include, as a minimum, the items outlined below:

- Introductory material describing the property location, including the drainage area tributary to the facility.

- A general description describing the operation of the SWM facility and applicable water quality, erosion and quantity control criteria.

- Description of the various design elements of the SWM facility (e.g. sediment forebay, permanent pool, extended detention and flood storage, drawdown time and how the facility operates under various storm events, inlet and outlet control structures including maintenance by-pass valve and drawdown valve.

- Provide details as to who is responsible for the SWM facility maintenance.

6.1.7.3.2 SWM Facility Inspection and Maintenance Procedures

- Provide a schedule of key inspection items including but not limited to the following:
  - check inlet and outlet structures for accumulation of miscellaneous construction debris and other trash that may affect performance
  - check for unusually long extended detention drawdown time that could indicate a blockage in the outlet structure
  - check for sediment accumulation in the forebay and downstream of the facility
  - check for evidence of seepage along the berms
  - check for vandalism including illegal access or encroachment into the perimeter of the facility
  - confirm that safety and security measures are in good working order
  - check for the presence of any unusual erosion around berms and inlet or outlet structures
  - complete visual inspection to confirm that vegetation is healthy
  - complete visual inspection to confirm no oil sheen present on water surface or the presence of other visible contaminants or odours
  - check drawdown valve for proper operation

- Provide recommended maintenance procedures for items including but not limited to the following: grass cutting; weed control; fringe plantings; aquatic vegetation replanting; outlet adjustments; survey to assess the need for sediment removal and trash removal.

6.1.7.3.3 Procedures for Removal, Handling and Disposal of SWM Facility Sediment

- Indicate the procedure to dewater the permanent pool prior to sediment removal and how to divert storm flows away from the facility during maintenance operations.
- Provide a sediment handling, removal and disposal plan.

6.1.7.3.4 Supporting Documents

- Estimated annualized operation and maintenance costs with supporting calculations
- Sediment accumulation and cleanout frequency calculations
- A SWM facility location plan
- Post-development drainage area plan tributary to the SWM facility
- SWM facility stage-storage-discharge relationship and curve
- A general plan for the SWM facility and detailed drawings of key elements (e.g., inlet, outlet control.

6.1.8 Stormwater Management Facility Performance Monitoring

6.1.8.1 General

The purpose of the monitoring program is to confirm to the satisfaction of the LDA that the SWM facilities have been constructed and are functioning in accordance with the design specifications.

Performance monitoring of the SWM facilities shall commence after 90% of the development have been constructed, within the facility's catchment area. The facilities shall be monitored until two (2) years with the occurrence of four (4) significant rainfall events as defined below.

A "significant rainfall event" is defined as an event where greater than 40 mm of rain has fallen in 4 hours..

A list of deficiencies, if any, and related data with respect to the SWM facilities will be required following each year of monitoring. The Owner is required to perform any remedial works identified by the monitoring program.

6.1.8.2 SWM Pond

- The purpose of the monitoring programme for the SWM pond is to confirm to the satisfaction of the LDA that the pond has been constructed and is functioning in accordance with the design specifications.
- The owner shall remove the sediments from the forebay on an annual basis or when the accumulated sediment volume is greater than 25% of the forebay permanent pool volume.
- The volume of sediments shall be estimated using at least 5 uniformly distributed measurements of sediment taken within the forebay.
- The Owner shall carry out a second topographic survey after all the sediment has been removed and submit it to LDA together with a comparative analysis to demonstrate the extent of sediments removed.
- Water quality samplers, if specifically required, shall be installed at the inlet and outlet of the SWM Pond to characterize the facility's removal efficiency for TSS.
- Flow measurement equipment, if specifically required, shall be installed at all inlets and outlets together with a water level sensor for the SWM Pond.

6.1.9 Legal Aspects of Stormwater Management

Legal issues may arise under the following circumstances:

- Legal disputes are most commonly associated with actual or perceived changes in stormwater runoff.
- Urban development can change the location, volume, rate, frequency, duration, velocity and quality of stormwater runoff.

Drainage issues are governed by Civil Law, in particular, Article 640, which states that:

« Les fonds inférieurs sont assujettis envers ceux qui sont plus élevés à recevoir les eaux qui en découlent naturellement sans que la main de l'homme y ait contribué. Le propriétaire inférieur ne peut point élever de digue qui empêche cet écoulement. Le propriétaire supérieur ne peut rien faire qui aggrave la servitude du fonds inférieur »

Unfortunately, common law issues are not commonly understood and often require legal advice to resolve. A person or organisation may be liable under common law principles for nuisance where there has been an unreasonable interference with a person's use or enjoyment of his land.

