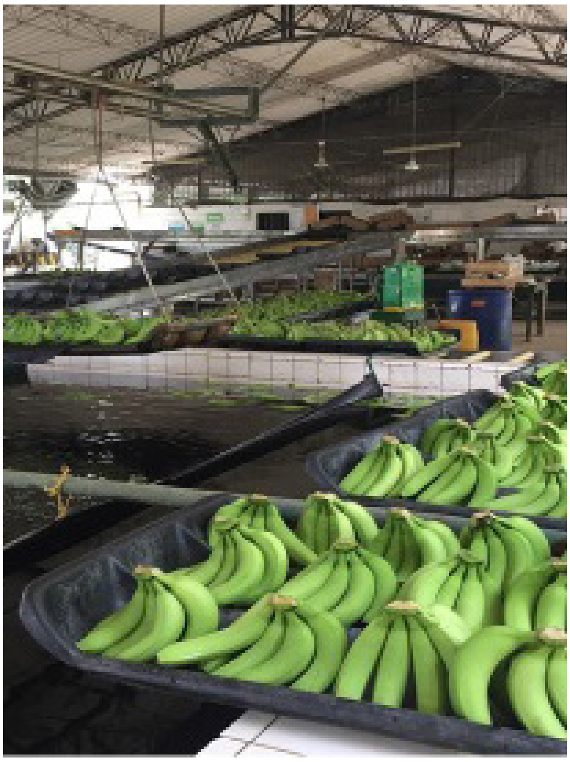

Water Management and Ecosystem Services

Contents

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Water Management and Ecosystem Services

The purpose of this guide is to provide contextual information regarding ecosystem services that influence the supply and management of water resources. The document demonstrates how the ecosystem service maps developed by Environment Systems and JNCC for the EO4cultivar project can be used to help inform decision making through the implementation of ecosystem-based management. Further information, online mapping tools, and additional management guides can be found on the EO4cultivar project website.

Water as an Ecosystem Service

A clean, reliable and well-managed water supply is critical to sustain life. It is required for the majority of biological and industrial processes, for example: drinking water; agricultural irrigation; industrial cleaning and cooling; climate regulation; and weathering and soil formation.

In the Zona Bananera and surrounding areas, equitable land use and water resource availability between different stakeholders is part of the socio-environmental history of the region. The resources of the Río Frío basin, for example, are in demand from five notable social actors:, agro-industry organisations, small scale local producers, cattle ranchers, indigenous communities and the urban population (which includes tourists)[1].

The functions that water provides that are of societal and ecological importance can be categorised under different ecosystem service typologies. Provisioning ecosystem services include:

- Clean drinking water and irrigation for crops.
- Critical to sanitation systems used to prevent spread of pathogens that cause disease.
- Use in the manufacturing process, Banana packing stations use water to remove insects and latex from the fruit.

Water is associated with regulating and maintenance services:

- Supporting ecosystems that drive nutrient cycling and carbon sequestration.
- Hydrological cycles drive weathering processes that contribute to soil formation and provide micro-nutrients that support ecosystems.
- Pollutant assimilation, wetlands in particular break down and disperse pollutants and help maintain good ecological status of ecosystems.

Provide cultural ecosystem service:

- Lakes, rivers and oceans provide countless recreation opportunities.
- Proximity to water has a positive impact on human health and well-being[2].
- Water is likely one of the only natural resource linked to all aspects of human civilization and culture[3].

Water is a vital natural asset to the global economy, especially to agriculture. Over 70% of global water extraction is used within the agricultural industry[4] and an adequate quantity of water is necessary to support crop growth. Banana production is a major industry within the Magdalena region, which is heavily reliant on secure supplies of water (see Figure 1). Key factors outlining the water dependencies of the banana industry include[5]:

- Large quantities of water are required throughout the banana growth season. Annual water requirements range between 1,200mm in the humid tropics to 2,200 mm in the dry tropics.
- Water is critical for leaf development, which affects the number of flowers and consequently the crop yield. During the yield formation period, water availability affects fruit size and quality.
- A reduced water supply in the early growth season can result in bananas being older than they appear, leading to premature ripening during the storage and transport phase.
- Once a banana crop has been harvested, water is required for processing. This includes removing pests and chemical residues, removal of latex, washing processing tanks.
- Water is required for cleaning workers' hands, clothing and for drinking.

