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Centre on Water and Environment

Securing Crucial Biodiversity, Carbon and Water Stores in the Congo Basin Peatlands

Report on Development and Climate Change Scenarios

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Executive Summary

The Congo Basin peatlands, particularly those in the Cuvette Centrale region, represent one of the world's most significant terrestrial carbon stores and are vital for biodiversity and hydrological stability. In response to increasing pressures from land use change, infrastructure development, and climate variability, the United Nations Environment Programme (UNEP) initiated a project titled **"Securing Crucial Biodiversity, Carbon and Water Stores in the Congo Basin Peatlands by Enabling Evidence-Based Decision Making and Good Governance".**

As part of the study to determine the impacts of development interventions and climate change on the peatlands in the Cuvette Centrale, a hydrological model and biodegradation model were developed. The results of the modelling exercise and study led to the development of a Hydrological Decision Support System (HDSS), designed to provide scientific guidance for sustainable peatland management in the Lac Télé/Lac Tumba landscape.

The HDSS provides a scientific basis for evaluating the potential impacts of various development interventions and climate scenarios on peatland hydrology and carbon dynamics. It supports decision-makers by providing guidance on the likely consequences of locally relevant interventions - identified through a consultative stakeholder process - on water balance and soil carbon stocks.

This report briefly summarises the technical methodology used and presents some of the key findings related to carbon flux for seven intervention types, across two hydrological regimes and with climate change considerations. For a full insight into the methodology the Technical Model Report should be consulted.

Hydrological model and Biodegradation model development

At the heart of the study is a conceptual hydrological model tailored to the unique conditions of the Cuvette Centrale peatlands. Due to limited georeferenced data, the model adopts a simplified but robust structure that captures the essential hydrological processes governing peatland function. It distinguishes between rainfall-driven and river-influenced regimes, enabling the simulation of both interfluvial domes and riparian zones. The model domain is a 40 km by 2.88 km slice through a peat dome, discretized into 80-meter grid cells, and initialized under saturated conditions. The simulation period spans from 2000 to 2019.

The hydrological model, built using the MIKE SHE platform, simulates the full water cycle, including precipitation, evapotranspiration, infiltration, groundwater flow, and overland flow. Actual evapotranspiration is calculated using the Kristensen & Jensen method, with reference evapotranspiration derived from the Priestley-Taylor equation. Leaf Area Index (LAI) data from MODIS and Copernicus Earth observation datasets are used to represent vegetation dynamics, while spatial climate inputs are sourced from ERA5 reanalysis data. The model captures a bimodal seasonal rainfall pattern and reveals a long-term trend of declining precipitation and increasing evapotranspiration.

To assess carbon dynamics, the hydrological model is coupled with a carbon accumulation and decay model inspired by DigiBog. Litter material generated by plant growth is divided into leaves, wood and roots. The decomposition of organic matter under oxic and anoxic conditions is simulated with a dual exponential decay function, including both the fast decay of labile compounds and the slow decomposition of recalcitrant material. Peat decay is more intense under oxic conditions, i.e. if air-filled porosity exceeds 10%, and increases exponentially with temperature. The parameters used to describe peat accumulation and decay are derived from field data in the Congo peatlands

Stakeholder consultations and inputs to the project

Between October 2023 and October 2025, stakeholder consultations were conducted in Brazzaville and Kinshasa to identify the water related challenges in the Lac Tele and Lac Tumba landscape. A broad range of actors from the public sector, academia, non-governmental organizations and development partners were engaged through a series of workshops to identify the water related challenges, refine

the scope of the study and provide inputs to the types of development interventions that are likely to be considered in the future in the Lac Tele Lac Tumba Landscape.

During the consultation process, it was noted that while many of the identified interventions could have significant impacts on the hydrology of the peatlands, a significant limitation to exploring these scenarios was the lack of in-situ data on the hydrology in the Cuvette Central. Coupled with the unknowns of many of these large-scale interventions (e.g. upstream dams, large scale exploration for petrol) this study focuses on the direct impact of small-scale interventions that are easily quantifiable and replicable across the project area. As a result, the development scenarios investigated in detail are small scale, local interventions taking place within the project landscape in the Cuvette Centrale.

Development interventions, climate change scenarios and hydrological regimes

The study evaluates seven generalized development interventions that were identified through stakeholder consultations, supplemented by inputs from CREBBaC.

Table 0-1 Generalized development interventions

Code	Name	Description
A	Baseline without Intervention	Vegetation and topography of the peatlands are according to the current conditions - between 2010 and 2020
B	Road Built and Operational	(a) A raised impervious road is built 1 meter above the natural surface. It is finished and operational. (b) Vegetation is removed, and the soil surface is flattened. (c) The road embankment is filled with permeable gravel. (d) The underlying peat is compressed due to the road's weight.
C	Road during Construction	(a) A raised impervious road is being built 1 meter above the natural surface. (b) Vegetation is removed, and the soil surface is flattened. (c) The road embankment is filled with permeable gravel. (d) The underlying peat is compressed due to the road's weight. (e) During construction, drainage is installed 2 meters below the ground, i.e., 1 meter below the surrounding surface.
D	Settlements Developed	(a) A settlement is developed in the peatland forest. (b) The topography is raised by 50 cm to prevent flooding. (c) Vegetation is cleared, and the soil surface is partially paved. (d) The peat is compressed under the load of buildings.
E	Forest Fire – Deforestation	(a) A forest fire completely clears the vegetation. (b) As a result, soil properties change: bulk density increases, and specific yield decreases.
F	Palm Plantation replaces Forest	Deforestation and Conversion to Oil Palm Plantations: (a) Natural vegetation is cleared to establish additional oil palm plantations. (b) Oil palms thrive with a mean water level 40 cm to 60 cm below ground. There is drainage at 50 cm depth. (c) Vegetation properties are altered according to 15-year-old mature oil palm plantation. (d) The microtopography is smoothed due to clearing. (e) Soil properties change by drainage: increased bulk density, reduced specific yield, and reduced hydraulic conductivity at saturation. (f) The topography is lowered by 50 cm due to soil subsidence induced by drainage.
G	Rice Cultivation replaces Forest	Deforestation and Conversion to Rice Cultivation: (a) Natural vegetation is removed and replaced with rice paddies. Rice is the most common seasonally flooded crop in the Cuvette Centrale. (b) There are two harvests per year. Vegetation and surface properties/roughness vary with crop stage.

Climate change scenarios are modeled using the delta change method, applying monthly scaling factors to precipitation, evapotranspiration, and temperature. From the IPCC AR6 emission scenarios the following form part of the scenario definitions:

Table 0-2 Climate change scenarios

Code	Name	Description
1	Current Climate	Rainfall, temperature and evapotranspiration between 2010 and 2020 are chosen to represent the current climate conditions.
2	CC Sustainable Growth	SSP1-2.6: (a) Global warming is limited to around 1.5°C-2°C above pre-industrial levels. (b) This scenario is in line with the objectives of the Paris Agreement and represents an optimistic future with sustainable economic growth and minimal impact on climate change.
3	CC Severe Impact	SSP3-7.0: (a) Projected warming: 3°C-4°C by 2100, with severe climatic consequences. (b) This scenario represents a high-risk future, characterized by significant climate change, social inequalities and environmental degradation.

To reflect the hydrological diversity of the Cuvette Centrale, the hydrological model incorporates two distinct representations: one for rainfall-driven peatlands and another for those influenced by river flooding. This ensures that both hydrological regimes are adequately captured:

Table 0-3 Hydrological regimes

Code	Name	Description
1	Rain-fed	Rainfall and Evapotranspiration only: The hydrological processes in the peatlands are only driven by rainfall and evapotranspiration. This is mostly the case in interfluvial peat domes, mostly located in the Republic of Congo.
2	River-fed	Rainfall and Evapotranspiration plus River Water Levels: The hydrological processes in the peatlands are driven by rainfall and evapotranspiration, as well as fluctuating water levels in bordering water bodies (e.g., river reaches). This is mostly the case in the riparian peatlands, mostly located in the Democratic Republic of Congo.

The hydrological regions are represented in the models as model boundary conditions: in the rainfall driven configuration, the western and eastern boundaries have a constant head set at surface level. These water levels fluctuate in the river-fed models. Boundary conditions are model drivers like the climate model drivers. The model structure and parameterization are designed to align with the region's hydrological, climatic, and geomorphological characteristics, while also accounting for existing data gaps.

By combining the seven development interventions with three climatic scenarios and two hydrological regimes, **the study and thereby the HDSS generates results for 42 different scenarios.**

Scenarios evaluation method with indicators

The evaluation of scenarios makes use of indicators that are derived from the detailed simulation results. The indicators are defined to allow simplified evaluation of scenarios and comparisons:

Table 0-4 Indicators used to generate results

Name	Indicator Description
Carbon Flux Inside	Carbon stock change in kg per m2 per year inside the footprint of the intervention
Carbon Flux Outside	Carbon stock change in kg per m2 per year outside the footprint of the intervention
Oxic Depth Inside	Average oxic depth inside the footprint of the intervention: Depth in the soil where oxygen is still present, affecting nutrient cycling, i.e., carbon transformations. This influences the rate of organic matter decomposition and thus carbon sequestration.

Name	Indicator Description
Oxic Depth Outside	Average oxic depth outside the footprint of the intervention: Depth in the soil where oxygen is still present, affecting nutrient cycling, i.e., carbon transformations. This influences the rate of organic matter decomposition and thus carbon sequestration.
GWT Depth Inside	Average ground water table depth inside the footprint of the intervention - in meters below the surface
GWT Depth Outside	Average ground water table depth outside the footprint of the intervention - in meters below the surface

Summary of results

The hydrological and carbon emission impacts of the interventions are assessed within and around the intervention footprint. Indicator values are summarised in the table below. Values highlighted in red and green indicate, respectively, high and low soil carbon losses.

Table 0-5 Results of development scenarios in current climate in rain-fed peatlands

Indicator Short Name	Unit	Indicator Values for Scenarios						
		A.1.1	B.1.1	C.1.1	D.1.1	E.1.1	F.1.1	G.1.1
Oxic Depth Inside	m	0.20	0.92	2.12	0.37	0.18	0.73	0.14
Groundwater Depth Inside	m	0.15	1.06	2.00	0.40	0.14	0.73	0.10
Carbon Flux Inside	kg/m^2/year	**-4.72**	0.00	0.00	-8.77	-4.67	-15.64	-3.77
Oxic Depth Outside	m	0.20	0.13	0.68	0.16	0.20	0.77	0.20
Groundwater Depth Outside	m	0.15	0.05	0.68	0.10	0.16	0.79	0.15
Carbon Flux Outside	kg/m^2/year	**-4.72**	-2.90	-14.26	-3.80	-4.78	-15.01	-4.70

Table 0-6 Results of development scenarios in current climate in river-fed peatlands

Indicator Short Name	Unit	Indicator Values for Scenarios						
		A.1.2	B.1.2	C.1.2	D.1.2	E.1.2	F.1.2	G.1.2
Oxic Depth Inside	m	0.12	0.89	2.12	0.34	0.12	0.71	0.09
Groundwater Depth Inside	m	0.03	1.03	2.01	0.35	0.03	0.69	0.00
Carbon Flux Inside	kg/m^2/year	**-2.82**	0.00	0.00	-8.10	-3.17	-14.55	-2.46
Oxic Depth Outside	m	0.12	0.07	0.61	0.09	0.12	0.65	0.12
Groundwater Depth Outside	m	0.03	-0.05	0.59	-0.01	0.03	0.64	0.03
Carbon Flux Outside	kg/m^2/year	**-2.82**	-1.40	-12.88	-2.08	-2.85	--13.53	-2.79

Climate change scenarios

Water levels in the peatland are expected to drop under both SSP1-2.6 and SSP3-7.0. Although rainfall should increase by 1.5% annually under SSP1-2.6, the rise in actual evapotranspiration is sharper. Under SSP3-7.0, a substantial increase in actual evapotranspiration coupled with a slight decrease in rainfall leads to lower water levels. As water levels drop under climate change, peat decay increases.

Focus on carbon flux outside the intervention area

Across all interventions except the settlement and fire interventions, carbon fluxes inside and outside the footprint follow the same trend relative to the baseline under all climate conditions: if carbon losses for a given intervention are lower than the baseline under current climate conditions, they are also lower under future climate change scenarios.

The results also demonstrate that any form of future development intervention which includes drainage will have a significant impact on the ability of the surrounding peatlands to sequester carbon and will result in an increase of carbon losses in the surrounding area.
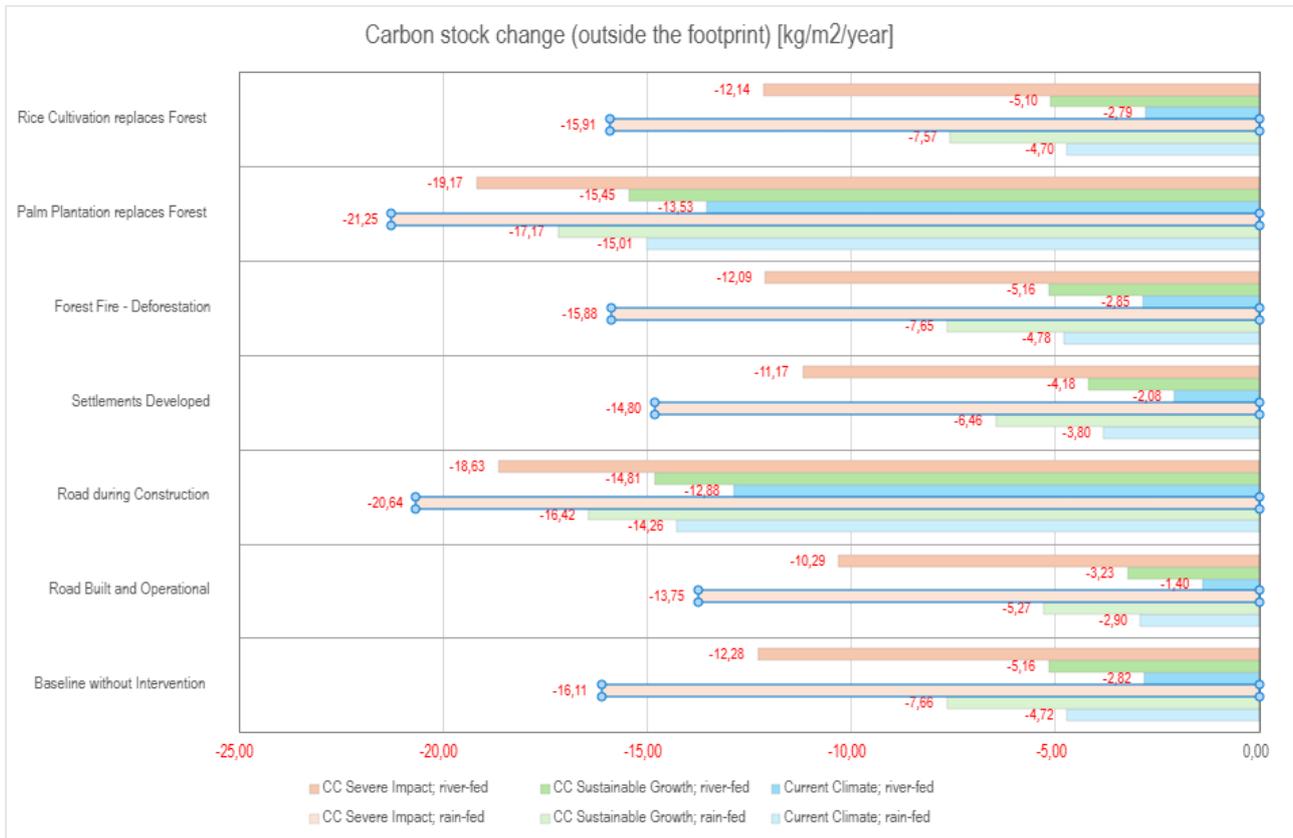

Figure 0-1 Summary of all intervention results for carbon stock change outside the intervention area

For other localised interventions without drainage, such as operational roads, settlements or areas exposed to fires, the loss of carbon is concentrated within the area of the intervention with limited impact on the surrounding peatlands.