The case Gartner versus Kidman (1962) in Australia provides precedence on this issue:

- An up-slope property owner must take reasonable steps to manage his stormwater runoff in a manner that allows the down-slope property owner to enjoy the ‘normal’ use of his land, and.
- the down-slope property owner must manage his property in a manner that allows the up-slope property to enjoy the ‘normal’ use of his land.

While it would not be considered reasonable for a property owner to prevent an adjacent property owner from constructing a boundary fence or wall on the ground that it may alter the natural flow of stormwater runoff, the property owner, while building the boundary fence or wall, must take reasonable care (regarding the fence or wall design) to minimise any nuisance caused to other persons or properties, namely that natural overland flow into and across his property should not be hindered or concentrated.

Figure 175: Holes drilled into wall to release hindered flow during flood event at Nouvelle France

Figure 176:Boundary walls diverting flows along street and to down- slope properties at Chemin Grenier

Gatner v Kitman outlined the following principles:

(i) The person from whose land the water flows is not liable merely because surface water flows naturally from his land onto another person’s land.
(ii) The up-slope landowner is liable if water flows from his land in a more concentrated form than it naturally would due to man-made alteration to the topography or the landform.
(iii) By putting in place measures to prevent the natural unconcentrated flow of water on his land, the down-slope landowner cannot divert the water onto the land of a third party to which it would not have naturally flowed.

It will be necessary for the land owner to investigate the potential impacts of changes to the location, peak discharge, frequency, duration, velocity, volume and water quality of stormwater runoff:

- A change in location where stormwater runoff enters a down-slope property may adversely affect the value of that property.
- A change in peak discharge would likely cause nuisance to a down-slope property if the property is prone to inundation of buildings as a result of local runoff.

A change in frequency of stormwater runoff would likely cause a nuisance to a down slope property if the property has waterlogged soils.

If a proposed land development is likely to increase the peak stormwater runoff, and the development incorporates flow attenuation systems, then the development would increase the duration of stormwater flows and this may, in isolated cases, cause an inconvenience to down-slope properties already suffering from water logged ground.

A change in the velocity of stormwater runoff, e.g through concentrated flows by a boundary wall would likely cause a nuisance to a third party through soil erosion.

A change in the quality of stormwater runoff would likely cause a nuisance to a down-slope property or a watercourse, e.g soil transport and sedimentation by construction activities.

6.2 Governance Recommendations

6.2.1 Governance measure

Good governance entails improving decision making, enabling better strategic planning, managing capital expenditures in the most optimum way and ensuring that the rules of law and common law issues are followed. It involves a good understanding of land drainage and stormwater management issues.

Good governance measures include but is not limited to:

- Preventative measures and pro-active preparedness to reduce vulnerability due to climate change.

- Education, awareness and public participation. Public awareness campaign on hazards, issues/vulnerability, risks and adaptation/resilience and shared responsibilities.

- Proper Land Use Planning through regulations governing the quantity and quality of stormwater runoff and the extent of impervious areas to be connected directly to the main drainage network by controlling production at source by means of micro controls spread over individual sites rather than the traditional approach of channelling it to large facilities.

- Information management system and data sharing for implementing a common line of defence against disaster risks.

- Provision of a map of the main drainage axes whether flowing, ephemeral or dry should be provided to all municipalities and District councils as reference for permit issuance.

- Regulations to reduce the release of contaminants such as pesticides and hazardous household wastes into stormwater.

- Removal of contaminated sediments from drains and preventing, locating and removing illegal connections and controlling leaks from wastewater sewers.

- Adoption of good operation and maintenance practices by municipal workers and the public for the storage, handling and transport of materials liable to be washed into the stormwater system.

- Monitoring of construction activities through the submission of documents to describe the specific planning and management of activities aimed at reducing the construction impacts on the quantity and quality of stormwater by such measures as control of erosion, disposal of sediments, control of wastewater from the site, storage and maintenance of plant, storage of construction materials and control over the illicit dumping of waste.

- Standard procedures for submission of stormwater management plans in support of site subdivision and development applications at conceptual/preliminary design stage, including stormwater management targets and objectives, pre-development conditions, post development conditions, storm drainage system design, facility design and water quality control for industrial development.

- Standard procedures for comparison of pre-development, unmitigated post development and mitigated post-development water balance volumes and infiltration volumes.