Figure 1 – Water is a critical resource supporting global economic activities. Quantities of water are required in banana packing process. Photos: Matt Smith

Water supply in the Magdalena region

The Magdalena region's water supply is provided by 35 rivers forming the river basin, 16 of which have their source in the Sierra Nevada de Santa Marta national park. These rivers provide water to almost 1.5 million inhabitants in several main cities, including Santa Marta and Cienega. The rivers feed aqueducts and channels providing water to coffee growers, banana plantations, palm oil plantations and livestock[6] with a range of different irrigation systems being employed (see Figure 3). Rivers Frio and Sevilla supply the agricultural activities within the Zona Bananera[7].

The Sierra Nevada de Santa Marta (SNSM) mountain range is the source of 40% of the water flowing into the Ciénaga Grande de Santa Marta (CGSM). The remaining 60% is supplied by the Magdalena river in the west but does not flow through the Zona Bananera[7].

The Magdalena region is supplied through a network of aquifers in the Quaternary beds and Tertiary sediments that extends through the Lower Magdalena Valley, the Cesar Valley, and along the Atlantic coast[8]. The aquifer within the watershed of Zona Bananera (see Figure 2) is used to irrigate crops and there is increasing concern about saline intrusion, as a result of overexploitation[7].

The upper elevations of SNSM is dominated by Andean páramo, where the soils have similar characteristics to upland peat soils. They contain high amounts of organic carbon, in wet locations such as the SNSM carbon content can exceed 40%. The páramo has a high water surplus and sustained base flow, feeding rivers in coastal regions and the Amazon basin. Precipitation in the Colombian páramo ranges from 700 to 3000 mm and water production is about 1400 mm, equalling 66.5 km3 yr−1. Despite a lack of data on these systems, there is general agreement that páramo rivers provide a sustained base flow throughout the year[9].

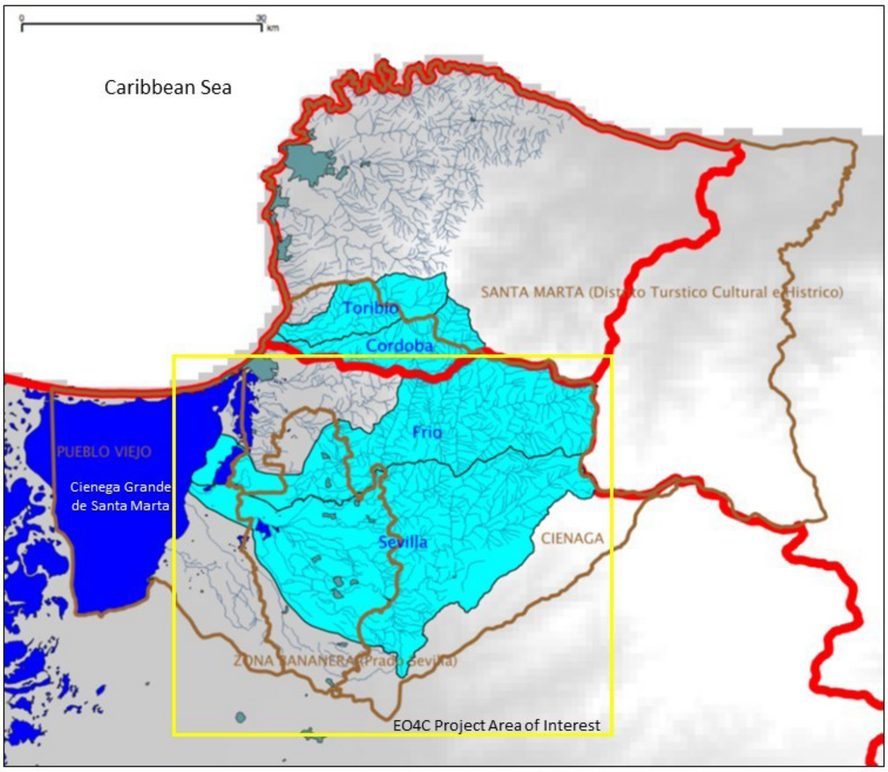

Figure 2 – Marked in turquoise are the watersheds of Toribio, Córdoba, Sevilla and Frio; Zona Bananera, Colombia. The red line marks the delimitation of sub-basins. Grey colour lines show the delineated boundaries of main urban conurbations. Areas marked in dark blue are permanent wetlands. The area of interest for the EO4cultivar project is highlighted in yellow. This figure has been adapted from the Risk Assessment and Opportunities for water basins in La Zona Bananera[7].