The indicator is a normalized value per square meter which characterizes the impact on a unit area. Hence, for specific sizes of interventions, the decision maker needs to multiply the respective indicator values with the significant areas of the concrete interventions.

Conclusions

The findings in this report highlights the critical role of groundwater depth and oxic conditions in determining peatland carbon fluxes. Scenario analyses reveal that infrastructure development and land-use change can significantly increase carbon loss, while restoration and adaptive water management can mitigate these impacts.

The report findings highlight the critical importance of five key management actions:

- **Maintain High Water Tables**: Prioritize hydrological management practices that keep the groundwater table close to the surface. Where drainage is unavoidable, limit the depth and duration of drainage to minimize peat oxidation and subsidence.

- **Protect and Restore Vegetation**: Retain natural vegetation buffers, especially along waterways and peat dome margins, to support water retention and ecosystem resilience. Restoration of degraded areas through rewetting and reforestation should be promoted to reduce emissions and enhance peatland function.

- **Minimize Surface Disturbance**: Avoid large-scale smoothing of natural microtopography and limit soil compaction from heavy infrastructure. Where possible, design interventions to preserve or mimic natural surface features.

- **Implement Adaptive Drainage**: Where drainage is necessary for development, employ controlled drainage systems (e.g., adjustable weirs) to allow dynamic management of water levels in response to seasonal and climatic variability.

- **Monitor and Adapt**: Establish long-term monitoring of hydrological and ecological indicators to inform adaptive management and ensure that interventions do not compromise peatland integrity.

The study also underscores the importance of long-term monitoring and stakeholder engagement to ensure effective governance and sustainable land-use planning. These findings offers actionable insights for sustainable land-use planning that can lay the foundation for evidence-based governance, long-term monitoring, and stakeholder engagement—essential components for safeguarding one of the world's most carbon-rich and ecologically vital ecosystems.

Next steps

The full results of the study can be explored in the Hydrological Decision Support System. The Democratic Republic of Congo and Republic of Congo will use these findings and the and the Hydrological Decisions Support System as an interactive tool to develop and sustainably manage the waters of the Lac Tele and Lac Tumba peatlands, respectively.

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1 Introduction

The Congo Basin peatlands, particularly those in the Cuvette Centrale region, represent one of the world's most significant terrestrial carbon stores and are vital for biodiversity and hydrological stability. In response to increasing pressures from land use change, infrastructure development, and climate variability, the United Nations Environment Programme (UNEP) initiated a project titled "Securing Crucial Biodiversity, Carbon and Water Stores in the Congo Basin Peatlands". This initiative led to the development of a Hydrological Decision Support System (HDSS), designed to provide scientific guidance for sustainable peatland management in the Lac Télé/Lac Tumba landscape.The Lac Tele and Lac Tumba Landscape

The Lac Télé–Lac Tumba landscape straddles the border between the Democratic Republic of the Congo (DRC) and the Republic of the Congo (RoC), covering an area of approximately 126,440 km² in the Central Cuvette of the Congo Basin. An estimated 72,439 km² lies in the eastern part of the landscape in the DRC, while 54,001 km² is located in the western part in the RoC. The landscape is home to three significant lakes: Lake Tumba and Lake Mai-Ndombe in the DRC, and Lake Télé in the RoC. The area is interconnected by a vast network of rivers, including the Congo River, the Ubangi River, the Sangha River, and the Likouala aux Herbes River.
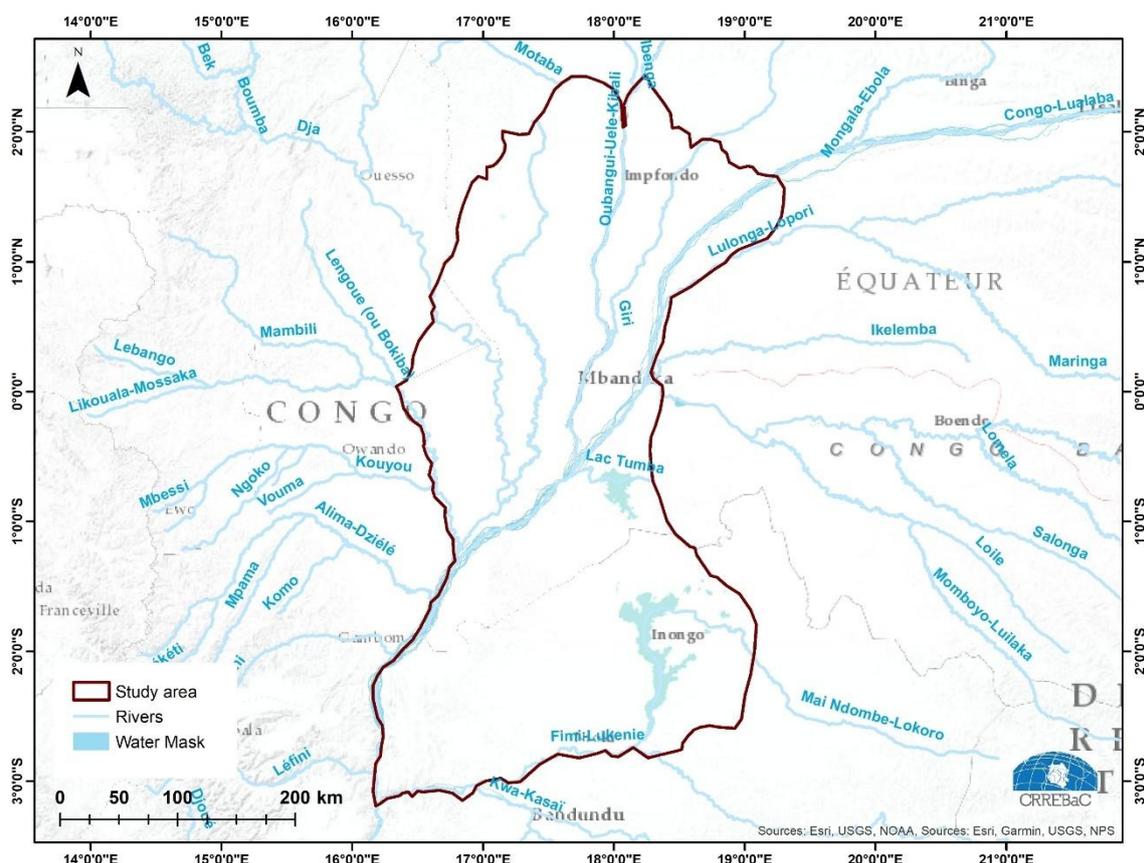
Figure 1-1   Overview of the project landscape (CRREBaC 2025)

Land classification in the landscape reveals peat swamp forests dominated by palm trees (particularly in the central and southeastern areas), terra firme forests and savannas (mainly in the southwest), and peat swamp forests dominated by hardwoods (especially in the northwest). This ecosystem is one of the most important hotspots for biodiversity and climate in the Congo Basin and supports the livelihoods of the local population within the landscape and surrounding areas.

The population of the landscape was estimated at 2 million in 2012 (mainly located in the DRC), primarily concentrated in areas such as Lukolela and Mbandaka in the DRC, and Epena and Impfondo

in the RoC. The landscape also includes smaller, scattered human settlements inhabited by local and Indigenous populations, particularly in terra firme and savanna regions, with settlements in places like Bobanga and Ikendji, among others. However, the landscape remains largely inaccessible, densely forested, and sparsely populated. The population, including the approximately 1.2 million people living in the city of Mbandaka, still lacks reliable access to basic services such as electricity, clean water, and sanitation. Economic poverty and associated challenges continue to afflict the region. Key activities in the area include fishing in rivers and peatlands, planting, gathering edible and non-edible forest products, hunting, and livestock farming for subsistence and income generation.

The importance of the landscape's ecosystem extends beyond its borders and surrounding areas in terms of environmental services; it also holds global significance, particularly from a climate perspective. The landscape is located in the Central Cuvette of the Congo Basin, where recent estimates show an area of 167,600 km² of peatlands storing 29 gigatonnes of carbon—equivalent to nearly two years of global CO_2-equivalent emissions. Therefore, conserving these peatlands and promoting ecosystem-friendly development pathways are crucial for climate, biodiversity, and the populations whose livelihoods depend on the ecosystem's health.

1.1   Scenario Analysis Approach

The Congo Basin peatlands represent one of the world's most significant stores of terrestrial carbon, biodiversity, and freshwater resources. Protecting these ecosystems is critical not only for regional environmental integrity but also for global climate regulation. However, the peatlands face increasing pressures from local development, land use change, and climate variability, all of which can profoundly alter their hydrological and ecological balance.

In response to these challenges, the project "Securing Crucial Biodiversity, Carbon and Water Stores in the Congo Basin Peatlands by Enabling Evidence-Based Decision Making and Good Governance", implemented by UNEP, aims to support sustainable peatland management in the Lac Télé/Lac Tumba landscape. Central to this effort is the development of a Hydrological Decision Support System (HDSS), which provides a scientific basis for evaluating the potential impacts of various development interventions and climate scenarios on peatland hydrology and carbon dynamics. Developing a hydrological model and decision support system for peatlands is a means for scenario analyses that result in recommendations for decision makers and stakeholders active in the project area.

This report documents the key findings of the scenario analyses underpinning the HDSS and provides guidance on the likely consequences of locally relevant interventions – identified through a consultative stakeholder process – on the water balance and soil carbon stocks in the Cuvette Centrale.

1.2   Structure of the report

Following the introductory chapter (Chapter 1), the report is organized into six substantive chapters that collectively present the study's approach, findings, and implications.

Chapter 2 outlines the stakeholder consultation process, detailing the range of inputs received from local, national, and international actors, and how these perspectives informed the study design.

Chapter 3 describes the evaluation methodology, including the analytical framework and the definition of scenarios used to assess peatland dynamics under varying climate and land-use conditions.

Chapter 4 presents the results across the defined scenarios, with particular emphasis on the change in carbon stock indicator results, highlighting spatial and temporal variations in carbon fluxes.

Chapter 5 synthesizes the findings for both rain-fed and river-influenced peatlands, integrating insights from climate change projections to assess differential impacts.

Chapter 6 discusses the applicability of the study's results to policy and practice, while also acknowledging methodological limitations and areas of uncertainty.

Finally, Chapter 7 offers a set of recommendations and outlines potential next steps for research, policy engagement, and implementation.

1.3 Target audience

This report is intended for decision-makers, stakeholders, NGOs, and researchers with an interest in the Cuvette Centrale and the impacts of development and climate change on its sensitive ecosystems. It responds to the limited availability of reliable, in situ data on hydrology, climate, and peatland dynamics in the region, and aims to support evidence-based policy and planning.

By identifying key knowledge gaps and areas requiring further investigation and investment, the report contributes to building a foundation for sustainable management and conservation efforts in one of the world's most ecologically significant landscapes.

2 Stakeholder consultations and inputs to the study

2.1 Identifying water related challenges

In October 2023, a scoping mission to Brazzaville and Kinshasa took place, highlighting several key points to inform this study. These included: limited in-situ hydrological data, the importance of engaging local communities and considering local water management practices, ensuring data transparency (including data sharing), and capacity building.

In March 2024, a second mission emphasized the need for greater synergies with other initiatives and projects, stakeholder engagement at various levels, leveraging existing data and national online platforms related to the environment, and integrating gender into activities. The mission resulted in mapping various water-related challenges in the landscape at both local and national levels to inform this study, with data limitations being particularly significant. The challenges identified by stakeholders are summarized below.

2.1.1 Water related challenges in Republic of Congo:

Environmental Challenges

- High acidity levels in Lake Télé.
- Frequent bushfires posing ecological risks.

Socio-Economic Challenges

- Unsustainable fishing practices.
- Lack of sustainable land-use planning.
- Limited access to clean water and sanitation (not directly within project scope but noted as a concern).

Institutional Challenges

- Need for clearer legislation related to natural resource management.
- Weak international cooperation frameworks.
- Overlapping responsibilities between the Ministry of Environment and other entities managing peatlands.
- Need for improved coordination and stakeholder dialogue.

Data and Monitoring Challenges

- Insufficient availability of environmental data.
- Lack of in-situ monitoring systems.
- Need for long-term sustainability of monitoring and conservation initiatives.

2.1.2 Water related challenges in Democratic Republic of Congo:

Environmental Challenges

- Pollution, land degradation, and soil erosion.
- Unsustainable agricultural practices affecting soil and water quality.
- Increased risks from natural disasters and changing rainfall patterns.

Socio-Economic Challenges

- Limited access to clean drinking water.
- Lack of effective communication and awareness initiatives.
- Resource use conflicts between communities.
- Need for sustainable income-generating alternatives to improve livelihoods.

Institutional Challenges

- Inadequate legal frameworks for peatland and water resource management.
- Absence of integrated water resource management plans.
- Limited participation of Indigenous communities in decision-making.
- Weak local decision-making tools and institutional capacity.

Data and Policy Challenges

- Lack of specific water management policies that include peatlands.
- Insufficient data collection and analysis to inform decisions.
- Need for clearer and more accessible information for stakeholders.

Collaboration Challenges

- Fragmented stakeholder engagement.
- Need for inclusive consultation frameworks to support integrated strategies.

2.1.3 From challenges to scenarios for improved peatland management

The challenges identified shed light on the need for improved understanding of the potential impacts of developments and climate change on the peatlands, as well as developing a tool to support decision making for planning purposes.

Following these consultations, the project set about designing a hydrological model and decision support system (HDSS) to further investigate the impacts of development scenarios and climate change impacts relevant for the Cuvette Centrale Peatlands.

2.2 Identifying development scenarios

In 2025, local experts from the region were integrated into the project team to provide inputs to identify relevant development interventions to be considered for the study.

In March 2025, a consultation was held in Brazzaville, gathering feedback from national stakeholders on the type of development scenarios and interventions that could be investigated using hydrological modelling to develop a decision support system. A similar stakeholder workshop intended to take place in Kinshasa was not held due to security concerns in March 2025, but contributions were made to the study by CRREBaC.

The following section provides a summary of the local interventions identified by stakeholders. Only the most hydrologically relevant scenarios were taken forward for modelling purposes.

2.3 Summary of intervention types identified by stakeholders

2.3.1 Republic of Congo

Planned road construction: Two major road projects in the Republic of Congo—crossing swampy terrain and peatlands—pose significant environmental risks if not carefully designed. Elevated embankments could disrupt natural water flow, leading to peat drying and increased greenhouse gas emissions. While these roads promise improved access, trade, and economic opportunities for remote communities, they also illustrate the delicate balance between development and ecological preservation.