- Stormwater management facility inspection & maintenance requirements and schedule & frequency of maintenance activities to ensure that the facilities will continue to operate as designed,

- Maintenance activities such as cleaning of streets, storm drains and streams, garbage collection, cleaning of infiltration sumps

6.2.2 Focus on implement a project validation process specifically for hydraulic issues before any development

Within the framework of the recommendations related to governance; **the technical instruction of the project appears to be the priority action to be implemented on the territory.**

In this context, we recommend the following steps for the assessment and monitoring of the **drainage impact assessment:**

- **Step 1 - Compatibility with risk maps:**
  The project developer (urban developer) locates his project on the NGZ, NEZ and buffer on Axes maps. He analyses the conformity of his project with the risk regulation. In case of incompatibility, he reviews the design of his project to respect the regulations in force, including those related to the Wetland bill.
  As the risk maps are public utility servitudes, he will adapt his project even in the case of contradictory information provided by the planning documents.

- **Step 2: Submission of the compatible project design**
  On the basis of a compatible design, the project promoter submits a complete technical file including
    - Plans and sections of the project
    - The delimitation of the project and the areas affected by the project.
      From 1 ha of intercepted watershed (the project surface plus all that is upstream according to the axes of natural path crossing the project), any request is examined.
      Below 1 ha, a simple opinion is requested from the LDA.
    - The flows before and after urbanisation, established in accordance with the LDMP hydrological guide
    - Compensatory measures integrated into the project, distinguishing between:
    - The plan for the surface covering (open spaces, porous covering, etc.)
    - Detailed description of the avoid, reduce, compensate sequence implemented for the project;
    - Best Management Practices techniques implemented;
    - Detailed hydrological and hydraulic studies related to stormwater management, in accordance with the LDMP stormwater zoning map (Zones 1 to 4), including :
        - Permeability and groundwater level studies and tests if infiltration is used. These studies must also be provided to demonstrate the impossibility of implementing infiltration, even partial
        - Hydraulic studies for the dimensioning of retention volumes (total or partial if infiltration devices are possible), studies that comply with the LDMP methodological guide (and comply with the zoning map);
        - Possibly, for urbanised areas, hydraulic studies aimed at qualifying the 100-year flood when this is not yet mapped (hydrogeomorphological areas)

- The final discharge point(s) of the project's internal rainwater network;
- The maintenance and monitoring of the stormwater management works;

- **Step 3: Joint examination of the drainage impact assessment by the LDA and the Ministry of Environment, Solid Waste Management and Climate Change**
  Both entities technically assess the validity of the hydrological and d hydraulic calculations, and verify the compatibility with the flood risk and environmental protection maps.

- **Stage 4: Project compliance, if necessary:**
  These two services require modifications to the project to make it compatible with all environmental and flood risk aspects, with avoidance, reduction and, as a last resort, compensation measures. If it is not compliant and the hydraulic impact is not satisfactory, then the project is refused.

- **Step 5: Monitoring of the implementation and certificate of conformity of the completed works**
  Carried out by the project manager and the LDA's control services to establish the certificate of conformity, which is equivalent to the final discharge authorisation.

6.3 Environmental Conservation

6.3.1 Organisation: Main Government Entities Responsible for Management of ESAs

Table 50: Responsibility for Management of ESAs

ESA Type	**Main Entity Responsible for ESA in Mauritius**	Government's responsibility **/ evolution and needs for reinforcement and adaptation of governance**
1. Coastal marshlands	MAIFS*	The National Parks and Conservation Service has set up a Wetlands Unit to deal with clearances for proposed developments. This unit will be reinforced with the passing of the proposed Wetlands Act.
2. Upland marshlands	MAIFS*	
3. Lakes and reservoirs	MEPU*	Lakes and Reservoirs have been merged with upland marshlands, although as separate categories due to their specificity. The Water Resources Unit and the Central Water Authority currently manage these ESAs.
4. Rivers and streams	MEPU*	The Water Resources Unit and the Central Water Authority currently manage these ESAs while the River Reserves are managed by the Forestry Department of the Ministry of Agro-Industry and Food Security.
5. Mangroves	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. Mangroves are protected and special permission should be asked before tampering with any mangrove tree.
6. Intertidal mudflats	MBEMRFS*	Often associated with mangroves, **they should form part of the areas managed by the Ministry and its technical arm, the Albion Fisheries Research Centre as it is located below the line of high water mark, and therefore forms part of the lagoon/sea**
7. Sand beach and dunes	MHLUP & MESWMCC*	The sand extraction act prevents any tampering with sand dunes. Sand dunes are explicitly mentioned as ESAs in the Outline Planning Schemes and any development thereon should be subject to an Environmental Impact Assessment Licence issued by the Ministry of Environment prior to any Building and Land Use Permit issued by the local authority.
8. Seagrass and algal beds	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. Seagrass beds are protected and special permission should be asked before tampering with any seagrass bed.
9. Coral reefs	MBEMRFS*	Managed by the Permanent Secretary of the Ministry with the technical views of the Director of Fisheries and the Albion Fisheries Research Centre. corals are protected and special permission should be asked before tampering with any coral
10. Islets	MAIFS*	Managed by the National Parks and Conservation Division of the Ministry and its director, any access or tampering is restricted and strictly managed by the said Division.
11. High native content (flora)	MAIFS*	Managed by the National Parks and Conservation Division of the Ministry and its director, any access or tampering with native flora is restricted and strictly managed by the said Division.
12. Native fauna content (endemic birds, bats, and lizards)	MAIFS*	Managed by the National Parks and Conservation Division of the Ministry and its director, any access or tampering with native flora is restricted and strictly managed by the said Division.

