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Summary

NbS is gaining global interest due to its potential to build climate resilience and address water-related risks to economies and society, such as floods, droughts, increasing water scarcity, food security, and biodiversity loss. It builds on existing concepts and ecosystem-based approaches and provides a more comprehensive framework for responding to societal challenges that ensures biodiversity and human wellbeing benefits.

WWF - the Netherlands would like to scope for NbS in Latin America, starting with the largest tropical wetland of the world, the Pantanal. The Pantanal, an important area of the Upper Paraguay River Basin, have suffered prolonged droughts and overexploitation over the last decades. The Pantanal has lost 74% of its surface water in the last 30 years, putting water security at risk for people and nature.

The aim of this study is to scope potential NbS that can address relevant challenges related to water security in the Upper Paraguay River Basin and Pantanal. This study is part of the first stage of the NbS project cycle and focus mainly on the questions: what is the water security challenge? And what NbS options are most relevant?

A brief overview of the main water-related challenges for the UPRB was prepared and related to pressures on the basin impacting the availability, supply, and quality of water, causing land degradation and erosion. These pressures are mainly of two types, namely infrastructure developments related and land use and conversion due to economic activities. Infrastructure developments related to energy generation, oil and gas distribution and navigation, in particular the Paraná-Paraguay Waterway. Economic activities causing land use conversion are livestock, agriculture, and mining.

Water-related challenges are different in the highlands and the Pantanal region, but intrinsically related. Environmental processes in the upstream of the Upper Paraguay River Basin will affect processes downstream of the basin. Water-related challenges in the highlands include the decrease in water production in headwaters, increase erosion and sediment transport, droughts, sedimentation of rivers, deforestation, alteration of natural regime of rivers due to energy infrastructure. In the Pantanal the water-related challenges include impact in the flood pulse, impact in water retention and infiltration, droughts and floods, sediment transportation from the highlands, increase erosion and sediment transport, alteration of the natural regime and water quality deterioration due to Waterway, and deforestation.

These challenges have significant impacts on ecosystem services, as they disrupt the natural functioning of ecosystems and can lead to various ecological consequences. Impacted ecosystem services are water supply, erosion prevention, extreme events moderation, water purification and regulation of water flows. Based on the combination of available georeferenced information for the whole basin this study attempted to assess in a simplified manner the locations and their land use that have the potential of providing impacted ecosystem services, namely water retention potential, runoff, infiltration and erosion potential.

An inventory of NbS was prepared for water challenges in the Pantanal and highlands region as a blueprint for responsible water resource management that benefits both people and the environment. Categories of NbS in the inventory include actions on all ecosystems present in the UPRB, namely, management of intensive land use systems, floodplain management, restoration of rivers and lakes, rivers and lakes management, conservation of wetlands, forest restoration, conservation, and creation.

The analysis focused on areas of interest as requested by the WWF local offices in Bolivia, Brazil and Paraguay. Six areas were selected by WWF (two per country) based on their own local knowledge and enabling conditions for conservation efforts. For each one of the areas of interest a diverse number of NbS opportunities were selected based on the ecosystem present in the area and the potential for providing impacted services.

Many of the NbS opportunities relate to the conservation and protection of natural vegetation, including forest formation, savanna formation, grassland / herbaceous and other non-forest natural formation. Another opportunity for NbS is the restauration of natural vegetation in priority areas as riparian forest (in riverbanks, drainage network and paleochannels), headwaters, ecological easement and connectivity areas. Conservation and sustainable management of wetlands (flooded forest and grasslands) also require attention. Reducing the impact of livestock in the basin requires sustainable practices and regenerative practices, including sustainable community livestock, livestock rotation, ecosystem-based management, silvopastoral practices, and soil restoration. Aquifers have an ecohydrological function for the entire Upper Paraguay River Basin. Strategic recharge sites for the basin can define the recovery of levels in the Paraguay River.

Contents

1 Introduction

Globally, there is increasing interest in the potential for Nature-based Solutions (NbS) to build climate resilience and to address water-related risks to economies and society, such as floods, droughts and increasing water scarcity and other societal challenges such as food security and biodiversity loss. NbS builds on existing concepts and ecosystem-based approaches[1] and provides a more comprehensive framework for responding to societal challenges that ensures biodiversity and community benefits (Andrade, et al., 2020). In March, 2022 the Fifth session of the United Nations Environment Assembly (UNEA-5, 2022) formally adopted the definition of NbS as '*actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits'*.

NbS are applicable to all terrestrial ecosystems and their different types encompass a broad range of actions related to enhance the services of natural or semi-natural ecosystems that can be classified in the following categories:

- Protecting ecosystems
- Restoring degraded landscapes
- Improve management of ecosystems
- Creating new ecosystems

WWF NL would like to scope for NbS in Latin America, starting with the largest tropical wetland of the world, the Pantanal. The Pantanal, an important area of the Upper Paraguay River Basin (UPRB), has suffered prolonged droughts and overexploitation over the last decades. Socioeconomic and infrastructure developments, intense settlement, urbanization, and land conversion are some of the factors that contributed to the significant environmental and social impacts within the region, such as land degradation, high deforestation and biodiversity loss.

The Brazilian Pantanal has lost 60.1% of its surface water in between 2000 and 2022 (MapBiomas, 2023), putting water security at risk for people and nature. (Tomas, et al., 2020) identified many ongoing threats in the Pantanal. Droughts have left communities without access to drinking water and irrigation for agriculture Climate change is affecting the region severely, increasing temperatures and evaporation. Besides the impact of global climate change, there is an additional impact on the local climate due to the high deforestation and conversion rate. It all leads to a perverse cycle where fires and climate change feed on one another. Fires have become a common occurrence with large-scale and tragic consequences. On top of this, there is high pressure on the region to develop infrastructure, especially the implementation of hydroelectric projects that are in the planning phase that will affect the river connectivity and natural water pulse. Also, improved navigation projects aimed at enhancing agriculture by facilitating the export of agricultural commodities (such as soy) lead to additional pressures on the region.

Continuing with a business-as-usual case in the Pantanal will lead to a further decrease of water availability which on the long run will be detrimental to people and nature.

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[1] Nature-based solutions as an umbrella concept (EC, 2021), including ecosystem-based adaptation (EbA); ecosystem-based disaster risk reduction (Eco-DRR), green infrastructure (GI), blue infrastructure (BI), green-blue infrastructure (GBI), urban forestry, sustainable urban drainage systems, ecological engineering, best management practices, low-impact design; water-sensitive urban design (WSUD) and ecosystem services (ESS).

It is therefore essential to build new strategies to address the above-mentioned water related challenges that include actions to protect, conserve, restore, sustainably use and manage ecosystems, but also actions to complement infrastructure developments as waterways and hydropower plants.

The present study aims at scoping NbS that can address relevant challenges related to water security and infrastructure developments (namely navigation and hydropower related) in the UPRB. Although water quality issues are also a relevant challenge in the UPRB, this is not part of the scope of the current study.

The main objective is further broken down into the following specific objectives:

1 To get a comprehensive and spatial overview of main water-related problems and their impacts in the UPRB that can be addressed by the implementation of NbS types;
2 To compile information from existing NbS cases in the UPRB and their impacts on water related problems;
3 To recommend the most promising types of NbS that can improve the water security issues in the Pantanal region.

This study is part of the first stage of the NbS project cycle as illustrated in Figure 1-1 and focuses mainly on the questions: "*What is the water security challenge?*", and *"What NbS options are most relevant?"* A second stage is the feasibility study, which should include the quantitative assessment of the impacts of the identified NbS options, including costs and benefits profiles for prioritized NbS, under different climate and socio-economic scenarios. Additionally, this stage needs to assess the enabling conditions for the implementation of these NbS options. The results of this study will contribute to showcase to governments, and national/ international private sector and other stakeholders, the opportunities for NbS implementation at a landscape level in the region.

Figure 1-1 Proposed stages of the NbS project cycle.

Reading guide
In Chapter 2 an outline of the approach of the study is provided. Chapter 3 describes briefly the UPRB and Pantanal characteristics, including natural pressures, climate conditions and specific overview of the areas in Brazil, Paraguay and Bolivia. Chapter 4 provides an overview of the water-related challenges within the region, considering impacts in water supply, availability, navigability, and land use, and Chapter 5 describes the impacted ecosystem services. The elaborated inventory of NbS is presented in Chapter 6. The scoping of NbS for the areas of interest in the three countries is presented in Chapter 7. Finally, conclusions and recommendations are presented in Chapter 8.

2 The approach

2.1 Nature-based solutions, societal challenges and ecosystem services

To tackle societal challenges and building climate resilience, there is an increasing call for the application of NbS. NbS builds on existing concepts and ecosystem-based approaches[2] and provides a more comprehensive framework for responding to societal challenges that ensures biodiversity and communities benefits (IUCN, 2020). In March 2022 the Fifth session of the United Nations Environment Assembly (UNEA-5) formally adopted the definition of NbS as '*actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits'*.

NbS are applicable to all terrestrial ecosystems, including major wetlands such as the Pantanal wetland. NbS types encompass a broad range of actions related to enhance the services of natural or semi-natural ecosystems and can be classified in the following categories:

- Protecting ecosystems
- Restoring degraded landscapes
- Improve management
- Creating new ecosystems

To be considered a NbS, a solution must address one or multiple societal challenges in an integrated manner. IUCN refers to 7 societal challenges. Out of these 7, in the context of the Pantanal region, the following water-related challenges will be addressed through the scoping of NbS for the Upper Paraguay river basin:

- Water security, namely water availability and supply
- Economic and social development, in particular navigation and land conversion
- Environmental degradation and biodiversity loss

Planning, designing, implementing, maintaining, and upscaling NbS requires an informed approach. We propose an approach that pays special attention to i) ecosystem services; ii) landscape level processes and iii) site-specific context. In the following paragraphs, these three aspects are further elaborated.

2.1.1 Ecosystem services

An ecosystem services approach will be considered to identify the opportunities of NbS for addressing the identified challenges in the Pantanal region. This is based on the premise that natural and semi-natural ecosystems provide services which support social, economic and environmental outcomes. In order to understand how ecosystem services can be leveraged through NbS in URPB and the Pantanal region, it is important to understand what services they can provide. As a reference and for the purpose of this project the CICES classification will be used[3]. CICES recognizes that the main categories of ecosystem outputs are the provisioning, regulating and cultural services.

[2] Nature-based solutions as an umbrella concept (EC, 2021), including ecosystem-based adaptation (EbA); ecosystem-based disaster risk reduction (Eco-DRR), green infrastructure (GI), blue infrastructure (BI), green-blue infrastructure (GBI), urban forestry, sustainable urban drainage systems, ecological engineering, best management practices, low-impact design; water-sensitive urban design (WSUD) and ecosystem services (ESS).

[3] https://cices.eu/

However, it does not cover the so-called ‘supporting services’ defined by other classifications and treats them as part of the underlying structures, processes and functions that characterize ecosystems.

2.1.2 Landscape level processes

Ecosystem health and integrity depend on landscape level processes (i.e., environmental processes that are influenced by anthropogenic activities and climate change), which in turn will determine the effectiveness of the NbS intervention. Therefore, the spatial coverage of NbS affects their ability to deliver expected outcomes. In some cases, the NbS implementation location and the location of the expected effects are not necessarily the same. For example, forest conservation measures can be implemented in the headwaters, but the effects can be observed downstream in the lower part of the basin. Additionally, different types of solutions (both NbS and grey engineered solutions) may need to be combined at a spatial scale to mitigate the risks and address water security, economic development, and environmental degradation. It is therefore that the design and implementation of NbS needs to be applied on a landscape scale (see box 1). For example, a landscape approach can support the combination of options of water storage during the wet season with measures to reduce water demand during dry seasons. In this, the linkage between groundwater and surface water processes is very important. In addition, ecosystems, such as wetlands and floodplains, can help reducing peak flows and increase baseflows and groundwater levels, thereby reducing risks of both floods and droughts. In the context of this project, for example, NbS impacts can be expected in the Pantanal region, nevertheless the NbS implementation location can compromise the highlands of the UPRB.

Box 1. Landscape scale

Although there is no single accepted definition of the landscape scale, the term is used to refer to a large spatial scale in which natural and human relevant processes and factors take place (including, a range of ecosystem processes, uses and policy objectives). The European Landscape Convention introduced a definition of landscape as “*an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors*”.

A landscape scale is therefore a manageable unit of scale which is substantially larger than an individual plot of land, or stream stretch, and normally smaller than an entire river catchment from the origin to the sea, in which relevant ecosystem processes, resource uses, and policy objectives take place, and that allows the intervention of stakeholders at different levels (local, basin, regional).

2.1.3 Site-specific context

They way different areas and sites are affected by the impacts of water-related challenges may be different, as well as the effect on their ecosystems and the services they provide. NbS are always specifically linked to the ecosystem they are implemented in, and thus based on a specific location, socio-economic context and climate zone. By aiming to improve the functioning of the natural processes in the ecosystems that are present in a project area, NbS can enhance the services of improving water security, building climate resilience, or reduce degradation, for example.

2.2 Planning water security in the UPRB

UN Water (2013) defines water security as "*the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*". Strategic plans are needed to develop a long-term vision to achieve water security, and to set medium-term goals, clear targets and roadmaps for policy makers and organizations. To support the strategic planning cycle of the water system and interventions for achieving water security, Deltares developed a framework of analysis (Figure 2-1) to structure and guide the process (Deltares, 2022). This framework has 5 phases, namely, the inception, the situation analysis, the strategy building, preparation for implementation and implementation.

The scoping of NbS types in the UPRB forms part of the situation analysis phase. In this phase, attention is paid to the current and future problems and issues under climate and socio-economic scenarios, and it is constructed based on an understanding of the system and its components (water resources sub-system, socio-economic subsystem, and administrative and institutional sub-system). Although, the current study does not cover all sub-systems, neither a quantitative analysis of the problems, the scoping of NbS allows to identify and screen potential measures to finally define and assess a set of promising measures.

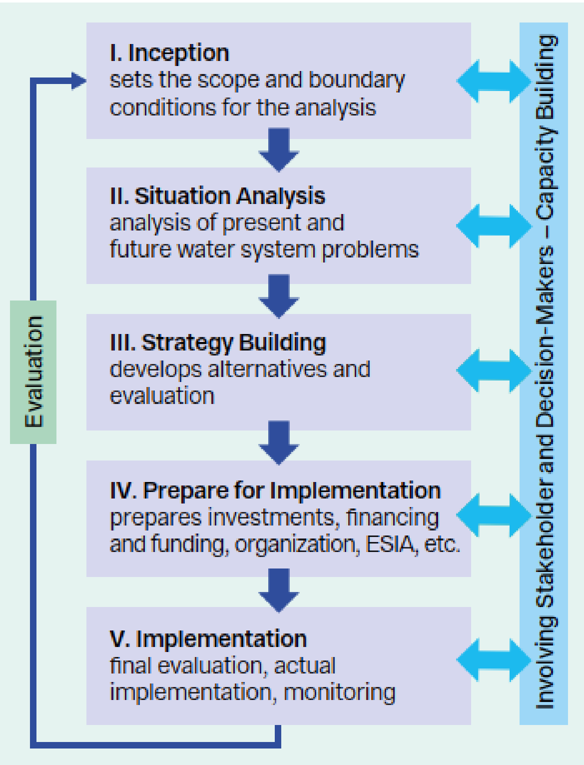

Figure 2-1 Analysis framework for strategic planning of water systems (Deltares, 2022).

3 The Upper Paraguay River Basin and the Pantanal region

3.1 The natural system

The UPRB (see Figure 3-1) covers an area of approximately 600,000 km^2, of which, 120,678 km^2 are located in Bolivia, 116,946 km^2 are in Paraguay and 362,376 km^2 are in Brazil, crossing Mato Grosso and Mato Grosso do Sul states (2 extensive states of Brazil). The basin is made up of two large ecosystems, defined by the relief and water regime: the Highlands, characterized by the biome Cerrado and part of the Amazon; and the Lowlands, where the Pantanal is located (Zumak, Tolone, & Larcher, 2021).

The Pantanal is one of the largest wetland areas on the planet, covering 147,574 km^2 and providing an essential link between the biomes of the Brazilian Cerrado and the Chaco plains of Bolivia and Paraguay (Tomas, et al., 2020). The Pantanal is a low altitude region, ranging between 100 and 150 meters, situated along the UPRB, whereas the highlands have slopes and reach an altitude of up to 1300 m.a.s.l. (see Figure 3-1). The Chiquitano Dry Forest (about 24 million of hectares[4]) in Bolivia and Brazil corresponds to the most extensive tropical dry forest in the world. By 2014 80% of the Pantanal was still covered by native vegetation (Bendoya, 2018). Moreover, it is considered a National Heritage Site, according to the Brazilian Constitution, and a Biosphere Reserve, according to the United Nations (Thielen, et al., 2021).

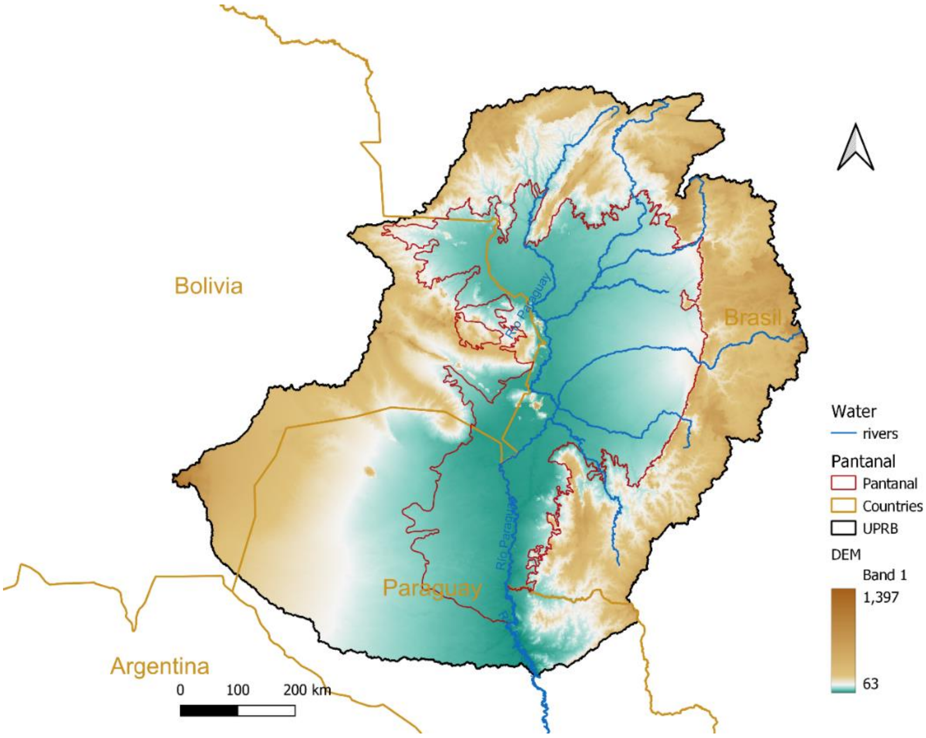

Figure 3-1 Digital Elevation Map (DEM) in m.a.s.l of the Upper Paraguay River Basin (black contour) and the Pantanal wetland (red contour).

[4] https://www.fcbc.org.bo/bosque-seco-chiquitano/

3.1.1 Climate

The Pantanal is a semi-arid region with some varieties in climate. The climate of the Pantanal is marked by a wet season with high and stable precipitation levels and a dry season (Hamilton, 2002; Marengo, et al., 2021). The wet season begins in October and ends in April with monthly precipitation ranging from approximately 100 to 300 mm, while in the dry season, monthly precipitation ranges from 0 to 100 mm, with lower year to-year variability than in the wet season. Figure 3-2 shows the long-term rainfall variability with monthly trends in precipitation from 1999 to 2020. The annual average precipitation during the years 1968−2000 ranged from 920 to 1540 mm, with a mean value of 1320 mm. Rainfall shows inter - annual variability with higher or lower rainwater amounts (Marengo, Alves, & Torres, 2015).

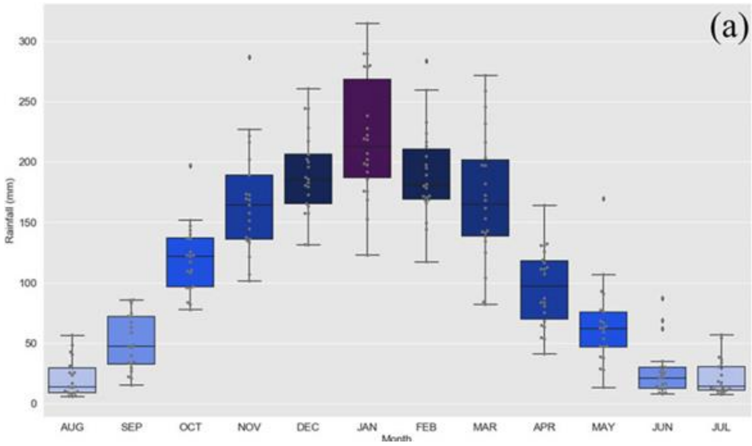

Figure 3-2 Monthly rainfall. Boxplot of monthly rainfall from July 1999 to June 2020. Source: Pereira et al., 2021

3.1.2 Hydrography

The Pantanal is highly dependent on watercourses located in the highlands (plateaus or Planalto region) of the UPRB (see Figure 3-1) that descend into the lowlands transporting water and sediments (Zumak, Tolone, & Larcher, 2021) (OAS, 2005). The Brazilian highlands have steep slopes and contribute significantly with water and sediment transport to the Pantanal, whereas the uplands to the west in Bolivia and Paraguay contribute less to the Pantanal recharge due to its small rainfall amount and gentle slopes (Hamilton, 2002; Thielen, et al., 2021). Figure 3-3 shows main rivers and slopes in the UPRB and Figure 3-4 present the various basins (based on HydroSHEDS[5], level 7).

The Brazilian UPRB occupies 52% of the total area of Mato Grosso do Sul State and 48% of State of Mato Grosso. The Taquari, Miranda, Negro and Apa rivers stand out in this region, on the left bank of the Paraguay river (ANA, 2018). Moreover, the sub-basin of Cabaçal (in Mato Grosso) is an important water producing basin (also called water tower) contributing to the Pantanal recharge (The Nature Conservancy; WWF Brazil, 2011). Nevertheless, the Cabaçal sub-basin is highly susceptible to erosion due to the fragility of its soil (The Nature Conservancy; WWF Brazil, 2011).The lowest runoff in the Paraguay River basin occurs in Mato Grosso do Sul, mainly because of the low drainage capacity of the Pantanal, and high water retention, reducing flows downstream, which characterizes a significant seasonal variability to be considered regarding water availability (WWF-Brazil, UCDB & Fundação Tuiuiú, 2017).

[5] https://developers.google.com/earth-engine/datasets/catalog/WWF_HydroATLAS_v1_Basins_level07

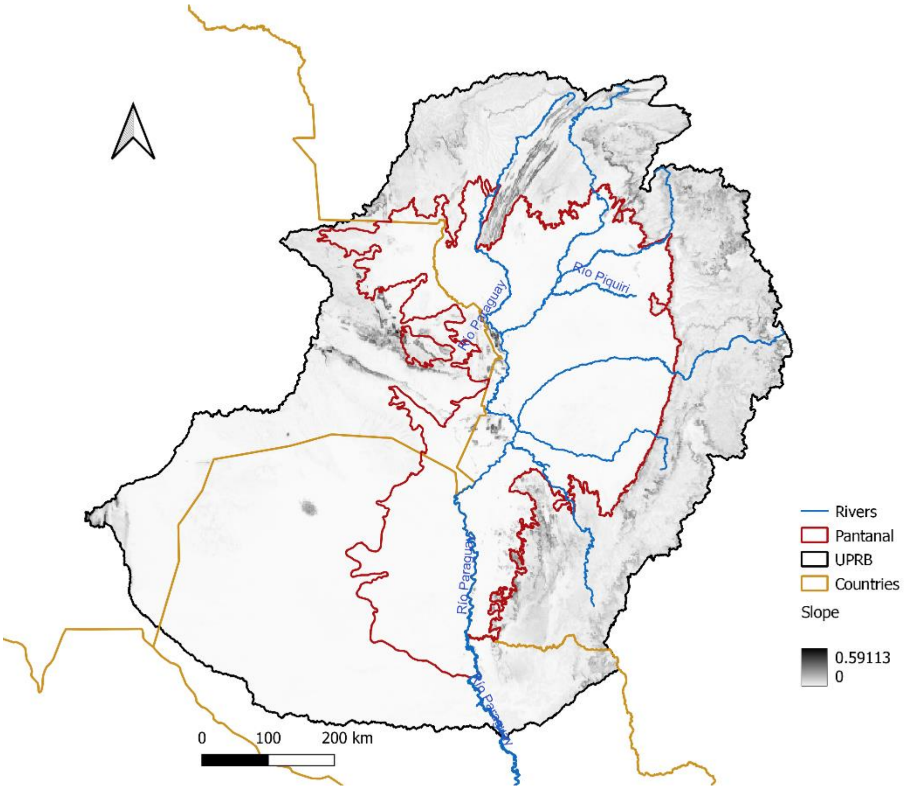

Figure 3-3 Slopes [-][6] in the Upper Paraguay River Basin and Pantanal region.

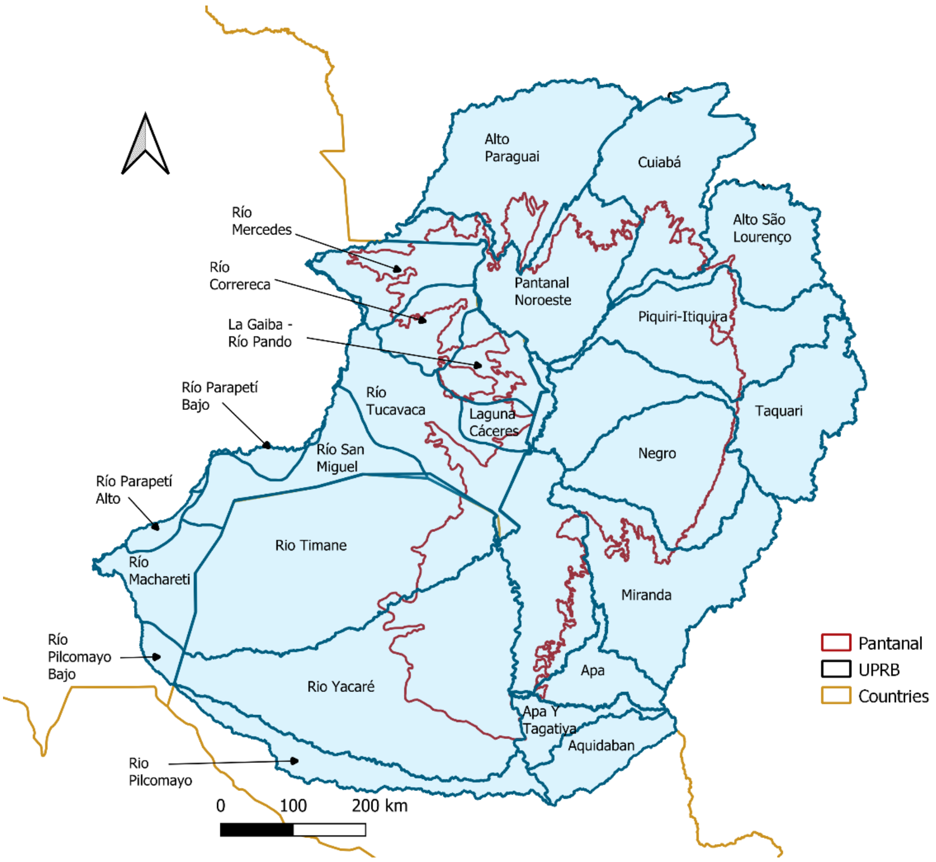

Figure 3-4 Subbasins per country of the Upper Paraguay River Basin.