- Epena-Mboua-Pokola, traversing approximately 300km of swampy terrain
- Pokola-Eyino-Bouanela
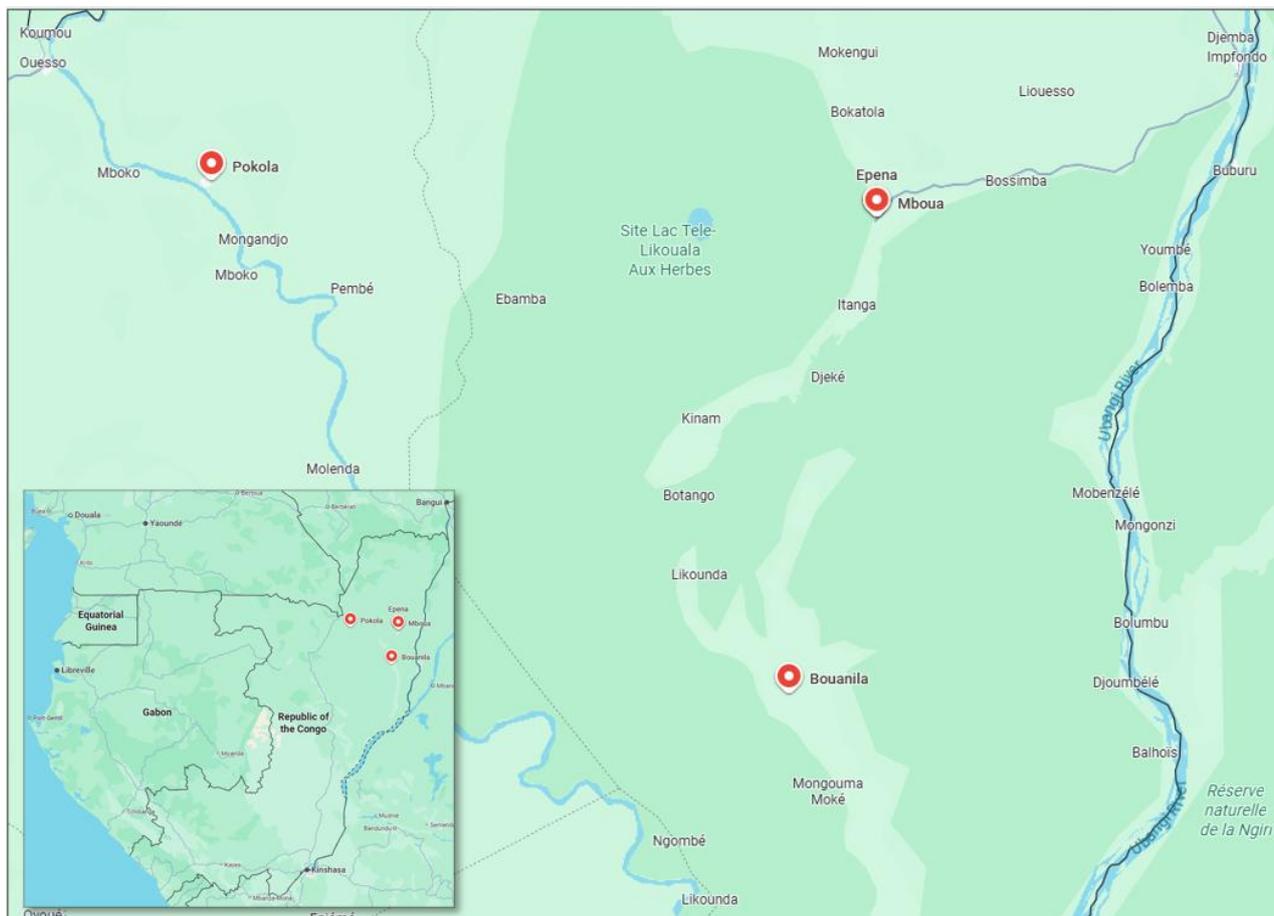
Figure 2-1 **Map showing the location of the identified towns where road expansion is envisaged to connect these communities, crossing through peatlands in the Lac Tele Community Reserve**

Agro-Industrial Expansion projects: Several projects were identified that aim to establish agricultural plantations near peatland areas in Northern Congo.

- Projet Paysage Forestier du Nord Congo (PPFNC)
- ProClimat
- Projet Agroforesterie Nord Congo (PANC)

Based on surveys conducted in 2016[1], three types of ecosystem users for agricultural production are identified in the landscape:

- Users of upland forests, located in the Kaboungas lands, the elevated plateaus of Boha, Impongui, and Dzeké, and the lands of the districts of Impfondo, Dongou, Liranga, and Loukolela.
- Users of floodplain forests in the northwest segment (Mabongo Koto, Bokatola, Matoko, Epéna), the central area (Mongouma Bailly, Botongo, Mossengué, Bouanela, Bokoma, Ebambi, and many other villages), and the southern area (e.g., Youmba, Boleko, Sossolo, and villages in the Mossaka district).
- Users of floodplains (Youmba, Botouali, Mikoungou, and villages in the Mossaka district).

In the central and southern regions, slash-and-burn agriculture is common in both forests and floodplains.

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[1] Madouka, G & B, Ikati. (2016). Rapport des enquêtes biologiques_Lac Télé –Lac Tumba

Unsustainable Fishing Practices: Local communities near peatland waterways have reported unsustainable fishing practices—such as poisoning fish, using fine mesh nets, and damming streams—that, while not formal development interventions, are causing environmental harm. These methods contribute to siltation, reduced water levels, and damage to aquatic life, particularly in vulnerable peat swamp channels. Over time, such practices can dry out peat soils and degrade the ecosystem. Though they provide short-term food security, their long-term impact threatens both fisheries and peatland health. The HDSS may not simulate these effects directly, but any management plan should address them through education and regulation.

Seasonal bushfires: Seasonal bushfires, often set for hunting or agriculture in nearby savannas, sometimes spread into peatland margins, posing serious environmental risks. If peat surfaces are dry, fires can ignite the peat soil itself, causing underground smouldering that releases large amounts of carbon and damages soil structure. The discussion emphasized that fire combined with drainage creates a worst-case scenario, as drained peatlands are more prone to burning.

Figure 2-2   Bushfire in the Lac Tele Community Reserve (WCS 2024)

Upstream dams: The Ministry of Energy and Hydraulics presented plans for small hydropower dams upstream of the Cuvette Centrale, which could significantly alter water flows into peatland areas. Dams may flood upstream zones and reduce downstream water replenishment, risking peat drying or permanent inundation—both of which can lead to carbon emissions and peat loss. Groundwater extraction through boreholes was also mentioned as a potential threat if done near peatlands. While hydropower offers economic benefits like electricity and growth, participants stressed the importance of locating such projects away from sensitive peat zones and managing water flows carefully to avoid ecological harm.

Mining and hydrocarbon development: The Ngoki oil field project was identified as an example that could introduce exploration infrastructure into or near peatland areas, raising concerns about peat degradation, pollution, and hydrological disruption. Activities like road building and drilling may dry out or flood peat zones, leading to carbon emissions and ecosystem damage. Mitigation measures, such as maintaining water flows and establishing exclusion zones in sensitive peat areas may be necessary.

Figure 2-3   **Location of the Ngoki exploration zone**

Peat extraction: Although peat extraction is not currently practiced in the region, participants raised it as a potential future scenario due to its severe environmental consequences. If pursued for horticulture or fuel, peat mining would directly remove peat deposits, releasing large amounts of carbon and destroying the habitat. It was identified as one of the most damaging and unsustainable practices, with the potential to accelerate climate change and drastically reduce peatland extent. Including this scenario in planning was seen as important, given that peat extraction is common in other countries and could be proposed under changing economic or policy conditions.

Eco-tourism: A scenario involving eco-tourism development in the Lac Télé Community Reserve was discussed as a positive example of sustainable land use. If carefully managed, activities like guided wildlife tours and boardwalks could generate income for local communities and support conservation efforts, with minimal impact on peatlands. Unlike large infrastructure projects, eco-tourism has a small footprint and can align with environmental goals, offering socio-economic benefits without significant hydrological disruption. This scenario highlights that not all development is harmful—some can actively contribute to protecting peatland ecosystems.

Good governance: Participants also discussed governance reform as a scenario with potentially transformative effects on peatland conservation. Strengthening legal protections, enforcement, and community co-management could significantly reduce harmful interventions and help maintain peatland integrity in line with the existing baseline scenario.

2.3.2 Democratic Republic of Congo

Planned road construction: The transport infrastructure in the study area is outdated and poorly integrated across road, rail, air, and river networks. Breaks in connectivity and inconsistent standards within transport modes hinder economic development and industrial growth, despite the presence of natural resources. This situation increases travel costs and raises the prices of goods, especially food. However, initiatives are underway to improve river transport and reform the broader transport sector. Lake Tumba is a vital navigable route, connecting key locations such as Bikoro and Ingende. Priority Axes for future road development include: Kisangani–Buta–Bumba–Gemena–Zongo and Mbandaka–Inongo–Kinshasa.
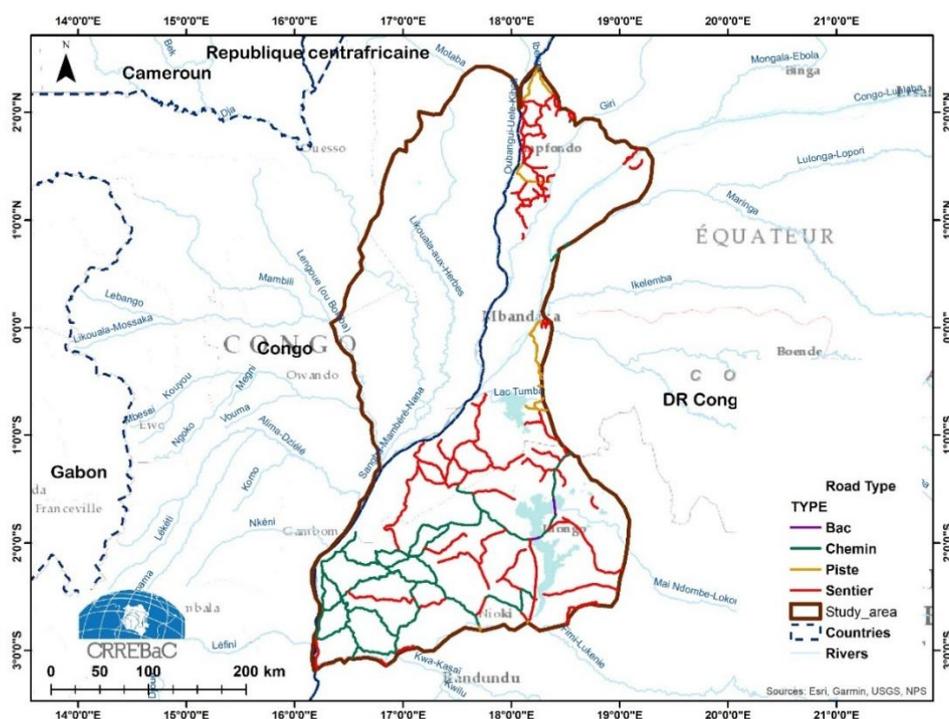
Figure 2-4   Existing Road types in DRC in the project landscape

Equateur province has an extensive road network, but it is currently in a state of disrepair. Nevertheless, there are favourable prospects for rehabilitation and maintenance, given the topography and the availability of construction materials. However, the significant presence of rivers and the large area they occupy in the southern forest zone make the continuous development of a well-maintained road network both difficult and costly. In Mai-Ndombe province, navigable waterways remain the most used transport system for people and goods.

Energy development: There is a near total absence of energy supply in the landscape. Several exploration blocks for petrol and hydrocarbon have been designated in the Lac Tumba landscape.
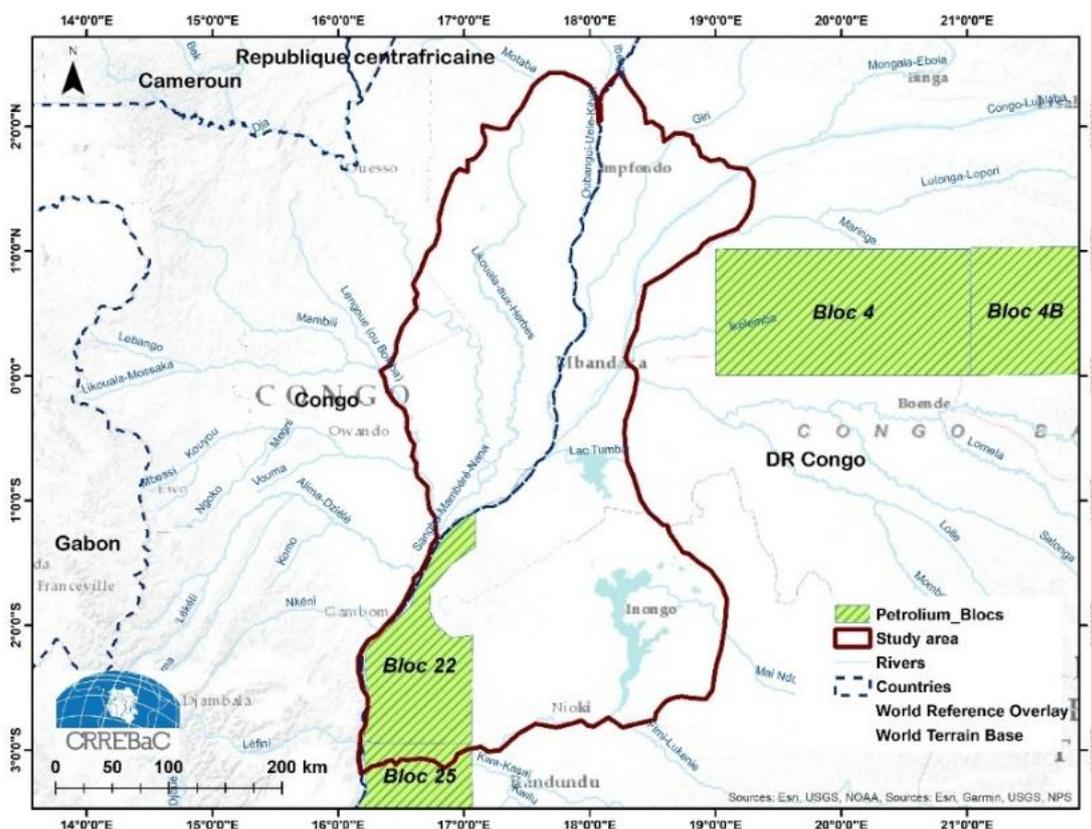
Figure 2-5 **Petrol blocks in the project landscape in DRC**

Mining development: In addition, the presence of **mining sites rich in iron, copper and associated minerals, gold, diamonds, limestone, kaolin, clay, granite, niobium, and ochre** could result in further exploration and drainage in the peatlands.

Large scale fishing in Mai-Ndombe: The project aims to boost fish farming in the Mai-Ndombe province by increasing production and improving market access, contributing to food security and the conservation of local fish species. It will introduce aquaculture innovations tailored to the region's environment, traditions, and the capacity of fishers to adopt new techniques responsibly, ensuring biodiversity protection for future generations.