Adopting a Landscape Approach to Water Management

The main water users within the area of interest include the irrigation associations Asosevilla and Asoriofrío, who are located in the lower part of the basin in the Zona Bananera. The associations, local producers and regional government have engaged with the EO4cultivar project. Stakeholders have explored how an ecosystems approach can , better define flood risk and mitigation options, and identify potential for the implementation of ecological restoration and nature-based solutions to help manage water related risks and opportunities (e.g. reforestation programs).

Figure 3 – Irrigation methods of banana crops can vary within the Zona Bananera. Commercial operations use specially designed irrigation infrastructures, whereas some smaller operations extract directly from the river and use specifically dug channels to deliver water to the crop. Photos: Matt Smith

Using Ecosystem Service Maps to Inform Management

Ecosystem-based management can help manage water quality, availability and quantity. Different ecosystems can play a critical role in reducing water flow rates, act as water stores, as well as filtering out nutrients and heavy metals. Working with nature can help delivering multiple ecosystem service through nature-based solutions.

The ecosystem service maps are designed to demonstrate the functions that natural ecosystems play in maintaining and regulating water supply. They are aimed at supporting land-use planning and promote sustainable ecosystem management in order to increase the long-term resilience of production systems. The maps provide an evidence-base for community and stakeholder engagement.

Maps in the EO4cultivar sustainable livelihoods portfolio[10] directly relevant to water management include:

- Ability of land to moderate surface water runoff - This map shows areas where the landscape can provide natural flood management through hydrological and morphological processes working together with habitat features to manage water runoff. The map was created by assessing geology, soil, slope, habitat and management. These attributes reflect the contribution of specific areas to natural regulation of overland flow which is affected by infiltration and interception rates; water storage capacity and sediment load control. The map can be used to target protection or enhancement of priority areas that limit surface runoff and prevent flooding.

- Opportunities to enhance surface water regulation in the Rio Frio catchment and places receiving high volumes of surface water flow – These two separate maps can be used to identify areas where there are potential opportunities to consider different management measures of grassland and agriculture to enhance water regulation in upper, mid and lower areas of the Rio Frio catchment. The areas identified are hydrologically connected, whilst management of water regulation in the upper catchment can benefit a larger area, feasibility of interventions at different sites needs to be considered.

- Ecological Network Connectivity – Wetland Ecosystem - This map shows the existing wetland network, these are areas of native and semi-natural wetlands that are connected within the landscape. Areas of high connectivity, with low chemical and nutrient levels, and high structural and species diversity are more resilient to environmental changes, such as fluctuations in temperature or precipitation. Such areas provide higher level of ecosystem service provision such as clean water and erosion control. The map could be used to ensure that any agricultural practices or land use changes do not reduce ecological connectivity further and impact ecosystem services and biodiversity.

- Places delivering multiple ecosystem service benefits: key areas for biodiversity and surface water regulation – The map identifies areas of source habitat (grassland, woodland, wetland) which coincide with areas providing high surface water regulation. The structure and 'naturalness' of the vegetation provides high biodiversity value. These vegetation characteristics combine with characteristics of the soil, geology and slope enables the identification of areas that also provide high levels of surface water regulation. This is a form of natural flood management, where hydrological and morphological processes, together with the habitat features, work together to regulate the sources and pathways for flood waters. Places providing high levels of multiple ecosystem services could be considered more valuable than those providing a single ecosystem service.

- Opportunities to deliver multiple ecosystem services: ecological connectivity and surface water regulation – The map shows places where it should be possible to restore or create new habitat to strengthen existing ecological networks and simultaneously enhance surface water regulation.

Table 1 provides examples of how the mapped outputs can be used to inform ecosystem-based management measures to help manage water and maintain ecosystem services critical to sustainable agricultural yield.

Delivery of benefits to increase the sustainability of production

Table 1 – Possible management measure to enhance soil ecosystem service delivery.