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[6] Slope corresponds to the amount of rise, or vertical distance, divided by the run, or horizontal distance. In this Figure is expressed as unitless.

3.1.3 The flood pulse of the Pantanal

The Pantanal is characterized by seasonal inundation and drought periods, which vary in depth and duration following the Flood Pulse Concept (Hamilton, 2002). According to (Junk, Bayley, & Sparks, 1989), the flood pulse (or pulsing of the river discharge) is the driving force for the existence, productivity and interactions of the major biota in river-floodplain systems and is produced by geomorphological and hydrological conditions. The flood pulse generates aquatic/terrestrial transitions (zones) with periods of drought and flooding.

(Lázaro, Oliveira-Junior, da Silva, Ikeda, & Muniz, 2020) summarizes the flood pulse in the Pantanal as follows: "*The flood pulse of the Pantanal is highly fed by the local precipitation and the rain in the headwaters where the Paraguay river slowly conducts the water downstream. The flat morphology of the Pantanal and the gentle slope of the Paraguay river are especially important for the seasonal lateral inundation processes. The water mostly enters the Pantanal from the North, where the rainfall is converted into runoff, and the riverbank overflows connecting water bodies feeding and forming lakes. Naturally, the water bodies of the Pantanal are shallow, which is a natural response of the sedimentary deposition character of the area, both in the river and in the surrounding lakes (caused by the low and flat topography and the associated slow flow of the Paraguay river)*". Precipitation occurs all over the Pantanal, but due to floodplain storage, inundation processes in the central and south part of the Pantanal can happen several months after peak rainfall. As the water recedes, processes in the floodplains become less dependent on the river channel and more subject to local climatic events. Some lakes and swamps are then isolated from the main channel for many months and their hydrological regimes are therefore independent of the main channel, except during periods of high water (Junk, Bayley, & Sparks, 1989). The Pantanal floodplain slowly releases the water to the lower areas of the Paraguay River, preventing the flood season of the Paraná River to coincide with the Paraguay River flood season, and thus avoiding possible disasters for the downstream inhabitants (Bendoya, 2018).

Large-scale climate phenomena such as El Niño, La Niña, or the variability linked to the Atlantic Ocean as well as regional-scale water balance, soil wetness, and soil moisture storage influence the seasonality of floods and droughts in the Pantanal.

There's a specific phenomenon that happens in the Pantanal, due to interactions between the terrestrial and aquatic environments, which reflects the peculiar characteristics of the natural functioning of the wetland system. It consists of limnological changes that occur periodically in the Paraguay River, which affects water transparency, electrical conductivity, concentration of dissolved gasses, nutrients, and materials in suspension, which in turn influence the cycling of nutrients and the transfer of energy in the trophic chain (Tomas, et al., 2020).

The flood and drought processes are essential to control the fauna and flora diversity and fish production in the rivers. The flood pulse creates aquatic and terrestrial transition zones, providing diversified food sources that support the aquatic fauna. The complex drainage of the Pantanal comprises small watercourses (streams), drainage lines with a moderate slope, lakes and lagoons (Marengo, et al., 2021). Flood intensity, together with climate, topography and soil type are factors on which vegetation within the Pantanal depends (Ivory, McGlue, Spera, Silva, & Bergier, 2019). For example, the species composition of swampy forests and grasslands in the floodplains is variable with respect to flooding and therefore very sensitive to flood stage and timing.

3.1.4 Climate change trends

Tomas et al. (2019) summarizes the temperature and rainfall projections for Pantanal and UPRB according to the IPCC climate change models.

An increase in the average air temperature of 5ºC to 7ºC is suggested until 2100, whereas rainfall changes remain uncertain for the Pantanal. Some of the most pessimistic scenarios indicate a decrease of 30% in the average rainfall at the UPRB until the end of this century. For example, Marengo, Alves, & Torres (2015) found higher values of annual warming for the Brazilian Pantanal based on the regional climate change projections derived from the Eta-HadGEM2 for the RCP8.5 for the period 2010-2100. The projections vary from 2.5-3.5ºC in 2011-2040 up to above 5-7ºC from 2071 and 2100. For precipitation, the model projects mean annual rainfall reduction on the order of 10-20% in 2010-2040 and 30% by 2071-2100. In a more recent study Silvia, et al. (2022) studied the future temperature perspective in the Pantanal through an ensemble of the CORDEX-CORE simulations assuming different Representative Concentration Pathways (RCP2.6 and RCP8.5). For the projected RCP8.5 periods the ensemble mean shows an average difference on maximum temperature for the mid-term (2051-2075) around 3.5ºC and for the long-term (2076-2099) above 4.5ºC relative to the historical period for April to October.

Recent studies show that Bolivia is passing through climatic changes such as lower annual precipitation levels and increase of daily temperature levels. These changes are increasing the duration and intensity of dry periods escalating the basin exposure to climate change (Seiler, Hutjes, & Kabat, 2013). CMIP3/5 models projected an increase in temperature (2.5°C–5.9°C), with seasonal and regional differences. In the lowlands, both ensembles agreed on less rainfall (–19%) during drier months (June–August and September–November), with significant changes in interannual rainfall variability, but disagreed on changes during wetter months (January–March) (Seiler, Hutjes, & Kabat, 2013).

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) assesses the trends of climate change and variability in Central and South America and subregions (Castellanos et al., 2022). The Pantanal is mainly located in the subregions Southeastern South America (SES) and South American Monsoon (SAM). In the case of the SES region the report indicates that there is a medium confidence that the intensity and frequency of extreme precipitation and pluvial floods are projected to increase for 2°C of global warming level and above. For the SAM subregion, the Sixth Assessment Report indicates a high confidence in the projected increased agricultural and ecological drought for the mid-21st century, for 2°C of global warming level and above. Also, increases in one or more aspects between drought, aridity, and fire weather (high confidence) will affect a wide range of sectors, including agriculture, forestry, health, and ecosystems. In the case of extreme precipitation and pluvial floods, there is a medium confidence in the projected increase for a 2°C of global warming level and above. There is a low confidence in projected precipitation changes, but high confidence that the South American monsoon will be delayed during the 21st century.

This low confidence in projected precipitation changes is the result of the uncertainty in the projected changes in hydrology of the Pantanal because of land surface processes that may not be well represented by climate models. Marengo, Alves, & Torres (2015) found out that some model projections for the same scenario and time slice show increases in rainfall and in the discharges of the Paraguay Basin, while others show reductions. However, in general they noted a reduction in rainfall by 2100, with a strong variability among time slices, particularly in summer, and drier conditions from fall to spring. They also concluded that projections of the impacts of climate change on wetlands, including effects in the Pantanal and its watershed, may be still too divergent. As such these uncertainties may make it insufficient for describing climate change impacts in this ecoregion.

For the whole region Central and South America, the Sixth Assessment Report highlights expected common regional changes including: 1) Mean temperatures will continue to increase at rates greater than the global average (*high confidence*).

Massive heatwave events and increase in the frequency of warm extremes are projected at the end of the 21stcentury (*high confidence*)[7]; and 2) Mean precipitation is projected to change, with increases in some subregions (North-West South America NWS and South-East South America SES) and decreases in others (North-East South America NES and South-West South America SWS.

In conclusion, projected increases in the air temperature in the Pantanal can be expected. This together with a projected reduction in rainfall by 2100 with drier conditions from fall to spring (as noted by Marengo, Alves, & Torres (2015) – although with uncertainties), an increased water deficit would be expected, which could affect the pulse of the Paraguay River and the Pantanal, altering ecosystem functioning and severely affecting biodiversity. Also, and as indicated by the Six Assessment report, more extreme pluvial floods and droughts can be expected in the subregions where the Pantanal is located.

3.1.5 Floods and droughts

The flood events in the Pantanal have an extension that ranges between ca. 10,000 and 55,000 km^2 in the period 2000-2020. Not in all cases a high annual rainfall coincided with a large, flooded area. The largest floods in 2011 do not seem to happen as a result of the highest annual rainfall. The relationship between rainfall and flood for the Pantanal can be observed in Figure 3-5.

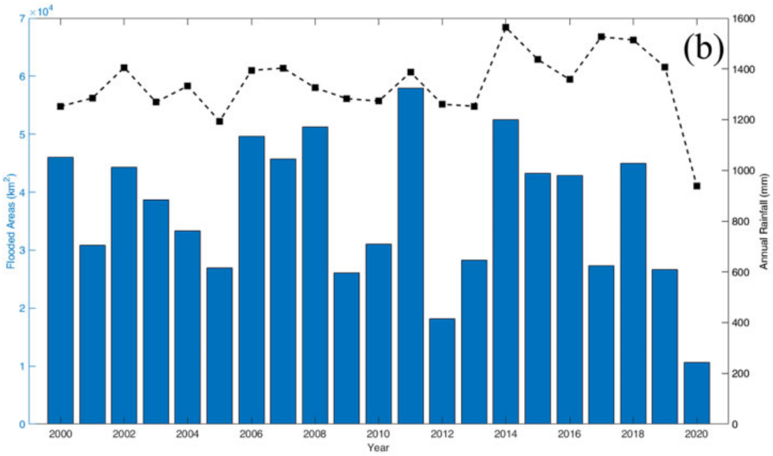

Figure 3-5 Annual flooded area and hydrological-based total rainfall. Annual flooded area (km2) from 2000 to 2020 is presented in blue bars and hydrological-based total accumulated rainfall from August to July in black line. Source: Pereira et al., 2021.

Marengo et al. (2021) studied the flooding and drought periods in the Paraguay river at Ladário (Mato Grosso do Sul). River levels at this location represent the hydrological regime of the UPRB. The Brazilian Navy defines river levels for flood and drought alerts at Ladário. The level for flood alert is ≥400 cm. The minimum level of 150 cm or below is considered as a limit for navigational alert[8]. Considering mean annual river levels, Figure 3-6 shows that the region has passed through eight flooding periods and eight dry periods in the last decade (2010-2020). In terms of floods, the years of 2011, 2014, and 2018 were alarming, with decrees of a state of emergency in the municipality Corumbá (Mato Grosso do Sul). The maximum level registered in 2011 was 562 cm and flooded 23% of the region. With respect to droughts, the most recent minimum level value was 32 cm below the zero level of the gauge in October 2020. This is the lowest level in 49 years.

[7] When comparing 2.0°C with 1.5°C of warming, the longest annual warm wave is projected to increase more than 60 days.

[8] This value is based on the danger for navigation and does not represent any minimum ecological value.

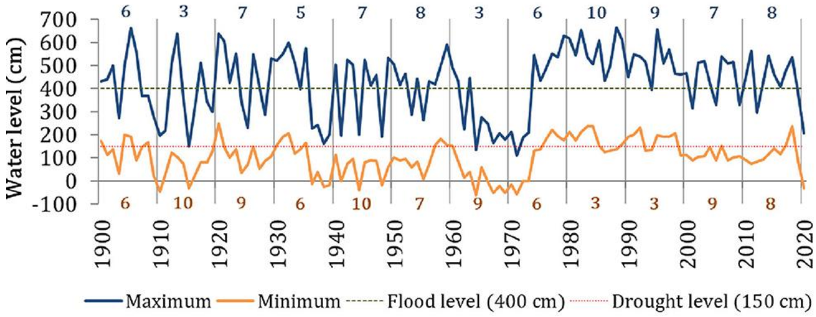

Figure 3-6 Number of flood and drought episodes per decade in the Paraguay River at Ladário, from 1900-2020. Floods are defined according to the Brazilian Navy when maximum river levels are equal or higher than 400 cm, and drought episodes are defined when minimum river levels are equal to or below 150 cm. Source: (Marengo, et al., 2021).

Overall, the Pantanal has been experiencing prolonged dry periods and slightly increased temperatures. Spatial dynamics of drought events in the Pantanal and the highlands have been studied from January 2019 to June 2021 (Thielen, et al., 2021). Drought severity was analyzed based on the Standardized Precipitation Drought Index[9] (SPDI) developed by (McKee, Doesken, & Kleist, 1993) and (Organization—WMO, 2021). Spatial analysis has found that the central section of the Pantanal was under severe drought period (SPDI between -1.5 and -2.0) from 2019 onwards. From 2020 first trimester, extreme drought conditions (SPDI >= -2.0) could also be seen in the northern section of the Pantanal reaching part of the highlands. Only the southernmost part of the basin and a small part of the highlands draining water to Cáceres showed normal precipitation patterns during this time (Thielen, et al., 2021).

Between 1985 and 2022 all biomes in Brazil have lost water surface, with emphasis on the Pantanal, where the retraction was 81.7%[10]. According to the Brazilian National Center for Natural Disaster Monitoring and Alerts, the volume of rainfall in the Brazilian Pantanal from October 2019 to March 2020, which is the rainy season, was 40% lower than the average of previous years (Thielen, et al., 2021). This situation had worsened because the summer 2019 had already been a dry year in the Pantanal, and water stress had accumulated. Without enough rain to fill wetlands, the biome was more susceptible to fires.

In the case of the Bolivian Pantanal, the climate is getting hotter and drier, with the dry season beginning earlier, before May and ending in late-September. This dynamic is different from previous decades (1980-2000), in which the dry season used to begin in late-May and last until end of August or early September ((FAN & WWF Bolivia, 2022).

3.2 Socio-economic activities

Literature shows that agriculture, mining and cattle grazing are the main economic activities developed across the region and important ones for the countries' economic growth and prosperity (FAN & WWF Bolivia, 2022; Tomas, et al., 2020; WWF-Brazil, UCDB & Fundação Tuiuiú, 2017). The Pantanal provides ecosystem services, such as climate regulation and a periodic floods regime that are essential for livestock raising and soil fertility (WWF, 2017; Tomas, et al., 2020). The following sections summarize the socio-economic activities per country.

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[9] The Standardized Precipitation Index (SPI-n) The SPI is based on the probability of precipitation for any time scale. The probability of observed precipitation is then transformed into an index. An SPDI >= 4.0 indicates an extremely wet period, while an SPDI >= -2 indicate an extreme drought

[10] https://brasil.mapbiomas.org/2023/02/15/brasil-ganha-17-milhao-de-hectares-de-agua-em-2022-mas-continua-secando/

3.2.1 Brazil

The most pressing activity in the region is livestock raising relying on high water demand and land conversion, followed by agriculture (WWF-Brazil, UCDB & Fundação Tuiuiú, 2017). In addition, almost 10% of the national livestock activity is concentrated in the basin, mostly in the highland. Livestock on the Pantanal has low productivity due to the flooding of pastures, requiring the cattle to take refuge in the highland (ANA, 2018; OAS, 2005; WWF-Brazil, UCDB & Fundação Tuiuiú, 2017).

Cattle ranching holds significant significance in the Pantanal, serving as a primary income source. Estimates of ecosystem service values in this region varied from 6000 USD/ha/year to 10,000 USD/ha/year (Baigún & Minotti, 2021). The cattle herd in the Brazilian Pantanal is estimated as 3.8 million heads, producing more than 1 million calves per year (Tomas W. , et al., 2019). These valuations encompass various ecosystem services, including water supply, disturbance regulation, waste treatment, cultural value, water regulation, nutrient cycling, recreation, and habitat worth (Baigún & Minotti, 2021).

Agriculture is the second most common water intensive economic activity that relies on the basin for irrigation. In the Pantanal region of Brazil, irrigation in agriculture isn't as prevalent compared to other regions. The area often relies more on natural water sources like rivers, lakes, and wetlands for farming due to its unique ecosystem. However, when necessary, farmers use methods such as floodplain irrigation or diverting water from natural sources to fields.

In the Highlands region of Brazil, there's more diversity in irrigation methods. Farmers use various techniques depending on factors like crop type, terrain, and available resources. Common methods include drip irrigation, sprinkler systems, and even gravity-fed systems using water from reservoirs or rivers (Carvalho, et al., 2020). The main production crops are soy, cotton, sugarcane, and corn (ANA, 2018). The expansion of monocultures is a main driver of land conversion in the Brazilian UPRB area (WWF-Brazil, UCDB & Fundação Tuiuiú, 2017).

Mining and other industrial activities correspond to 10% of the total water abstraction in the basin. Mining extraction is diverse in the region, with a higher presence in Mato Grosso State. Limestone, gold, diamond, charcoal for the steel industry and iron and manganese extraction are the most common mining activities in the region. In Mato Grosso do Sul, there are records of more than 1,225 registered charcoal kilns (ANA, 2018). Previous studies have established a direct connection between significant demand for charcoal and deforestation. These studies highlight that charcoal production, when not produced in accordance with Sustainable Forest Management practices, has resulted in a depletion of resources (Numazawa, Krasovskiy, Kraxner, & Pietsch, 2020).

Mining investments in Mato Grosso do Sul are forecasted to surpass R$ 5 billion in the coming two years, driven by the region's abundant natural resources concentrated mainly in Corumbá, Ladário, Miranda, Bodoquena, Bonito, and Porto Murtinho. These estimations, provided by Semagro, originate from mineral companies engaged in various sectors like aggregates, iron, manganese, copper, limestone, and soil remineralizers, essential for sustainable farming practices.

The mining sector in Mato Grosso do Sul has witnessed significant activity, with the National Mining Agency (ANM) reporting 72 research requisitions, 21 Research Grants, and 10 licensing requests as of May 2022 (O Pantaneiro, 2022) . Notably, in 2022, Vale sold the Corumbá mining company to J&F for $1.2 billion, involving assets contributing US$110 million in adjusted EBITDA to Vale in 2021 (SEMADESC, 2022).

Mato Grosso do Sul holds significant reserves of high-grade iron ore, ranking as a primary manganese reserve holder in Brazil and possessing considerable phosphate reserves, garnering notable investor attention (O Pantaneiro, 2022).

Hydropower generation in the basin accounts for around 1% of the national hydropower energy production, not improving social-economic circumstances locally. Hydropower projects in Brazil have adversely affected low-income communities in multiple ways. These large-scale initiatives have resulted in the forced relocation of these communities, leading to the loss of their homes, lands, and traditional sources of livelihood (Von Sperling, 2012).

Moreover, such projects often cause environmental harm, impacting ecosystems, water quality, and biodiversity, thereby disrupting the local sources of income that rely on natural resources (Alho, 2020). The social repercussions are significant, triggering challenges like the loss of cultural identity, increased poverty, and internal conflicts within these displaced communities. Additionally, the benefits generated from hydropower initiatives tend to favor larger industries or wealthier groups, creating an unequal distribution of advantages that bypasses the most vulnerable populations.

In 2020, a study released discussed renewable energy alternatives within the Upper Paraguay Basin (BAP), focusing on 125 Small Hydroelectric Power Plants (SHPs) proposed for the Pantanal and Alto Araguaia basin, potentially impacting the region's sensitive ecosystem. The study highlights the feasibility of generating the same 1,172 MW projected by these SHPs through locally available renewable sources such as sugarcane biomass, animal waste, municipal solid waste, liquid effluents, and solar energy (WWF-Brazil, 2019). Moreover, it calls for a shift away from heavy reliance on SHPs to embrace multiple renewable energy sources, promoting job creation and reduced environmental disruption in the region. Additionally, it addresses concerns regarding SHPs’ environmental impacts, emphasizing the importance of exploring alternative energy sources to ensure sustainability and minimize ecological damage in the Upper Paraguay Basin (WWF-Brazil, 2019).

Tourism is an important economic activity that generates income to the local population. Millions of tourists travel to the Pantanal region attracted by its rich wildlife, transparent water courses and sport fishing. In 2017, a study revealed that jaguar-based tourism in the northern Pantanal region brought in a gross annual income of $6.8 million. In contrast, losses from cattle depredation amounted to $121,500. This means that jaguars contribute up to 56 times more in tourism revenue than the expenses they cause to ranchers (Tortato, Izzo, Hoogesteijn, & Peres, 2017).

The fishing industry is an important economic activity in the Pantanal area from a social perspective. According to official data, more than 12,3 thousand professional, artisanal and industrial fishers are present in the region. In general terms, ecotourism and subsistence fishing are highly valuable socioeconomic activities contributing to environmental conservation and water quality.

The fishing industry generates jobs and income to the riverside and indigenous population rely on it for subsistence (Shrestha, Seidl, & Moraes, 2002) . Moreover, previous studies have found that recreational fishing values in the Brazilian Pantanal have a significant consumer surplus (CS) per fishing trip, ranging between $540.54 and $869.57. This resulted in a total social welfare estimate of $35 million to $56 million, showcasing the substantial economic importance of recreational fishing in the region (Shrestha, Seidl, & Moraes, 2002). More recent studies have found that artisanal fishermen can have net earnings from $90 per month to $297 per month in the low and high season respectively (Chiaravalloti, 2019). However, when it comes to artisanal fishermen owning a boat this value increases to $153 per month to $1,323 per month in the low and high seasons respectively (Chiaravalloti, 2019) .

More specifically in the Cuiaba River, located in the Brazilian Pantanal the annual economic value of recreational fishery was estimated at around US$1.8 million, which highlights the importance of this activity to the local economy (Massaroli, et al., 2021)

The Paraná Paraguay Waterway serves as an important commodity transportation route between the Atlantic and Pacific oceans. The Waterway flows from Cáceres to Corumbá in Brazil and to Aguirre in Bolivia, passing through the Pantanal. Although there's an intergovernmental committee focused on the functioning of the Waterway as transport route between Argentina, Bolivia, Brazil, Paraguay and Uruguay, there's no integrated committee in the river basin to ensure the integrated management of water resources (Zugaib, 2006; Tomas, et al., 2020).

The Waterway utilization in Brazil surged by 5.36% in 2022, according to the National Waterway Transportation Agency (Antaq). The overall inland transportation reached 38.4 million tons, with notable cargo increases in specific regions, such as a 45.9% surge in the Paraguay hydrographic area. Corn transport showed the most significant growth, with an 87.2% increase, while petroleum oil and derivatives rose by 14.4% in 2022 (Datamar , 2023). Iron ore is the dominating cargo in the Paraguay Waterway Region. In the first half of 2023, 2 million tons of iron ore were moved between Brazil and Paraguay through the Waterway (Pix News MS, 2023).

Moreover, in August 2023 the Brazilian government announced a Growth Acceleration Project with investments in waterway transports summing R$ 4.1 billion. A total of 131 projects are planned and the Waterway is part of the major project. The project seeks to transform the Paraguay River into a primary route for continuous barge transportation, operating around the clock throughout the year. This plan involves significant alterations, like permanent dredging in currently pristine areas of the Pantanal. These changes may result in severe environmental consequences, leading to adverse social effects (Ecology and Action, 2023).

Another important aspect of the Brazilian UPRB is the presence of riverside, indigenous and Quilombola populations, which are groups that have a high dependence on water resources. These groups rely on the nature of the basin as food and income source, besides its cultural heritage value.

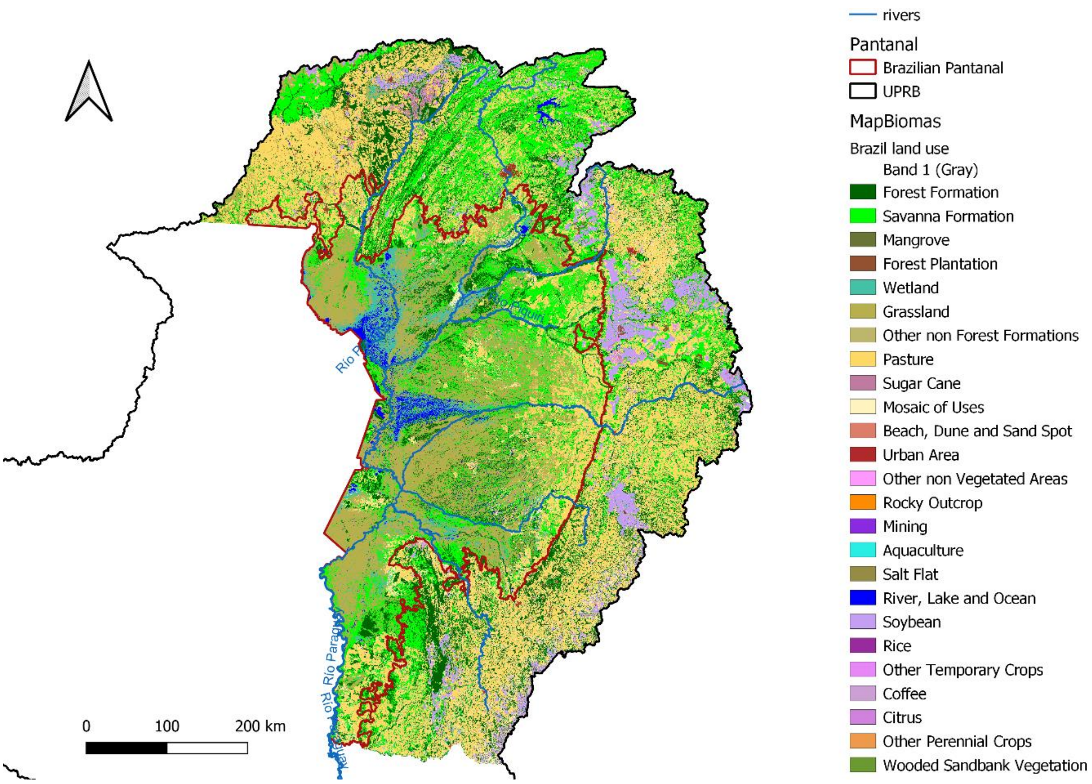

Figure 3-7. Land use map of the Brazilian UPRB and Pantanal in 2021. Source: MapBiomas Brazil[11].

3.2.2 Bolivia

The Bolivian part of the UPRB has a very low Human Development Index (HDI). The population is distributed between urban (most of it) and communal rural. Economic developments, such as wood and charcoal demand from the steel and mining industry are present in the region, although not developed yet. Agriculture and livestock are scattered throughout the area and are greatly relevant to the local economy (MapBiomas Bolivia, 2023). Part of the UPRB comprises the Bolivian Pantanal and a small part of the Chaco region (FAN & WWF Bolivia, 2022).

A segment of the rural populace engages in forestry practices, while the majority sustains themselves through small-scale subsistence agriculture. The significant economic contribution stems from extensive livestock farming, predominantly on both native and cultivated pastures. The urban sector primarily focuses on service-oriented businesses. The urban part of the basin embraces important cities for the economic development of the country, such as Puerto Suárez, Roboré and Puerto Quijarro, where farmers, cattle grazing and agricultural land can also be found (FOBOMADE & IUCN, 2004).

Regarding tourism and hospitality services, there are a few lodges and eco-friendly accommodations catering to visitors interested in exploring the Pantanal. The tourism industry is often focus on eco-tourism, offering guided tours and experiences to observe the region's wildlife and ecosystems.

Bolivia's Pantanal comprises a mosaic of distinct forests, including the Cerrado, Chaco, and Chiquitano forest.

[11] https://brasil.mapbiomas.org/en/#

This area experiences prolonged dry seasons, coinciding with the traditional use of fire for various productive purposes, often leading to forest fires that occasionally spread across borders. These fires are linked to land clearance for both small and large-scale agricultural sites.