The operational base will be in Inongo, on Lake Mai-Ndombe, with activities spread across three intervention zones along the Lokoro and Lutoyi rivers, and the lake itself. Expected outcomes include a hatchery in Inongo, a feed production facility, floating cages in various water bodies, improved landing sites, production of 200,000 fingerlings per cycle, 240 tonnes of fish annually, and inputs for fish product processing.

Agriculture development at the small and large scale: The landscape is home to over two million people, almost half of whom live in the town of Mbandaka in the north and the rest in the smaller towns (Lukolela, Makanza, Bikoro, Bomongo, Inongo, Kwamouth, Bolobo, etc.) and villages along the rivers and lakes. Agriculture, alongside fishing, hunting and the collection of non-timber forest products (NTFPs), is one of the main sources of income for rural communities. Types of agriculture development include:

- Food crops: Rice, maize, cassava, vegetables, cattle, and fish
- Fruits: Pineapples, bananas, citrus fruits, mangoes, etc.
- Cash crops: Robusta coffee, cocoa, oil palm, rubber, cotton

Rice cultivation development can have cumulative effects on peatland saturation, flooding, and drainage. In addition, the presence of large agro-industrial companies in the palm oil sector in the region could have significant implications for the landscape. Other potential types of interventions include:

- Revival of abandoned sectors: rubber (hévéa), coffee, cocoa
- Development of rice farming
- Pharmaceutical and cosmetic industry using high-value plants
- Special Economic Zones (ZES)
- Agro-pastoral activities

Settlement development: Development of the Kisangani River Corridor via Lisala–Mbandaka to Lukulola, including urban centres along the river corridor, as part of the wider infrastructure development plans to connect Central Africa.

Forest exploitation: Mai-Ntombe province has significant forest reserves with high-quality timber species (Wenge, Tola, Bokungu, Kambala, etc.) Due to its forest potential, the timber industry and pharmaceutical industry could develop further in the landscape. Logging (cutting of timber) does not create local wealth, but rather benefits foreign interests. Ultimately, forest concessions can alter the water regime, vegetation cover and wildlife. Uncontrolled exploitation could have severe and cumulative impacts on all ecological dimensions.

Seasonal bushfires: have been identified as one of the main environmental threats in this landscape, particularly dangerous when peatlands experience seasonal drying. Dry peat becomes highly flammable, and fires can spread underground, causing slow combustion of organic matter, releasing large amounts of carbon into the atmosphere, and leading to irreversible soil transformations. Such peat fires are extremely difficult to control and can persist for days or even weeks. They also reduce local biodiversity, destroy habitats for many species, and compromise the natural ability of peatlands to store carbon. Finally, the literature highlights that fire frequency generally increases after drought periods, revealing a strong interaction between extreme events: drying sets the stage, and fires then amplify ecological degradation.

Burning is used as land-clearing method for agriculture near Yangambi, Democratic Republic of Congo. Axel Fassio, CIFOR

Large scale hydrologic infrastructure, with a potential to significantly shift the hydrology of the peatlands, including:

- Construction of upstream dams and the proximity of several sites with hydroelectric potential, including the Zongo and Mobayi-Mbongo sites currently in operation.

The Inter-Basin Water Transfer Project between the Congo River and Lake Chad is a proposed large-scale initiative aimed at addressing water scarcity and environmental degradation in the Lake Chad Basin. The project envisions diverting a portion of water from the Congo River system—one of the world's largest freshwater sources—through a network of canals and pumping stations to replenish Lake Chad, which has significantly shrunk over the past decades due to climate change and overuse. The goal is to restore ecological balance, support agriculture and livelihoods, and enhance regional stability across Central and West Africa. However, the project involves complex environmental, technical, and geopolitical considerations.

2.4   Translation of interventions into scenarios

During the consultation process, it was noted that while many of the identified interventions could have significant impacts on the hydrology of the peatlands, a significant limitation to exploring these scenarios was the lack of in-situ data on the hydrology in the Cuvette Central. Coupled with the unknowns of many of these large-scale interventions (e.g. upstream dams, large scale exploration for petrol) this study focuses on the direct impact of small-scale interventions that are easily quantifiable and replicable across the project area.

As a result, the development scenarios investigated in detail are small scale, local interventions taking place within the project landscape in the Cuvette Centrale.

In general, any large-scale interventions that significantly change the hydrology of the peatlands by changing the water regimes, creating water reservoirs upstream or transferring water outside of the basin will have a negative impact on the peatlands if they result in a lowering, even if only seasonal, of the water table.

2.4.1   Small scale interventions with local impacts

All development scenarios identified by stakeholders in Brazzaville were analysed and categorized into types of interventions that can be modelled during a participatory consultation process. The same

categories of interventions are relevant for the scenarios identified in the Democratic Republic of Congo by CRREBaC which can be modelled in a peat dome.

Table 2-1 Overview of the categories of interventions developed in Brazzaville in March 2025 with stakeholders.

Thème	SC#	Nom du scénario	Type d'intervention						
			1	2	3	4	5	6	7
			Remblais de terre	Drainage	Abaissement du niveau de l'eau	Pas de végétation	Nouvelle végétation	Retenue d'eau	Change du régime
Groupe 1	1	Route Epena-Mboua- Pokola	X			X			
Groupe 1	2	Route Pokola- Eyino-Bouanela	X			X			
Groupe 2	3	Projet Paysage Forestier Nord Congo (PPFNC)					X		
Groupe 2	4	Proclimat					X		
Groupe 2	5	Projet Agroforesterie Nord Congo (PANC)					X		
Groupe 4	6	Mauvaises techniques de Péche						(x)	(x)
Groupe 4	7	Contstruction des barrages hydroélectrique				X			(x)
Groupe 4	8	Construction des forages d'eau							
Groupe 4	9	Projet NGOKI				X	X		
Groupe 5	10	Extensions des plantations agricoles (Plantation de Cacao et du palmier à huile)					X		
Groupe 5	11	Développement de Eco-tourisme							
Groupe 5	12	Exploitation de la tourbe							
Groupe 5	13	Renforcement du cadre juridique, institutionnel et legal							
Groupe 6	14	Zone Economique Special	X				X		X

Table 2-2 Overview of scenarios identified by CREBBaC for DRC

Catégorie	Types d'interventions	Programme	Niveau de saturation des Tourbières	Mode d'inondation des Tourbières	Drainage et Assèchement des Tourbières	Qualité d'eau	Sédimentation et minéralisation	Végétation des Tourbières	Faune des Tourbières
Agro-industrie	Relance des filières abandonnées (hévéa, café, cacao	PDI				x			
	Développement de la riziculture	PDI	x	x	x				
	Pèche industriel (conserverie, transformation)	PDI							
	Industrie pharmaceutique et cosmétique avec plantes à valeur ajoutée	PDI						x	
	Zone Economique Spéciale	PDI	x	x	x	x			
	Agropastoral				x	x			
Industrie du bois	Concession forestière	Privés	x	x	x	x		x	x
	Exploitation forestière	Non contrôlée	x	x	x	x	x	x	x
Transport, communication et infrastructure	Construction chantiers navales: SCPT, entreprises privées;	PNUD	x	x	x		x	x	x
	Réhabiliter 354 km des routes de dessertes agricole, entretenir 1176 km et construire 15 ouvrages d'art (pont, ponceaux et dalots)	PDL 145	x	x	x	x	x	x	x
	Aménagement de dix ports	PDL 146	x	x	x				x
	Implantation de la dorsale à fibre optique	PDL 147	x						
Eau et Energie	Développement des centrales à biomasse et des centrales solaires	PNUD, KOICA							

			A	B	C	D	E	F	G
	Vingt mini-centrales solaires en cours de de construction pour améliorer l'accès à l'électricité et 26 km d'artères seront éclairés (Equateurs)	PDI							
	Pico et micro barrages	PDI			-				
	158 forages avec pompes intégrées, 23 sources d'eau aménagées	PDL 145			-				
	Transfert d'eau vers le lac Chad	Transaqua	x	x	-	x	x	x	x
	Construction barrage de Palambo (RCA)	RCA	x	x	-	x	x	x	x
	Construction barrage de Cholet (Cameroun)	Gouv. Camerounais	x	x		x	x	x	x
Mines	Exploitation du fer, cuivre et minéraux associés, or, diamant, calcaire, kaolin, argile, granite, niobium, ocre	PDI	x		x	x	x	x	x
	Exploitation blocs pétroliers et gaziers	PDI	x		x	x	x	x	x
Chaines de valeurs et artisanat	Structuration de 500 ménages de producteurs par territoire	PDL 145							
	Pisciculture en cage flottantes (écloserie, provenderie, points de débarquement, entrepôts):	ERA Congo							
	*Axe 1: Nkolobeke-Lokolama sur la rivière lokoro;								
	*Axe 2: Nkolobeke- Ndongese-Kiri sur la riviere Lutoyi;								
	*Axe 3: Inongo-Kutu et hinterland, sur le lac Mai-Ndombe,								
	Les petites et moyennes entreprises de transformation et de conservation (Huileries, Brasserie, Distilleries, Savonneries, Boulangeries, Pêcheries et conserveries, Charbonneries, Fabriquant de pirogues et hors-bords, Extraction des moellons et du sable	PDI							

Seven types of interventions were derived as an outcome of the stakeholder consultation and are explored in this study as scenarios. The generalized development interventions are listed below, and are presented in more detail in Chapter 4.

- A. Baseline without Intervention
- B. Road Built and Operational
- C. Road during Construction
- D. Settlements Developed
- E. Forest Fire - Deforestation
- F. Palm Plantation replaces Forest
- G. Rice Cultivation replaces Forest

A summary of the impacts of these scenarios are presented in Chapter 5 of this report. For a full overview of the results, consult the Model Technical Report or the HDSS tool.

3 Evaluation Methodology and Scenario Definitions

The purpose of the evaluation methodology is to assess how different development interventions and climate change scenarios affect change in soil carbon stock in the peatlands. To achieve this, the approach integrates two complementary models - a hydrological model and a biodegradation model. While both models generate results for a wide range of state variables, the focus is on indicators that reflect changes in water table depth, soil oxygenation, and carbon fluxes. The coupling of hydrology and biodegradation is essential, as peat decomposition and carbon release are strongly governed by soil moisture saturation.

This chapter summarises the evaluation methodology used to derive the study results. For a full overview of the methodology used to developed the hydrological model and biodegradation model consult the Technical Model Report.

3.1 Evaluation Methodology

The evaluation methodology is designed to assess the impacts of development interventions and climate change scenarios on carbon emissions from the Congo Basin peatlands. This assessment is carried out using two models:

1. A **hydrological model**, which simulates hydrological cycle including water dynamics in the different sold layers of the peatlands
2. A **biodegradation model**, which estimates change in soil carbon stock based on the hydrological state of the peatlands

Carbon emissions in peatlands are highly sensitive to hydrological conditions - particularly groundwater levels and soil saturation. Therefore, accurately simulating these hydrological states is a prerequisite for evaluating biodegradation and its associated carbon fluxes.

The biodegradation model used is a heuristic model, meaning it applies simplified rules and relationships to approximate complex biological processes. While not mechanistic, it effectively captures the essential link between water table dynamics and peat decomposition, enabling scenario-based comparisons of soil carbon stock under varying development and climate conditions.

3.1.1 Hydrological Model

The hydrological model forms the backbone of the scenario evaluation framework and is implemented using the MIKE SHE modeling tool. It simulates the complete terrestrial hydrological cycle, which is essential for understanding the water dynamics that govern peatland stability and change in soil carbon stock.

The model captures the following key processes:

- Precipitation: Input of water from rainfall, which initiates the hydrological cycle.

- Evapotranspiration: Loss of water through evaporation from soil and transpiration from vegetation, influenced by climate and vegetation type.

- Infiltration: Movement of water from the surface into the soil and peat layers.

- Groundwater Flow: Subsurface movement of water through the saturated zone, critical for maintaining peatland water tables.

- Overland Flow: Surface runoff generated during rainfall events, especially in areas with low infiltration capacity.

- River Interactions: Exchange of water between peatlands and adjacent rivers, which can recharge or drain the peat system depending on water levels.

Two distinct hydrological regimes are modelled to reflect the diversity of peatland types in the Congo Basin:

1. **Rain-fed** peatlands – Found primarily in the Republic of Congo, where relevant hydrological processes are dominated by direct rainfall and evapotranspiration. In these peatlands there aren't major rivers with significant water level fluctuations that would affect groundwater levels substantially - ground water levels in these regions can be assumed to be rather constant. The boundary conditions are set accordingly.

2. **River-fed** peatlands – Located mainly in the Democratic Republic of Congo, where relevant hydrological processes are not only driven by rainfall and evapotranspiration but also by fluctuating water levels of adjacent rivers. These areas are modelled with dynamic boundary conditions, allowing groundwater levels to fluctuate in response to river stage variations.

This hydrological modelling approach enables simulation of seasonal and spatial variations in water table depth, which is a critical determinant of peatland vulnerability. Lower water tables increase oxic conditions in the soil, accelerating peat decomposition and carbon dioxide emissions.

By accurately representing the hydrological cycle, the model provides the necessary input for the biodegradation model, ensuring that carbon flux estimates are grounded in realistic water dynamics.

3.1.2 Biodegradation Model

The biodegradation model is a heuristic model designed to estimate carbon accumulation and biodegradation in the peatlands of the Cuvette Centrale. It is a simplified approach that captures key relationships between hydrological conditions and carbon fluxes.

Key features include:

- Differentiation between oxic and anoxic soil zones

- Decomposition rates for labile and recalcitrant organic matter

- Temperature-modified decay rates based on climate scenarios

- Static assumptions for carbon storage and soil subsidence

The model is coupled with the hydrological model, as biodegradation in peatlands is highly dependent on water table depth. Lower water tables increase oxic conditions, accelerating decomposition and change in soil carbon stock. This coupling is essential to realistically simulate the impacts of development and climate change on carbon dynamics.

3.2 Scenario Definitions

Scenarios are representations of answers to questions of the type "What happens if…?". For each scenario models are developed. These represent the questions. The respective simulation results of the models represent the answer to the question.

The "if" part in the question that defines a scenario has the following aspects:

- **Development intervention**: What happens if infrastructure is developed, or what happens under agricultural development conditions? The development interventions investigated in the analyses are derived from stakeholder consultations.

- **Climate**: What happens under current climatic conditions and under specific climate change conditions?

- **Hydrological region**: Are the hydrological processes in the peatlands only driven by rainfall and evapotranspiration? Or are the hydrological processes in the peatlands driven by rainfall and evapotranspiration, as well as fluctuating water levels in bordering water bodies (e.g., river reaches), as this is the case in central parts that are adjacent to the main rivers in the region.