Measure type	Mechanisms towards management	Affiliated management option
Constructed Wetland creation	Use opportunity maps to identify areas that provide opportunity to improve water regulation. Within these areas, select unproductive land where wetland habitat can be created. Consider how the intervention will provide benefits to production areas and local communities through reduced flood risk. Also consider where wetland construction can enhance key areas for biodiversity and ecological connectivity by consulting ecological connectivity maps.	Creation of new, or expansion of existing, wetland habitat can slow water discharge into river channels and prevent flood water surges; retain water for use in irrigation; act as natural filtration by removing chemicals and sediment before water enters channels. Wetlands can also be used to enhance biodiversity; consideration can be made to encourage species beneficial to production (i.e. crop pest predators and pollinators). It is important to consider these actions in relation to crop health, ensuring habitat creation encourages a balanced ecological community structure and not one that could provide a source of pest species outbreak.
Create meanders in the main channel	Use map of wetland connectivity and satellite images to identify focal areas for potential re-meandering interventions. Meanders can also help improve ecological connectivity between wetland habitats	Flood prevention measures often result in building concrete defences to contain water. If defences fail, the level of damage can be increased. Creating meanders in head waters can slow the rate of water discharge, reducing pressure on defences further down the catchment[11]. Meanders can also improve the attractiveness of the landscape, offer recreation areas and provide habitat for animal and plant species[12].
Create additional water storage facilities (e.g. micro dams and flood storage reservoirs)	Use maps highlighting areas with a low or moderate contribution to surface run-off along with maps showing areas delivering multiple benefits. Consult maps highlighting opportunities to improve water regulation and look for areas of overlap.	A flood storage reservoir is an artificially raised body of water used to store water temporarily and thereby mitigate flood risk[14]. Micro dams can be constructed of wood or rocks and act to deflect and diverter water. Dams can be designed to suit the location, and use local and natural materials. They can be easily installed at low cost and designed to offer multiple benefits for managing flooding and wildlife[15].

Measure type	Mechanisms towards management	Affiliated management option
Create additional water storage facilities (e.g. micro dams and flood storage reservoirs) contd	Once suitable sites are identified, conduct site visit(s) to ascertain feasibility of creating flood control reservoirs and consider construction methods that can enhance delivery of flood protection, water storage for irrigation and potential for ecological benefits[13].	It is important to ensure interventions do not damage existing ecosystems, impose higher risks to other areas, or present injurious effects to human health (i.e. increasing risk of waterborne disease). Interventions should be undertaken only after an impact assessment has been carried out.
Habitat Restoration	Consult habitat map and map showing areas contributing to surface water run off to identify habitat types contributing to water regulation. Consult maps showing opportunities to enhance ecological connectivity to identify types of habitat that could be restored. Identify areas for site visit to identify areas, stakeholder and additional ecosystem and societal benefits that could be delivered from restoration activities.	Restoring ecosystems can clean water at source and safeguard environmentally sensitive areas. Adopting an ecosystems approach using spatial information can help guide development towards areas where activities will have lower impact on ecosystems[16 17]. Strategic restoration of riparian areas can regulate rainfall and run-off, protecting freshwater, filtering sediments and pollutants, stabilising riverbanks, maintaining vegetation that provides shade and stabilises water temperatures and protect aquatic systems from extreme temperatures[18 19].
Cover crops and mulching	Use the habitat map to identify agricultural areas. Consult water regulation maps to identify areas delivering negligible water regulation. Consider mulching and cover crop planting in these areas to enhance water regulation capacity.	Mulching using organic material (e.g. bark, wood chips, pulp, shell nuts, green waste, leftover crops, compost, manure, straw, dry grass, leaves etc.) to cover the surface of the soil can significantly increase the capacity of soil to store water[20]. A cover crop is a crop that is grown between main crops and can assist in protecting soils, reduce flood risk, and improve subsequent crop yields. Other benefits of cover cropping include soil stability and erosion reduction, reducing chemical leaching through run off, improved soil structure and infiltration, increasing organic content, improving water quality and retaining soil nutrients[21].
Crop rotations	Use the habitat map to identify agricultural areas. Consult water regulation maps to identify areas delivering negligible water regulation. Consider crop rotation potential in these areas to enhance water regulation capacity.	Selecting particular crops on a seasonal rotation can improve soil structure and fertility by alternating plants that have different root depths. This can reduce erosion and increase infiltration capacity, helping reduce downstream flood risk[22 23].

Knowledge requirements to inform water management

Changing global conditions make water resource management increasingly complex. Factors to consider when planning a water management strategy should include issues such as:

- Population number and demographics
- Increasing urbanisation, industrialisation and economic development
- Changes in environmental quality and conditions
- Ecosystem water requirements
- Changing societal attitudes and perceptions

These factors are interrelated and information and data on these dynamics, and their interactions, should be considered in addition to earth observations and ecosystem modelling[24].