For instance, close to Puerto Suárez, the Chaco region is located, subject to intense dry periods, which coincides with the deliberate use of fire causing forest fires. These anthropic forest fires are promoted due to the need to grow grass for extensive livestock raising and for clearing land for agricultural use. The practice is legal and justified by the sectors as cost-beneficial since it saves time and money. A common consequence of slash-and-burn practice is that fire can get out of control and spread rapidly, becoming extensive and eventually crossing country borders (FAN & WWF Bolivia, 2022; Mongabay News, 2021).

Over the last decade deforestation doubled, compared to the previous two decades, in important areas of the Bolivian Pantanal, such as Roboré, San Matías, and Puerto Quijarro, impacting the environment and vulnerable groups, such as indigenous population and riverside communities (FAN & WWF Bolivia, 2022). In particular, the Tucavaca region has been exploited by mainly the mining industry and the agrobusiness sector (The Nature Conservancy; WWF Brazil, 2011; FAN & WWF Bolivia, 2020).

In the Bolivian part of the basin, although not a predominant activity, there are mining poles in the regions of Urucum, Rincón Del Tigre and the Tucavaca Valley (PNUD, 2009).

Additionally, the logistics and transportation services in this area are crucial for connecting remote communities and facilitating trade and commerce. The movement of goods, especially agricultural produce, relies on navigable waterways, emphasizing the importance of maintaining the navigability of the Paraguay River and its tributaries.

Finally, the Paraná-Paraguay Waterway has a length of 48 km between Bolivia (Aguirre) and Brazil (Corumbá). Although Bolivia has the smallest part of the Waterway, it’s an important commodity route, especially to grains, cereals, wood and fertilizers between the Atlantic and Pacific oceans (Capra, 2003). Currently, Bolivia has three private port facilities on the Waterway: Gravetal, Aguirre and Jennefer, facilitating the mobilization of millions of tons of cargo from international trade (not counting gas) between El Mutún and Puerto Busch (Capra, 2003; FOBOMADE & IUCN, 2004).

Moreover, according to the National Statistics Institute (INE), Bolivia's exports of traditional and non-traditional products from 1992 to 2023 indicate that in 2022, the country exported soy and its derivatives valued at 2,229.8 million dollars, with over 90% of this export movement taking place via the waterway. From 1980s until half of 2023, 2 million tons of cargo originated from Bolivia were flowed through the Waterway to other countries (Barbosa, 2023)

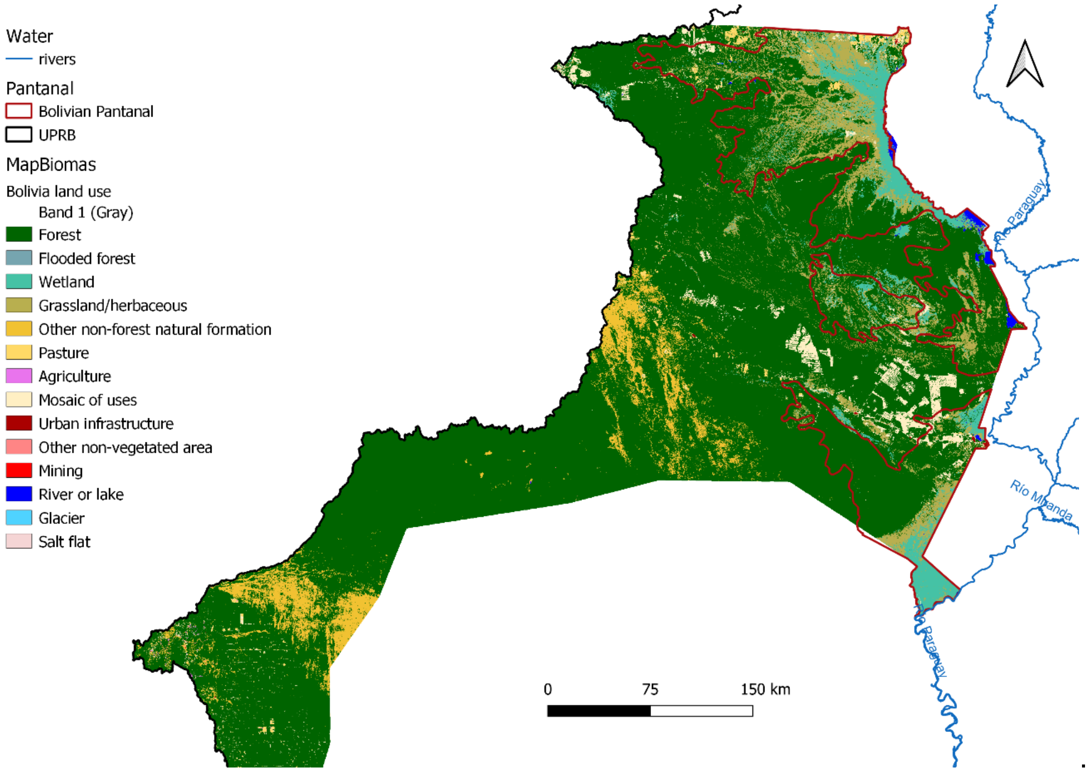

Figure 3-8 Land use map of the Bolivian UPRB and Pantanal in 2021. Source: MapBiomas Bolivia[12].

3.2.3 Paraguay

The UPRB in Paraguay is low populated. Most of the Pantanal has a low population, such as in Bahía Negra, Carmelo Peralta, Isla Margarita (INE, 2023) (Carrón, 2003). The UPRB and Pantanal are subjected to economic activities, such as agriculture, cattle grazing, and fishing. Mining is also present, but as an activity with less economic relevance. An array of social actors can be found in the Paraguayan part of the basin, such as rural and indigenous communities and livestock and agriculture large farmers.

The whole Rio Paraguay basin is of high importance for the country's economy since it concentrates 56% of its industries, especially sugar and alcohol, cotton and tobacco, which are highly water dependent (IDB, 2020). However, specific details regarding the importance of the Upper Paraguay River Basin are not currently available.

Further studies are necessary to understand the accurate economic worth of agriculture, cattle grazing, and fishing in the Paraguayan part of the basin. These investigations are needed to capture crucial factors like production yields, market pricing, and productivity. However, earlier assessments indicate that cattle grazing stands as the primary economic driver in the Paraguay River Basin, with a cattle count exceeding 30 million heads within the basin (WWF, 2018)

Within the Upper Paraguay River Basin, approximately 27% of the entire cattle grazing industry operates. This practice is located in specific ecoregions: the Dry Chaco (32.8%), Wet Chaco (19.6%), and the Pantanal (13.2%) (DNCC/MADES; VMG; DGP/MAG; INFONA, 2022). The Pantanal region dedicates 130 hectares to cattle grazing and 141 hectares to silviculture (DNCC/MADES; VMG; DGP/MAG; INFONA, 2022). Despite this, detailed specifics about the Upper Paraguay River Basin and the Pantanal remain scarce.

[12] https://bolivia.mapbiomas.org/

Fishing plays a vital role as a means of subsistence within the basin. In 2021, discussions arose about potentially imposing a fishing ban lasting over 90 days along the basin's borders with Brazil (RCC, 2020). The ban caught nationwide attention due to its potential impact on low-income and indigenous communities, which heavily rely on the income from fishing. Cities like Bahía Negra and Fuerte Olimpo alone are home to approximately 900 fishermen, predominantly from indigenous communities such as Ishir and Tomarahos. Species like Surubí and Pacú hold significant market value within these communities, fetching prices of, ₲ 25,000 and ₲ 30,000 per kilo, respectively (ABC, 2021).

Although with less economic relevance, mining activities also take place in the region due to the Brazilian demand for charcoal from the steel industry (Carrón, 2003). Moreover, gas and oil pipelines were installed in the region between Bolivia and Paraguay and a bio-oceanic corridor is under construction (Carrón, 2003).

Most of the Paraná Paraguay Waterway is in Paraguay with 557 km within the UPRB and 332 km between Brazil and Paraguay borders. It's an important route to transport grains, cereals, wood and fertilizers between the Atlantic and the Pacific Oceans (Capra, 2003). It also facilitates an important economic activity for the Paraguay economy, the transportation of minerals, grains, and soy and it's planned to be expanded (IDB, 2020). According to the Paraguayan government, around 14 million tons of products were transported in 2020 via the Waterway. Moreover, the government assesses that around 10 to 11 million tons of national products are transported annually, with soy and flower leading the numbers (Juárez, 2022).

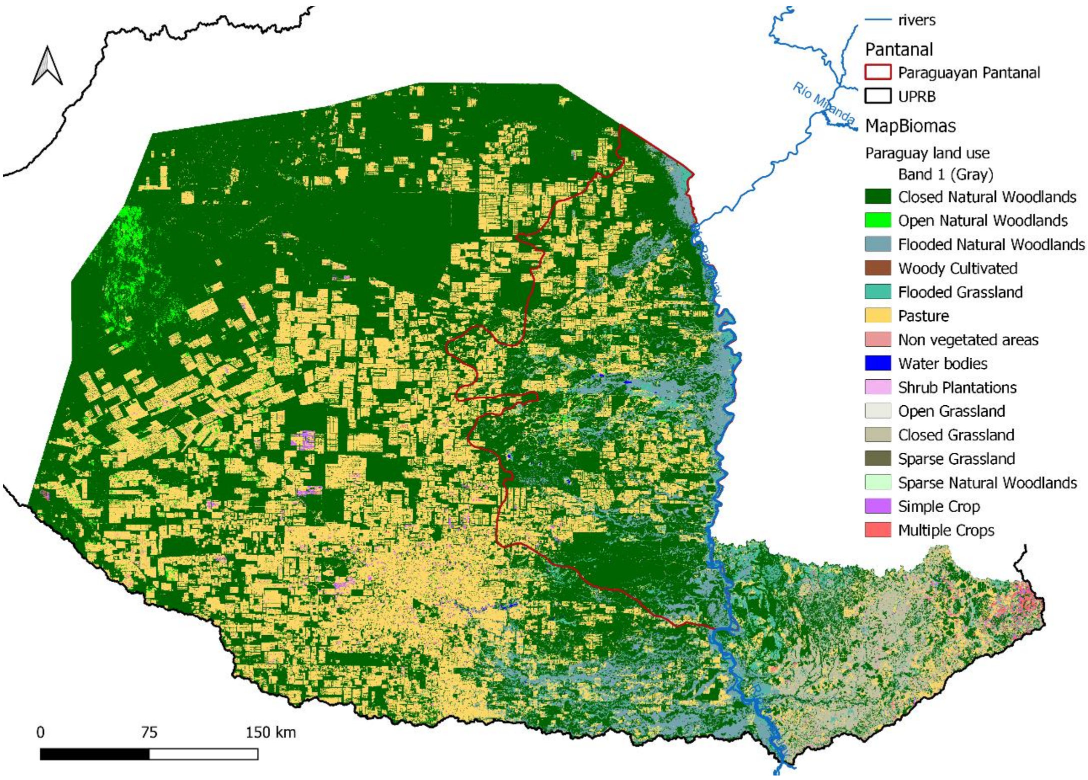

Figure 3-9 Land use map of the Paraguayan UPRB and Pantanal in 2021. Source: MapBiomas Chaco[13].

[13] https://chaco.mapbiomas.org/

3.3 Protected and indigenous areas

Previous research found that the Pantanal is rich with different cultures, such as indigenous peoples and traditional riverside communities that live in this territory and rely in the Pantanal for fishing, for clean water access, for temporary settlements, and for obtaining other natural goods (Bolzan, Roque, & Louzada, 2022).

Figure 3-10 display the protected areas (in green) and indigenous areas (in pink) in the UPRB and the Pantanal region.

The Paraguayan UPRB has lost almost 40% of its terrestrial ecosystems and is under high environmental risk, which resulted in the creation of many protected areas. It has 61 protected areas covering 12.5% of its area. The basin comprises the Paraguayan Pantanal, an important wetland and biodiversity refuge (IDB, 2020). The Paraguayan Pantanal region is composed by sub-humid forests, wetlands and periodically flooded forests and the Río Negro National Park, which is a protected area, ensuring the maintenance of part of the Pantanal (USAID, 2006).

About 10% of the Bolivian Pantanal area is comprised of indigenous reserves and 65% of protected areas (MapBiomas Bolivia, 2023). Key areas of the Bolivian Pantanal are the Tucavaca, Laguna Cáceres, Correreca and Curichi Grande, which supply water to the northern part of the Pantanal (The Nature Conservancy; WWF Brazil, 2011). The Tucavaca region is an important area of the Bolivian Pantanal due to its natural richness, biodiversity refuge and provider of water to the Paraguay river. It also encompasses the Tucavaca valley, which is a protected area. Also, it provides other ecosystem services, such as regulation and mitigation of climate risks, support and cultural services. Otuquis is a National Park and Integrated Management Area in the Pantanal ecoregion and San Matías is an Integrated Management Natural Area located in Santa Cruz. Both protected areas are highly important to the conservation of the fauna and flora of the Bolivian Pantanal and the UPRB.

In Brazil, around 4.7% of the Pantanal is protected by law as 28 Conservation Units, of which 6 are fully protected and 22 are bound to sustainable use (Ministerio do Meio Ambiente, 2023)[14]. In the Brazilian Pantanal protected areas such as headwaters of the Paraguay rivers are important as well as the Pantanal Matogrossense National Park and the Special Reserves of Acurizal, Penha and Doroche, covering a total area of more than 185,000 hectares. This protected area complex is located in western central Brazil, in the extreme south-west of the Mato Grosso e Mato Grosso do Sul State and the international border with Bolivia and Paraguay (UNESCO, 2023). Moreover, in the Brazilian Pantanal an immense private protected area is located called Private Natural Heritage Reserve (RPPN) SESC Pantanal. More than 20 years ago, a private social corporation called SESC purchased a number of cattle ranches in the Pantanal area, restoring over 2% of the Pantanal in the State of Mato Grosso (IUCN, 2018).

[14] Sustainable use under the Conservation Units seeks to reconcile the use of natural resources with nature conservation in a sustainable manner. Therefore, it permits the presence of residents in these units and activities involving the collection and use of natural resources, provided it occurs in a responsible manner, not depleting environmental resources and harming ecological processes. On the other hand, the full Conservation Units only permits its indirect natural sources use and forbids any anthropic interference (ANA, 2023).

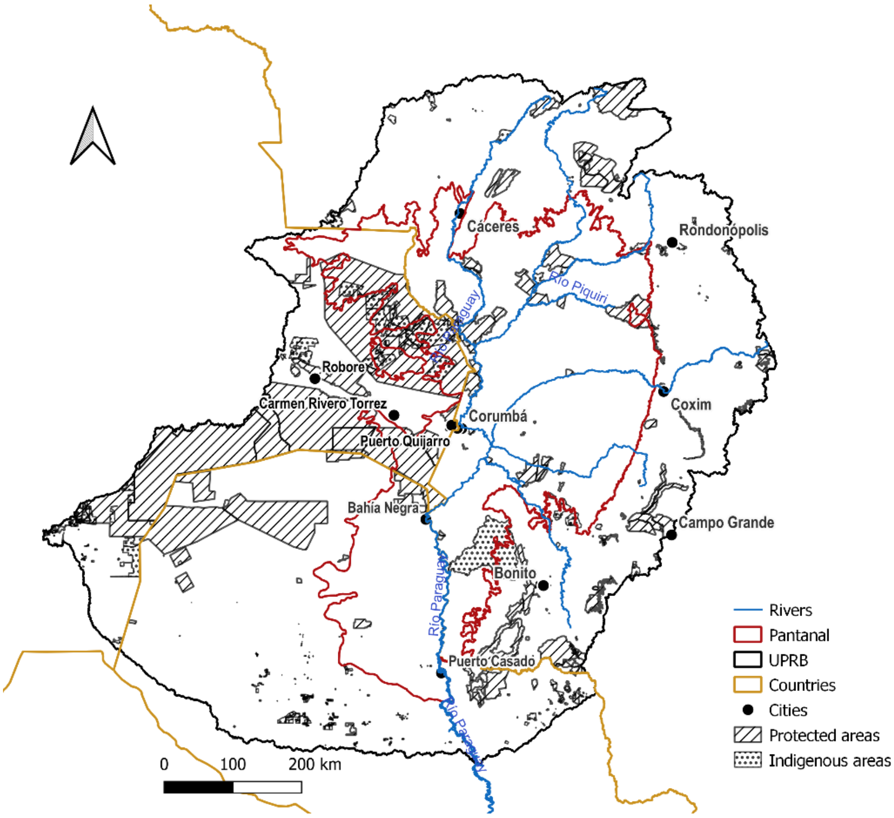

Figure 3-10 Protected and indigenous areas in the UPRB and the Pantanal region.

3.4 Jaguar corridors

The vision of the WWF Jaguar Strategy for 2030 (WWF, 2020) is to secure *"a continental network of priority landscapes that ensures the permanence and recovery of jaguars, their habitats and the ecosystem services they provide, and provides connectivity within and between jaguar priority areas, whilst also contributing to the sustainable development of people and communities coexisting with jaguars".* The strategy covers WWF priority jaguar landscapes and some of them also overlap with or are contiguous to jaguar corridors of other organizations doing jaguar conservation work. Figure 3-11 shows the draft Jaguar corridors in UPRB jointly identified by a group of experts of Bolivia, Paraguay and Brazil in the framework of the Wildlife Connect initiative. The map also shows the presence of WWF through different projects.

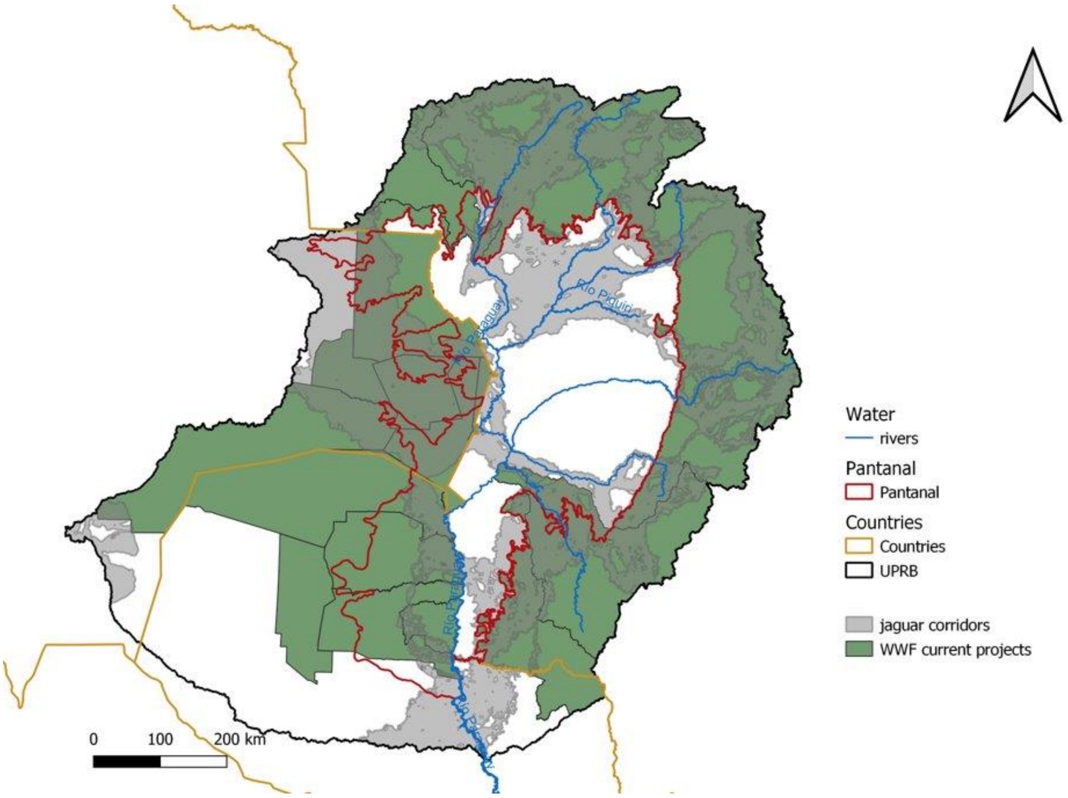

Figure 3-11 Locations of draft Jaguar corridors and current projects of WWF.

4 Overview of water-related challenges

Previous studies have already identified the main challenges in the UPRB and Pantanal region (FAN & WWF Bolivia, 2022; Tomas, et al., 2020; WWF-Brazil, UCDB & Fundação Tuiuiú, 2017; Bedoya, 2018). In most cases, these challenges are specific to each country and relate to pressures on the basin impacting the availability, supply and quality of water, causing land degradation and erosion. Understanding current water exploitation within the region provides insights in actors who benefit from water security and navigation purposes and the ones benefiting from land exploration. As discussed in Section 3.2, main activities and economic sectors exercising pressure over the water resources on the UPRB are agriculture, livestock, mining, industry, transportation and energy.

The overview of water-related challenges is grouped into two categories and described in the following sections:

1 Infrastructure developments affecting water availability, water supply and water quality.
2 Land use and conversion due to economic activities.

4.1 Infrastructure developments affecting water availability, water supply and water quality

Water availability and supply, although intrinsically related to natural pressures within the Pantanal, are impacted by infrastructure developments, such as the construction of hydropower plants, dams, reservoirs, oil and gas pipelines and the Paraguay-Paraná Waterway. At the same time, infrastructure services can be affected by the natural system.

The alteration of river flows, water quality deterioration and water related conflicts resulting from the development of economic activities in the region are the main challenges to water availability and supply. Figure 4-1 shows the infrastructure development in the UPRB. The figure displays a map with the navigation routes, including the Paraná-Paraguay Waterway and Port facilities in the basin. Moreover, it also shows oil and gas pipelines, reservoirs, dams and hydropower plants implemented in the basin covering the three countries. More importantly, it displays how these infrastructure developments are placed in relation to river streams.

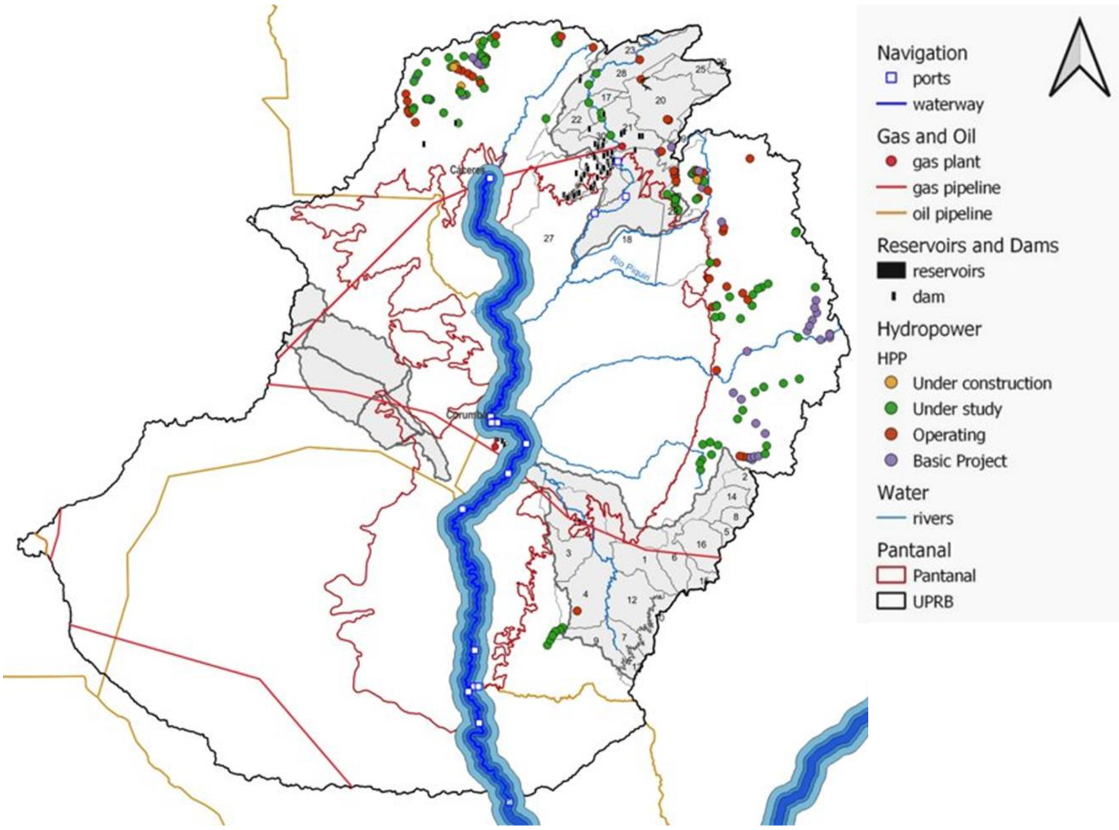

Figure 4-1. Infrastructure developments in the UPRB. Around the Waterway a buffer of 5, 10 and 20 km is defined. Sources: Ports: GeoBolivia[15]; Waterway: MapBiomas (Souza et al. 2020); Dams and reservoirs: MapBiomas (Souza et al. 2020), GeoBolivia; Hydroelectric power plants: ANA; Gas and oil pipelines: Global Energy Monitor, MapBiomas (Souza et al. 2020).

Infrastructure for energy generation

Figure 4-1 shows hydropower plants in the waterheads of the UPRB, mainly in the highlands in Brazil. Red dots are plants in operation, yellow dots are plants under construction, green dots are plants under study and grey dots plants with basic projects.

Currently, the UPRB has 53 operational dams (small and big) and according to (IUCN, 2021) more than 100 dams are in the planning. The installation of small hydropower plants in the Brazilian Pantanal are strategic for Brazil's energy mix. Future dams have the potential to alter the natural flow of the wetland (flood pulse), decrease floodplains, lose river connectivity, alter nutrient cycling, sedimentation processes and water quality downstream, impacting multiple water uses (such as ecotourism and fishing) and the fauna and flora in the region, and causing irreversible damage to the ecosystems (Tomas, et al., 2020); (IUCN, 2021). The cumulative effect of several small hydropower plants on the hydrological dynamics of the Pantanal is still unknown but expected to be huge (The Nature Conservancy; WWF Brazil, 2011). It also impacts the riverside population, due to the lasting drastic environmental change that feeds into significant losses to the riverside communities in the Pantanal.

15 http://geo.gob.bo/portal/

Infrastructure for oil and gas distribution
Figure 4-1 displays the oil pipelines (light brown lines) and gas pipelines (red lines) in the three countries. The oil and gas production in the region contributes to water pollution due to production of hydrocarbons and chemical compounds that are harmful to human health; therefore, halting water availability for domestic supply.

In Bolivia, the oil and gas extraction in the UPRB is one of the main drivers of water contamination by organic compounds. In addition, precipitation can increase the dissolution of such compounds, increasing the contamination area (The Nature Conservancy; WWF Brazil, 2011). In Paraguay, although oil and gas are not extracted, there have been recent attempts to eliminate public protected areas to start prospecting activities.

Navigation (Paraná – Paraguay Waterway)
Infrastructure projects have massive implications for the transborder regions (OAS, 2005). Brazil, Paraguay, and Bolivia are part of the agreement for the construction and use of the Paraná-Paraguay Waterway, a navigable canal that crosses the UPRB, through the Paraguay and Paraná rivers and some of their tributaries that allows the navigation of deep-draft ships and large volumes of cargo. The Waterway, shown in Figure 4-1 as a blue line along the Paraguay river, connects the Atlantic and Pacific oceans and has impacts on the basin and Pantanal regions of the three countries. Through the Waterway important agricultural products are transported, such as soybeans and corn, livestock and to a lesser extent, iron ore from mines in the region (Zugaib, 2006). As previously mentioned, droughts have affected the hydrologic dynamics of the Pantanal, also affecting transportation in the river as its level reached extremely low values, making difficult for the transportation of soybeans through the Waterway Paraná-Paraguay (Marengo et al, 2021). The exploration of the Waterway by the mining industry for production flow is a big challenge for the region, especially in the part from Corumbá towards Argentinian ports, as a great part of Brazil's internal load transportation relies on the Waterway (Zugaib, 2006).