ESA Type	Main Entity Responsible for ESA in Mauritius	Government's responsibility **/ evolution and needs for reinforcement and adaptation of governance**
13. Boreholes (aquifer wells)	MEPU*	The Water Resources Unit and the Central Water Authority currently manage these ESAs and issue licences to ensure that their use is sustainable. 200 m buffer zones are generally laced around boreholes to prevent any contamination.
14. Steep slopes (soil stabilisation, viewscape)	MHLUP*	Development on Steep Slopes exceeding 20% is normally not permitted. Control is effected through the requirement for an Environmental Impact Assessment Licence to be issued by the Ministry of Environment, Solid Waste Management and Climate Change as they are considered as ESAs, and through the issue of Building and Land Use Permits while some steep slopes are protected due to the presence of native fauna or flora or their location on mountain reserves.

* In Mauritius, the MESWMCC has an overarching role of overseeing development on ESAs through the EIA Process.

6.3.1.1 General approach

Source: Ministry of Environment, Solid Waste Management and Climate Change

6.3.1.1.1 EC 1 Conservation of Environmentally Sensitive Areas (ESAs)

Further to more detailed identification, mapping and classification of Environmentally Sensitive Areas (ESAs) by the Ministry responsible for Environment and in addition to any requirements under the Environment

Protection Act 2002 as amended, the natural functions, biodiversity, habitat and amenity of ESAs should be protected from adverse effects of development.

The ESA study has assessed the relative importance of different ESAs for their long term maintenance of their integrity. Each ESA type has been categorized on their sensitivity in maintaining environmental functions and provides sufficient flexibility in proposed land uses to strike a balance between environmental protection and sustainable development needs.

Where the ESAs are indicated on the Development Management Maps there should be a general presumption against development other than for educational or environmental management purposes or in order to sustain local economies or where development is deemed to be in the national interest and is acceptable on planning and environmental grounds. In case of discrepancy between the ESAs shown on the DMM and the ESA map at the Ministry of Environment, the project proponent should consult the Ministry of Environment.

Any development proposed within ESAs will be required to first obtain an Environmental Impact Assessment licence under the Environment Protection Act 2002 as subsequently amended, prior to seeking a building and land use permit.

Development adjoining ESAs should obtain the prior approval of the Ministry responsible for Environment and should be in accordance with the policies defined in the Study of Environmentally Sensitive Areas (ESAs) in Mauritius.

Opportunities for the sustained management of ESAs, which may form part of developments, should be pursued through planning agreement/obligation mechanisms. In all such cases, proposals for development within or adjoining Environmentally Sensitive Areas will need to demonstrate how they contribute to maintaining and enhancing the environmental character of the area and that they comply with relevant criteria in the Design Guidance outlined in SD5.

For the purposes of this Policy, ESAs are defined as follows:

- State Lands including State Forest Lands and privately- owned Mountain Reserves;
- Habitat for Endemic Flora and Fauna - which have strong links tothe Reserves identified in Policy EP 1;
- Mountain Slopes and Range Peaks – for moderately steep to steep/ very steep hillsides and mountain slopes and ridgelines;
- Coastal Features - including parts of the coastline and coastal wetlands and mangroves;
- Water Resources - major aquifers, surface water catchment areas and identified reservoirs and boreholes and existing weirs;
- Geological Features - the location of lava tubes and pits which are associated with cave networks and groundwater supplies.