3.2.1 Development Interventions

The generalized development interventions derived from the stakeholder consultations are the following:

Table 3-1   Overview of development interventions

Code	Name	Description
A	Baseline without Intervention	Vegetation and topography of the peatlands are according to the current conditions - between 2010 and 2020
B	Road Built and Operational	(a) A raised impervious road is built 1 meter above the natural surface. It is finished and operational. (b) Vegetation is removed, and the soil surface is flattened. (c) The road embankment is filled with permeable gravel. (d) The underlying peat is compressed due to the road's weight.
C	Road during Construction	(a) A raised impervious road is being built 1 meter above the natural surface. (b) Vegetation is removed, and the soil surface is flattened. (c) The road embankment is filled with permeable gravel. (d) The underlying peat is compressed due to the road's weight. (e) During construction, drainage is installed 2 meters below the ground, i.e., 1 meter below the surrounding surface.
D	Settlements Developed	(a) A settlement is developed in the peatland forest. (b) The topography is raised by 50 cm to prevent flooding. (c) Vegetation is cleared, and the soil surface is partially paved. (d) The peat is compressed under the load of buildings.
E	Forest Fire - Deforestation	(a) A forest fire completely clears the vegetation. (b) As a result, soil properties change: bulk density increases, and specific yield decreases.
F	Palm Plantation replaces Forest	Deforestation and Conversion to Oil Palm Plantations: (a) Natural vegetation is cleared to establish additional oil palm plantations. (b) Oil palms thrive with a mean water level 40 cm to 60 cm below ground. There is drainage at 50 cm depth. (c) Vegetation properties are altered according to 15-year-old mature oil palm plantation. (d) The microtopography is smoothed due to clearing. (e) Soil properties change by drainage: increased bulk density, reduced specific yield, and reduced hydraulic conductivity at saturation. (f) The topography is lowered by 50 cm due to soil subsidence induced by drainage.
G	Rice Cultivation replaces Forest	Deforestation and Conversion to Rice Cultivation: (a) Natural vegetation is removed and replaced with rice paddies. Rice is the most common seasonally flooded crop in the Cuvette Centrale. (b) There are two harvests per year. Paddies are flooded during the wet season. (c) Vegetation and surface properties/roughness vary with crop stage.

3.2.2 Climate Scenarios

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), (IPCC,2021) climate change scenarios were used to assess the impact of climate change. The basis of the IPCC AR6 results are the Coupled Model Intercomparison Project Phase 6 (CMIP6) in which multiple climate modelling groups around the world run Global Climate Models (GCMs) with agreed input parameters to simulate different scenarios.
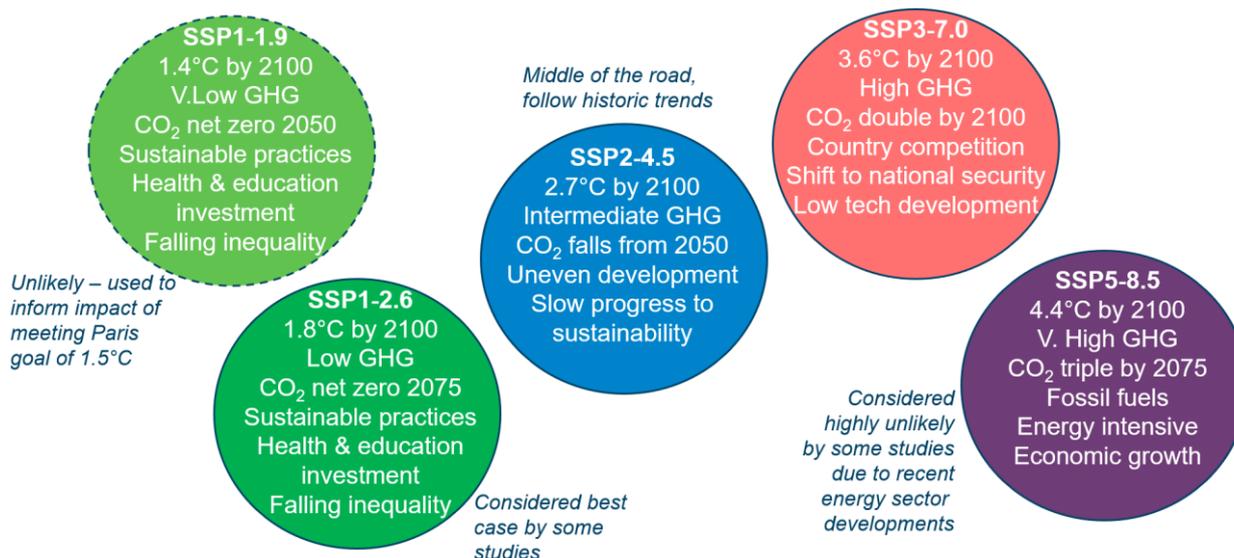
Figure 3-1   Summary of the five emissions' scenarios that inform the latest IPCC AR6 report

From the IPCC AR6 emission scenarios we choose the following to form part of our scenario definitions:

Table 3-2   Overview of climate change scenarios

Code	Name	Description
1	Current Climate	Rainfall, temperature and evapotranspiration between 2010 and 2020 are chosen to represent the current climate conditions.
2	CC Sustainable Growth	SSP1-2.6: (a) Global warming is limited to around 1.5°C-2°C above pre-industrial levels. (b) This scenario is in line with the objectives of the Paris Agreement and represents an optimistic future with sustainable economic growth and minimal impact on climate change.
3	CC Severe Impact	SSP3-7.0: (a) Projected warming: 3°C-4°C by 2100, with severe climatic consequences. (b) This scenario represents a high-risk future, characterized by significant climate change, social inequalities and environmental degradation.

Climates are represented with timeseries of rainfall and evapotranspiration used as forcings to the hydrological model. The effect of projected temperature change is included indirectly as input for projected reference evapotranspiration and directly as a temperature modification parameter in the biodegradation model. The projection period is the future climate, and we chose the period 2041-2060 (20 years) with the centre year in 2050. The climate model baseline period is 1990-2014 (25 years) and our model baseline is 2012-2019 (7 years).

3.2.3 Hydrological Regions

The following hydrological regions are parts of the scenario definition:

Table 3-3   Overview of hydrological regions

Code	Name	Description
1	Rain-fed	Rainfall and Evapotranspiration only: The hydrological processes in the peatlands are only driven by rainfall and evapotranspiration. This is mostly the case in interfluvial peat domes, mostly located in the Republic of Congo.

Code	Name	Description
2	River-fed Hydrology plus Water Levels	Rainfall and Evapotranspiration plus River Water Levels: The hydrological processes in the peatlands are driven by rainfall and evapotranspiration, as well as fluctuating water levels in bordering water bodies (e.g., river reaches). This is mostly the case in the riparian peatlands, mostly located in the Democratic Republic of Congo.

The hydrological regions are represented in the models as model boundary conditions: in the rainfall driven configuration, the western and eastern boundaries have a constant head set at surface level. These water levels fluctuate in the river-fed models. Boundary conditions are model drivers like the climate model drivers.

3.3 Indicators for Evaluation Purposes

Behind each scenario definition is a comprehensive model with its input parameters and simulation results. The two models generate a wide range of hydrological and ecological state variables.

The evaluation of scenarios makes use of indicators that are derived from the detailed simulation results. The following indicators are defined to allow simplified evaluation of scenarios and comparisons:

For scenario evaluation and comparison purposes, these state variables - with spatial and temporal variations - are aggregated as follows:

- **Groundwater Table Depth (GWT):** Lowest depth of water table below ground inside the footprint of an intervention and in an adjacent zone outside the footprint

- **Oxic Depth**: Lowest depth of oxygenated soil layer inside the footprint of an intervention and in an adjacent zone outside the footprint

- **Carbon flux**: Carbon stock change in kg/m²/year inside the footprint of an intervention and in an adjacent zone outside the footprint

These indicators are used to evaluate and compare the scenarios.

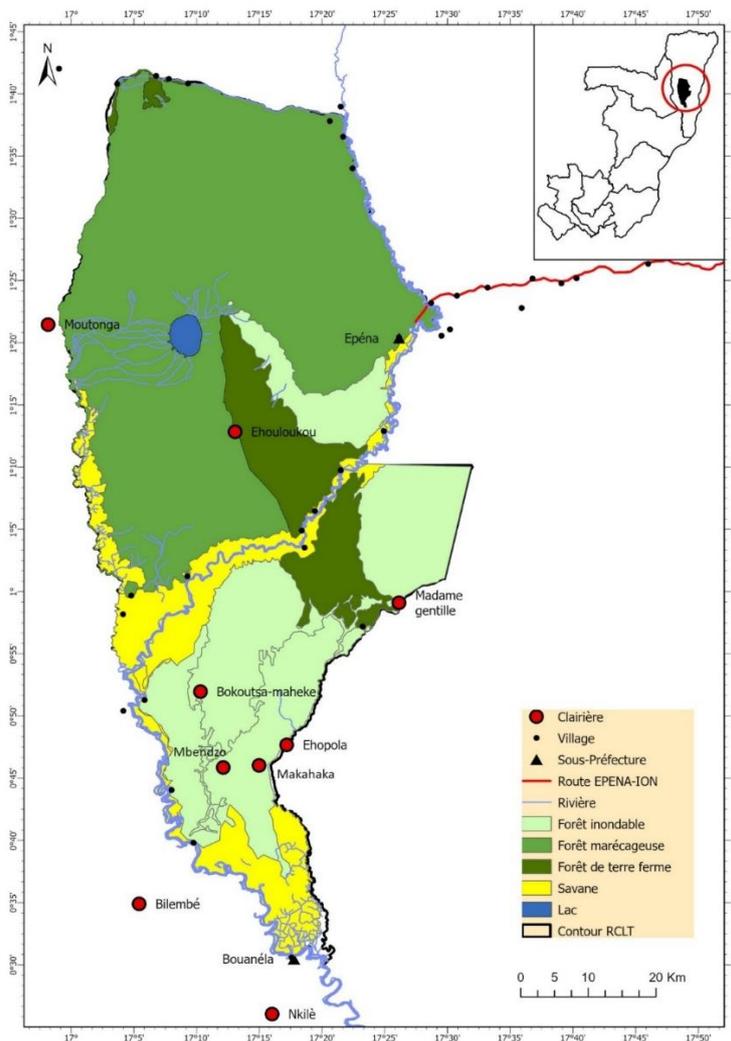| Name	Indicator Description
Carbon Flux Inside	Carbon stock change in kg per m2 per year inside the footprint of the intervention
Carbon Flux Outside	Carbon stock change in kg per m2 per year outside the footprint of the intervention
Oxic Depth Inside	Average oxic depth inside the footprint of the intervention: Depth in the soil where oxygen is still present, affecting nutrient cycling, i.e., carbon transformations. This influences the rate of organic matter decomposition and thus carbon sequestration.
Oxic Depth Outside	Average oxic depth outside the footprint of the intervention: Depth in the soil where oxygen is still present, affecting nutrient cycling, i.e., carbon transformations. This influences the rate of organic matter decomposition and thus carbon sequestration.
GWT Depth Inside	Average ground water table depth inside the footprint of the intervention - in meters below the surface
GWT Depth Outside	Average ground water table depth outside the footprint of the intervention - in meters below the surface

Figure 3-2   Map of the Lac Tele Community Reserve, showing the various landscape types – the light and medium light green indicates the forest flood plain and the swamp forest where peatlands are found (WCS 2025).

4 Summary of results

For a full overview of all the modelling results, please consult the Technical Model Report.

4.1 For rain-fed peatlands

Water levels and carbon dioxide emissions across the model area were analysed for various interventions. The model area is hydrologically heterogeneous, with a flat peat dome centre that is nearly permanently waterlogged and rather steep boundary zones where water levels are deep. The 7-year simulation period includes both wet and dry years, allowing the effects of interventions to be assessed under different climate conditions. During dry periods, deep groundwater tables and oxic zones at the western and eastern model boundaries result in significant peat degradation. In the baseline scenario, peat decay in the dome centre is low because the water table is mostly above ground and the oxic depth is therefore very low.

The modelled interventions modify topography, peat hydraulic properties, vegetation, and land use. These changes are represented in a 240-m-wide horizontal stripe extending along the entire length of the model area. The hydrological and carbon emission impacts of the interventions are assessed within and around the intervention footprint. Indicator values are summarised in the table below. Values highlighted in red and green indicate, respectively, high and low soil carbon losses.

Table 4-1   Summary of indicator values for rainfed peatland scenarios

Indicator Short Name	Unit	Indicator Values for Scenarios						
		A.1.1	B.1.1	C.1.1	D.1.1	E.1.1	F.1.1	G.1.1
Oxic Depth Inside	m	0.20	0.92	2.12	0.37	0.18	0.73	0.14
Groundwater Depth Inside	m	0.15	1.06	2.00	0.40	0.14	0.73	0.10
Carbon Flux Inside	kg/m^2/year	**-4.72**	0.00	0.00	-8.77	-4.67	-15.64	-3.77
Oxic Depth Outside	m	0.20	0.13	0.68	0.16	0.20	0.77	0.20
Groundwater Depth Outside	m	0.15	0.05	0.68	0.10	0.16	0.79	0.15
Carbon Flux Outside	kg/m^2/year	**-4.72**	-2.90	-14.26	-3.80	-4.78	-15.01	-4.70

Topographic changes significantly affect water levels, with impacts extending beyond the intervention footprint. This is particularly evident in the road, urbanisation, and oil palm scenarios. The ground is raised by 1 m in the road scenario (B.1.1) and by 50 cm in the urbanisation scenario (D.1.1), which leads to higher water levels but also deeper water tables within the footprint. Water levels also rise sharply outside the intervention zone, though the effects diminish with distance from the footprint. In the oil palm scenario (F.1.1), a ground subsidence of 50 cm resulting from peat oxidation has been accounted for. Subsidence causes a substantial increase in water table depth both within and around the footprint, resulting in higher peat carbon losses. In this case, subsidence happens alongside drainage, and both processes together cause the water table to drop.

Drainage has a strong impact on water levels and therefore on soil carbon stocks, as illustrated by the drained road and oil palm scenarios. In the drained road scenario (C.1.1), the soil is drained at 2 m below ground, while in the oil palm scenario (F.1.1) drainage occurs at 50 cm below ground. Because all water above the drain level is emptied, water table depth increases sharply within the footprint. This results in higher carbon losses in the oil palm plantation. This differs from the drained road case, where gravel - not peat - makes up the soil above the drain. Drainage also causes a pronounced lowering of the water table outside the intervention zone, leading to significant peat decay across the entire model area.

Changes in soil properties and vegetation affect water levels to a lesser extent, and typically only within the intervention zone. Actual evapotranspiration is reduced in the fire footprint (E.1.1) and in the rice paddies (G.1.1), leading to a rise in groundwater. These effects are noticeable near the boundaries,

where the water table is deep, but not at the centre of the dome, where water levels are above ground and evaporation occurs from ponded water. Peat compaction (B.1.1, C.1.1, D.1.1), burning (E.1.1), and oxidation (F.1.1) were represented in the models through decreases in soil porosity, permeability, and/or water storage capacity. The most evident impact of these changes was larger fluctuations in water table levels and deeper water tables during dry seasons. In the fire scenario (E.1.1), which combines changes in both soil properties and vegetation, carbon fluxes are similar than in the baseline within and outside the footprint.

Soil artificialization and vegetation changes lead to reduced carbon uptake by vegetation, resulting in a higher net carbon outflow when peat decay remains constant. This implies that shallower water levels do not necessarily translate into a lower net carbon outflow if the hydrological benefits are offset by reduced litter production. This situation occurs in the fire intervention (E.1.1), where the change in soil carbon stock is comparable to the baseline scenario despite higher average water levels.