The functioning of the Waterway requires anthropic interventions on the north part of the Waterway, which has low navigability conditions, and requires annual dredging, open channels,, increase depth, impacting the water quality and aquatic ecosystem of the basin, damaging and destroying fish spawning grounds which directly affects the fishing industry (IUCN, 2021), but also the tourism industry. In Brazil, the Waterway has been reported to contribute to water-related conflicts, alteration of flow regimes, water quality deterioration, impact of the surrounding areas and deterioration of aquatic species (The Nature Conservancy; WWF Brazil, 2011). Moreover, the zone between Paraguay and Brazil is rocky and requires even more extreme measures to open space for navigation, such as dynamite the bottom of the canal to increase its depth (Capra, 2003). The Waterway crosses the Pantanal region in Bolivia, contributing to its environmental impact, such as biodiversity loss and aquatic species halt, due to dredging activities (Capra, 2003). Furthermore, the Waterway alters the water regime due to the expansion, deepening and rectification of channels, decreasing the area occupied by the Pantanal, halting it’s flood regulatory effect and increasing sediment suspension, decreasing the water quality of the rivers (FOBOMADE & IUCN, 2004).

Finally, the expansion of the Paraná-Paraguay Waterway is the planning phase (Tomas, et al., 2020). Extensive interventions, such as channel straightening, dredging, and rock removal, have been planned in the Paraguay River. Most of these irreversible interventions will happen along the 1,270-km section of the river that crosses the Pantanal. Questions regarding the potential impacts of the Waterway, for example on ecosystems, remain open.

4.2 Land use and conversion

For over 50 years the UPRB has undergone significant socioeconomic development, such as intense settlement, urbanization of the region and land use and conversion. Previous land use monitoring studies show that around 70% of the UPRB is composed by natural areas, whereas 23% is destined to anthropic uses, including livestock raising, mining and agricultural lands (WWF-Brazil, UCDB & Fundação Tuiuiú, 2017). Currently, more than 90% of the Pantanal is owned by agrobusiness companies (Tomas, et al., 2020).

Land use and conversion related problems, such as erosion and silting up of water courses and reservoirs, embrace challenges related to the economic activities exerting pressure in the area. Although erosion processes are part of the natural dynamics of the UPRB, they have been highly accelerated due to land use and occupation profiles. Also, the agroindustry exerts great pressure on the basin, due to high water demand and waste discharges (ANA, 2018). Some of these activities are developed in close proximity to protected and indigenous areas, which can feed water-related conflicts due to multiple water use and land use disputes.

Flood regimes have become increasingly problematic as a result of the changes in land use that have occurred in recent decades. This is associated with the phenomena of erosion and sediment transport, generated by the drag and deposit of sediments by the action of water, the force of gravity and the wind.

During the dry season, fires occur as part of the natural dynamic of the Pantanal to renew native pasture, facilitating the regrowth of many species. Nevertheless, anthropic activities have been further intensifying fires, severely impacting the hydrology of the Pantanal (Marengo, et al., 2021).

Livestock
Poor livestock management contributes to soil and water degradation, increasing erosion which results in sedimentation of water courses and siltation of rivers (The Nature Conservancy; WWF Brazil, 2011). Livestock is one of the main activities, together with agriculture, responsible for the deforestation that occurs in the Brazilian highlands. Currently, more than 60% of its native forest was converted into pasture and agriculture land (Bolzan, Roque, & Louzada, 2022). As such, these are areas with an elevated erosion potential (ANA, 2018). Upstream activities are highly detrimental to downstream activities (such as the fishing industry that is highly impacted by the closure of avulsion canals by landowners) (ANA, 2018). In the Pantanal, livestock has low productivity compared to the highlands, which occurs due to peak floods and flooding of pasture areas in its plain region (ANA, 2018). Another threat in the Brazilian part of the basin are the non-natural forest fires related to the agrobusiness that impact directly the water quality and facilitate erosion by degrading the soil (Bolzan, Roque, & Louzada, 2022).

In the Bolivian UPRB, livestock is also an important driver of land conversion, contributing to increase deforestation and anthropic forest fires, known as slash and burn, to open space for cattle grazing and pasture renew. This technique can change climatic conditions, causing droughts to become more prolonged and intense, cause conflicts with indigenous communities nearby and increase municipalities exposure to climate change impacts and water quality deterioration (FAN & WWF Bolivia, 2022; Mongabay News, 2021; FCBC, 2019). In 2019, Bolivia experienced one of the most extensive and ecologically impactful forest fires, with more than 5 million hectares affected by flames. Part of the affected region embraced two protected areas, Otuquis and San Matías, and indigenous communities (ANA Bolivia, 2021; Mongabay News, 2021).

In 2021 the deforestation and land conversion reached 33.4% of the average of the previous five years in the Paraguayan part of the UPRB. Recent deforestation is also linked to severe degradation of land which reduced forest covers generating an increase of non-natural unforested areas and loss of ecosystems (Revista Nomadas, 2023). Also, areas of the Paraguayan Pantanal have been affected by the fires.

Agriculture
The expansion of the agricultural sector is a topic of great relevance in the whole UPRB, since it currently exerts significant pressure on water resources in quantitative and qualitative terms (ANA, 2018). Agriculture and livestock activities developed in the highlands highly affect economic activities (as fishing and tourism industry) in the Pantanal due to rivers siltation and high nutrients load on water from agriculture runoff (ANA, 2018; Bolzan, Roque, & Louzada, 2022; The Nature Conservancy; WWF Brazil, 2011). The occupation of naturally sensitive areas, with high potential for sediment production, and inadequate soil management on the plateau cause erosion and siltation of water bodies on the wetland. In this regard, Paraguay river springs are one of the most critical areas that suffer the direct impact of siltation (Bolzan, Roque, & Louzada, 2022; WWF-Brazil, UCDB & Fundação Tuiuiú, 2017). The pollution of rivers and riverbeds with high nutrient loads cause the eutrophication of water sources which compromises water supply. Pesticides and fertilizers are highly utilized by the agrobusiness which contributes to bioaccumulation of toxic compounds in the food chain, impacting aquatic ecosystems and human health (ANA, 2018).

Furthermore, agriculture expansion is increasing deforestation and changes in infiltration and runoff. Farmers and fishermen conflicts are also common in the region. Barriers built from farmers directly impact other activities, such as subsistence fishing, and feed water-related conflicts. It also affects the availability of water for indigenous and traditional communities.

In Brazil, agriculture practices take place mostly in the highlands, producing sediments that are transported to the Pantanal. During the passage of water from the rivers of the Brazilian highlands through the Pantanal floodplains, sediments are retained in the land, and there is a decrease in the sediments that are then exported downstream of the rivers. Even when there is no land conversion in the Pantanal, the influence of land use changes in the highlands can affect the sediment retention capacity of the floodplain (WWF-Brazil, UCDB & Fundação Tuiuiú, 2017), in particular when the floodplain get overloaded and sediment cannot be retained further.

Agriculture expansion in Bolivia is increasing deforestation of rivers headwaters contributing to soil degradation and water quality deterioration (FOBOMADE & IUCN, 2004). Recent deforestation levels are increasing in the Tucavaca Valley, which is under agriculture expansion (FAN & WWF Bolivia, 2022). In the Chaco region recent studies show that agrobusiness is expected to develop which will increase deforestation and enhanced erosion and sediment transport due to the implementation of mechanized agriculture techniques (FAN & WWF Bolivia, 2020).

The Paraguayan part of the basin is scarcely populated It is occupied almost entirely by cattle ranches of different typologies (from silvopastoral based on native grasses to ore intensive based on conversion of forest to exotic pastures). Additionally, the largest Protected Areas of the Country are located within, as well as IP’s territories. Clearing natural vegetation to establish pastures deteriorates organic matter levels and soil physical properties.

Mining
Land use and conversion to mining activities causes problems of water availability and quality, as well as deforestation and erosion.

Mining in the Brazilian UPRB is primarily focused on extracting iron and manganese, which comes with high water demand. The region of Morraria do Urucum is an important mining area but also a high-water stressed area. According to ANA (2018), the mining industry contributes to deforestation, increasing erosion and soil subsidence and impacting the local flora and communities' subsistence activities. Mining also contributes to the contamination of springs used for domestic supply and may lead to water conflicts among water users in the region (e.g., agriculture, drinking water, mining, tourism and leisure).

Mining in Bolivia causes direct and indirect impacts to water systems, including overexploitation of water resources, putting other water sources at risk, as it is the case in Laguna Cáceres (FAN & WWF Bolivia, 2020). Furthermore, mining has accumulated impacts since the colonization periods, such as water quality deterioration due to untreated waste discharges directly in local rivers (PNUD, 2009).

In Paraguay, water quality deterioration stands out due to pollution from the mining industry, especially on the borders. In addition, cassiterite deposits and acid drainage can be seen because of mining (IDB, 2020).

5 Impacted ecosystem services in the UPRB

The main challenges related to the activities that take place in the UPRB are different in the highlands and the Pantanal region but are intrinsically related. It is noteworthy that the challenges have significant impacts on ecosystem services, as they disrupt the natural functioning of ecosystems and can lead to various ecological consequences.

5.1 Water-related challenges and ecosystem services in the Highlands

In the Highlands, main water-challenges and impact on ecosystem services include:

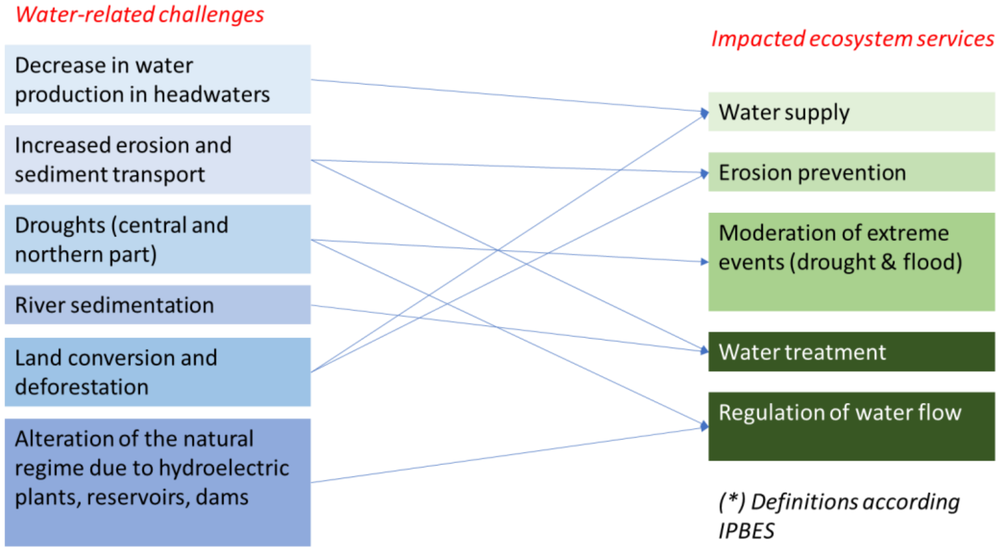

Figure 5-1 Water-related challenges and impact in ecosystem services in the Highlands.

- Water Supply:
  - Headwaters in the Highland region are the upper reaches of river systems where water potentially originates. Reduced water production in headwaters can lead to decreased water availability downstream, affecting water supply for communities, agriculture, and industries (Bendoya, 2018; Rachael H. Nolan, 2022).
  - Drought leads to reduced water availability, affecting water supply for human needs, agriculture, and ecosystems.
  - Deforestation reduces water availability for indigenous and local communities, which depend on local resources to acquire food and water. Deforestation affects habitat availability and can lead to the loss of plant and animal species, impacting ecosystem diversity and consequently local communities and indigenous routine and long-term life (Guerra, et al., 2019).
  - Changes in river flows due to dam operations can influence downstream water availability, affecting human water supply and agricultural irrigation.

- Erosion prevention
    - High erosion can affect the erosion prevention function in the Highlands ((Colman, Oliveira, Almagro, Soares-Filho, & Rodrigues, 2019).
    - Deforestation increases soil erosion rates, leading to sedimentation in rivers and degrading water quality (Guerra, et al., 2019; Colman, Oliveira, Almagro, Soares-Filho, & Rodrigues, 2019) .
    - Erosion removes fertile topsoil, reducing soil productivity for agriculture and impacting food production.
    - Dams can trap sediment, reducing downstream sediment supply and potentially leading to riverbed erosion (IUCN, 2021).
    - Increased sedimentation can hinder river navigation, affecting transportation and trade (Capra, 2003; Guerra, et al., 2019).
- Extreme events moderation
    - Drought stress can lead to increased extreme events consequently affecting the ecosystem, plants and wildlife, causing biodiversity loss and reduced ecosystem resilience and also affecting local communities and cities access to water (Crossman, Nedkov, & Brander, 2019).
- Water purification
    - Eroded sediment can enter water bodies, leading to increased siltation, reduced water clarity, and degraded water quality. This affects aquatic life and also other uses of water, such as human consumption, industry and agricultural use.
    - Excessive sedimentation can lead to reduced water clarity, impacting aquatic life and making water unsuitable for certain uses. It can also affect the aquatic habitat by degrading aquatic habitats, affecting fish spawning areas and other critical habitats impacting the subsistence and fishing industry (Colman, Oliveira, Almagro, Soares-Filho, & Rodrigues, 2019).
- Water Flow Regulation:
    - Droughts disrupt the natural functioning of ecosystems and water flows, consequently affecting nutrient cycling, water uses along the water bodies (e.g., use of water resources by local communities) and other ecological processes (Crossman, Nedkov, & Brander, 2019).
    - The alteration of river flows can lead to changes in plant and animal communities, affecting biodiversity (Crossman, Nedkov, & Brander, 2019).

5.2 Water-related challenges and ecosystem services in the Pantanal region

When it comes to the Pantanal, a unique wetland, the challenges can have significant impacts on ecosystem services, disrupting the already sensitive Pantanal dynamic.

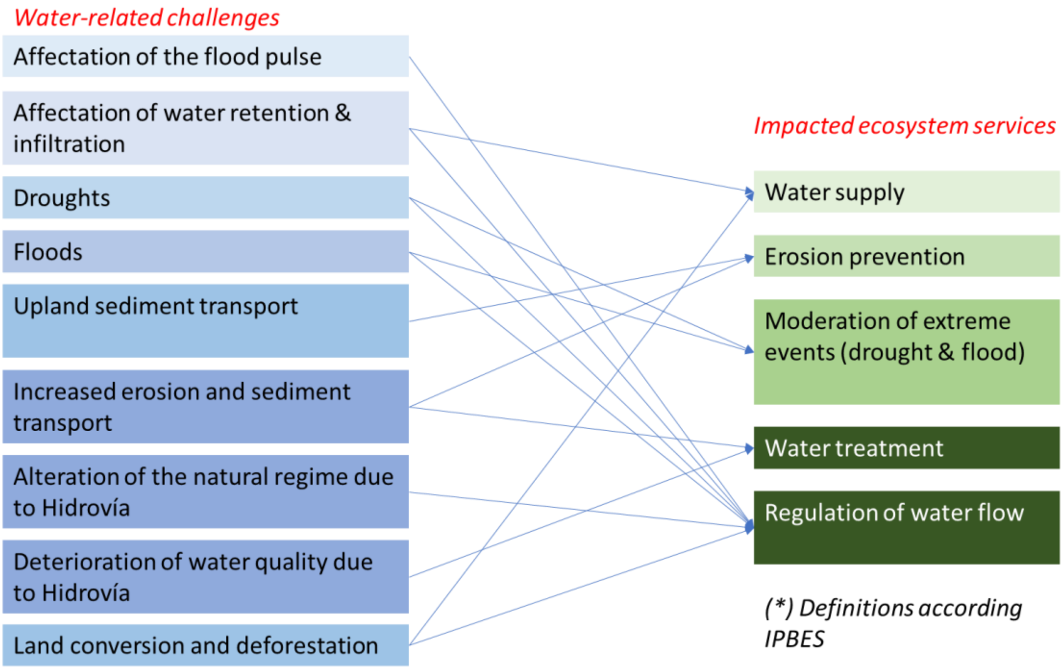

Figure 5-2. Water-related challenge and impact in ecosystem services in the Pantanal.

- Water supply:
  - Changes in water retention and infiltration can impact water availability in the wetland during both dry and wet seasons, affecting wildlife and human communities that rely on these water resources (Bendoya, 2018).
  - Deforestation reduces water availability impacting ecosystem diversity and human uses.
- Erosion Prevention:
  - Sediments carried from highland areas to the Pantanal play an important role in the wetland's nutrients and fertility of Pantanal soils supporting vegetation and wildlife. However, economic activities taking place in the Highlands contribute to disproportionately carrying sediments to the Pantanal, affecting soil fertility and erosion prevention capabilities. Sediments contribute to the formation and maintenance of wetland areas, such as riverbanks. Once sediments are overly transported by the Highlands, it decreases erosion prevention and have negative impacts on Pantanal's water and services that economic sectors rely on (Colman, Oliveira, Almagro, Soares-Filho, & Rodrigues, 2019).
  - Once erosion increases, sediments are carried more easily, contributing to a decrease in erosion prevention (Colman, Oliveira, Almagro, Soares-Filho, & Rodrigues, 2019).

- Moderation of extreme events:
  - Prolonged droughts can lead to habitat loss, reduced food availability, and increased stress on wildlife populations, impacting events moderating, therefore impacting the economic activities in the region that feed into the loop of extreme events (Marengo, Alves, & Torres, 2015).
  - While floods are a natural part of the Pantanal's ecosystem, extreme or poorly managed floods can negatively impact ecosystem services. Unplanned or excessive floods can damage infrastructure and disrupt human activities in the region. In addition, severe floods can affect local communities' livelihoods, such as agriculture and tourism, which depend on stable and predictable flood patterns (Crossman, Nedkov, & Brander, 2019).
- Water purification:
  - Excessive sedimentation can degrade water quality, affecting aquatic life and making water less suitable for human use.
  - Pollution from waterway operations can deteriorate water quality, harming aquatic life and making water unsafe for various uses. Besides, changes in river flows can affect water quality in the Pantanal, potentially impacting wildlife and human communities that depend on the water resources.
- Water Flow Regulation
  - The Pantanal's flood pulse is a vital natural process where seasonal floods inundate the region, creating diverse wetland habitats that support a wide variety of plant and animal species. The flood pulse is essential for maintaining the unique biodiversity of the Pantanal. Changes in flood timing and intensity can impact the distribution and abundance of flora and fauna due to alteration of river flows (Crossman, Nedkov, & Brander, 2019).
  - Proper water retention and infiltration help maintain diverse wetland habitats that support a variety of plant and animal species, essential for the economic activities in and around the region (Crossman, Nedkov, & Brander, 2019).
  - Droughts can lead to water scarcity, impacting wetland habitats and the animals that depend on them (Crossman, Nedkov, & Brander, 2019).
  - Natural River flow patterns help regulate flooding in adjacent areas. When river flow is altered, the risk of floods or the severity of flood events can increase, leading to property damage and loss of life (Crossman, Nedkov, & Brander, 2019).
  - The Waterway can disrupt aquatic habitats and migration patterns of fish species, affecting the fishing industry and other activities such as tourism, recreation and subsistence use of water (Capra, 2003).
  - Deforestation increases soil erosion rates, leading to sedimentation in rivers, altering regulation of river flows (Crossman, Nedkov, & Brander, 2019).

Overall, these challenges highlight the interconnectedness of ecosystem services with natural processes and addressing them requires a holistic approach that considers the ecological implications of human activities on water resources and ecosystems. Moreover, the challenges in the Pantanal region have complex interactions with the Highlands and ecosystem services. Thus, addressing them requires a comprehensive and integrated approach that considers the ecological, social, and economic aspects of the wetland ecosystem. Conservation efforts, sustainable land and water management practices, and collaboration between stakeholders are essential to protect and preserve the valuable ecosystem services the UPRB provides.

5.3 Potential of providing the relevant impacted ecosystem services in the UPRB

As presented above relevant impacted ecosystem services in the UPRB are water supply, erosion prevention, extreme events moderation, water purification and water flow regulation.

To assess the locations in the UPRB with potential of providing the relevant impacted ecosystem services, a simplified method was applied through which relevant variables are studied with available georeferenced information (or GIS information) for the entire UPRB (and not for each country separately). Table 5-1 summarizes the relevant variables and the parameters used for the spatial analysis. The following sections provide a description of each relevant variable.

Table 5-1. Simplified method for assessing locations with potential provision of impacted ecosystem services (relevant variables) based on available georeferenced information (selected parameters).

Impacted ecosystem services	**Simplified method: Relevant variables**	**Selected parameters based on available georeferenced information**
Water supply	Water potential (potential for water retention and potential for water runoff)	Slope, precipitation, potential evapotranspiration
Erosion prevention	Erosion potential	Slope, roughness
Moderation of extreme events (drought and flood)	Infiltration potential Water retention potential	Slope, saturated hydraulic conductivity Slope, precipitation, potential evapotranspiration
Water purification	Erosion potential	Slope, roughness
Regulation of Water Flow	Infiltration potential Water retention potential	Slope, saturated hydraulic conductivity Slope, precipitation, potential evapotranspiration

5.3.1 Water potential

To get an indication of the water potential in the UPRB, the variables precipitation (P), potential evapotranspiration (PET) and slope have been studied. The highest rainfall occurs in the highlands of the basin, and it is the rain in the headwaters that largely feeds the flood pulse of the Pantanal.

We focused on the seasonal water deficit (i.e., precipitation minus potential evapotranspiration, P-PET). We obtained monthly data for P and PET for the period 2000 to 2022 and analyzed them per season. As we were looking into water potential in the UPRB we focused on the rainy season (March, April and May). The analysis was done for the average of the total P-PET in the rainy months per year. Precipitation has been obtained from CHIRPS daily rainfall series that were aggregated to monthly values (Funk et al. 2015). PET data were obtained from ERA5 by ECMWF[16].

[16] https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5

The slope of the land has an influence on surface water runoff. Gentle slopes on the land can facilitate water retention and limit runoff. Slopes in the basin vary approximately between 0 and 60%. For our analysis, we have grouped the slopes in 3 categories: Low slopes (<= 2%), medium slopes (>2%, <=10%), and high slopes (>10%). The slopes have been obtained from MERIT Hydro[17], which is a global hydrographic database (Figure 5-3 presents schematically the combination of the above-mentioned variables to define areas with great potential for water retention and runoff. Water retention potential is defined as the intersection of layers low slopes and high P-PET and medium P-PET. Runoff potential is defined as the intersection of layers high slopes and high P-PET and medium P-PET.

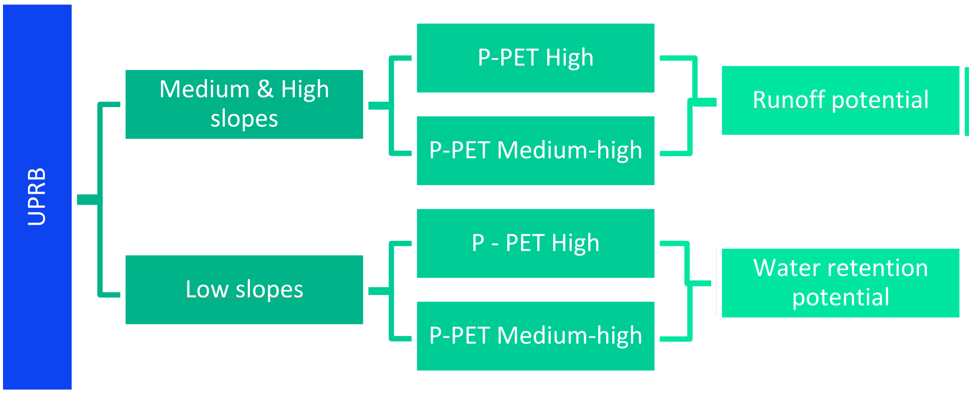

Figure 5-3 Combination of variables slopes and P-PET to define runoff potential and water retention potential.

Figure 5-4 shows the maps of water retention potential and runoff potential as result of the intersection variables P-PET and slope.

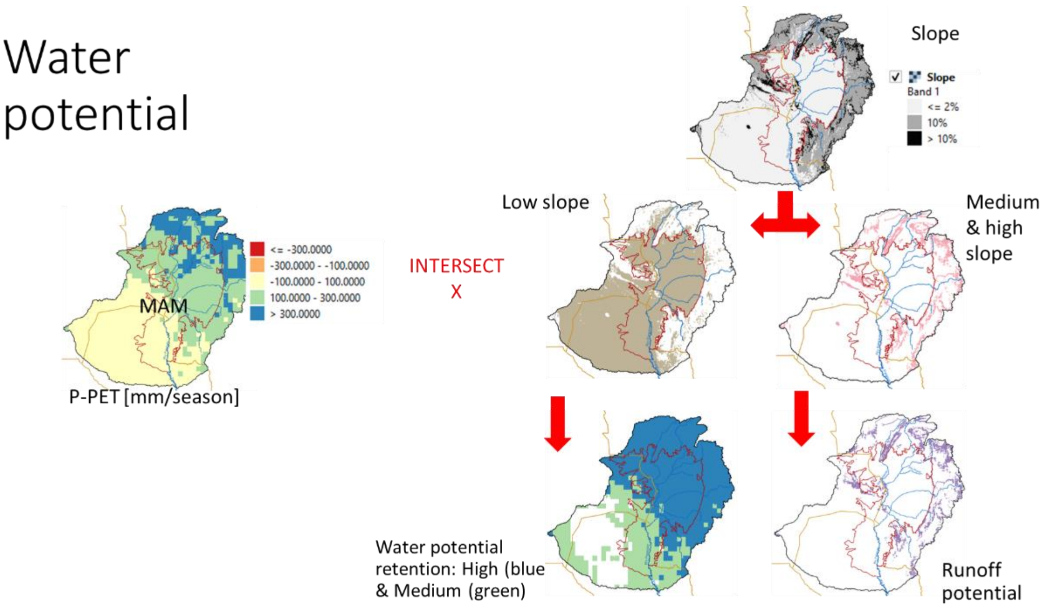

Figure 5-4 Maps of water retention potential and runoff potential in the UPRB as result of the combination of slopes and P-PET.

[17] http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/

5.3.2 Erosion potential

The areas susceptible to greater erosion have been defined based on slopes and soil roughness. The speed of the flow depends on the roughness or amount of friction between the water and the channel or soil. Smoother channels will have less friction and therefore faster flow. Channel roughness contributes to turbulence, which dissipates energy and reduces flow velocity. Flow speed is directly related to erosion potential in the sense that the faster a stream moves, the more energy it has. The roughness is represented by the Manning coefficient (N). A high N number corresponds to a rougher soil. Softer soils with lower friction have lower N values. Areas with low roughness offer a higher flow velocity and a greater probability of erosion. This coefficient is widely used for hydrological modelling of watercourses. Manning values in the UPRB range between 0.01 to 0.5. For our analysis we have identified areas with an N value lower or equal than to 0.3 (low roughness), which excludes vegetation such as forests, shrublands and mangroves. The roughness was obtained using the Hydromt-wflow table (Eilander, D. et al. 2022).

Likewise, the slope influences the flow speed and therefore the erosion potential. Areas with steep slopes are more prone to erosion. In this case we use high and medium slopes.