Justification:

ESAs represent national environmental assets and their on-going management, protection and enhancement is vital if sustainable development goals are to be achieved. ***The intent of policy EC 1 is to reinforce a general presumption against major development in or adjacent to identified ESAs.***

The adoption of a precautionary approach to development is considered appropriate; the policy also incorporates the principles of Policies SD 2, SD 3 and SD 4 requiring additional environmental information for developments when considered necessary to inform the decision-making process.

The management of ESAs is achievable within this policy through permitting environmental management measures in sensitive locations. This should enable private sector management of ESAs, some good examples of which currently exist in tourism developments in the Eastern Tourism Zone where longer term maintenance, monitoring and enhancement measures have been put in place.

Identification of ESAs on the Development Management Map should afford protection while more detailed studies are completed. As the boundaries of ESAs become more well-defined, Policy EC 1 and supporting mapping base should be adjusted.

6.3.1.1.2 EC 2 Conservation of Water Resources

The existing and proposed dams/reservoirs and their catchment areas and the rivers that supply water into them should be safeguarded against pollution, erosion and deforestation. **Development within 30 metres of the high water level of the dams and adjacent to rivers, rivulets and streams, open canals or within the catchment areas should not normally be permitted, unless the developer has obtained written agreement from the Water Resources Unit/Ministry of Public Utilities (WRU/MRU) and the Sanitary Authority that the proposals do not pose a threat to the quality or quantity of surface or groundwater resources.**

A passage 1 metre wide shall be left along one or other side of every canal along its whole length and kept free from obstruction.

No development should be permitted within a 200 metre radius of a borehole or spring without consultation and prior written approval of the WRU/MPU.

Justification:

The economic treatment of water to render it safe for human consumption is of paramount importance to health and quality of life: any potentially polluting industries should be sited in appropriate locations where a failure to meet the relevant WRU/MPU effluent discharge standards will not jeopardise the nation's water supply. Regardless of the location of an industry there is still a need to ensure that effluent water treatment plants are provided and operated satisfactorily to ensure that the effluent meets the standardsrequired by the WRU/MPU or Wastewater Management Authority (WMA).

Deforestation of catchment areas causes an increased "peakiness" in surface water run-off, as does increasingly dense development, with a consequential increase in the volume of water that will be lost to the sea and a reduced dry season flow rate. Deforestation also exacerbates soil erosion, leading to silting of dams and intakes, more turbid water to be treated and potential harm to the lagoon ecosystems.

Protection of groundwater from contamination is recognised as being very important. The WRU/MPU normally requires a development exclusion zone of 200 metres around all new boreholes, springs and around as many existing boreholes as is practicable. Any development within 200 m of a borehole should not be permitted unless the WRU/MPU has given written confirmation that the proposals pose no threat to the groundwater resources; the WRU/MPU should consider giving a "no objection" response where the area is fully sewered and the development will be connected to a mains sewer.

6.3.1.1.3 EC 3 Wetland Conservation

Wetlands have been defined on the Development Management Map in order to prevent development on such sensitive areas. **Development should not normally be allowed within wetlands or buffer areas (30 metres from the edge of the wetland) except in cases for educational or environmental management purposes or where in the national interest and is acceptable on planning and environmental grounds.**

In view of the valuable functions they serve, the opportunity should be taken to implement wetland restoration and creation projects that are sensitively designed to be self-sustaining and persistent features of the landscape.

Any development proposed to directly adjoin wetlands (or within wetlands as specified above) will be required to first obtain an Environmental Impact Assessment licence under the Environment Protection Act 2002, prior to seeking a building and land use permit.

The filling in of wetlands should not normally be permitted, unless the proposed development is in the national interest or is located on a small parcel of land or infill site which is required to sustain the local economy and where the majority of the site has already been developed and the remaining smaller portion is not capable of restoration. In these cases clearance should be sought from the Chairman of the National RAMSAR Committee set up under the aegis of the Ministry of Agro-Industry and Food Security.

Justification:

For the purposes of this Policy, wetlands are defined in accordance with the definition provided by the National RAMSAR Committee within the Ministry of Agro-Industry and Food Security which is “ areas of marsh or water, whether natural or artificial, permanent or temporary, with water which is static or flowing, fresh or brackish or salt including areas of marine water.”

Wetlands are a water-based ecosystem – they provide a transition zone between terrestrial systems which are mostly dry and aquatic systems which are permanently wet. Being the interface between the two systems they share characteristics of both. Wetlands have both an environmental and an economic function – they are reservoirs of biodiversity, assist in flood control by gradually releasing rainfall and stormwater, enable vegetation to grow which assists in bank and coastline stabilisation and act with mangroves to trap sediment before it enters the marine system where it could adversely affect coral reefs and filter runoff to remove contaminants before they enter groundwater reserves.