Water management policies and plans all over the world often adopt a sectoral focus, and fail to consider future environmental pressures and drivers from other sectors that may affect water management. Integrated Water Resources Management and Integrated River Basin Management must take a wider view on water related issues, at the macro and meso scale, to develop sustainable and achievable solutions. To attain this, water managers need to consider[25]:

- Collaboration to achieve policy compliance
- Establishing transboundary partnerships
- Stakeholder participation and co-design of strategies
- Developing local capacity to meet compliance
- Obtaining political buy-in and administrative support
- Adopting new tools and techniques

Pressures Affecting Water Ecosystem Services

The ecosystem services associated with water can be compromised by different abiotic, biotic and anthropogenic factors. Those that are particularly relevant to the case study area are:

Drought

Droughts constitute natural hazards that affect water supply to ecosystems and therefore humans. In 2013–2016, the Caribbean experienced the worst drought since the 1950s, with climate projections for the southern Caribbean predicting less rainfall by the end of the 21st century[26]. In 2014, severe drought caused by the El Niño phenomenon led to 600ha bananas not being replanted due to water shortages, equating to losses of $10 million.[7]

El Niño–Southern Oscillation (ENSO)

ENSO is a climatic cycle driving global weather patterns. In Colombia, El Niño typically brings drought whilst La Nina leads to excessive rainfall. During the first three months of the 2010-11 El Niño event, rainfall was below normal in 95% of the Caribbean region. During the La Nina event that extended from April to June 2011, it was reported that 800ha of bananas were lost and that 20,000 ha flooded across the region, equating to $13 million of losses within the Zona Bananera.[7]

Sedimentation

As water flows from source in Sierra Nevada, sediment is transported from the upper and middle basin and deposited in the lower basin. Whilst this is considered a natural process, industrialised land use change has increased erosion and sediment transfer. Increased sediment loads are affecting the mouth of the rivers and altering freshwater flow into the Cieneaga Grande de Santa Marta, leading to deterioration in water quality. This heightened sedimentation processes is often linked to drought and flooding, with drought conditions reducing water flow required to flush sediments into the lagoon and flooding event eroding more soils and increasing sediment loads in water courses.

Irrigation

Redirecting water to crops puts pressure on the water supply further downstream. As bananas can grow all year round, irrigation is required during dry periods to combat the reduction in rainfed water supply. During dry periods, where evapotranspiration is high, irrigation is required to control saline content in the soils. Challenges remain in the Zona Bananera as to how water resources and infrastructure can be designed and managed to ensure an equitable use of water resources.

Damming and channel diversion

Artificially diverting or blocking water flow during periods of low water flow can lead to a lack of water in other areas within the same region. Water shortages not only affect human population, but also alter the ecology of wetland habitats and reduce their ability to maintain hydrological function, further exacerbating the problem in subsequent years. Designing infrastructure, supported by nature-based solutions at a landscape scale, can help preserve water flow during drier periods, including storing excess water during periods of high flow.

Climate change

It is thought that climate change is intensifying the ENSO cycle. It is estimated by 2100 there will be a 30% reduction in water availability during El Niño and 40% increase in water flow during La Nina (see Figure 4). The Zona Bananera will also be affected by sea level, resulting in negative effects on agriculture in low lying regions through increased flooding and salinity. Saline intrusion into aquifers is already a problem in the Zona Bananera and surrounding regions, and bananas are highly salt sensitive.[7]

Use of agrochemicals

Pesticides and herbicides leach into the water course, making the water supply unsafe to drink and use in agriculture. Concerns have been expressed by stakeholders during workshops and through previous studies in the area[4] regarding pollution levels, agrichemicals, agricultural practices and basic sanitation.

Fertilisers leaching into water courses increase nutrient content and can lead to increases in phytoplankton, causing algal blooms. This can deplete oxygen levels in the water, which can kill aquatic life. The result being a reduction in water quality and a decrease in biodiversity.

Figure 4 – Fluctuations in water levels can be dramatic. The images above are of the Rio Sevilla in April 2018 during the dry season. The images below are of the same area in October 2019 during the rainy season. Managing these seasonal fluctuations is a challenge for businesses and communities in the area. Photos: Matt Smith

Annex A

Factors influencing water supply

There are number of factors that drive water provision and influence the quality and quantity of waters in rivers and aquifers.

Precipitation

Rainfall is the principle recharging mechanism for both rivers and aquifers in the region. Close proximity to the Caribbean Sea, where high sea surface temperatures lead to significant evapotranspiration, and the presence of the Sierra Nevada de Santa Marta, drives warm moist air upwards where it is rapidly cooled and leads to condensation and rainfall. Regional precipitation shows clear distinction between dry and rainy seasons (Figure 5).