Figure 5-5 presents schematically the combination of the above-mentioned variables to define areas with high potential for erosion. Erosion potential is defined as the intersection of layers high slopes and low and medium Manning coefficient.

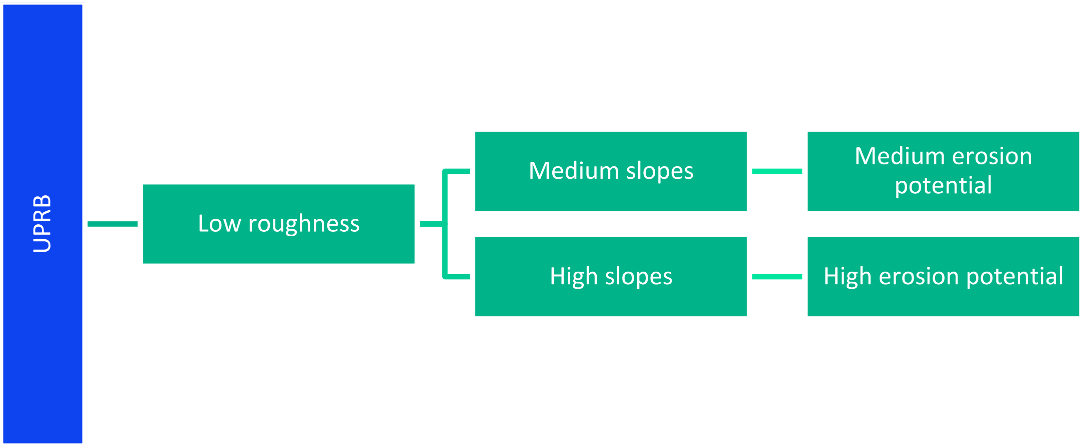

Figure 5-5 Combination of variables slopes and manning coefficient to define erosion potential.

The map in Figure 5-6 shows the areas with a greater erosion potential as result of the intersection of the two variables in the UPRB. That is, areas with low roughness and steep slopes.

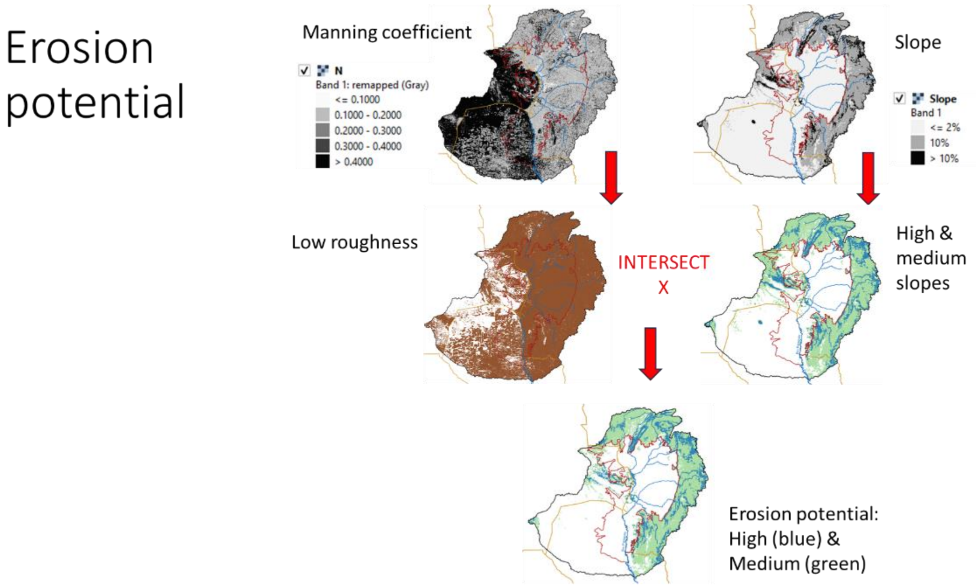

Figure 5-6 Maps of erosion potential in the UPRB as result of the combination of slopes and roughness.

5.3.3 Infiltration potential

The infiltration capacity of a soil refers to the flow rate of water that passes through it, also known as saturated hydraulic conductivity. It is expressed as the height of filtered water per unit of time (mm/h). Depending on the textures of the soil, different infiltration values will be reached, and the curves will in turn be different depending on whether they are heavy soils such as clay or light soils such as sandy ones. A high hydraulic water conductivity indicates a greater height of infiltrated water per unit of time. For our analysis, we have identified the areas with high saturated hydraulic conductivity (KSatVer >= 1,500 mm/day) and with medium saturated hydraulic conductivity (500 mm/day <= KSatVer < 1,500 mm/day). The source of information is RO Imhoff (2020).

Low slopes offer likely conditions for the flow of water to be held up or run off very slowly. For our analysis we consider areas with a low slope (<=2%).

For the generation of this map, the areas with high saturated water conductivity were intersected with the areas with low slopes. In addition, the map presents all the floodplains.

Figure 5-7 presents schematically the combination of the above-mentioned variables to define areas with great potential for infiltration. Infiltration potential is defined as the intersection of layers low slopes and high KSatVer and medium KSatVer.

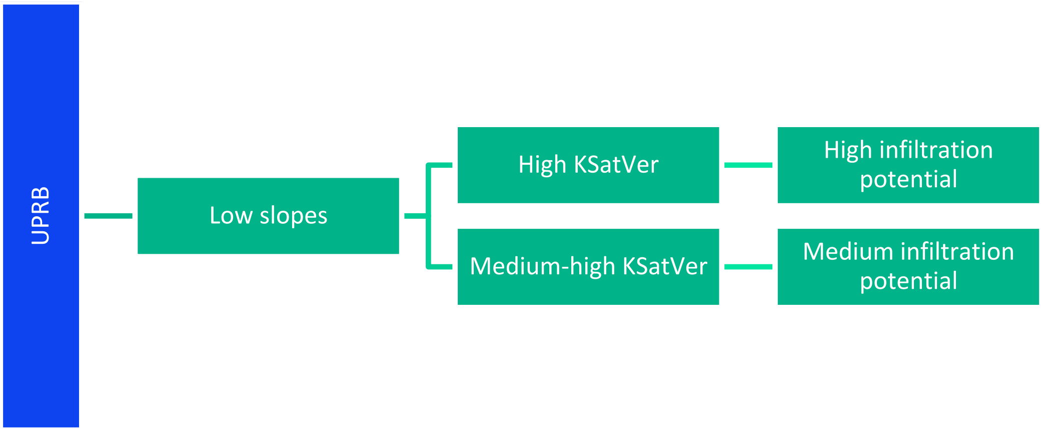

Figure 5-7 Combination of variables slopes and saturated hydraulic conductivity to define infiltration potential.

The map in Figure 5-8 shows the areas with a greater infiltration potential as result of the intersection of the two variables in the UPRB. That is, areas with low slopes and medium and high saturated hydraulic conductivity.

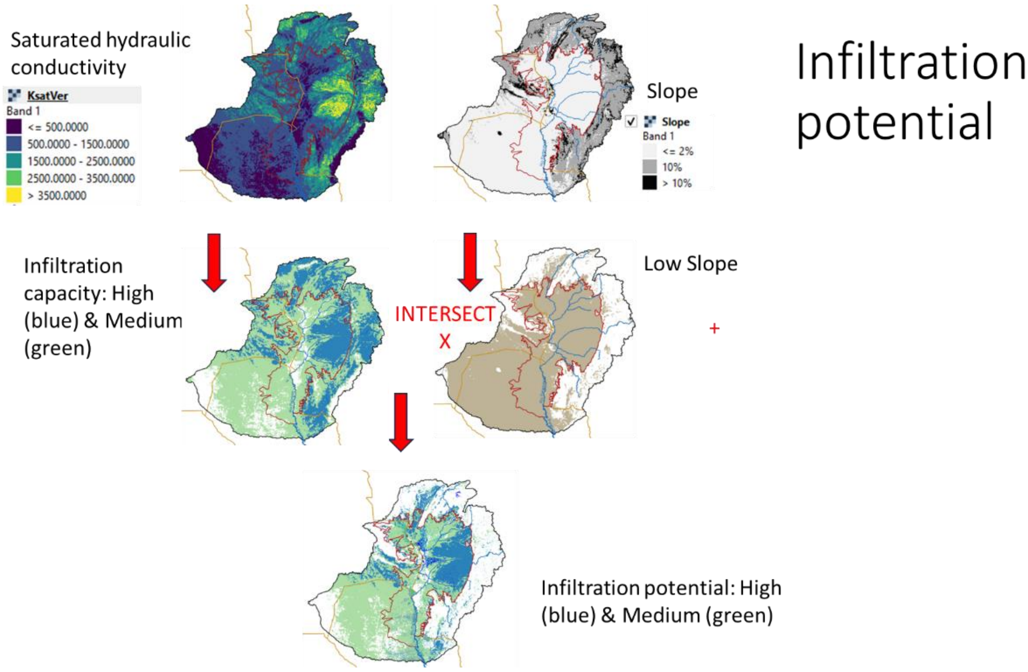

Figure 5-8 Maps of infiltration potential in the UPRB as result of the combination of slopes and saturated hydraulic conductivity.

6 Inventory of Nature-based Solutions

To address the challenges that impact the Highlands and the Pantanal region in the UPRB, the development of an inventory of nature-based solutions (NbS) emerges as a promising approach that leverages the power of nature to tackle water-related issues while promoting social and economic well-being.

NbS refer to strategies that utilize natural processes and ecosystems to address environmental challenges. Instead of relying solely on traditional engineering approaches, NbS harness the resilience and efficiency of nature to restore, enhance, or mimic natural functions. These solutions integrate ecological, social, and economic perspectives, providing multifaceted benefits while contributing to climate change mitigation and adaptation efforts.

NbS can restore the natural hydrological balance in the Pantanal and Highlands region by promoting better water retention, infiltration, and floodplain restoration. This approach can help maintain the unique flood pulse of the Pantanal and alleviate issues caused by altered river flows and water scarcity in the Highlands. In addition, implementing NbS can contribute to cleaner water sources that support both human communities and wildlife.

Moreover, nature-based solutions can enhance the region's resilience to the impacts of climate change, including extreme weather events, droughts, and floods. By preserving natural ecosystems, NbS provide natural buffers against climate-induced challenges.

Figure 6-1 presents the steps followed for developing the NbS inventory.

Step 1 NbS recopilation

- The first step involves identifying and sourcing NbS catalogues to select potential solutions that can fit the area and/or were implemented in similar wetlands and/or to address similar challenges. Moreover, exchanges with local WWF offices from Brazil, Bolivia and Paraguay was held to understand the measures already implemented there and more in-depth characteristics of the critical areas

Step 2 NbS assessment

- The second step includes gathering the collection of NbS identified and assessing its benefits related to ecosystem services, scale of implementation and potential location (e.g. highland, lowland, headwaters and etc). The inventory includes a range of NbS, such as related to conservation, restoration, gray infrastructure complementation, and sustainable land management practices. Each solution is tailored to the unique characteristics of the critical areas of the Pantanal and Planalto region.

Step 3 NbS categorization

- The third step involves developing categories that fit the characteristics of the area to group potential applicable NbS. In this step, eight categories were created to group 37 NbS.

Figure 6-1 Steps followed for developing a NbS inventory for the UPRB and Pantanal.

6.1 NbS List

Developing an inventory of nature-based solutions for water challenges in the Pantanal and highlands region represents a visionary step towards sustainable water management and ecosystem conservation. With effective implementation and collaborative efforts, the inventory can serve as a blueprint for responsible water resource management that benefits both people and the environment. In the ANNEX B the complete NbS inventory can be found with NbS, description, benefits to ecosystem services, scale, and potential location.

Table 6-1. NbS List.

1.	**MANAGEMENT OF INTENSIVE LANDUSE SYSTEMS**	**ECOSYSTEM**
1.1	Crop rotation	Agricultural land
1.2	Strip cropping	Agricultural land
1.3	Terraces	Agricultural land
1.4	Securing land tenure rights increasing natural resources resilience	Agricultural and pasture land
1.5	Transferring rights for traditional land management practices	Agricultural and pasture land
1.6	Target ponds/wetland creation to trap sediment/pollution runoff in farmed landscape	Agricultural and pasture land
1.7	Payment for ecosystem services	Agricultural and pasture land
1.8	Establishing a water fund	Agricultural and pasture land
1.9	Windbreaks	Agricultural and pasture land
2	**FLOODPLAIN MANAGEMENT**	
2.1	Floodplain restoration and management	Floodplains
2.2	Modification of channels (See 3.1, 3.3)	Floodplains, lakes, rivers
2.3	Removing of the legacy sediment (see 4.5)	Floodplains, rivers
2.4	Creation of lakes or ponds in the floodplain	Floodplains
2.5	New/modification of agricultural practices (See 1)	Floodplain, agricultural and pasture land
2.6	Afforestation (See 8)	Floodplain, flooded forest
2.7	Plantation of shrubs and trees (See 6, 8)	Floodplain, flooded forest
2.8	Riparian buffer (See 3.4)	Forest, rivers
2.9	Meadows and pastures for flood storage, increased water retention in the landscape and runoff attenuation	(Flooded) meadows and pasture land
3	**RESTORATION OF RIVERS AND LAKES**	
3.1	Reconnection of oxbow lakes and similar features for flood control	Rivers and lakes
3.2	Removal of dams and other longitudinal barriers	Rivers
3.3	Re-meandering to control the river flow and increase sedimentation	Rivers
3.4	Planted embankment mat	Rivers

3.5	Revetment with cuttings or living revetments	Rivers
3.6	Restoration or reconnection of seasonal streams	Seasonal streams and rivers
3.7	Riverbed material restoration	Rivers
3.9	Removing or reducing the height of embankments	Rivers
3.10	Restoration of lowland rivers	Rivers
4	**RIVERS AND LAKES MANAGEMENT**	
4.1	Diverting and deflecting elements	Rivers
4.2	Innovative river training and stabilization structures	Rivers
4.3	Replacing groynes	Rivers
4.4	Reuse of local large woods	Rivers
4.5	Reuse of rocks	Rivers
4.6	Bank protection measures (gravel bars or timber pilings)	Rivers
4.7	Beneficial reuse of dredged sediments	Rivers
5	**CONSERVATION OF WETLANDS**	
5.1	Maintain and enhance natural wetlands	Wetlands
5.2	Installation of ditches for rewetting or reducing terrain to enable flooding	Wetlands
5.3	Change in land-use and agricultural measures, such as adapting cultivation practices in wetland areas (see 1)	Wetlands, agricultural and pasture lands
6	**FOREST RESTORATION**	
6.1	Forest landscape restoration as a priority policy	Forests
6.2	Replenishing groundwater through reforestation	Forests
7	**FOREST CONSERVATION**	
7.1	Maintenance of forest cover in headwater areas	Forests
7.2	Protect forests from clearing, degradation, logging, fire and unsustainable levels of non-timber resource extraction	Forests
8	**FOREST CREATION**	
8.1	Targeted tree planting for "catching" precipitation	Forests
8.2	Riparian forest	Forests
9	**AQUIFER RECHARGE**	
9.1	Ecosystem-based adaptation in groundwater management (e.g., protection of pollution critical recharge areas, protection of groundwater dependent ecosystems, protection and restoration of riparian zones and floodplains, adaptation of soil and vegetation cover, investing in natural infrastructure like preservation of flood-prone vegetation and grasslands, artificial basins, ponds).	Aquifer recharge areas

6.2 Linking NbS with the areas with impacted ecosystem services

The connection of potential NbS to the impacted ecosystem services in specific locations in the UPRB responds to the following questions:

1. What are current land uses in the locations with a high and/or medium potential for water retention, water infiltration and erosion?
2. What potential NbS options from the inventory can be implemented in the current land use of those locations that enhance the potential of water retention and water infiltration?

3 What potential NbS options from the inventory can be implemented in the current land use of those locations that can reduce the erosion potential?

For the first question, the locations with high and medium potential for water retention, water infiltration and erosion (as presented in Section 5.3) were intersected with the land use maps in the UPRB of each country (Section 3.2). The information source of land use corresponds to MapBiomas Brazil, MapBiomas Bolivia and MapBiomas Chaco[18]. This exercise provides the land uses categories for the different locations that have the potential of providing high or medium level of services.

The second and third questions required the analysis of the NbS in the inventory and the identification of potential NbS options that could be implemented in each relevant land use categories to provide the impacted ecosystem services. As indicated in Chapter 5 challenges and thus impacts on ecosystem services in the UPRB are different in the highlands and the Pantanal region but are intrinsically related. Therefore, potential NbS were identified for the highlands and the Pantanal. Additionally, information on protected and indigenous areas (Section 3.3) and jaguar corridors (Section 3.4) in the UPRB was analyzed.

Then, potential NbS for those areas were identified from the NbS inventory. This analysis was conducted for the Highlands and Pantanal areas, since they have different characteristics and activities in one interfere on the other.

Figure 6-2 to Figure 6-4 present examples of potential NbS for enhancing the impacted ecosystem services in the highlands and the Pantanal.

The list of potential NbS options was discussed with the WWF offices in Bolivia, Brazil and Paraguay in order to validate the applicability of the options in the local context of each country.

[18] Noted that the land use categories of each country are not always the same. Therefore, a simple homologation of the categories was performed for the presentation of the results.

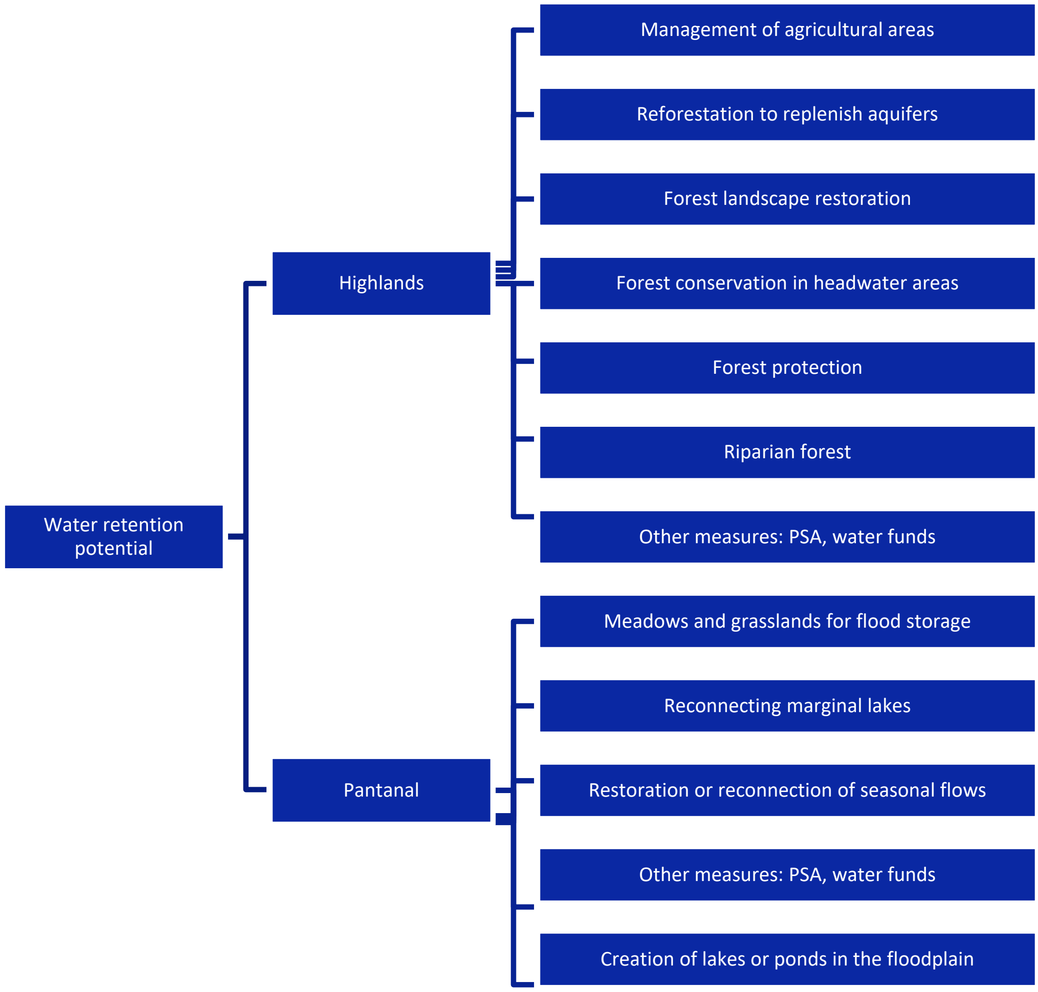

Figure 6-2 Example of potential NbS for enhancing the water retention potential in the highlands and the Pantanal.

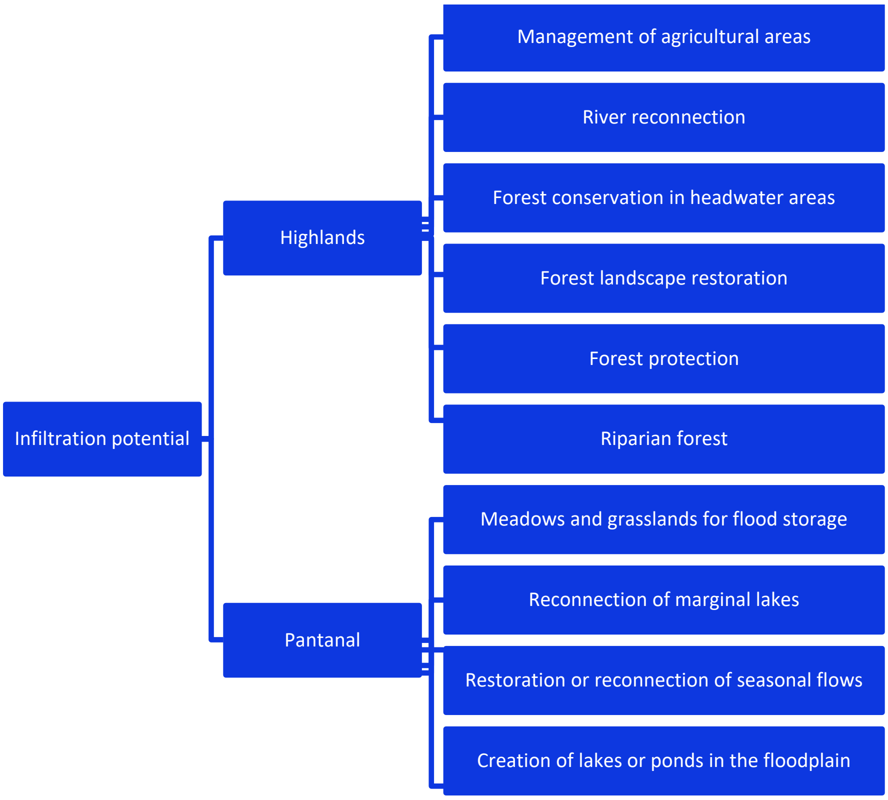

Figure 6-3 Examples of potential NbS for enhancing the infiltration potential in the highlands and the Pantanal.

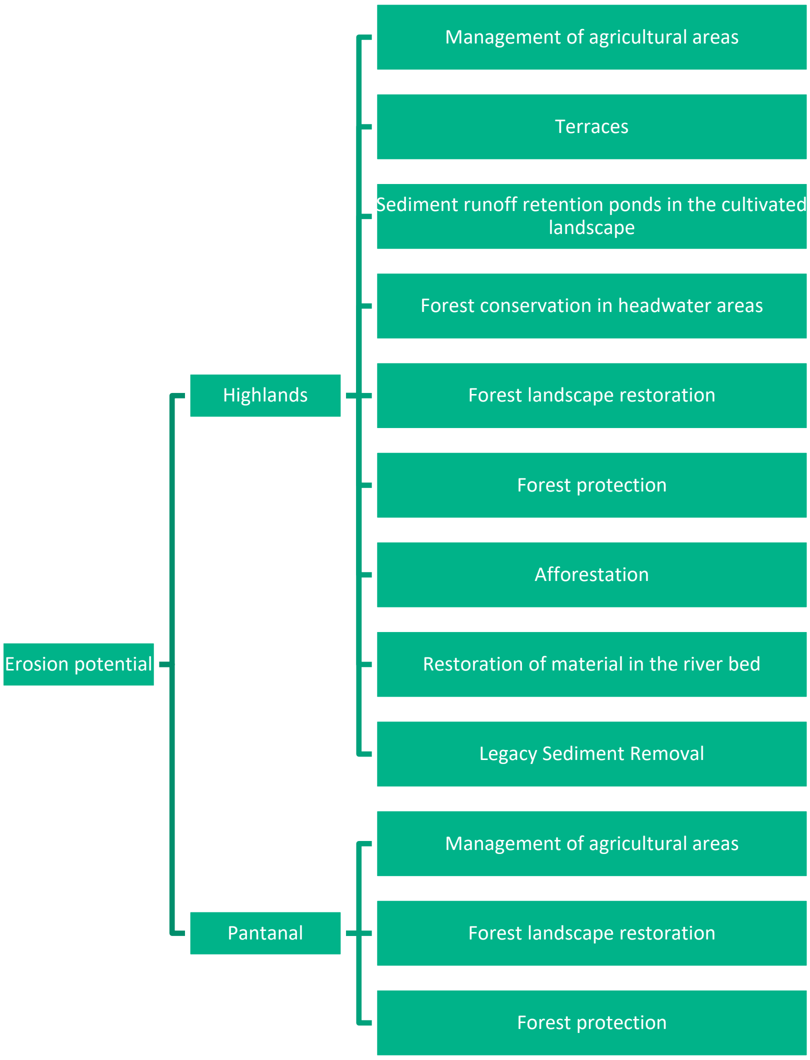

Figure 6-4 Examples of potential NbS for controlling the erosion potential in the highlands and the Pantanal.

7 Scoping NBS for areas of interest

7.1 Areas of interest

Scoping NbS in the UPRB requires a landscape level approach as ecosystem health and integrity depend on environmental processes that may not necessarily happen at a local scale (e.g., location of NbS implementation), but rather broader scale (e.g., basin or sub-basin). Understanding these processes for the whole UPRB is challenging and requires other approaches and tools (e.g., hydrological modelling, sediment modelling). Additionally, WWF offices have a particular interest in the UPRB within their own country. For these reasons, areas of interest were selected by the WWF offices. Criteria for this selection were mainly the urgency and challenges encountered in relation to water or navigation, political momentum, local knowledge, and partners present, and the enabling conditions for conservation efforts.

The following are the areas of interest:

- Bolivia
  - Tucavaca river basin
  - Pimiento river basin and Caceres Lake
- Brazil
  - Cuiabá river basin (and Poconé municipality)
  - Miranda river basin
- Paraguay
  - Basins in Bahia Negra
  - Basins downstream of the confluence of the Apa river with the Paraguay river (between Riacho Capitan and Riacho Gonzalez)

These areas are displayed in Figure 7-1.