The policy thus provides a precautionary approach to development including identifying buffer areas around wetlands to ensure their on-going protection. This is essential given the preparation of the Wetlands Protection Bill which, when enacted, should offer increased protection for this ecological and hydrological resource. In cases of small scale developments proposed on small parcels of land or infill sites identified as wetlands, where these can be shown to have minimal adverse environmental impact and which are needed to sustain local economies, there should be a general presumption in favour of suchschemes subject to clearance of the National RAMSAR Committee.

6.3.1.2 Specific approach identified in the LDMP

6.3.1.2.1 In relation to runoff and overflow risks: wetlands, reservoirs and lakes

The governance of coastal marshlands and upland marshlands, in accordance with the Wetlands Bill project, shoul be **under the aegis of the authority of the Department of Environment, Solid Waste Management and Climate Change specifically integrated with flood management.**

Lakes and Reservoirs have been merged with upland marshlands. **The Water Resources Unit and the Central Water Authority currently manage these ESAs and it is foreseen that they will form part of the committee set up under the new Wetlands Bill.**

6.3.1.2.2 In relation to coastal risks

Objectifve: Coastal risk management strategies that need to change to return to the natural functioning of ecosystems.

It is necessary to protect the Mangrove in particular in this context.

The Ministry of Blue Economy, Marine Resources, Fisheries and Shipping is the custodian Ministry responsible for the protection of Mangroves under section 69 of the Fisheries and Marine Resources Act, the enforcement of which is tantamount to protecting our coastal zone from the impacts of coastal squeeze or submersion**.**

6.3.1.2.3 Synthesis

The hydrological functions of Environmentally Sensitive Areas should be preserved at all costs through the application of existing laws and the passing of the Wetlands Bill in order to prevent flooding in Mauritius.

In fact, Environmentally Sensitive Areas, and more particularly mangroves, sand beach and dunes, lava and calcarenite caves, forests with high native fauna or flora content, coastal marshlands, upland marshlands and lakes and reservoirs, rivers and streams and boreholes should be fully protected and given their true value in terms of ecosystemic services.

In this case, no development zones should be proclaimed to ensure that those functions are maintained and protected for future generations.

The provisions of the proposed Wetlands Bill, as well as the Fisheries and Marine Resources Act and the Environment Protection Act and the Planning Development Act should be used and amended accordingly to enforce and create

6.3.2 Develop new governance mechanisms

In order to organise the enforcement of these recommendations, it is necessary to develop a new system of governance integrating the stakeholders in a more global approach.

The aim is to develop a new integrated governance based on:

- **Environmental challenges**, integrating the hydraulic component: Integreated Approach, from ridge to reef approach
- **Speciphic hydraulic challenges**, based on source control

6.3.2.1 Governance mechanisms based on an integrated approach – "from ridge to reef approach"

- ***Control of stormwater disposal and removal of chemical contaminants from stormwater***

These measures advocate recourse to planning as well as environmental and building regulations to reduce the release of toxic chemicals into stormwater. This is generally achieved by modifying certain activities, the use of certain products, and the associated handling and disposal practices. Pesticides and hazardous household wastes are examples of chemicals that can be controlled and managed through regulations and programmes.

The Central Water Authority and the Water Resources Unit of the Ministry of Energy and Public Utilities have a network of surface water quality monitoring stations in order to ensure that the water characteristics comply with the Water Quality Regulations passed under the Central Water Authority Act. The National Environmental Laboratory equally carries out water analyses for the Ministry of Environment, Solid Waste Management and Climate Change.

Moreover, the the UNDP/GEF funded project entitled: Mainstreaming Biodiversity into the Management of the Coastal Zone in the Republic of Mauritius has made provision for the drawing up of **Integrated Coastal Zone Management plans for Mauritius and Rodrigues with a concept of "ridge to reef" approach by the Ministry of Environment, Solid Waste Management and Climate Change.**

- ***Recommendation***

In view of the above, it would be beneficial to vest the surface water quality monitoring powers into the Ministry of Environment, Solid Waste Management and Climate Change which has the appropriate structure, legal framework and enforcing agency through the Police de l'Environnement to ensure full compliance with the law.