The impacts of each intervention differ depending on location within the peatland. The two drained scenarios (C.1.1 and F.1.1) are characterized by a drop in water levels and, consequently, an increase in carbon dioxide emissions across the entire model area - most markedly where water levels are high, i.e. near the center of the dome. All other interventions primarily affect water levels in the boundary zones, where the water table is deep, while water levels in the dome centre remain mostly above ground. The models presented here are configured as domes with steep gradients and constant boundary water levels. This setup produces deep water tables and, therefore, high carbon dioxide emissions near the boundaries. However, the low-lying areas at the dome edges are subject to river flooding. The analysis in the next section will focus on how fluctuating boundary water levels influence groundwater dynamics and carbon dioxide emissions - both at the boundaries and across the entire peat dome.

4.2 For river-fedpeatlands

Water levels and carbon dioxide emissions across the model area were analysed for various interventions. The model area is hydrologically heterogeneous, with a flat peat dome centre that is nearly permanently waterlogged and steep boundary zones which are subject to yearly river flooding. Rivers flood the cells near the boundaries and replenish the aquifer. Carbon dioxide emissions in the floodplain area occur between the river flooding events when water levels are below ground.

The river inflow produces a sustained rise in the water table compared to the baseline rainfall driven scenario, which results in low carbon losses in the boundary zones. As in the baseline rainfall driven scenario, the carbon outflow from the dome centre is low because the water table is mainly above ground and the oxic depth is therefore very low. The highest carbon losses are located at the periphery of the river-flooded area.

The modelled interventions modify topography, peat hydraulic properties, vegetation, and land use. These changes are represented in a 240-m-wide horizontal stripe extending along the entire length of the model area. The hydrological and carbon emission impacts of the interventions are assessed within and around the intervention footprint. Indicator values are summarised in the table below. Values highlighted in red and green indicate, respectively, high and low peat carbon losses.

Table 4-2   Summary of indicator values for river influenced peatland scenarios

Indicator Short Name	Unit	Indicator Values for Scenarios						
		A.1.2	B.1.2	C.1.2	D.1.2	E.1.2	F.1.2	G.1.2
Oxic Depth Inside	m	0.12	0.89	2.12	0.34	0.12	0.71	0.09
Groundwater Depth Inside	m	0.03	1.03	2.01	0.35	0.03	0.69	0.00
Carbon Flux Inside	kg/m^2/year	**-2.82**	0.00	0.00	-8.10	-3.17	-14.55	-2.46
Oxic Depth Outside	m	0.12	0.07	0.61	0.09	0.12	0.65	0.12
Groundwater Depth Outside	m	0.03	-0.05	0.59	-0.01	0.03	0.64	0.03
Carbon Flux Outside	kg/m^2/year	**-2.82**	-1.40	-12.88	-2.08	-2.85	--13.53	-2.79

Carbon fluxes inside and outside the footprint follow the same trend relative to the baseline as in the rainfall driven scenarios: if carbon losses for a given intervention are lower than the baseline in the rainfall driven case, they are also lower in the river-fed case.

As in the rainfall driven case, drainage and topographic changes have a significant impact on water levels both within and outside the footprint, while changes in soil properties and vegetation have a lesser impact. Since the results outside the river floodplains are like those in the rainfall driven scenarios, only the situation in the areas flooded by rivers is described here.

As drainage reduces soil moisture in the unsaturated zone compared to the river-fed baseline scenario, more infiltration occurs into the peat during river flooding events. Floods therefore propagate more slowly, which explains why the floodplain is smaller in the drained road scenario (C.1.2) and in the oil palm scenario (F.1.2) than in the river-fed baseline. Soil carbon losses within the floodplains are higher in both scenarios, as water levels are deeper during dry seasons. Drainage thus results in higher carbon losses in both rainfall driven and River water level induced zones.

Topographic changes affect water tables in the floodplain and thus carbon fluxes, mainly in the same way as in rainfall driven areas. Nevertheless, a few specific features of river-fed areas can be highlighted. In the road scenario (B.1.2), flood peaks beneath the road are smaller and broader because the water table lies below ground and groundwater dynamics are much slower than overland flow. Flood peaks are also broader under the elevated settlement (D.1.2). In the oil palm scenario (F.1.2), the floodplain expands further under the plantation because of ground subsidence.

Although less significant than in rainfall driven areas, changes in soil properties and vegetation also influence water tables and thus carbon fluxes in the floodplain. Microtopography is smoothed in the fire (E.1.2) and rice (G.1.2) scenarios, reducing ponding compared to the river-fed baseline and increasing overland flow towards lower-lying cells. This outflow causes the water table in the floodplain to drop more quickly in the footprint at the beginning of the dry season. In the fire scenario (E.1.2), the decrease in water level during dry periods may also be partly explained by the higher specific yield of the soil resulting from peat smouldering.

The specific features of River water level induced peatlands highlighted here should not disguise the fact that the simulated interventions have broadly similar impacts in both rainfall driven and the River water level induced cases. Within the footprint, soil carbon losses increase in the settlement (D.1) and oil palm plantation (C.1), but decrease in the rice paddies (G.1). Outside the footprint, carbon losses rise for the drained road (C.1) and oil palm scenarios (F.1), while they decrease for the road (B.1) and settlement (D.1) scenarios. These simulations were carried out under current climate conditions.

The next section examines climate change scenarios to assess whether the impacts of the interventions would remain similar in the future.

4.3 Impact of climate change

Water levels in the peatland are expected to drop under both SSP1-2.6 and SSP3-7.0. Although rainfall should increase by 1.5% annually under SSP1-2.6, the rise in actual evapotranspiration is sharper. Under SSP3-7.0, a substantial increase in actual evapotranspiration coupled with a slight decrease in rainfall leads to lower water levels.

As water levels drop under climate change, peat decay increases. In rainfall driven peatlands, soil carbon losses should rise consistently throughout the model area, the cells located near the western and eastern boundaries remaining important carbon sources. In river-fed peatlands, carbon losses also rise throughout the whole model area, while the floodplain is narrower than under current climate conditions.

Across all interventions except the settlement and fire interventions, carbon fluxes inside and outside the footprint follow the same trend relative to the baseline under all climate conditions: if carbon losses for a given intervention are lower than the baseline under current climate conditions, they are also lower under SSP1-2.6 and SSP3-7.0. In the road scenarios (B and C), carbon fluxes from the gravel embankment are zero. This means they are lower than the baseline under all climate scenarios.

For the settlement intervention, carbon losses inside the footprint are higher than the baseline under current climate conditions and under SSP1-2.6 but lower under SSP3-7.0. Under the current climate, the water table under the footprint is deeper than in the surrounding cells as the ground is raised. Actual

evapotranspiration is slightly reduced compared to the area outside of the footprint. Under SSP3-7.0, as actual evapotranspiration in the baseline is so high compared to the settlement, the average water table is shallower in the settlement footprint than in the baseline, which results in reduced peat decay.

For the fire intervention, soil carbon losses inside the footprint are lower than the baseline under SSP1-2.6 and SSP3-7.0, unlike under current climate conditions. In river-fed peatlands, carbon losses in the burnt area are higher than the baseline under the current climate, because of ground smoothening, peat compaction through burning and reduced carbon uptake by the burnt vegetation. In rainfall driven peatlands, carbon fluxes in the burnt area are similar to the baseline as the aforementioned effects are offset by the lower actual evapotranspiration. As water levels drop under SSP1-2.6 and SSP3-7.0, actual evapotranspiration increases sharply in the baseline intervention but only slightly in the burnt area because the top soil layer dries out, resulting in comparatively lower carbon losses for the fire intervention.

5 Results by intervention type: Focus on carbon stock change in adjacent peatlands

This chapter demonstrates the type of results that can be generated in the HDSS tool. The full results across all indicators are available for review and comparison within the tool.

This chapter summarizes the results of each intervention type across all scenarios for one key indicator: carbon stock change beyond the footprint of the intervention area.

These results provide an insight into how certain interventions can impact the surrounding environment, demonstrating that interventions can have a significant impact in the surrounding area and not only locally where changes to land use are made. Model results show that some intervention types may be preferrable to others if the goal is to limit carbon stock change in the landscape.

5.1 A: Baseline

Development Intervention   Vegetation and topography of the peatlands are according to the current conditions - between 2010 and 2020
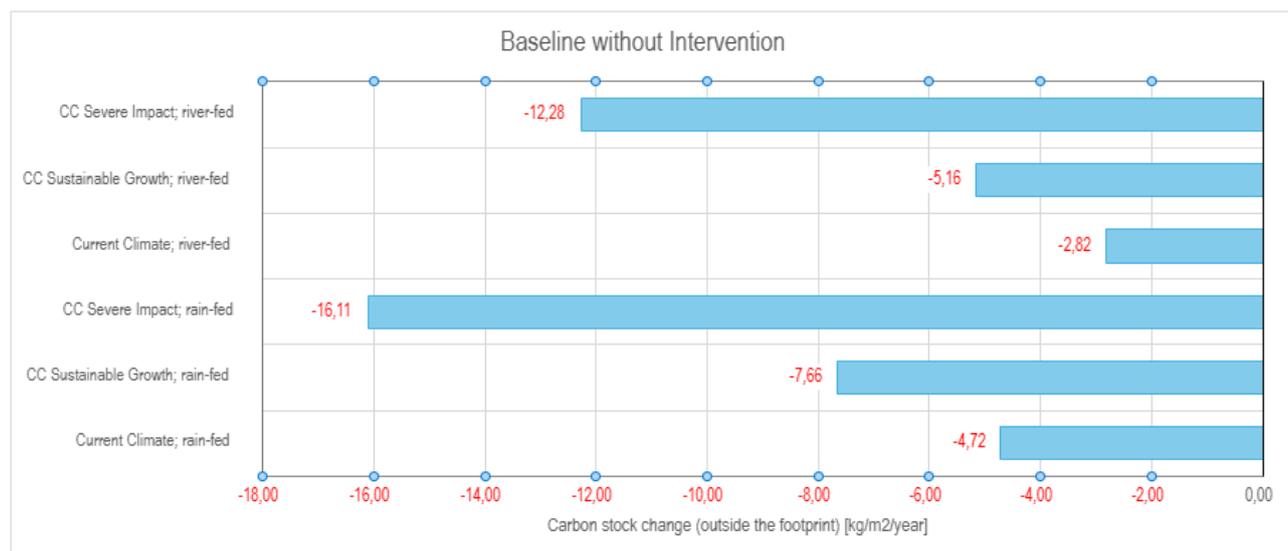

Figure 5-1   Carbon stock change outside the footprint of the baseline

For the baseline scenarios, where the peatland is intact, results show that for both climate change scenarios, peat decay is higher than under current climate conditions because of lowered water levels and increased exposure of peat to aerobic conditions.

A baseline scenario in a river-fed peatland acts fractionally better as a carbon sink in both sustainable growth and severe impact climate scenarios than in peatlands that are only rainfed, where the change in carbon stock for the severe future climate scenario decreases the carbon stock three-fold. This is because the water table drops severely. The lower water tables in both climate change scenarios can be explained by a greater increase in evapotranspiration compared to rainfall.

5.2   B: Road

Development Intervention   (a) A raised impervious road that requires 80 m width is built 1 meter above the natural surface. It is finished and operational. (b) Vegetation is removed, and the soil surface is flattened. (c) The road embankment is filled with permeable gravel. (d) The underlying peat is compressed due to the road's weight.
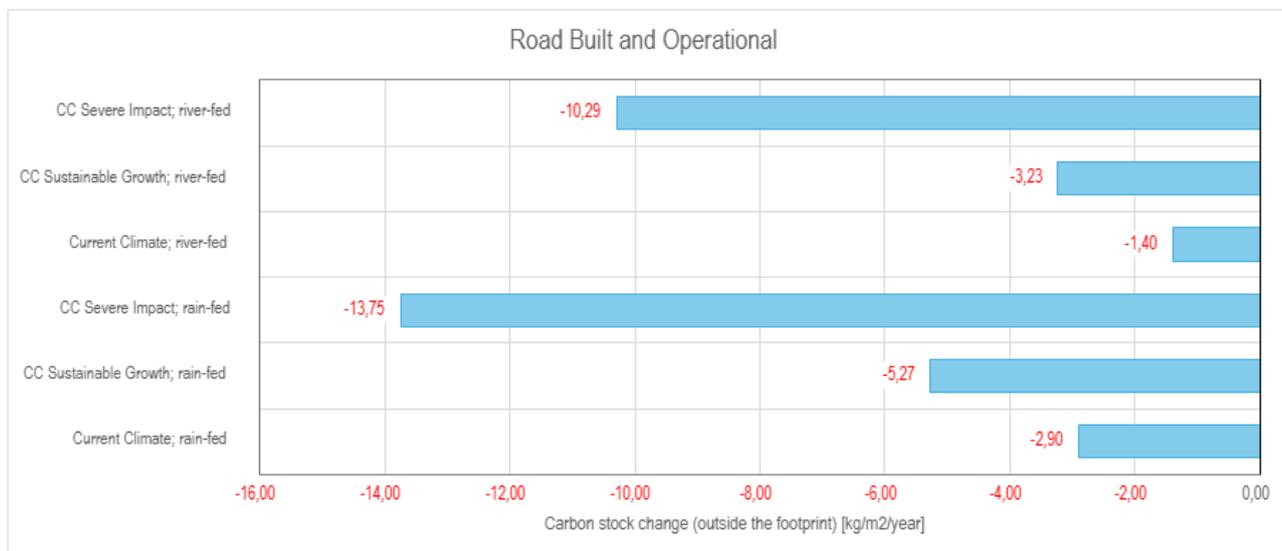

Figure 5-2   Co2 emissions in proximity to an operational road

For the developed and operational road scenario, the results are similar to the baseline. Once the road is operational, we can see from the results in the surrounding peatland beyond the intervention that the peatlands store carbon in a similar manner to the baseline (current conditions). In fact, as water levels drop with climate change, peat decay increases near the road footprint while remaining lower than in the baseline scenario.

However, it is important to consider the impacts of construction of the road, especially when large areas may need to be drained during construction - see the next scenario "C".