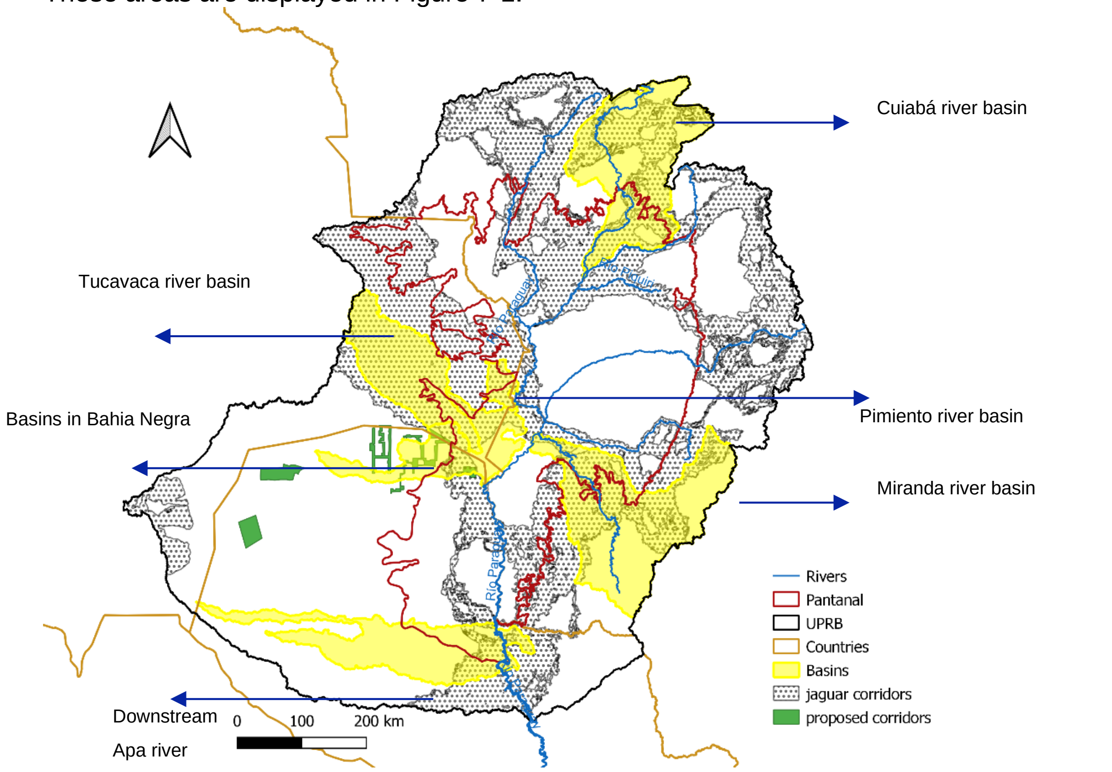

Figure 7-1 Areas of interest for WWF (in yellow). Map includes the current and proposed jaguar corridors.

For the scoping of NbS in the areas of interest the following steps were followed:

1 Identification of location within these areas with the potential (medium and high) of providing the impacted ecosystem services, as described in Section 5.3
2 Intersection of locations identified in step 1 with the land use information layer per country (Section 3.2). This step generates information of the land uses in locations that have a high and medium potential for water retention, infiltration and erosion.
3 Based on step 2, selection of potential NbS for the respective ecosystems represented by the land use categories.
4 Discussion of the potential NbS options with the local WWF offices to define preferred NbS opportunities.

The following sections present the results per country and area of interest.

7.2 Bolivia

The locations within the Tucavaca river basin and Pimiento River basin with high and medium potential for water retention, infiltration and erosion are presented in Figure 7-2 and Figure 7-3, respectively. In particular, the Pimiento River basin corresponds to areas with medium-high water contribution known as water towers and is fundamental for the hydrological dynamics of the region and for maintaining the flood pulse of the Pantanal (WWF – Brazil, 2018). This can also be observed in the water retention potential map in Figure 7-3.

This information together with potential NbS options from the NbS inventory were discussed with WWF Boliva in an online workshop on July 20th, 2023. As result, the NbS opportunities for the Tucavaca river basin are presented in
Table 7-1 and Figure 7-4, while for the Pimiento river basin the opportunities are summarized in Table 7-2 and Figure 7-5. Both tables include an indication of the water retention potential, infiltration potential, erosion potential and the presence of jaguar corridors.

Currently WWF Bolivia does not have specific work in the Caceres Lake. However, there is interest as it is an important contribution to the Tamengo canal, which is the outlet for exports and communication on this side of Bolivia to the Atlantic Ocean. Additionally, and according to WWF Bolivia, the lake is decreasing in depth or water volume due to factors such as accelerated sedimentation probably caused by peripheral deforestation, obstruction of feeder channels (two connected to Brazil) and historically low levels of the Paraguay River and the water level needs to be maintained.

The conservation and protection of natural vegetation (options A1-A5 in the Tucavaca river basin and options A1, A2 in the Pimiento River basin) include, forest, grassland / herbaceous and other non-forest natural formation, and depends on the specific biome (Chiquitano or Pantanal). This is also the case for the restauration of natural vegetation (B1-B6 in the Tucavaca river basin and B1-B3 in the Pimiento River basin). Non-forest natural formation refers to vegetation, forest and scrub ecosystem called Abayoy chaparrals. Wetlands correspond to flooded vegetation and include forest seasonally flooded by stagnant waters and hydrophytic savannahs in Chiquitanía, and grasslands, grasses and herbaceous savannahs in the Pantanal. The descriptions of forest and non-forest natural formations according to Mapbiomas Bolivia can be found in Annex A.

Restauration of natural vegetation in pasture areas is not considered as an opportunity as these areas correspond to private productive areas or active communal areas and the owners of the land may not easily agree with changes in their economic activity. These areas experienced land use changes with the respective loss of forest and natural vegetation. Therefore, attention has been paid to priority areas, as the riparian forest and the headwaters (options A1, A3, B3-B6 in the Tucavaca river basin and options A2, B1-B3 in the Pimiento River basin), but also ecological easement[19], connectivity[20] areas of protected areas and jaguar corridors, and areas for the wetland hydraulic connectivity.

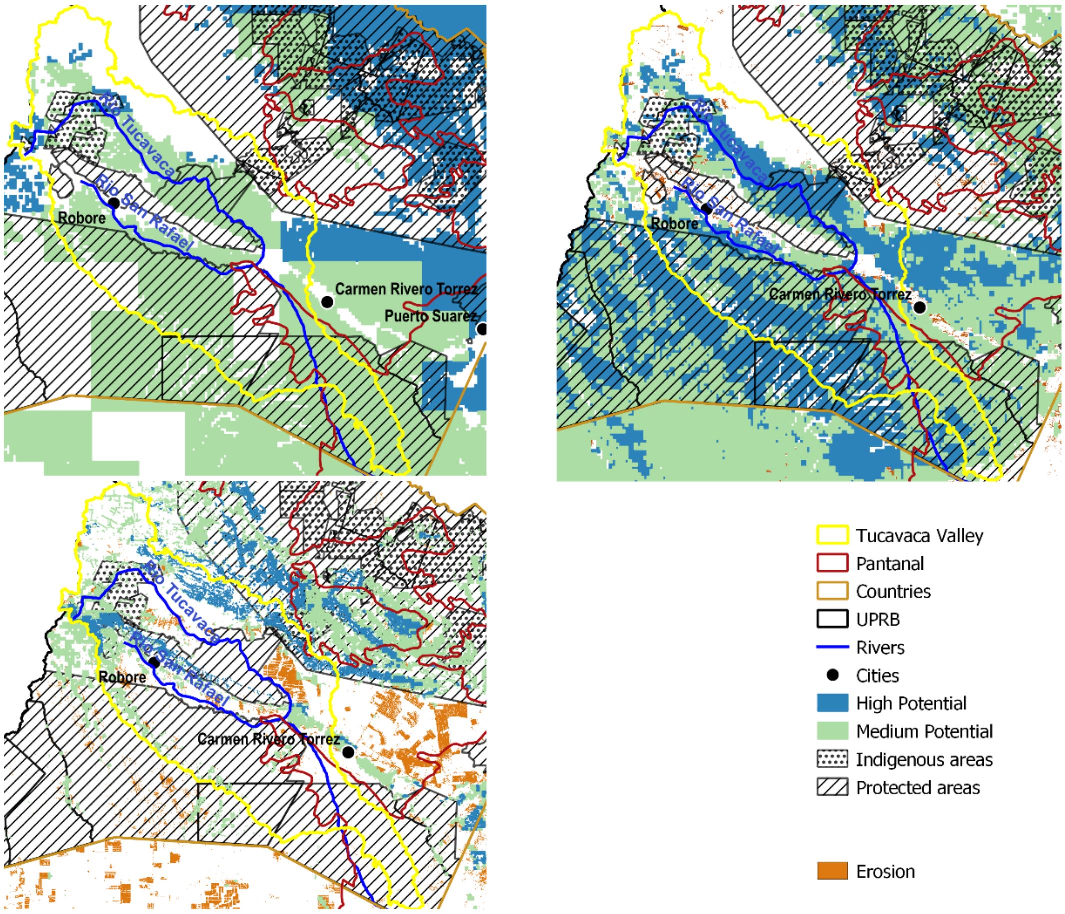

Figure 7-2 Locations within the Tucavaca river basin with the potential for providing the impacted ecosystem services. Upper left: water retention. Upper right: infiltration. Lower: erosion. In orange erosion areas due to land use.

For NbS to have a real impact on the Pantanal, major works need to take place and for that to happen, the participation of many state institutions and different stakeholders is required. Some NbS options may affect current easements.

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[19] An ecological or conservation easement is an agreement between two or more owners in which at least one of them agrees voluntarily to limit the use of part or all of their property called the servant estate in favour of any natural or legal person for conservation purposes and protection of natural resources and biodiversity. Source: Proaves.org

[20] "Connectivity" can be broken down into "structural connectivity" and "functional connectivity." Structural connectivity refers to the physical relationship between landscape elements whereas functional connectivity describes the degree to which landscapes actually facilitate or impede the movement of organisms between areas of habitat. Source: landscape.org

To reduce the impact of livestock on the water retention capacity of this part of the landscape, the application of good livestock and regenerative practices (options D1, D2 in the Tucavaca river basin and options D1-D3 in the Pimiento River basin) is recommended, which includes management of both the herd and the productive area. Current practices that can be highlighted include “sustainable community livestock” (semi-intensive management in communities with sustainable and rational use of the forest and water, and rigorous management of the livestock herd. Mainly in Bolivian Chaco), and livestock rotation (due to the lack of water in the Bolivian Chiquitano).

In the Pantanal zone, at least where there is cattle ranching in flooded areas, there are only native grasses and no areas of bare soil, unless there was previously a land use conversion process with associated deforestation. In this case when it occurs, exotic species that are not flood resistant are planted. Native tree plantation is opportune in areas converted into ecological easement zones.

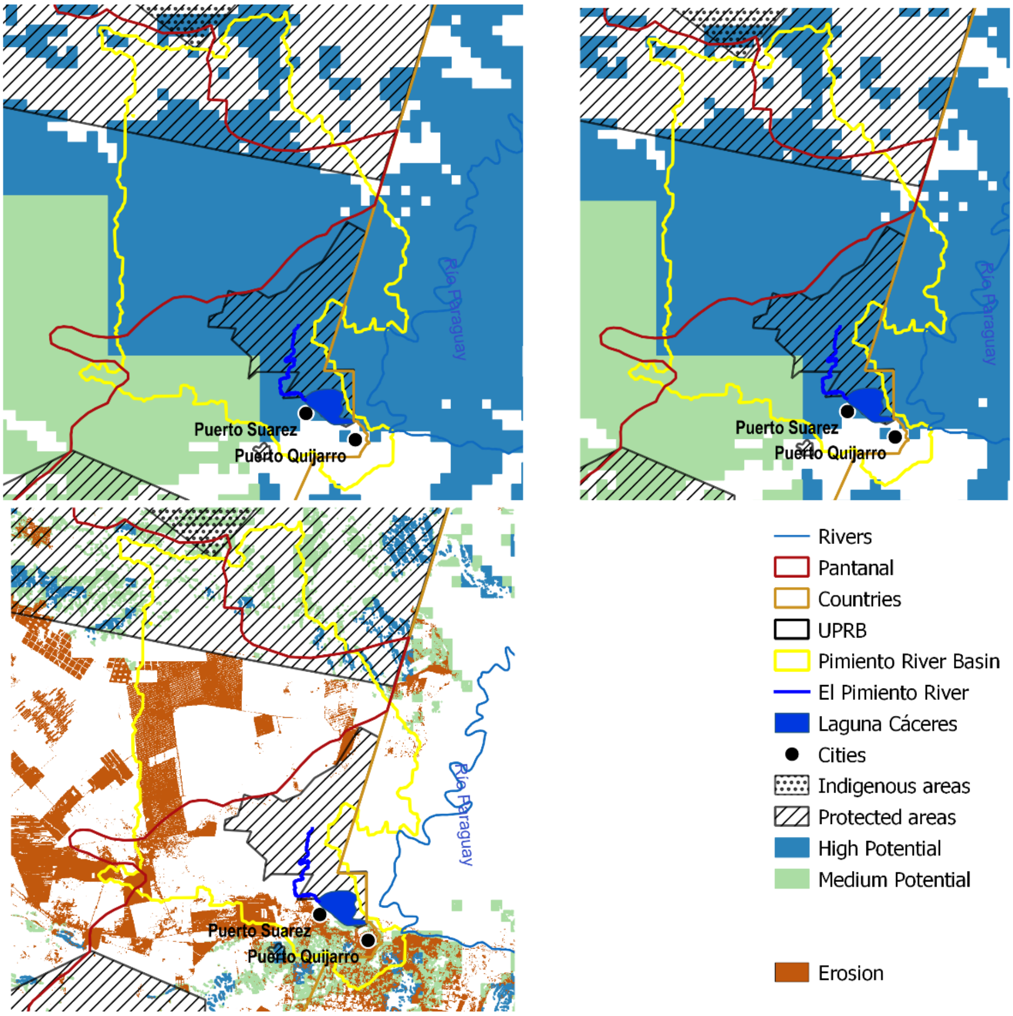

Figure 7-3 Locations within the Pimiento River basin with the potential for providing the impacted ecosystem services. Upper left: water retention. Upper right: infiltration. Lower: erosion. In orange erosion areas due to land use.

Table 7-1 NbS opportunities in the Tucavaca river basin.

NbS opportunity	Land use	Water retention Potential	Infiltration potential	Erosion Potential	Jaguar corridors
A1. Conservation and protection of natural vegetation in headwaters in Q. Santa Maria (UH140258) and Chaquipoc (UH140256)	Forest Other non-forest natural formation Grassland / herbaceous	Medium / High	Medium / High	Low / Medium	Yes
A2. Conservation and protection of natural vegetation between PA San Matias and PA Valle de Tucavaca	Forest	High	High	High / Land use caused	Yes
A3. Conservation and protection of vegetation in headwaters San Lorenzo (UH140250)	Forest Other non-forest natural formation	High	Medium	Low-High / Land use caused	Yes
A4. Conservation and protection of natural vegetation north to the PA Otuquis	Forest	Medium	Medium	Medium / High / Land use caused	Yes
A5. Conservation and protection of natural vegetation south to PA San Matias (U140347)	Forest	High	High	Low	Yes
B1. Restauration of natural vegetation in PA Kaa-Iya del Gran Chaco	pasture	Medium	Medium / High	Low / Medium	Yes
B2. Restauration of natural vegetation in PA Rio Grande Valles Cruceños	pasture	Medium	Low	Medium / High	Yes
B3. Riparian forest restauration in San Rafael River	Pasture	-	-	-	Yes
B4. Riparian forest restauration in Tucavaca river, north to PA Valle de Tucavaca	Pasture	-	-	-	Yes
B5. Riparian forest restauration in Tucavaca river, southeast to PA Valle de Tucavaca	Pasture	-	-	-	Yes
B6. Restauration of natural vegetation in headwaters San Lorenzo (UH140250)	Pasture	Medium	Low	Medium / High	Yes
C1. Maintain and improve wetland and connection with main channel close to Carmen Rivero Torres	Wetland (Flooded vegetation) Forest	Medium	Medium	Low	Yes
C2. Maintain and improve wetland in Protected Area PA Otuquis	Wetland (Flooded vegetation)	Medium	Low / Medium	Low	Yes
D1. Sustainable livestock and regenerative practices in the National Park Gran Chaco Kaa-Iya	Pasture	Medium	Medium / High	Low / Medium	Yes
D2. Sustainable livestock and regenerative practices in the ANMI Rio Grande Valles Cruceños	Pasture	Medium	Low	Medium / High	Yes

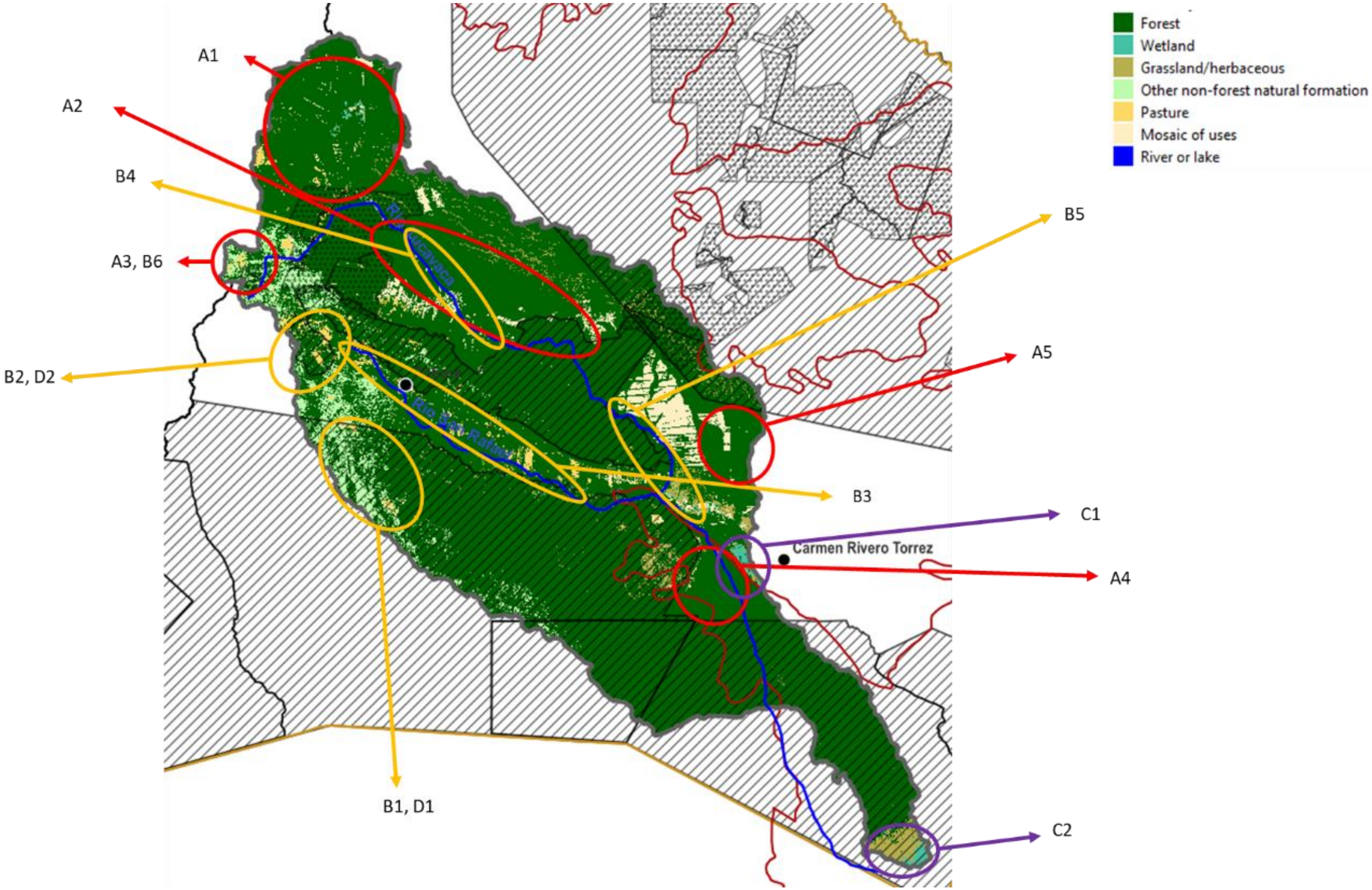

Figure 7-4 Potential location of NbS opportunities in the Tucavaca river basin.

Table 7-2 NbS opportunities in the Pimiento River basin and Caceres Lake.

NbS opportunity	Land use	Water retention	Infiltration	Erosion	Jaguar corridors
A1. Conservation and protection of natural vegetation south to PA San Matias, north PA German Busch (UH130402)	Forest	High	Medium / High	Low	Yes
A2. Conservation and protection of vegetation in headwaters south to PA San Matias (UH130402)	Forest	High	Medium / High	Low	Yes
B1. Restoration of natural vegetation (riparian forest, ecological easement, structural or functional connectivity area) south to PA San Matias (UH130402)	Pasture	High	Medium / High	Medium	Yes
B2. Restoration of natural vegetation (riparian forest, ecological easement, connectivity area) south to PA San Matias, north PA German Busch (UH130402)	Pasture	High	Medium	Medium	Yes
B3. Riparian forest restoration in Pimiento River, upstream and around Caceres Lake	Pasture Mosaic of uses	Low / High	-	Low / Medium	Yes
C1. Maintenance and improve wetland and connection with main channel west to PA German Busch	Wetlands Forest Grassland / herbaceous	Medium / High	Medium	Low	Yes
D1. Sustainable livestock and regenerative practices south to PA San Matias (UH130402)	Pasture	High	Medium / High	Medium	Yes
D2. Sustainable livestock and regenerative practices south to PA San Matias, north PA German Busch (UH130402)	Pasture	High	Medium	Medium	Yes
D3. Good livestock and regenerative practices south to Caceres Lake (UH 130101)	Pasture	Low / High	Low / Medium	Medium	Yes

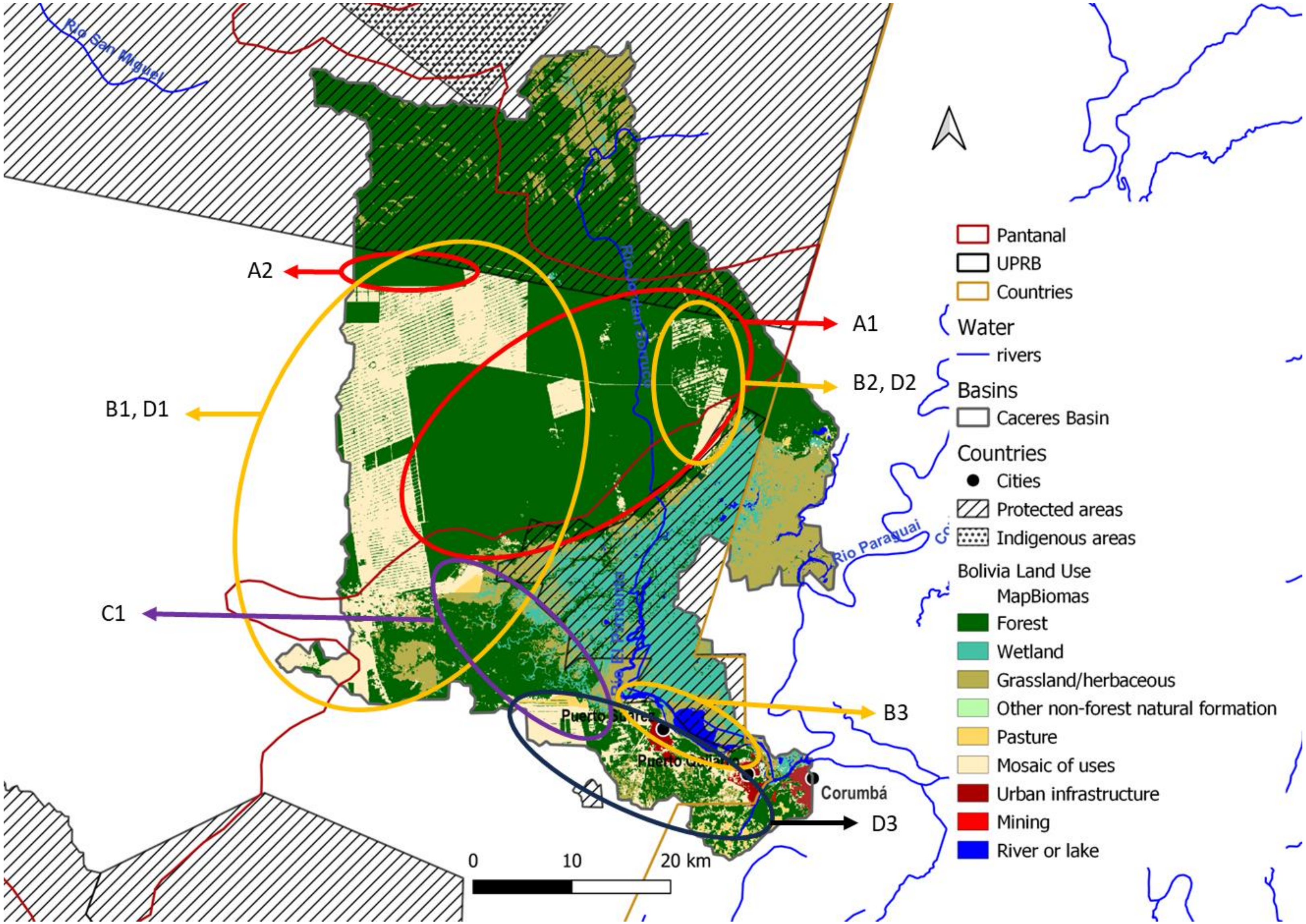

Figure 7-5 Potential location of NbS opportunities in the Pimiento River basin and Caceres Lake.

7.3 Paraguay

The locations within the Basins in Bahia Negra and downstream of the confluence of the Apa River with the Paraguay River (between Riacho Capitan and Riacho Gonzalez) with high and medium potential for water retention, infiltration and erosion are presented in Figure 7-6 and Figure 7-7, respectively.

This information together with potential NbS options from the NbS inventory were discussed with WWF Paraguay in an online workshop on Augusth 24th, 2023. As a result, the NbS opportunities for the Basins in Bahia Negra are presented in Table 7-3 and Figure 7-8, while the opportunities for the area downstream of the confluence with the Apa River summarized in Table 7-4 NbS opportunities in subbasins downstream the confluence with the Apa river. (*) refers to the whole basins Table 7-4 and Figure 7-9. Both tables include an indication of the water retention potential, infiltration potential, erosion potential and the presence of jaguar corridors. Additionally, for the area downstream of the confluence with the Apa River, as it includes a section of the Paraguay River, NbS opportunities for the challenges related to navigation are discussed at the end of Section 7.3.