6.3.2.2 Governance mechanisms based on control at source (Structural and non Structural Measures)

6.3.2.2.1 In order to promote actions in runoff production areas:

- **Objective**

The action plan should not be restricted to the construction of drain networks within the urban areas being affected by flooding, but should intervene on the runoff production areas or upstream of the drain networks in order to attenuate the damage(floods, drain network overflow, etc.).

- ***Recommendation***

These actions should then be carried out in consultation between, the Ministry of Environment, the Ministry of Agro Industry, the owners and the LDA. For example, biodiversity corridors in agricultural areas should be promoted (see details on hedges for examples). It is recommended to create an inter-ministerial committee between the Ministry of Agro-industry and the Ministry of Environment (among others) in order to implement with the agricultural owners the installation of NdS (hedges and fascines) on the areas of runoff production: control of runoff, land erosion and participation in the creation of a green frame and ecological corridor.

Hedges exemple:

The UNDP/GEF funded project entitled: Mainstreaming Biodiversity into the Management of the Coastal Zone in the Republic of Mauritius has made specific recommendations in the Integrated Coastal Zone Management Plans for Black River and Rodrigues for the setting up of biodiversity corridors within agricultural areas. It is therefore proposed to intrduce vetiver (Chrysopogon zizanioides) and fataque (Panicum maximum) as nature-based solutions in those areas. The said species can also be used for the production of perfume base and for co-gheneration in the existing cane/bagasse power plants in Mauritius.

6.3.2.2.2 In order to promote in urban areas, Nature-based solutions and best management practices:
In order to provide an appropriate framework for the development of these practices, the Government of Mauritius will have to adopt a strategic approach of creating the necessary policy frameworks and removing the obstacles to enable the widespread use of nature-based solutions by decision-makers in all situations and territories where it is relevant.

The strategy should meet eight targets. Recommendations for Mauritius are associated with these targets:

Table 51: Strategy Approach for Nature Base Solution

Targets	Recommendations
Establish an institutional framework to encourage the generalisation of NbS through a national governance system	**Action to be taken by the Ministry of Environment, MoH & LUP, LDA and NDU, supported by territorial focal points, such as Local Authorities** **Within this institutional framework, give priority to NdS in water policies (non-artificialization of soils, low imperviousness, preservation of wetlands, alternative stormwater management)**

Targets	Recommendations
Dedicate a share of public and private investment to NbS	Creation of government-supported funding and financial aid schemes (tax reduction);
To provide decision-makers with the technical means to respond to their needs, qualified contacts, professionals trained in existing techniques, and the necessary assistance in the design, planning, implementation and sustainability of NbS;	Develop university environmental and hydraulic training, through the creation of university exchanges and interventions by international specialists in island and tropical environments
Adjust knowledge acquisition and transfer to local needs and better inform decision-makers about the value, effectiveness and relevance of NB	First projects should be carried out by the LDA or the NDU to serve as demonstrators for decision-makers, planners and the public.
Improve understanding, generate support, mobilise and involve the public in NbS initiatives	Implement public communication actions, especially for schools, with communication tools such as models and videos.
Reinforce the integration of approaches leading to NbS in territorial planning	Include in the planning (MoH & LUP) and PPG a priority for the implementation of NdS. The project promoter will have to demonstrate the technical impossibility to implement the NdS in order to use more traditional devices. Impose NdS for all Smarcities projects.
Create new frameworks for cross-cutting approaches to develop thematic strategies (for different economic sectors) that address climate change adaptation and ecological restoration together.	Create an inter-ministerial committee between the Ministry of Agro-industry and the Ministry of Environment (among others) in order to implement with the agricultural owners the installation of NdS (hedges and fascines) on the areas of runoff production: control of runoff, land erosion and participation in the creation of a green frame and ecological corridor
Making better use of past and present projects by creating networks to share feedback at different levels (international, regional, Indian Ocean with Reunion Island, national, local) and on different issues and topics.	Create a cooperation with the State departments in Reunion Island to organise visits of installations and share feedback and good practices

6.3.2.2.3 In order to promote nonstructural measures for control at source:
Control at source using non-structural measures is the most cost-effective method to reduce the impacts of urban runoff.

These methods are generally non-structural and include the following general practices:

- ***Education, awareness and public participation – Objectives and method***

It is essentially an institutional practice designed to change the method which the public at large manages a large number of parameters that may have an impact on pollution.