5.3   C: Road Construction

Development Intervention   (a) A raised impervious road that requires 80 m width is being built 1 meter above the natural surface. (b) Vegetation is removed, and the soil surface is flattened. (c) The road embankment is filled with permeable gravel. (d) The underlying peat is compressed due to the road's weight. (e) During construction drainage is installed 2 meters below the ground, i.e., 1 meter below the surrounding surface.
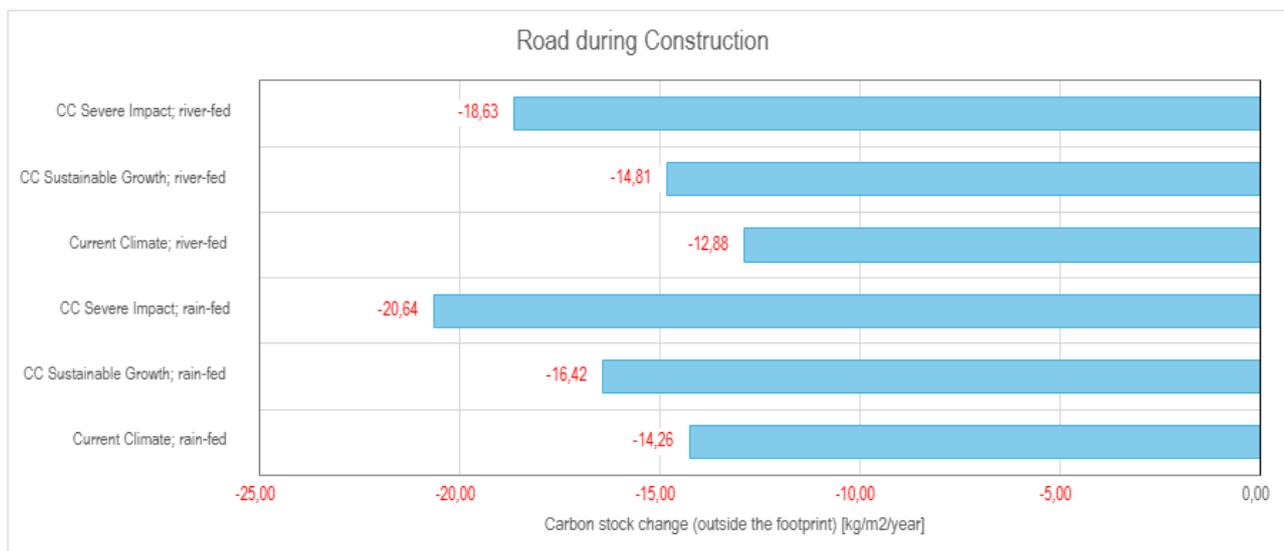
Figure 5-3   Co2 emissions in proximity to a road during construction

The results show that if drainage in installed during construction of the road, peat decay in the surrounding area increase significantly. The decrease in water level due to drainage is so important that the impact of climate change on water levels is reduced compared to the baseline intervention under the current climate. This is true for all scenarios that have a drainage element.

5.4   D: Settlement

Development Intervention

(a) A settlement is developed in the peatland forest. (b) The topography is raised by 50 cm to prevent flooding. (c) Vegetation is cleared, and the soil surface is partially paved. (d) The peat is compressed under the load of buildings.
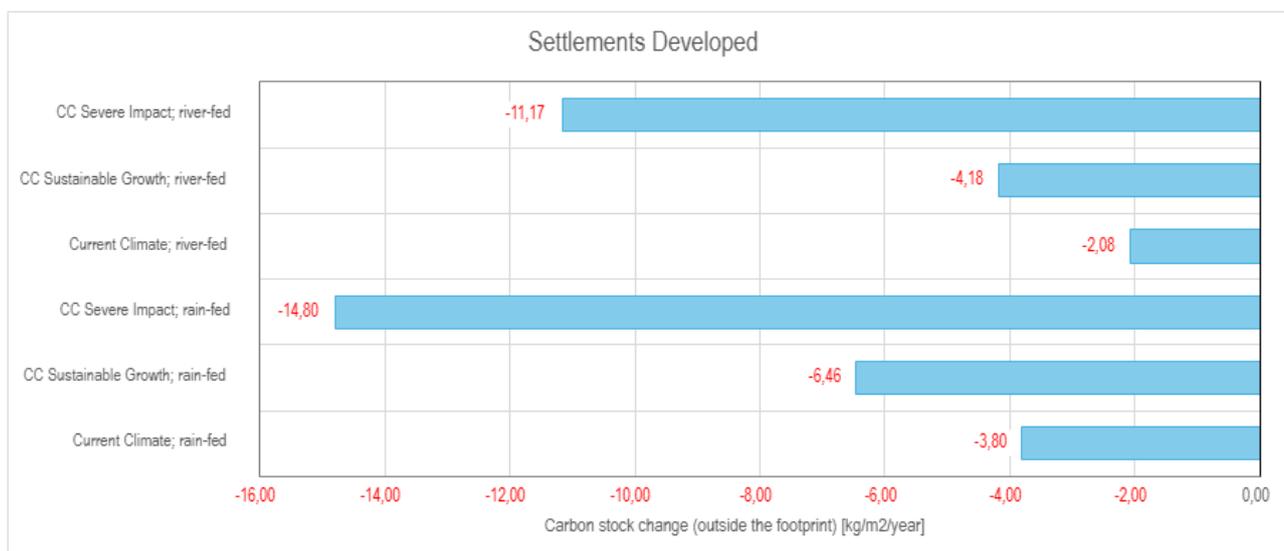

Figure 5-4   Co2 emissions in proximity to a new settlement

As water levels drop with climate change, peat decay increases both inside and outside the settlement footprint, while remaining lower than the baseline outside the footprint.

If drainage were needed to develop the settlement, we know based on the results of scenario C that this will significantly increase the carbon losses.

5.5   E: Forest Fire /Deforestation

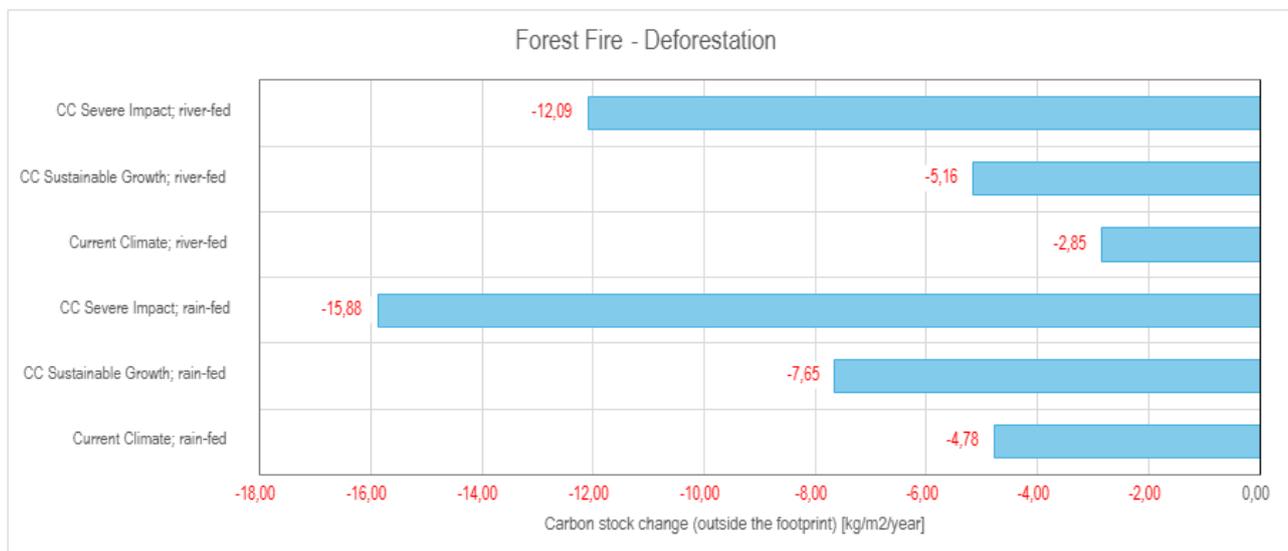|	
Development Intervention	(a) A forest fire completely clears the vegetation. (b) As a result, soil properties change: bulk density increases, and specific yield decreases.

Figure 5-5   Co2 emissions in proximity to a fire that removes all vegetation

 As water levels drop with climate change, peat decay increases both inside and outside the fire footprint. Evapotranspiration from the burnt area is reduced when the water table drops deep below ground, which results in an increase in the water table. Carbon fluxes outside the fire footprint are similar to the baseline. If fires or slash and burn techniques are used in conjunction with other development interventions, e.g. to clear land for agricultural purposes, construction or drainage, then other scenario results must be considered.

5.6   F: Deforestation and Oil Palm

|	
Development Intervention	Deforestation and Conversion to Oil Palm Plantations: (a) Natural vegetation is cleared to establish additional oil palm plantations. (b) Oil palms thrive with a mean water level 40 cm to 60 cm below ground. There is drainage at 50 cm depth. (c) Vegetation properties are altered according to 15-year-old mature oil palm plantation. (d) The microtopography is smoothed due to clearing. (e) Soil properties change by drainage: increased bulk density, reduced specific yield, and reduced hydraulic conductivity at saturation. (f) The topography is lowered by 50 cm due to soil subsidence induced by drainage.
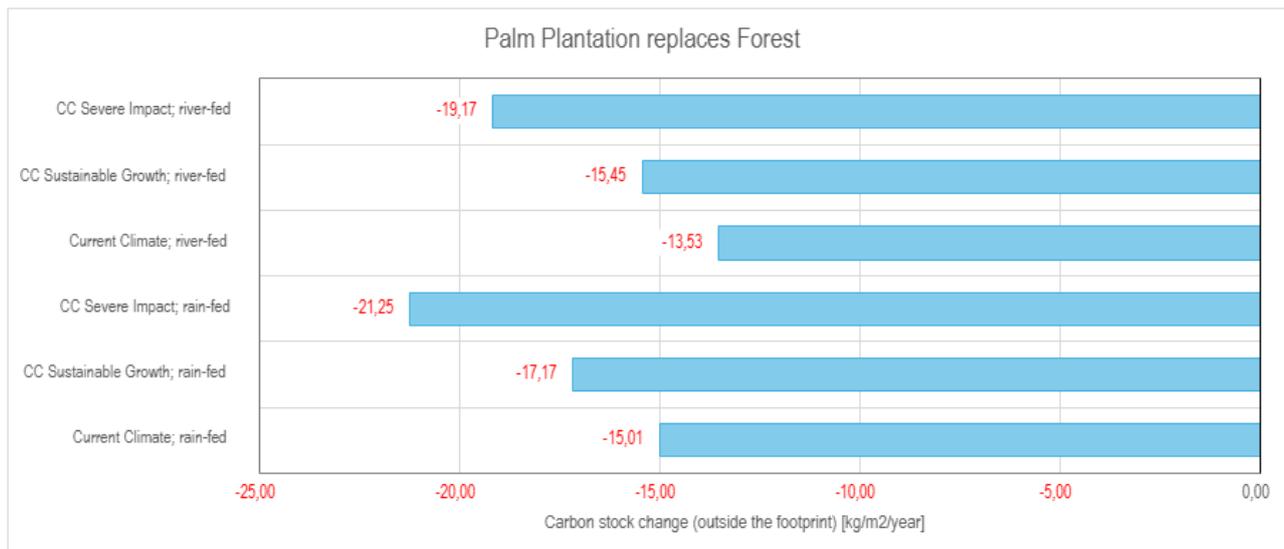
Figure 5-6   Co2 emissions in proximity to an Oil Palm plantation

the decrease in water level due to soil subsidence and drainage in this scenario is so important that the impact of climate change on water levels is reduced compared to the baseline intervention. Peat decay increases compared to current climate conditions due to lower water tables. Carbon losses remain much higher than in the baseline scenario, both inside and outside the plantation footprint.

The results of this scenario are on par with the results of the drainage for road development scenario. Significant carbon losses are to be expected across all drainage scenarios in both current, sustainable growth and severe impact climate models. While the drain in this scenario is at a depth of 50cm compared to the 1m in the road building scenario, the carbon losses are marginally higher in this oil palm development scenario.

5.7   G: Deforestation and rice cultivation

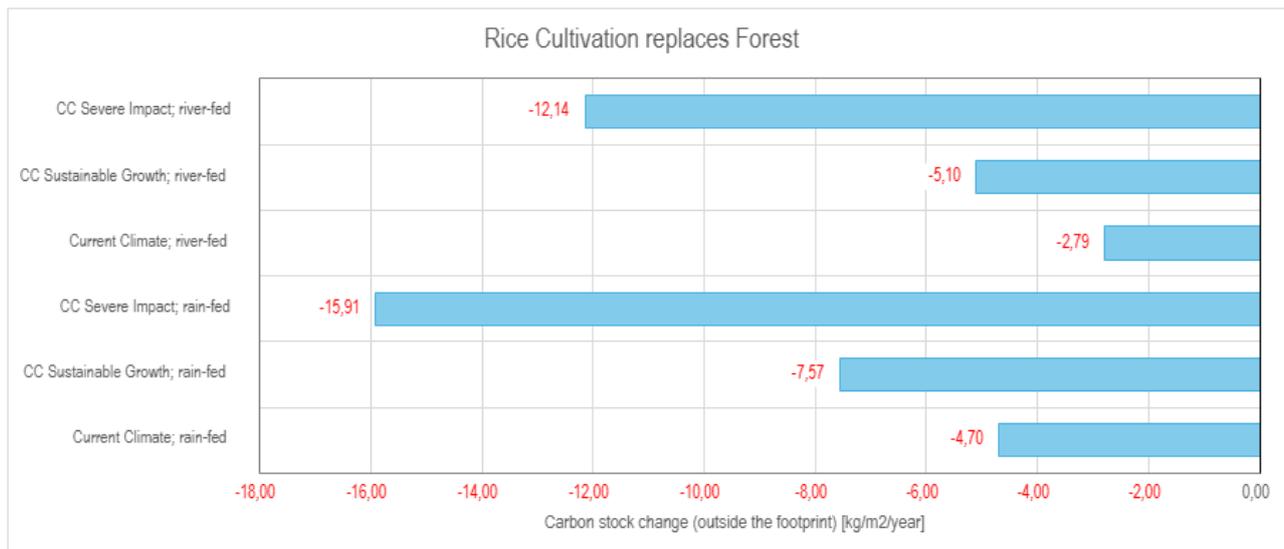|	
Development Intervention	Deforestation and Conversion to Rice Cultivation: (a) Natural vegetation is removed and replaced with rice paddies. Rice is the most common seasonally flooded crop in the Cuvette Centrale. (b) There are two harvests per year. Paddies are flooded during the wet season. (c) Vegetation and surface properties/roughness vary with crop stage.