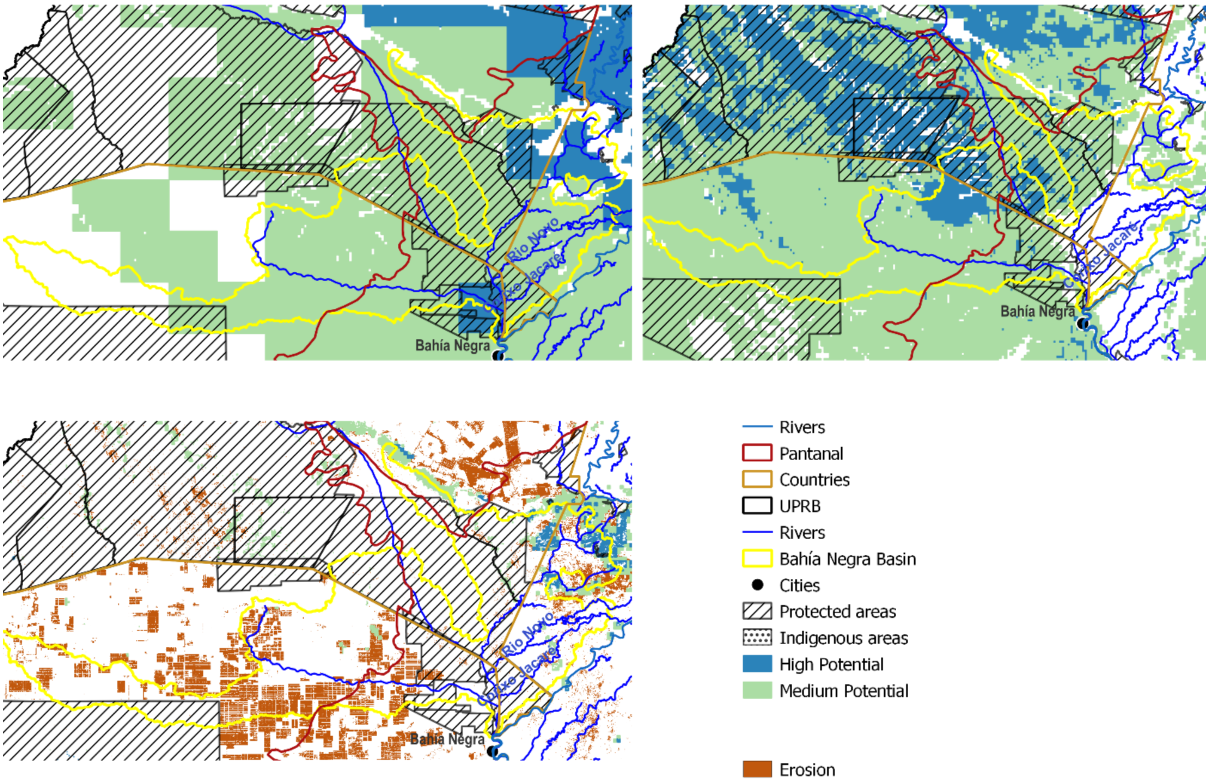

Figure 7-6 Locations within the Basins in Bahia Negra with the potential for providing the impacted ecosystem services. Upper left: water retention. Upper right: infiltration. Lower: erosion.

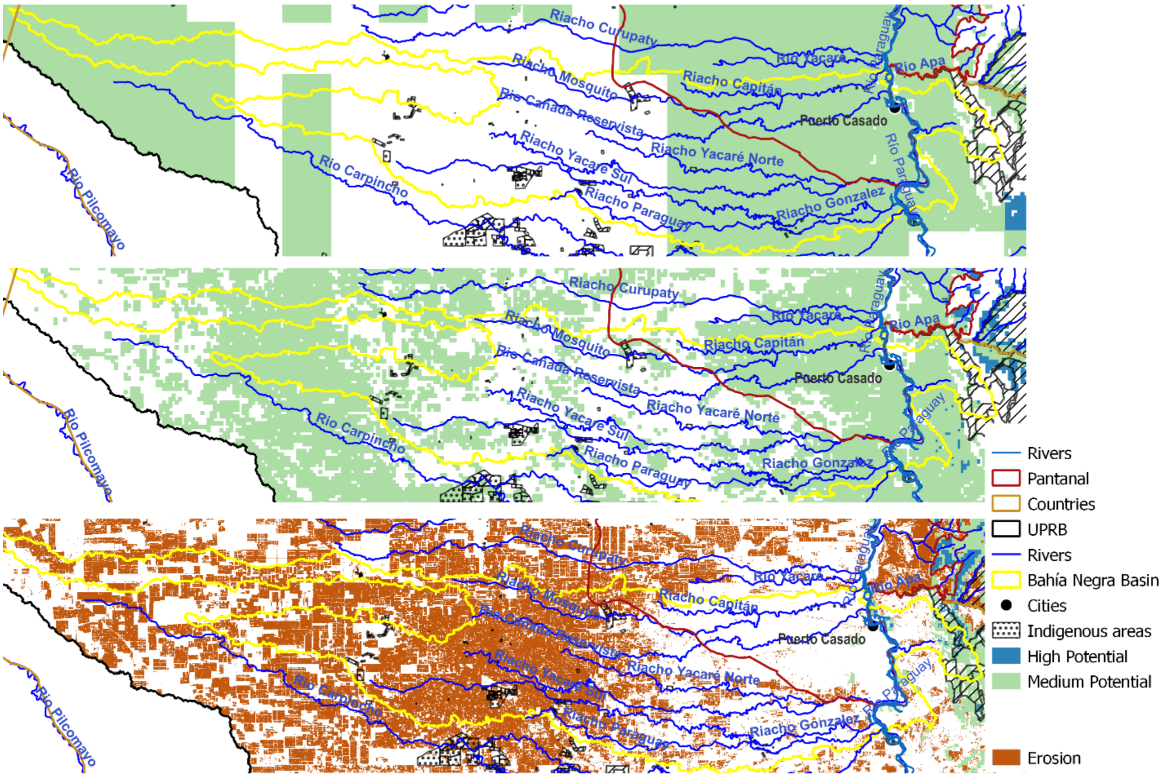

Figure 7-7 Locations downstream the confluence with Apa river with the potential for providing the impacted ecosystem services. Upper: water retention. Middle: infiltration. Lower: erosion.

Permanent preservation of forests and native vegetation on the riverbanks and drainage networks (options B1, B2 in Basins in Bahia Negra and options B1, B2 in locations below the confluence with Apa river) are important NbS opportunities. There are regulations[21] for the permanent preservation of forests and native vegetation on the riverbanks in the Chaco. Infona is responsible for establishing the conditions as outlined in the following paragraph. For rivers with a width of 10 meter or higher, a buffer of minimum 100 m for each side of the channel is defined[22] (INFONA/PNUD/FMAM, 2019). However, since the slope in this area is very low and the drainage network is not clear, there is no official map where the drainage network is located. For the analysis in the Basins in Bahia Negra, the used drainage network layer has been provided by WWF Paraguay and corresponds to information generated to support the Land-use and Plan submitted to the Ministry of Environment in 2020, and in process of approval by the Municipality of Bahia Negra. Currently, Paraguay is developing the National Forest Restoration Plan[23].

A main approach of this plan is the reforestation (rather than restoration) along waterways. An official recognition of not only channels but also paleochannels is important together with a clear definition of the drainage network.

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[21] Law No. 4241/10 - Law on the reestablishment of forests protecting water channels within the national territory. This Law declares of national interest the reestablishment of forests protecting the water channels of the Eastern Region, and the conservation of the same and in the Western Region of the Republic of Paraguay, to contribute to compliance with environmental adaptation and protection measures that are required to guarantee the integrity of water resources. In accordance with the provisions of this Law, protective forests must be permanently conserved in their natural state. Those properties that have not conserved them must reestablish them with native species, to recover and conserve them.

[22] DECRETO N° 9824/12

[23] https://infona.gov.py/paraguay-continua-la-construccion-del-plan-nacional-de-restauracion-forestal/

This will facilitate the identification of opportunities for reforestation along the waterways. Nowadays farmers don't respect (paleo)channels drainages, even when they know that it is not recommended to prepare areas for production in the lowlands, because land can be eroded, and crops or pastures washed out during run-off process.

Aquifers have an ecohydrological function for the entire basin. The Adrian Jara aquifer is located close to the Protected Area Natural Monument Cerro Chovoreca, where relevant hydrological processes (e.g., medium water retention and high and medium infiltration) take place supporting flow regulation (flood pulse). This condition provides an opportunity for the recharge of the Adrian Jara aquifer (option E1 in the Basins in Bahia Negra). In the locations downstream of the confluence of the Apa river with the Paraguay river, recharging of aquifers is an interesting opportunity (option E1 and E2). Paleochannels in the Yrenda aquifer are the main areas for infiltration of rainwater, not for deep aquifers, but for shallow unconfined aquifers. Aware of this and the sandy soil characteristics of paleochannels, some producers practice infiltration and aquifer recharge, avoiding salinization of water. Therefore, they don't cultivate the paleochannels. Close to the Bolivian border the aquifer is about 150 m depth (there is no shallow water) of freshwater. Due to groundwater extractions, this area is very dry but productive. The natural recharge of the deep aquifer takes place in Bolivia. In the center of this area of interest there is a phenomenon of salinization of the shallow groundwater (1 or 2 m depth) because of the presence of soils containing high salt concentrations and the water table is approaching the surface. Close to the Paraguay river, aquifers interact with it (area subject to flooding) and the water has brackish characteristics. The recharge of the Adrian Jara aquifer and Yrenda aquifer can be supported by ecosystem-based adaptation (EbA) measure. EbA measures can be implemented to secure groundwater resources and ecosystem services (e.g., water retention and infiltration). These measures include protection of pollution critical recharge areas, protection of groundwater dependent ecosystems, protection and restoration of riparian zones and floodplains, adaptation of soil and vegetation cover, investing in natural infrastructure (e.g., preservation of flood-prone vegetation and grasslands, artificial basins, ponds).

There are three main WWF strategies for the pasture zones (options D1 and D2 in the Basins in Bahia Negra and options D1-D4 in the locations downstream of the confluence with the Apa river): i) Management of private areas for land conversion[24]; ii) Adaptation of management plans of livestock production without an active restoration process (in order to respect the drainage network, to improve connectivity, to reduce impacts of livestock activity and maintain the different cycles); and iii) Payments for environmental services in areas of indigenous communities (strategy in initial exploratory stage) to manage and conserve natural areas.

In the flooded area of the Pantanal, in the Paraguayan Pantanal Reserve "Tres Gigantes" local private partners have purchased land for conservation in perpetuity. Next to it livestock farming with very low impact on land and water is taking place. Example is the Zuccolillo family in the Guaira area. Natural water reservoirs (option F1 in locations downstream confluence with Apa river) for biodiversity or in support of low-impact livestock activities can be an opportunity of water source, in particular during very dry seasons, when fauna and vegetation suffer stress. Natural water reservoirs can be also a source of water during fire periods.

Integrated management of fires together with the impact of floods is needed in the floodplains, in particular in dry seasons. Fire is unavoidable, as the dry material produced is very flammable, but it must be managed so that large events do not occur.

[24] Examples of the characteristics of farmland conversion can be found here: https://www.oecd-ilibrary.org/sites/3a1ff3b0-en/index.html?itemId=/content/component/3a1ff3b0-en#chapter-d1e2318

Or, instead of staying in the savannah zone, fires enter the dry forest – where there is no adaptation of the ecosystems to fire (pyrophilic). Keeping the savanna in good condition and well managed prevents high intensity fires that could affect other areas not adapted to fire.

Table 7-3 NbS opportunities in the Basins in Bahia Negra.

NbS opportunities	Land use	Water retention potential	Infiltration potential	Erosion potential	Jaguar corridors
A1. Conservation and protection of natural woodlands in headwaters north of National Park Defensores del Chaco	Closed natural woodlands Open natural woodlands	Low / Medium	Medium	Low	No
A2. Conservation and protection of natural woodlands between National Park Cerro Chocovera and National Park Rio Negro	Closed natural woodlands Open natural woodlands	Medium	High	Low	Yes
B1. Permanent preservation of forests and native vegetation on the banks of main drainage courses	Pastures	Medium	Medium	Mede	Yes
B2. Permanent preservation of forests and native vegetation on the margins of the drainage network, south of National Park Cerro Chocovera	Pastures	Medium	Medium / High	Medium	Yes
C1. Conservation and protection of natural woodlands and flooded natural woodlands and flooded grasslands between locations of National Park Rio Negro	Closed natural woodlands Flooded natural woodlands Flooded grasslands	High	Low / Medium	Low	Yes
D1. Good livestock and regenerative practices, silvopastoral systems between Natural Monument Cerro Chocovera and National Park Rio Negro	Pastures	Medium	High	Medium	Yes
D2. Good livestock and regenerative practices, silvopastoral systems, in National Park Rio Negro and jaguar corridors	Pastures	Medium	High	Medium	Yes
E1. Adrian Jara aquifer recharge between Natural Monument Cerro Chocovera and National Park Rio Negro	Closed natural woodlands Open natural woodlands Pastures	Medium	High	Low/Medium	Yes
F1. Creation of natural water reservoirs for biodiversity in flood-prone areas between locations of National Park Rio Negro	Closed natural woodlands Flooded natural woodlands Flooded grasslands	High	Low / Medium	Low	Yes

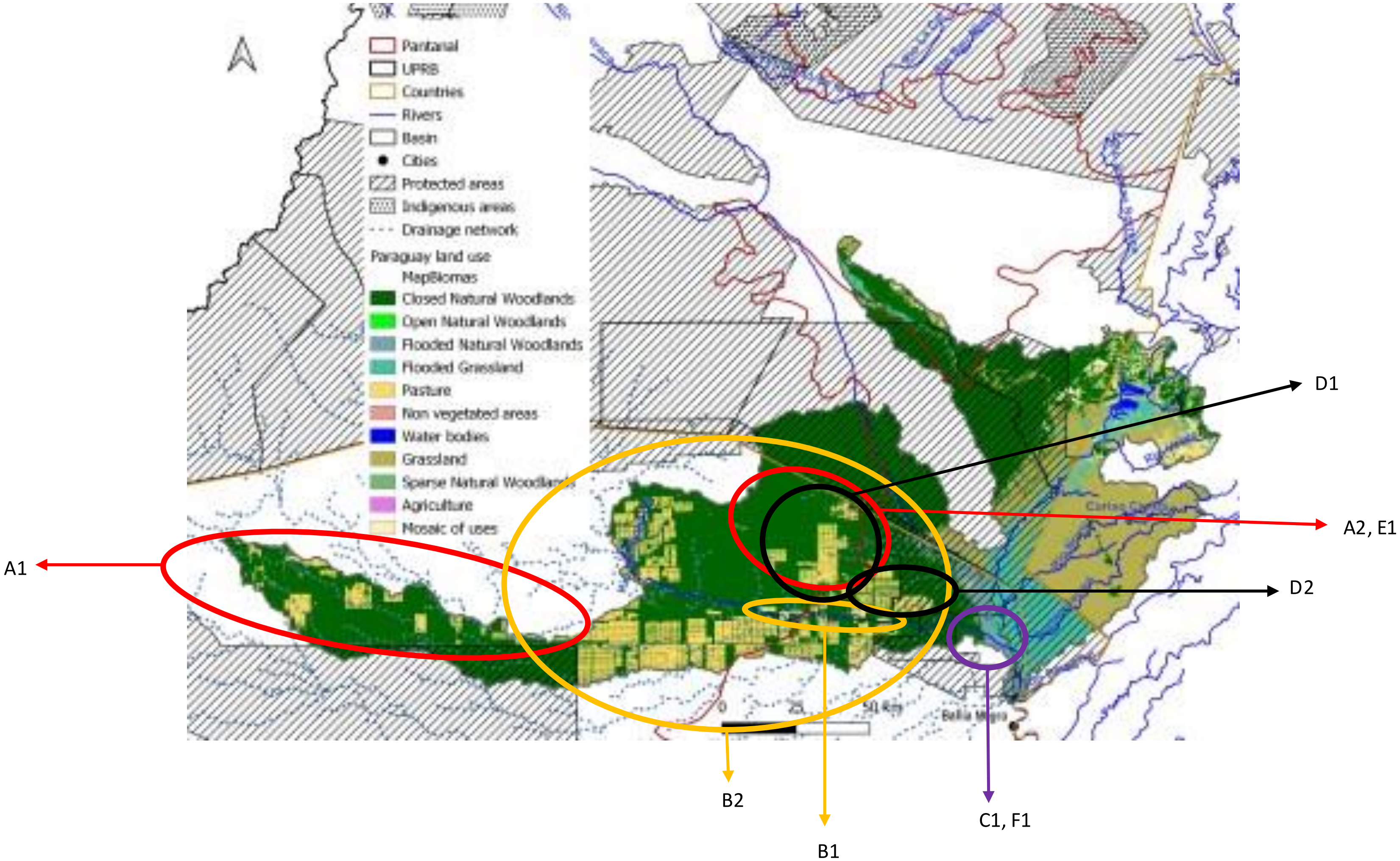

Figure 7-8 Potential locations for NbS opportunities in the Basins in Bahia Negra.

Land use change in private areas is difficult to intervene due to producer investments and regulation compliance at the time of building the land. It requires negotiations and depends hardly on the willingness to reach agreement and compromises of the owners. A better management of these territories is possible with ecosystem-based management as for example silvopastoral practices (options D1 and D2 in the Basins in Bahia Negra and options D1-D4 in locations downstream confluence with Apa river). Silvopastoral systems are those that combine tree growing with the production of livestock. They typically include pasture systems containing trees that are widely spaced or planted in clusters throughout the pasture. Conservation of natural grassland and use for low-intensity livestock production (except in protected areas) is another interesting ecosystem-based management option for this region. Other relevant management practices include the optimization of productive space through good farming practices, better pasture management, soil restoration, cattle rotation. Capacity development or pilots of silvopastoral practices are needed to showcase the benefits of this management strategy. WWF is piloting some of these practices as no knowledge is available in the country to demonstrate the opportunities of combining natural forest cover with livestock. Producers that are legally established based on exploitation plan or alternative use plan must reforest areas that they are not allowed to convert. All rural property of more than 20 hectares in forest areas must maintain 25% of its area as natural forests. In case it does not have that minimum percentage, the owner should reforest at least 5% of its surface[25].

There is the commitment of owners to preserve the area, although not all of them share the same vision. Reserves for natural parks are in private hands. An area can be declared by decree as a protected area, but the process of getting the legal title needs to be initiated and finalized, and a management plan needs to be prepared for the area to be considered as formally protected. For example, in the Chaco Biosphere Reserve there are a limited number of protected areas with property title. Until an area has the title of protected area, the private owner can ask for permission to deforest, and the authorization may be given. Supporting the titling of these areas is the strategy of WWF.

Ecosystem-based adaptation (EbA) in aquifer recharge is an interesting NbS opportunity as it can support water retention and infiltration in the basin. EbA measures can be implemented to secure groundwater resources and ecosystem services in the Yrenda Paleo causes close to the border with Bolivia (E1) and upstream Riacho Yacare Sur (E2). These measures include protection of pollution critical recharge areas, protection of groundwater dependent ecosystems, protection and restoration of riparian zones and floodplains, adaptation of soil and vegetation cover, investing in natural infrastructure (e.g., preservation of flood-prone vegetation and grasslands, artificial basins, ponds).

Hydrological connectivity is crucial for the functioning of floodplain ecosystems. It refers to the movement of water that facilitates the transport of matter, energy, and organisms between different hydrological cycle components (Rij, 2023). Hydrological connectivity occurs longitudinal, lateral, and vertical dimensions. Anthropogenic disturbances such as channelization for navigability, constructions of dams and levees, alter the hydraulic connectivity (e.g., floodplain loss, altered hydrological regimes, diminished biodiversity). In this specific area of interest, improving hydrological connectivity in the floodplains where pasture zones are located with low hydraulic connectivity are important opportunities (option G1 in locations downstream confluence with Apa river). Examples of measures for improving hydraulic connectivity include avoiding cultivation areas in the drainage network, lower (or remove) flood barriers or levees, restoration of degraded floodplains, rewetting floodplains, reconnecting secondary channels and oxbow lakes with the main channel.

[25] Decree 7,702/17, modified the regulations of article 42 of Forest Law 422/73

Table 7-4 NbS opportunities in subbasins downstream the confluence with the Apa river. (*) refers to the whole basins

NbS opportunity	Land use	Water retention potential	Infiltration potential	Erosion potential	Jaguar corridors
A1. Conservation and protection of natural woodlands in headwaters close to the border with Bolivia	Closed natural woodlands Open natural woodlands	Medium	Low	Low	No
A2. Conservation and protection of natural woodlands in headwaters upstream Riacho Yacare Sur	Closed natural woodlands Open natural woodlands	Medium	Medium	Low	No
A3. Conservation and protection of natural woodlands in jaguar corridors in the confluences with Paraguay river	Closed natural woodlands Open natural woodlands	Medium	Medium	Low	Yes
B1*. Permanent preservation of forests and native vegetation on the banks of the Riacho Yacaré North and South rivers, Riacho Capitán, Riacho Mosquito, Río Canada Reservista, Riacho Gonzales, Riacho Paraguay – Special attention to jaguar corridors	Pastures	Low / Medium	Low / Medium	Medium	No
B2*. Permanent preservation of forests and native vegetation on the margins of the drainage network – Special attention to jaguar corridors	Pastures	Low / Medium	Low / Medium	Medium	No
C1. Conservation and protection of natural woodlands and flooded natural woodlands and flooded grasslands – Special attention to jaguar corridors in middle and lower sections of riachos (streams)	Closed natural woodlands Flooded Natural woodlands flooded grasslands	Low / Medium	Low / Medium	Low	Yes
D1. Good livestock and regenerative practices, silvopastoral systems – Special attention in jaguar corridors – in middle and lower sections of riachos (streams)	Pastures	Low / Medium	Low / Medium	Medium	Yes
D2. Good livestock and regenerative practices, silvopastoral systems, in headwaters, close to the boarder with Bolivia	Pastures	Medium	Low	Medium	No
D3. Good livestock and regenerative practices, silvopastoral systems, in headwaters, upstream Riacho Yacare Sur	Pastures	Medium	Medium	Medium	No
D4*. Good livestock and regenerative practices, silvopastoral systems, in indigenous areas	Pastures	Low / Medium		Medium	No
E1. Ecosystem-based adaptation in Yrenda Paleo causes aquifer recharge close to the border with Bolivia	Closed natural woodlands Open natural woodlands Pastures	Medium	Low	Low / Medium	No

NbS opportunity	Land use	Water retention potential	Infiltration potential	Erosion potential	Jaguar corridors
E2. Ecosystem-based adaptation in Yrenda Paleochannels aquifer recharge upstream Riacho Yacare Sur	Closed natural woodlands Open natural woodlands Pastures	Medium	Medium	Low / Medium	No
F1. Creation of natural water reservoirs for biodiversity in flood-prone areas in the confluences with Paraguay river	Closed natural woodlands Flooded natural woodlands Flooded grasslands	Medium	Medium	Low	Yes
G1. Improving water connectivity in middle and lower sections of riachos (streams)	Closed natural woodlands Flooded natural woodlands Flooded grasslands	Low / Medium	Low / Medium	Low	Yes

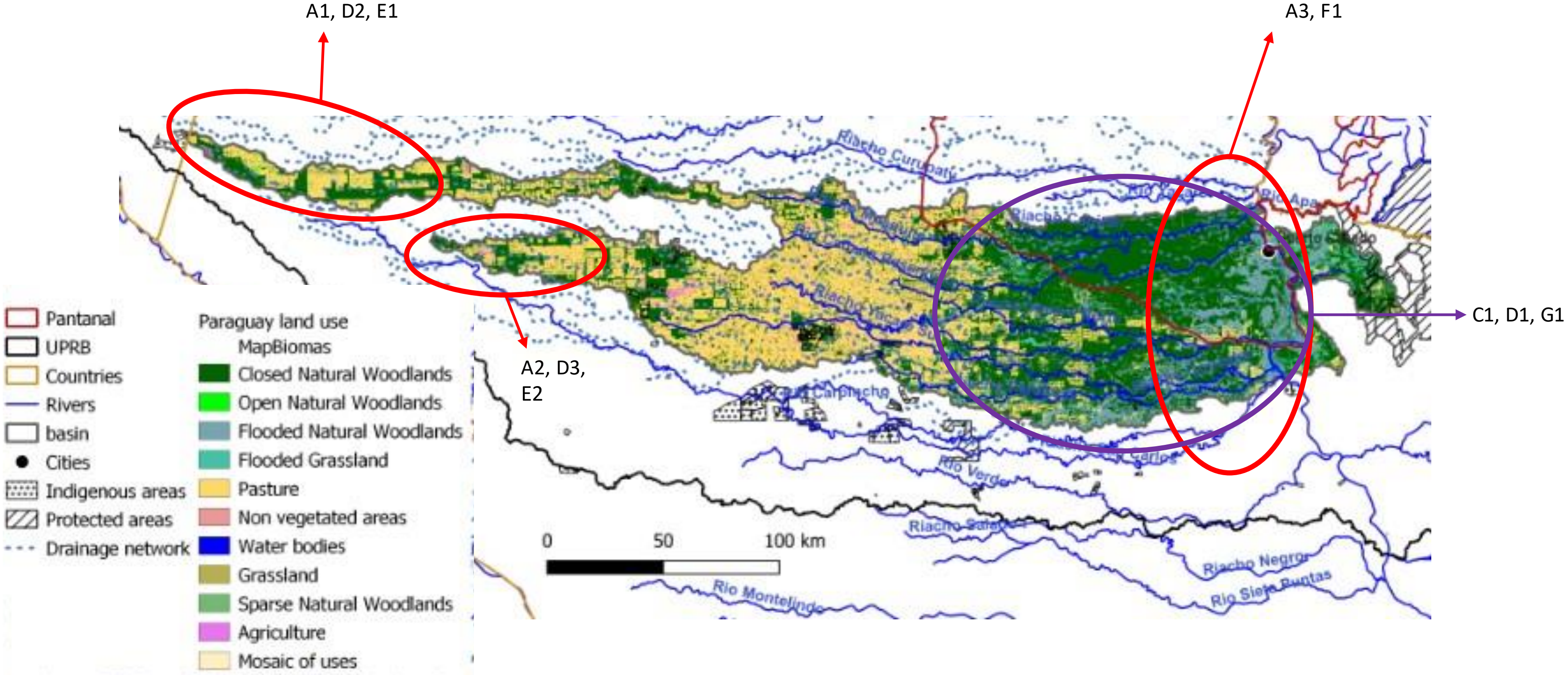

Figure 7-9 Potential locations of NbS opportunities in subbasins downstream the confluence with the Apa river.

7.3.1 NbS opportunities for navigation

This section of Paraguay River is part of the section 3 (Ponta do Morro – Foz do Rio Apa, see Figure 7-10) of the Parana-Paraguay Waterway (CSI Ingenieros SA, 2009). It is part of the so-called "Middle Paraguay River", between the confluence with the Apa River and Itá Pyta Punta (located 47 km south of Asunción) and constitutes a relatively deep stretch of river with areas of up to 8.0 m, with the presence of numerous sandbanks and rocky outcrops and a wide valley that, during floods, expands by about 10.0 km. In this section, the navigation channel is slightly sinuous and with adequate depths with the exception of some critical passes and curves.