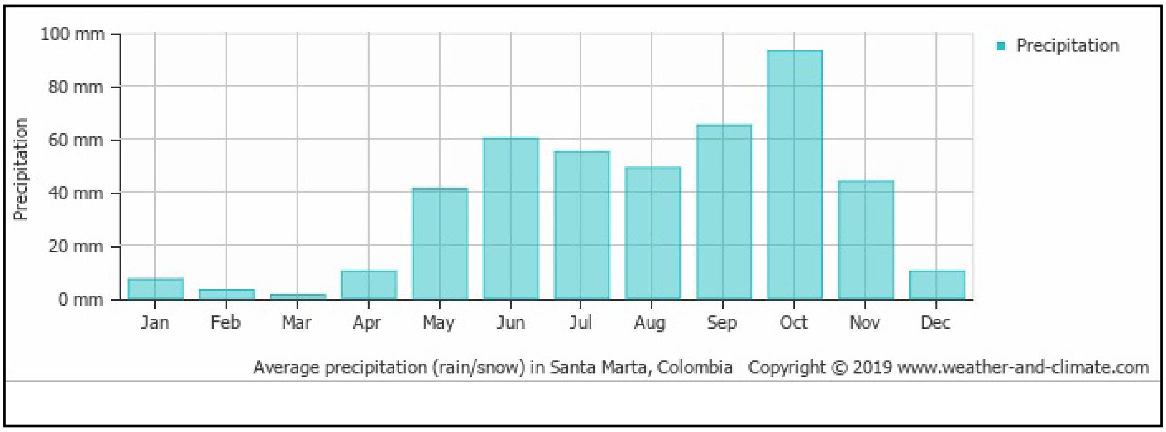

Figure 5 – Average precipitation for 2019 recorded by the Santa Marta weather station

Vegetation

Vegetation performs a number of roles within the hydrological system. Interception by vegetation reduces the peak flow following a rain event, reducing flooding risks. Transpiration of water from plants back into the atmosphere increases humidity following a rainfall event, leading to increased likelihood of subsequent rainfall.

At low elevations (0-1200m above sea level) vegetation is dominated by lowland humid tropical forests, tropical dry forests, and xerophytic and sub-xerophytic scrub. Mid-elevations (1300 -3500m) are covered by Andean forests. Higher elevations are dominated by paramo grasslands up to ~4800m. Most of the native vegetation has transformed as a result of dynamic social and economic processes that have driven land use change since colonial times.[11]

The environment is characterised by vegetation that extracts moisture from low cloud cover in a process known as horizontal precipitation. This is a key factor to maintaining the hydrologic cycle during dry periods. Vegetation at lower altitudes helps maintaining water quality through the filtering of debris and pollutants.

Geology

The geology of a catchment determines the permeability of the bedrock, and therefore its capacity for aquifer formation and recharge through infiltration of surface water into ground water. The land's ability to moderate surface runoff and prevent flooding is also affected by the permeability of the underlying geology. The Magdalena region is principally sedimentary rock. Fault lines and fractures in rock formations are important geological features, allowing for recharging from nearby aquifers and facilitating movement of water between rivers and aquifers.[7]

Soil

Soil type affects water retention, percolation and filtration, making it another important factor to consider as part of water management. For more information on the links between soil, water and ecosystem service delivery refer to the accompanying Soil Guide.

Topography

Topographical features such as the gradient at which a river flows, the profile of the channel cross section, and the number of meanders in a river will affect water flow rates and water quality.

Slope gradient affects the risk of flooding and erosive potential of precipitation, thus impacting water quality and increasing sedimentation downstream. Steep gradients lead to a higher risk of flash floods as water from a rainfall has insufficient time to disperse through evaporation or interception, leading to higher rates of peak flow overland and in river channels. Conversely, shallow gradients may lead to reduced water dispersal within a catchment and give rise to flooding. A shallow gradient leads to better water retention, which can be advantageous in drought prone areas where rainfall is low.

The sinuosity of a river indicates how many meanders it has, another important topographical feature affecting the speed of water flow. Rivers with more meanders are likely to have a slower flow speed than those without, providing improved resistance to flash floods, increased water retention and reduced erosion risk. Rivers with a bigger cross section (deeper and wider) are able to hold more volume, reducing risk of flooding and increasing water retention.

Although the majority of rivers in the area of interest are fed by rainfall, melting in the Sierra Nevada de Santa Marta is also a minor contributing factor. The Santa Marta Paramo has a small permanent snow cap above 5000 m despite being located just 10 degrees North of the equator.

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