Figure 5-7   Co2 emissions in proximity to rice cultivation

In this final scenario, rice cultivation mimics the results of the baseline scenario. As water levels drop with climate change, peat decay increases both inside and outside the rice plantation. In comparison to the oil palm plantation, cultivation of rice in the cuvette centrale would result in lower carbon losses and keep the peatlands surrounding the interventions more intact.
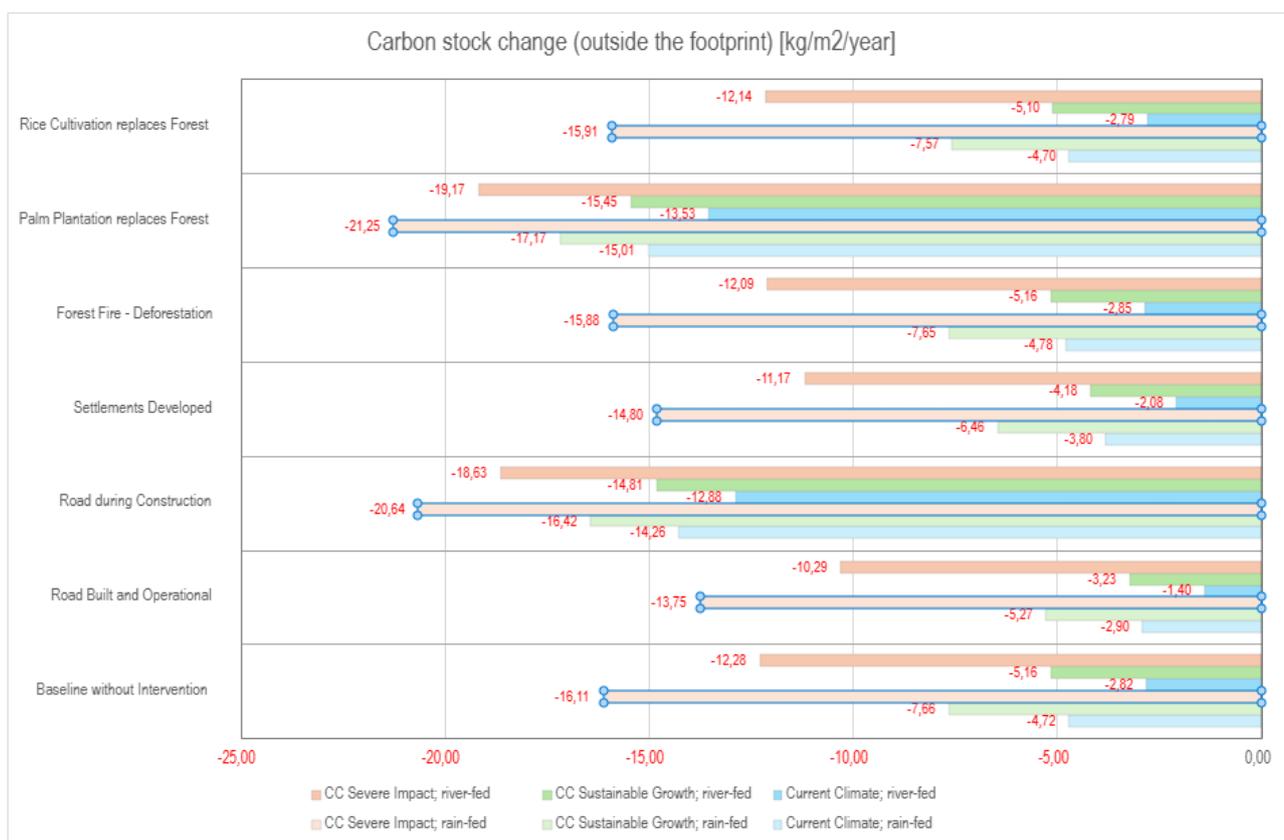
5.8   Conclusion

Figure 5-8   Overview of Co2 emissions in proximity to all scenarios

Across all interventions except the settlement and fire interventions, carbon fluxes inside and outside the footprint follow the same trend relative to the baseline under all climate conditions: if carbon losses for a given intervention are lower than the baseline under current climate conditions, they are also lower under future climate change scenarios.

The results also demonstrate that any form on intervention which includes drainage will have a significant impact on the ability of the surrounding peatlands to sequester carbon and will result in an increase of carbon losses in the surrounding area.

For other localised interventions without drainage, such as operational roads, settlements or areas exposed to fires, the loss of carbon is concentrated within the area of the intervention with limited impact on the surrounding peatlands.

5.8.1 Note to the indicator "Carbon stock change in kg per m2 per year" inside and outside the footprint of the intervention":

The indicator is a normalized value per square meter which characterizes the impact on a unit area. Hence, for specific sizes of interventions, the decision maker needs to multiply the respective indicator values with the significant areas of the concrete interventions.

Example with assumptions: For a peatland area of 20 km x 20 km the decision maker wants to compare the following:

- Scenario A: the current situation (no intervention); reference area = 4×10^8 m^2 (400 km^2)

- Scenario B: Road Built and Operational, let one assume that the road is 30 m wide and traverses the peatland: road footprint area = 30 m x 20×10^3 m = 6×10^5 m^2; outside footprint area = 4×10^8 m^2 - 6×10^5 m^2 = 399.4 km^2

- Scenario F: Palm Plantation replaces Forest: let one assume that the plantation area is 10 km x 10 km: plantation footprint area = 10^8 m^2 (100 km^2); outside footprint area = 4×10^8 m^2 - 10^8 m^2 = 3×10^8 m^2 (300.0 km^2)

If we take for example the results for scenarios A.1.1, B.1.1 and F.1.1, the carbon stock changes would be as follows:

- Scenario A: -4.716 kg/m^2/yea

- Scenario B: -17.975 kg/m^2/year inside the footprint and -2.905 kg/m^2/year outside the footprint

- Scenario F: -15.639 kg/m^2/year inside the footprint and -15.010 kg/m^2/year outside the footprint

Hence for the above example the carbon stock changes would be as follows

- Scenario A: -1.89 million tons/year

- Scenario B: -1.17 million tons/year if area of impact outside footprint is overestimated, -1.89 million tons/year (same as baseline) if impact outside footprint is neglected

- Scenario F: -6.09 million tons/year

6 Applicability and Limitations

This chapter presents a critical evaluation of the integrated hydrological and carbon flux modeling approach used to assess peatland dynamics and changes in soil carbon stocks in the Cuvette Centrale. It highlights the method's strengths in scenario analysis and decision support, while also acknowledging the limitations imposed by data scarcity, model assumptions, and uncertainties in climate projections.

6.1 Hydrological Setup and Model Validation

Due to limited availability of comprehensive data, a georeferenced model could not be developed. Instead, a conceptual model was adopted, focusing on the dominant hydrological processes that shape peatland dynamics This model captures both rain-fed and river-fed peatland regimes, allowing for a broad representation of hydrological diversity in the Cuvette Centrale. Validation was carried out through qualitative comparisons with field measurements from 2013–2014 and 2018–2019, which showed that simulated water levels generally matched observed seasonal fluctuations. However, certain dynamics, such as rapid groundwater rise following rainfall, were not well reproduced. The model also simulated deeper water tables at the dome edges, though field data do not support this pattern, raising concerns about potential overestimation of carbon losses in river-fed peatlands. These discrepancies underscore the need for additional fieldwork to better understand spatial water level variability and improve model accuracy.

6.2 Hydrological Processes

Accurate estimation of evapotranspiration is crucial for understanding the water balance of the Cuvette Centrale. In MIKE SHE, transpiration is modeled using reference evapotranspiration and plant-specific parameters, with a logarithmic root-density distribution that assumes greater water uptake in the topsoil and depends on maximum root depth, set to 1 m based on Sciumbata et al. (2023). However, observed sharp declines in fine root production with depth contrast with MIKE SHE's default gradual distribution, potentially leading to overestimated transpiration and water table depth during dry periods. Hydraulic properties of peat, such as conductivity and specific yield, are derived from Southeast Asian peatlands due to lack of local data, introducing uncertainty in subsurface water dynamics. Additionally, the model shows minimal lateral flow toward boundaries, despite evidence of significant outflow to rivers, suggesting groundwater interactions may be underestimated. Field measurements of hydraulic properties and lateral groundwater flow are needed to improve model accuracy.

6.3 Scenario Modeling

River-fed simulations show that flooding expands gradually over time as river inflows recharge the unsaturated zone, indicating that hydrological equilibrium is not reached within the current timeframe; thus, longer simulation periods are recommended. Improving intervention models requires local data, including geotechnical information for roads and settlements, drainage patterns for plantations, and soil measurements in degraded peatland areas, while monitoring peat properties under compression, burning, or drainage is essential for assessing intervention impacts. Climate projections from CMIP6 models present high uncertainty, with conflicting rainfall trends and wide variability between scenarios, meaning climate change results should be interpreted cautiously. Considering p10 and p90 rainfall projections and conducting further studies on river discharge impacts would enhance understanding of future hydrological dynamics in river-fed peatlands.

6.4 Carbon Accumulation and Loss

In the current model, carbon storage is assumed constant, but in reality, Gross Primary Productivity (GPP) varies with weather and hydrology, slowing on cloudy days and decreasing under smoke from peat fires, as observed by Hirano et al. (2012). Incorporating these effects and introducing a reduction factor when water tables fall outside optimal ranges would improve accuracy. Soil subsidence from prolonged peat decay is represented by a fixed 50 cm lowering in the oil palm model, but dynamically coupling carbon flux and hydrology would be more precise, albeit complex. Decay rates also depend on peat hydraulic properties, yet limited data prevent their inclusion. The study focuses on carbon balance rather than greenhouse gas emissions, meaning effects on global warming cannot be fully assessed; most decomposition occurs under oxic conditions, producing CO_2, but anoxic conditions can generate methane and dissolved organic carbon. A comprehensive evaluation of carbon outflows under varying conditions requires additional field measurements.

6.5 Conclusion

The combined modelling approach described here enables decision-makers to assess the effects of specific interventions on water levels and carbon dioxide emissions under various hydrological and climate conditions. The accuracy of the model is constrained by the limited understanding of peatland hydrology in the Cuvette Centrale, particularly the exchanges between rivers and peatlands. Field measurements would help refine the model, especially soil hydraulic parameters and water level time series for validation. To estimate more precisely the impacts of a given intervention in a specific area, the current conceptual rectangular-shaped model could be converted into a georeferenced model that covers the actual intervention zone with appropriate site-specific parameters.

7 Summary and Conclusion

This report has presented the development and application of a Hydrological Decision Support System (HDSS) tailored to the unique characteristics of the Congo Basin peatlands. Through the integration of a conceptual hydrological model (MIKE SHE) and a heuristic biodegradation model, the HDSS provides a framework for understanding the interplay between water dynamics and carbon emissions in the Cuvette Centrale.

The hydrological model simulates key processes such as precipitation, evapotranspiration, infiltration, groundwater flow, and overland flow. Two distinct hydrological zones are modelled: (1) rainfall driven only, and (2) rainfall driven and river water level induced. Despite the conceptual nature of the model and the limited availability of in-situ data, the calibration results align well with observed seasonal and spatial patterns of groundwater levels from literature. The model captures the sensitivity of the peatland system to climatic variability, particularly the drying trend observed over recent decades.

Coupled with the biodegradation model, the carbon fluxes are estimated based on oxic and anoxic soil conditions. The heuristics distinguish between labile and recalcitrant organic matter and account for their respective degradation rates under varying saturation levels. This approach provides an understanding of how hydrological changes - whether from climate variability or human interventions - translate into carbon fluxes.

Scenario analyses demonstrate the significant impact of development interventions such as road construction, settlement expansion, and land-use conversion on peatland hydrology and carbon emissions. For example, drainage associated with infrastructure development can drastically lower groundwater tables, increasing oxic depth and accelerating peat decomposition. Conversely, scenarios that maintain or restore high water tables show reduced emissions and better preservation of peat carbon stocks.

The scenario analyses conducted in this study highlight several critical vulnerabilities of the peatlands, arising from their hydrological sensitivity, the nature of development interventions, and the impacts of climate change.

- **Hydrological Vulnerabilities**: The peatlands are highly sensitive to changes in water table levels. Lowering of the groundwater table - whether through drainage, infrastructure development, or prolonged dry periods - exposes peat to oxic conditions, thereby accelerating decomposition and increasing carbon dioxide emissions. The loss of microtopography and increased overland flow further exacerbate water loss, particularly in areas where natural surface features are altered.

- **Vulnerabilities from Development Interventions**: Infrastructure development, such as road construction, settlement expansion, and conversion to agriculture (e.g., oil palm or rice cultivation), typically involves drainage and compression of peat soils. These interventions result in a significant lowering of the water table, increased oxic depth, and enhanced peat decomposition. Removal of natural vegetation and smoothing of the land surface reduce the peatland's capacity to retain water and buffer against hydrological extremes.

- **Climate Change Vulnerabilities**: : With climate change, the peatlands of the Cuvette Centrale are expected to become drier. Evapotranspiration rates are projected to increase substantially, driven by rising temperatures in the region. This projection is particularly concerning for the Cuvette Centrale, where peatlands are more vulnerable to drought than their Southeast Asian counterparts due to lower annual precipitation. The region could experience longer and more intense dry seasons, leading to lower water tables, an increased risk of fire, and accelerated carbon loss.

  The interaction between these uncertain climate trajectories and ongoing human interventions poses a significant challenge to the long-term resilience and stability of the peatland ecosystem. However, these findings should be interpreted with caution given the high uncertainty of CMIP6 rainfall projections. While the ensemble median shows only modest rainfall changes, individual models project a much wider range—from strong increases to strong decreases—highlighting

the importance of also considering p10 and p90 scenarios. Additional research on regional river discharge is needed, as it is a key driver of water levels in river-fed peatlands.

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7.1 Recommendations

To address these vulnerabilities, the following management actions are recommended:

- **Maintain High Water Tables**: Prioritize hydrological management practices that keep the groundwater table close to the surface. Where drainage is unavoidable, limit the depth and duration of drainage to minimize peat oxidation and subsidence.

- **Protect and Restore Vegetation**: Retain natural vegetation buffers, especially along waterways and peat dome margins, to support water retention and ecosystem resilience. Restoration of degraded areas through rewetting and reforestation should be promoted to reduce emissions and enhance peatland function.

- **Minimize Surface Disturbance**: Avoid large-scale smoothing of natural microtopography and limit soil compaction from heavy infrastructure. Where possible, design interventions to preserve or mimic natural surface features.

- **Implement Adaptive Drainage**: Where drainage is necessary for development, employ controlled drainage systems (e.g., adjustable weirs) to allow dynamic management of water levels in response to seasonal and climatic variability.

- **Monitor and Adapt**: Establish long-term monitoring of hydrological and ecological indicators to inform adaptive management and ensure that interventions do not compromise peatland integrity.

In summary, the Congo Basin peatlands are highly vulnerable to hydrological disturbance, unsustainable land use, and climate change. Maintaining high water tables, protecting natural vegetation, and restoring degraded areas are essential to safeguard their carbon stocks, biodiversity, and hydrological functions.

The HDSS developed in this project lays the groundwork for evidence-based governance and sustainable planning in the Congo Basin peatlands. Looking ahead, the following key direction can be envisioned for stakeholder engagement and policy integration: The HDSS outputs can inform land-use planning, conservation strategies, and infrastructure development guidelines. Continued collaboration with local stakeholders and policymakers will be essential to ensure the system's relevance and impact.

In conclusion, this study represents a critical step toward safeguarding the ecological integrity and carbon storage function of the Congo Basin peatlands. By linking hydrology, carbon dynamics, climate projections and human development, it provides a tool for balancing conservation and sustainable development in one of the world's most important tropical peatland regions.

7.2 Next steps

The full results of the study can be explored in the Hydrological Decision Support System. The Democratic Republic of Congo and Republic of Congo will use these findings and the and the Hydrological Decisions Support System as an interactive tool to develop and sustainably manage the waters of the Lac Tele and Lac Tumba peatlands, respectively.

The understanding and knowledge of the hydrology in the Cuvette Centrale could be significantly strengthened by further investment and research in the Congo Basin, including in monitoring and data collection of river flow and water levels in the Lac Tele and Lac Tumba landscape.

8 Abbreviations

CREBBAC   Congo Basin Water Resources Research Center,

DRC: Democratic Republic of Congo

ET: Evapotranspiration

GCM: Global Climate Model

GPP: Gross Primary Productivity

GWT: Groundwater

HDSS: Hydrological Decision Support System

IKI: Internationale Klimaschutzinitiative (International Climate Initiative)

IPCC: Intergovernmental Panel on Climate Change

LAI: Leaf Area Index

MODIS: Moderate Resolution Imaging Spectroradiometer

RCP: Representative Concentration Pathway

SSP: Shared Socioeconomic Pathway

UNEP: United Nations Environment Programme