An effective programme can be developed through the following steps to lead by LDA:

- Define and analyse the problem (the sources of pollution, their causes, etc)
- Identify stakeholders (business, industries, landowners and residents, schools or youth groups, municipal employees);
- Know the target group. Create a complete profile, develop the best possible methods of communication;
- Set goals: informative, sentiment-based, responsibility, stimulating and action messages (simple and clear language, technically reliable statements, division of the concept into simple sentences);
- Design a methodology by selecting techniques most appropriate to the target group;
- Develop action plans and activity schedules;
- Specify the costs, the source of funding and adapt the project to available resources;
- Monitor and evaluate. Collect and collate data and record them to determine the effectiveness of the method, while acknowledging that the public may be slow to respond.

- ***Land use planning and management of areas under development – developing the skills of staff***
  - **Objective**

    It is important to include stormwater management when planning a new land development or an existing area to be rehabilitated. They can have significant impact on the control of volume and quality. Regulations are needed to implement and enforce land use planing, including **regulations** governing the quantity and quality of stormwater runoff. One of the basic parameters to minimise is the extent of **impervious areas to be connected directly**.

    Low-impact development is a relatively new concept. It is a design strategy that aims to maintain or restore natural hydrologic regime prior to development by creating a hydrological landscape with similar functions. The principles of low-impact development are based on controlling stormwater at source by means of micro controls spread over the site. This practice differs from traditional approaches, which usually involve managing stormwater runoff after channelling it to large facilities located at the lower end of drainage basins.

The term LID (Low Impact Development) comprises different approaches, including review of development practices and use of micro control mechanisms spread over the territory. It **is therefore based on the implementation of best management practices and nature-based solutions.**

It is possible to control stormwater runoff effectively at relatively low cost by planning and designing the site in an adequate and responsible manner. The maintenance costs which follow should also be be taken into account.

- Recommendation**s**

  What: Provide training on **best management practices** to design, monitor and evaluate good practices.

  The "Center for Watershed Protection" website (www.cwp.org) provides detailed technical information on how to develop and enforce regulations.

  Who : LDA, NDU, Engineering consultancies and urban promoters

- ***Integrated stormwater management planning***
  - **Objective**

    All municipalities have to integrate stormwater management into land use planning. An ever increasing practice is to incorporate watershed-based planning approaches, such as land drainage master plans and stormwater management plans. Incorporating these methods addresses the impact of stormwater management on values that the community considers relevant. According to this approach, stormwater ia a resource to be protected.

  - **Recommendations**

    What: Provide training on best management practices to design, monitor and evaluate good practices. / Application of stormwater zoning.

    Who: LDA

    Targets: LDA for local authorities.

- ***Development of regulations on drains and their applications***
  - **Objective**

    Relevant activities include controlling illegal spills, removing contaminated sediments from drains, preventing, finding and removing illegal connections, and controlling leaks from wastewater sewers.

  - **Recommendations**

    What: Train agents from the LDA and the Ministry of the Environment in the function of Water Police.

    Publish laws enabling these staff members to play the role of the police (verbalisation, obligations to restore and regulate conformity).

Who: LDA and Ministry of Environment, Solid Waste Management and Climate Change.

- ***Servicing and maintenance practices***
  - **Objective**

    The amount of toxic substances released into stormwater can be reduced, on the condition that the public, municipal workers, business and other users adopt good operation and maintenance practice. These measures focus on introducing and abiding by effecient procedures for the storage, handling and transport of materials liable to be washed into the stormwater system. Success of these implementation measures depends on education and training.

  - **Recommendations**

    What: Education and training, raising the awareness of stakeholders

    Publish laws enabling these staff members to play the role of police (verbalisation, obligations to restore and regulate conformity).

    Who: LDA and Ministry of Environment, Solid Waste Management and Climate Change.

    Targets: the public, municipal workers, business

- ***Monitoring of construction activities***
  - **Objective**

    Submission of documents is of necessity to describe the specific planning and management of activities aimed to reduce the construction impacts on the quantity and quality of stormwater. These techniques generally have many similarities to other structural techniques, except that they are short term methods. The measures within this framework include in particular control of erosion, the disposal of sediments, control of waste water from the site, storage and maintenance of plant, the storage of construction materials and control over the illicit dumping of waste.

  - **Recommendations**

    What: Control during the construction phase

    Who: LDA and Ministry of Environment, Solid Waste Management and Climate Change as Water Police function

    Targets: Urban promoters, work companies

- ***Maintenance activities***
  - **Objective**

    Cleaning of streets, park maintenance, efficient household garbage collection, cleaning of infiltration sumps and general maintenance of roads, storm drains and streams are generally included in this control at source measure.

  - **Recommendations**

    What: Hiring and training municipal officers

    Who: LDA

Targets: local Authorities