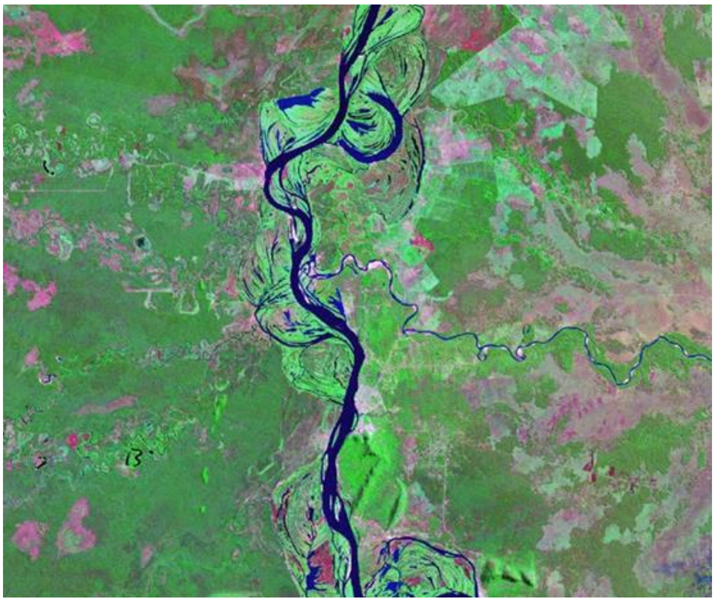

Figure 7-10 Image Section 3 of the Parana-Paraguay Waterway (Villasanti, No date)

The current navigation route in Paraguayan Paraguay River is well defined and varies very slowly over time. However, in periods of low water and on sections with multiple arms, navigation may take another arm that has better navigability. (Monte Domecq, 2013) describes the navigation in the section 3 as follows:

- Main navigation problems are high sandy bottoms and high rocky bottoms, which force convoys to reduce their drafts and narrow radius curves that require splitting up convoys for navigation.
- In the section (between the mouths of the Pilcomayo and Apa rivers), the navigation channel responds, essentially, to its natural morphological and sedimentological conditions, and it is possible to assume that there is a balance between the water flow, the sediment that the river transports and the size and grading of bed materials. Thus, as a consequence of the erosion – transport – deposition processes, sand banks (passes) are formed that tend to reduce the depth of the river and which constitute an important determinant for navigation.
- On the other hand, the geological characteristics of the area determine the appearance of passes linked to the presence, in the riverbed, of hard materials of various natures (including igneous and metamorphic rocks).
- The sandy passes in this section are 37 sandy passes, 7 well-known rocky passes and 11 small radius curves.
- In the high-water period (May-September) navigation has a significant water depth, from 3 to 6 meters, and can follow a fairly direct route. There are practically no length and beam limitations for convoys.

- In periods of low-water (November – February) navigation must follow a much more sinuous route to navigate the depths and avoid obstacles. The average distribution of water depths can be up to 3 m but also below 2 m. It is noted, however, that because to the natural phenomenon of self-dredging, the available depth is never less than 1m – 1.20 m.
- These particularities determine that this section is one of the most difficult of the entire Paraguay – Paraná Waterway

(CSI Ingenieros SA, 2009) provided a technical definition of the maintenance works of the Waterway and includes project criteria for opening and maintenance dredging works. In the case of opening dredging works difference is made between the sandy and the rocky passes.

Potential NbS opportunities

Sustainable management of the navigability of large natural rivers
In large natural rivers, with unregulated hydrology and unconstrained morphology, it is often not technically feasible nor environmentally desirable to improve navigability through river training works (Creech, Mosselman, & Hiver, 2022). The only solution is then to assist the river in maintaining a navigable channel through specific actions. The PIANC (World Association for Waterborne Transport Infrastructure) identified specific interventions and measures to meet the dual goals of maintaining morphological river function and improving navigability conditions. They include dynamic charting; morphological dredging and disposal management; temporary, adaptable, and flexible training structures (TAFTS); riverbed armoring and sediment nourishment; rock excavation; meander cutoffs; localized traditional river training structures; and channel closure strategies. Definitions can be found in Creech, Mosselman & Hiver (2022).

Morphological steering by dredging and deposition in large rivers
According to the study of (CSI Ingenieros SA, 2009), the location defined for dumping dredging material is downstream in the riverbed, in secondary arms and/or at the ends (or downstream) of islands and, preferably, in places where the discharge does not adversely influence the stability of the dredged channel and helps to maintain the cross-sections of the watercourse and sediment transport. Only in exceptional situations material discharge will be accepted on the banks of the river, particularly in low areas, flood-prone areas with high water levels, or swampy lands. In all cases, consideration must be taken to not cause environmental impacts.

Modifying the riverbed by dredging and deposition is a flexible way of steering the morphological evolution of a river into a desired direction, for instance to improve navigability, mitigate riverbank erosion or improve ecological connectivity. This opportunity offers beneficial reuse of dredged sediments. A study of (Mosselman, Roukema, Ingil, & and Mamur, 2022) in large rivers concluded that the success of interventions depends on the large-scale alignment and evolution of channels upstream and recommended giving due account to the large-scale situation, as well as implementing the intervention over a sufficiently long channel stretch to create a buffer for unforeseen erosion.

It can also be an opportunity to create an island habitat. According to (Eekelen & Bouw, 2020) strategic placement of fine sediment can have beneficial application in the growth of ecosystems. Placement in shallow tidal environments can exploit waves and currents for dispersal.

Reuse of rocks to stabilize and protect riverbanks
According to the (CSI Ingenieros SA, 2009), the location defined for final disposal of removed rock material is on the riverbed and, preferably, distributed along the river – at a distance from the navigation channel of no less than 50 m – and in places where their disposal does not adversely influence the maintenance of the cross-section of the watercourse or the transport of sediments.

Only in exceptional situations, the material disposal will be accepted on the banks of the river, for the purposes of carrying out riverbank stabilization and protection works. Replacing breakwaters with rocks helps for increasing flow, reducing waves, or avoiding sand settling, reducing riverbed erosion, restoration of natural shoreline, improved fish passage. However, in all cases it must be taken into consideration not to cause environmental impacts. The reuse of rocks offers opportunities to create habitats for aquatic species.

Flexible river training structures

In all cases these interventions must be taken into consideration not to cause environmental impacts. Examples of this option include:

- Chevron-forming structures that use the energy of the river to maintain navigable depths in the main channel, divert some of the flow from the main channel to the wet bank, and deposit sediment downstream of the chevrons to increase environmental diversity. The ultimate benefit is the reduction of future dredging requirements. Additionally, these structures can be made more sustainable by using local materials to build them.
- Tetrahedron frames (‘porcupines’) provide hydraulic resistance, generating energy loss through turbulence that may reduce velocities and promote sediment deposition. Porcupine systems can be used for bed or bank protection.
- Notched closure structure or dike that includes an open section within the structure to allow continuous passage of river flow, thereby maintaining aquatic habitat with sufficient discharge into the secondary channel.
- Gravel bars near the shore that act as breakwaters, and wooden piles outside the shore that act as wave protection walls. The operating principle of the structures is based on the dissipation and reflection of the kinetic energy of the waves to the point that the remaining energy behind the breakwaters can be reduced to a reasonable level.
- Wood material can be reused to construct and influence the transport of currents and sediments. Examples are wooden pile dams, palisades, and formation structures.

Figure 7-11 Examples of flexible river training structure in order of appearance: Chevron-forming structures (www.engr.colostate.edu); tetrahedron frames (https://link.springer.com/chapter/10.1007/978-981-19-7100-6_17); notched closure structure (www.mvs-usace.army.mil); gravel bar (https://guides.nynhp.org/riverside-sandgravel-bar/)

Constructing secondary channels
According to (Eekelen & Bouw, 2020) secondary channels along rivers corridors can improve water quality and provide depth variations, slowing water flow and expanding space for sedimentation. They also increase flood conveyance capacity and support habitat development.

Managing retreat and alignment
The strategic alignment of riverbanks and shorelines can support flood conveyance and storage (Eekelen & Bouw, 2020). It can also create opportunities for wetland development and recreation. Realignment is most applicable in locations where river channels have been constricted by artificial embankments. Controlled breaching of riverfront dikes allows for periodic inundations of wetlands.

Other potential NbS opportunities are:

- *Eliminate or reduce the height of embankments:* This option allows for more dynamics on the riverbank and reconnecting the arms.
- *Unblocking the mouths of streams and secondary rivers.*

7.4 Brazil

The locations within the Cuiabá River basin and the Miranda River basin with high and medium potential for water retention, infiltration and erosion are presented in Figure 7-12 and Figure 7-13, respectively.

This information together with potential NbS options from the NbS inventory were discussed with WWF Brazil in an online workshop on July 21st, 2023. As result, the NbS opportunities for the Cuiabá river basin are presented in Table 7-5 and Figure 7-14, with the opportunities for the Miranda river basin summarized in Table 7-6 and Figure 7-15. Both tables include an indication of the water retention potential, infiltration potential, erosion potential and the presence of jaguar corridors.

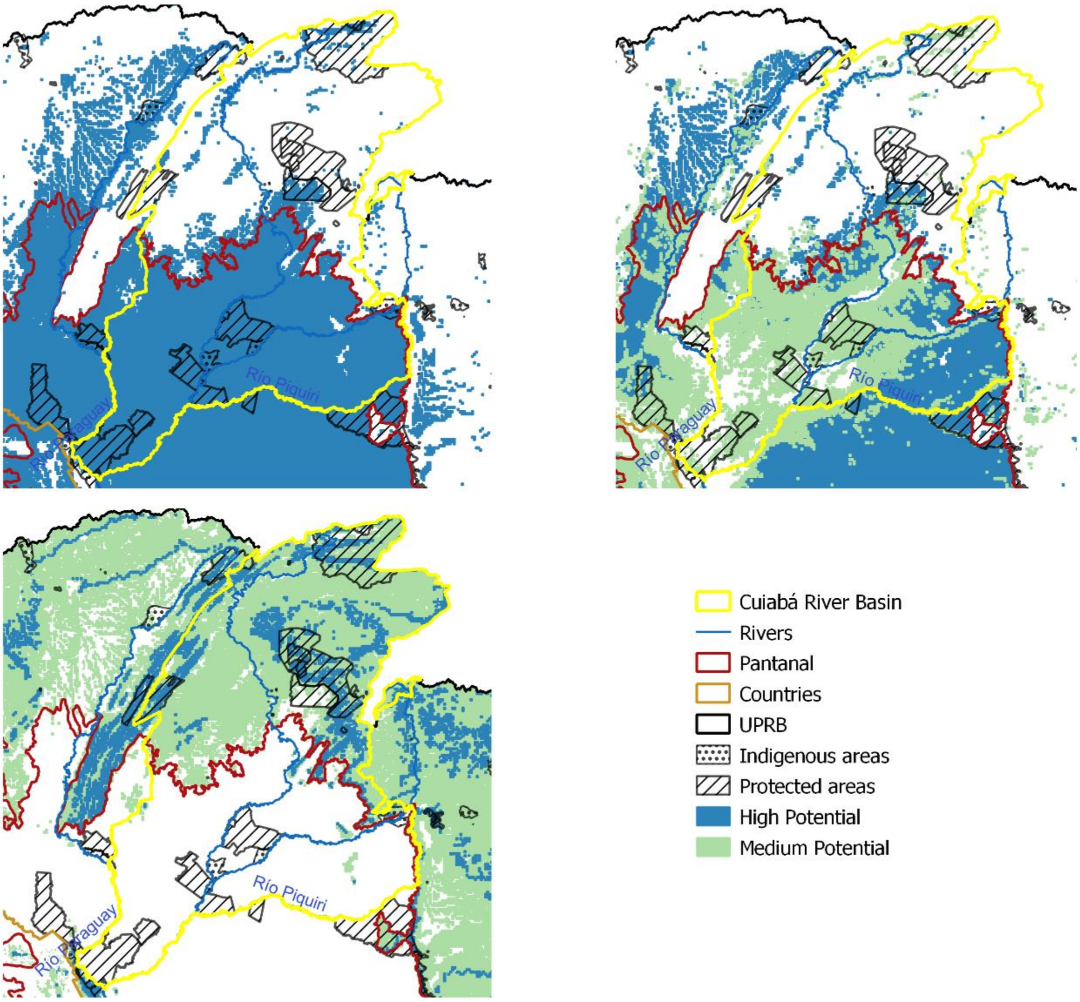

Figure 7-12 Locations in the Cuiabá River basin with the potential for providing the impacted ecosystem services. Upper left: water retention. Upper right: infiltration. Lower: erosion. High potential in blue, medium potential in green.

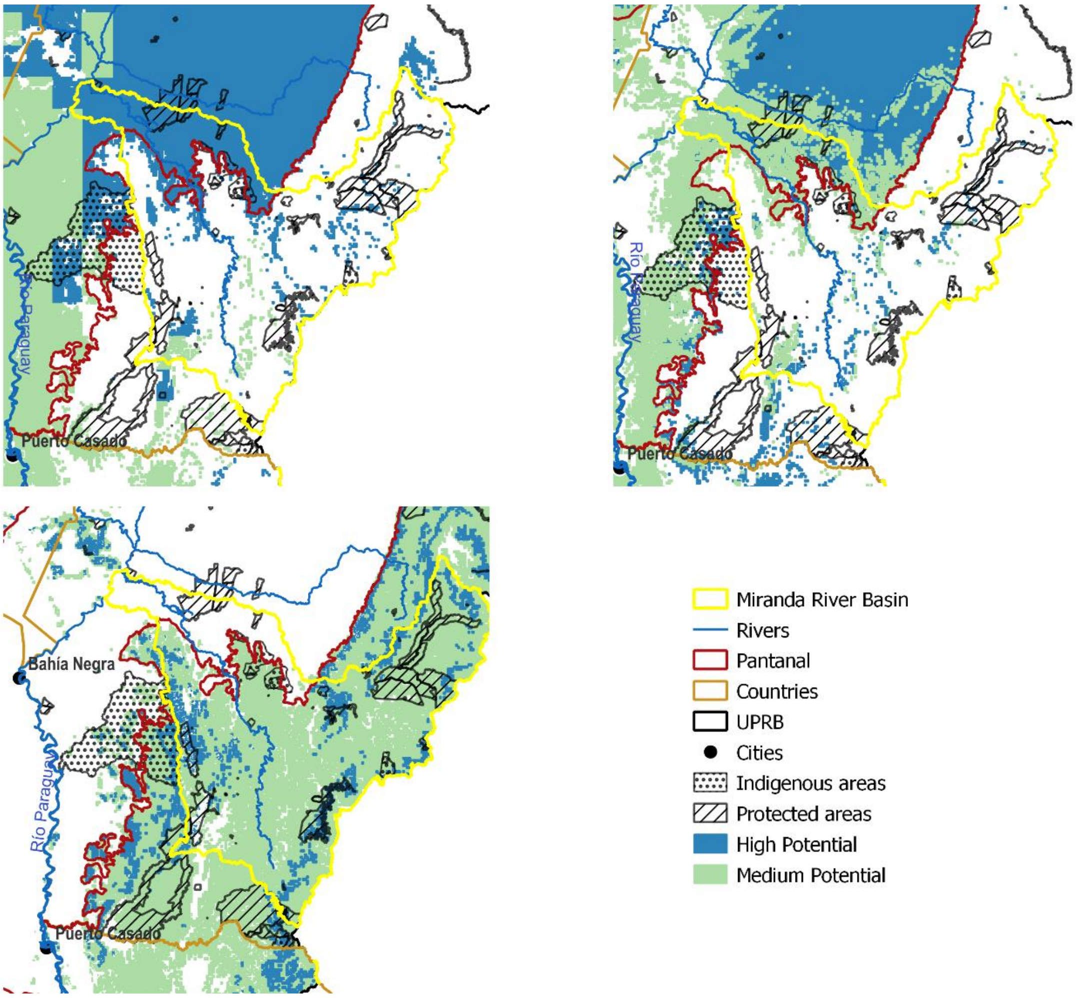

Figure 7-13 Locations in the Miranda River basin with the potential for providing the impacted ecosystem services. Upper left: water retention. Upper right: infiltration. Lower: erosion. High potential in blue, medium potential in green.

Conservation and protection of natural vegetation (options A1, A2, B1 in the Cuiabá River basin and options A1, B1, B2 in the Miranda River basin) includes forest formations, Savanna formation and non-forest natural formations (countryside formations and rocky outcrop). The various formation will depend on the biome Amazon, Cerrado or Pantanal. A description of the land use categories according to MapBiomas Brazil is presented in Annex A.

Conservation of wetlands (option C1 in the Cuiabá River basin and option C1 in the Miranda River basin) refers to areas of flooded forest and flooded non-forest natural formations, which again depend on the specificities of the biome.

Modifications to the natural environment are invariably necessary to ensure socioeconomic development and support population growth. However, these activities require sustainable agriculture and livestock practices (options D1-D7 in the Cuiabá River basin and options D1-D7 in the Miranda River basin), including regenerative and silvopastoral practices. This is particularly important in protected areas, indigenous areas and jaguar corridor areas.

The Cuiabá basin is a strategic recharge site (options E1 and E2) for the basin and defines the recovery of levels in the Paraguay River.

This is particularly important in dry years, for example 2021[26], when the water level in the Paraguay river reached low values. Ecosystem-based adaptation (EbA) in aquifer recharge is an interesting NbS opportunity as it can support water retention and infiltration in the basin. Measures include protection of pollution critical recharge areas, protection of groundwater dependent ecosystems, protection and restoration of riparian zones and floodplains of the Cuiabá River and tributaries, adaptation of soil and vegetation cover, investing in natural infrastructure (e.g., preservation of flood-prone vegetation and grasslands, artificial basins, ponds).

An additional potential NbS opportunity is the reconnection of marginal lakes and seasonal flows in the Pantanal (land use mainly flooded vegetation and flooded grasslands). However, the identification of adequate locations requires proper information and additional analysis.

Table 7-5 NbS opportunities in subbasin Cuiabá

NbS opportunity	Land use	Water retention	Infiltration	Erosion	Jaguar corridors
A1. Conservation and protection of natural vegetation in headwaters (upstream of the Pantanal)	Forest formation Savanna formation Grassland	Low	High	Medium / High	Yes
A2. Conservation and protection of natural vegetation in Pantanal (lower part of the Cuiaba River basin)	Forest formation Savanna formation Grassland	High	Medium / High	Low	Yes
B1. Permanent preservation of forests and native vegetation on the banks of the upper part of Cuiaba River	Pasture Agriculture	Low / High	Low / Medium / High	Medium / High	Yes
B2. Permanent preservation of forests and native vegetation on the banks of the middle part of Cuiaba River	Pasture Agriculture	Low / High	Low / Medium / High	Medium	No
C1. Conservation and protection of woody and flood-prone vegetation and flood-prone grasslands in the Lower Cuiaba River	Flooded vegetation Flooded grasslands	High	Medium	Low	Yes
D1. Good livestock and regenerative practices, silvopastoral systems, in Protected area Cabeceras do Rio Cuiaba and jaguar corridors	Pasture Agriculture	Low / High	Low/ Medium	Medium / High	Yes
D2. Good livestock and regenerative practices, silvopastoral systems, in Protected Area and National Park Chapala dos Guimaraes and jaguar corridors	Pasture Agriculture	Low / High	Low / High	Low / Medium / High	Yes
D3. Good livestock and regenerative practices, silvopastoral systems, in Protected Area Nascentes do Rio Paraguai and jaguar corridors	Pasture Agriculture	Low	Low	Medium	Yes

[26] In 2021 the Cuiabá river registered the lowest historical level of water in the Paraguay river basin with a return period of 40 to 60 years. This event was the result of a rainfall deficit accumulated over the year 2021.

NbS opportunity	Land use	Water retention	Infiltration	Erosion	Jaguar corridors
D4. Good livestock and regenerative practices, silvopastoral systems, in Protected Area Serra das Araras and jaguar corridors	Pasture Agriculture	Low	Low	High	No
D5. Good livestock and regenerative practices, silvopastoral systems, in Protected Area Encontro das Aguas and jaguar corridors	Pasture Agriculture	High	Low / Medium	Low	Yes
D6. Good livestock and regenerative practices, silvopastoral systems, in indigenous area and jaguar corridors	Pasture Agriculture	High	Medium / High	Low	Yes
D7. Good livestock and regenerative practices, silvopastoral systems, in the Pantanal	Pasture Agriculture	High	Medium / High	Low	Yes
E1. Ecosystem-based adaptation in Aquifer recharge	Forest formation Savanna formation Grassland	High	High	Low	Yes
E2. Ecosystem-based adaptation in Aquifer recharge	Forest formation Savanna formation Grassland	High	Medium	Low	Yes
H. Reconnection of marginal lakes and seasonal flows in Pantanal	Flooded vegetation Flooded grasslands	High	Medium / High	Low	Yes

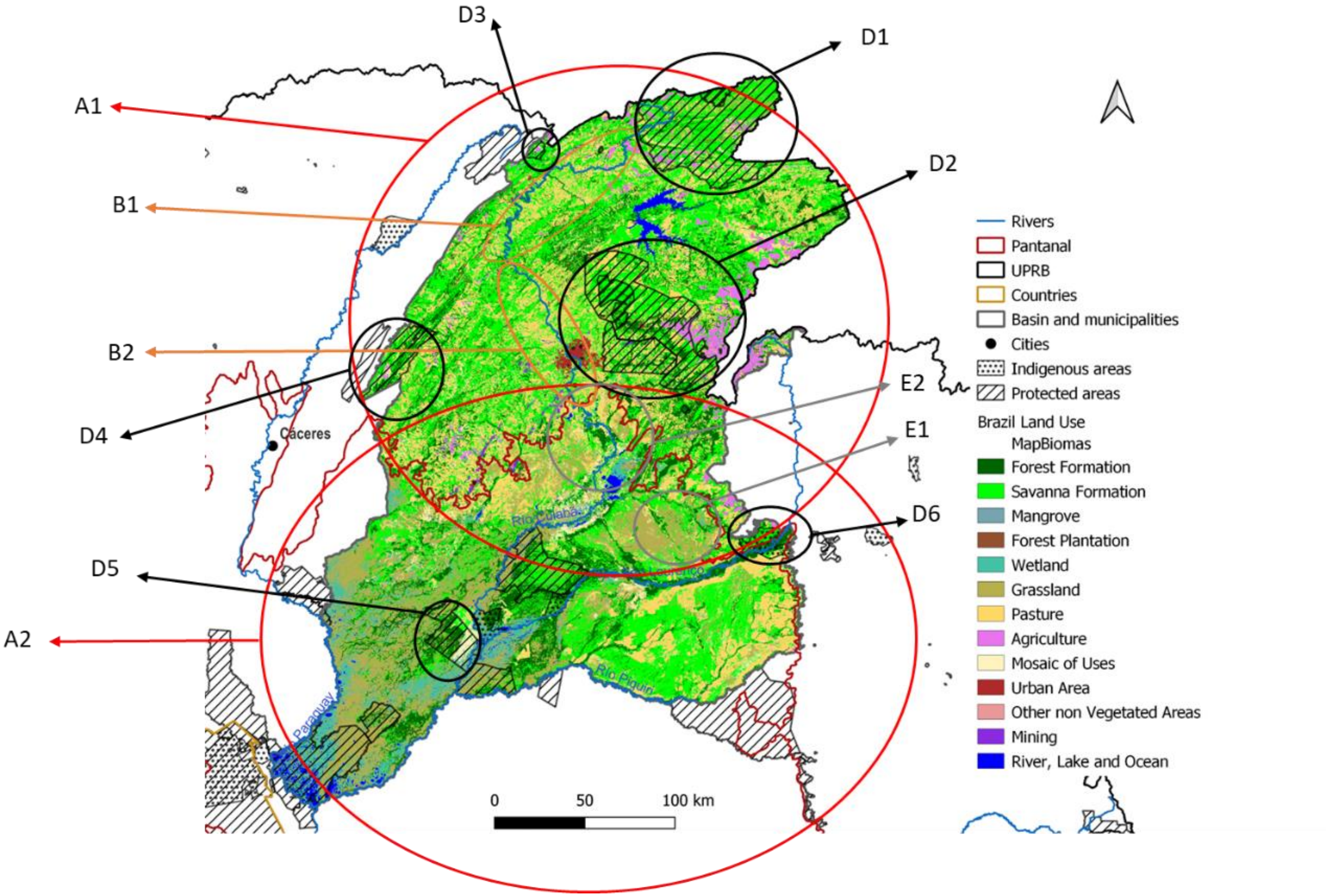

Figure 7-14 Potential locations of NbS opportunities in subbasin Cuiabá.

In the Miranda River basin, the occupation of land on slopes has occurred with the removal of vegetation, changes in the natural flow of water, earth movements (excavations and landfills), incorrect disposal of solid and liquid waste, actions that contribute to the destabilization and landslides of land. This results in environmental, social, and economic damage. Erosive processes occur in its various forms to a greater or lesser extent throughout the basin. In the most environmental vulnerable areas to erosion, terrain-forming processes prevail, and in the more stable areas, soil-forming processes prevail. Areas with low vulnerability to erosion processes in the Pantanal are the areas of the Abobral, Aquidauana, Miranda and Nabileque municipalities. Areas with moderate vulnerability to erosion include most of the Miranda River basin (medium and lower reaches).

Restoration measures here are challenging to implement because of the need of negotiations with producers. Although the Pantanal remains well preserved, it lacks preservationist and conservationist measures, mainly due to the use of the soil in its surroundings – areas of dry land – for agriculture and livestock, which increase siltation, loss of biodiversity and contamination of the rivers that enter the plains. Therefore, measures as conservation and protection of natural vegetation (NbS opportunity A), permanent preservation of forest and native vegetation on riverbanks (NbS opportunity B), conservation of flood-prone vegetation and grasslands (NbS opportunities C), and food livestock and regenerative practices (NbS opportunities D) have high potential in the Miranda River basin as they contribute to water retention, infiltration and erosion control.

Ecosystem-based adaptation (EbA) in aquifer recharge in the middle part of the Aquidauana river (E1) is an interesting NbS opportunity as it can support water retention and infiltration in the basin. Measures include protection of pollution critical recharge areas, protection of groundwater dependent ecosystems, protection and restoration of riparian zones and floodplains of the Aquidauana river, adaptation of soil and vegetation cover, investing in natural infrastructure (e.g. preservation of flood-prone vegetation and grasslands, artificial basins, ponds).

An additional potential NbS opportunity is the reconnection of marginal lakes and seasonal flows in the Pantanal (land use mainly flooded vegetation and flooded grasslands). However, the identification of adequate locations requires proper information and additional analysis.

Table 7-6 NbS opportunities in subbasin Miranda

NbS opportunity	Land use	Water retention	Infiltration	Erosion	Jaguar corridor
A1. Conservation and protection of natural vegetation in the lower Miranda River basin	Forest formation Savanna formation Grassland	High	Medium	Low	Yes
B1. Permanent preservation of forests and native vegetation on riverbanks in the lower Miranda River	Pasture Agriculture	High	Medium	Low	Yes
B2. Permanent preservation of forests and native vegetation on riverbanks in the Upper Miranda River	Pasture Agriculture	Low / Medium	Low / Medium	Low / Medium	Yes
C1. Conservation and protection of woody and flood-prone vegetation and flood-prone grasslands in the Pantanal	Flooded vegetation Flooded grasslands	High	Medium	Low	Yes

NbS opportunity	Land use	Water retention	Infiltration	Erosion	Jaguar corridor
D1. Good livestock and regenerative practices, silvopastoral systems around Aquidauana river	Pasture Agriculture	Low / High	Low / Medium	Low	Yes
D2. Good livestock and regenerative practices, silvopastoral systems in indigenous areas around Aquidauana river	Pasture Agriculture	Low / Medium	Low / High	Low	Yes
D3. Good livestock and regenerative practices, silvopastoral systems in the west boarder of the basin, including Protected Area Cara da Onafasa	Pasture Agriculture	Low	Low	High	Yes
D4. Good livestock and regenerative practices, silvopastoral systems in the west boarder of the basin	Pasture Agriculture	Medium / High	Medium / High	Medium	Yes
D5. Good livestock and regenerative practices, silvopastoral systems, in Protected Area Serra de Maracaju and jaguar corridors	Pasture Agriculture	Low	Low	Low / High	Yes
D6. Good livestock and regenerative practices, silvopastoral systems, in indigenous area and jaguar corridors	Pasture Agriculture	Low	Low	Low / High	No
D7. Good livestock and regenerative practices, silvopastoral systems, including Protected Areas Rio Cachoeria, Caferrego Ceroúla, Rio Aquidauana Rochedo, and Rio Aquidauana Corguinho	Pasture Agriculture	Low / High	Low	Low / Medium	Yes
D8. Good livestock and regenerative practices, silvopastoral systems, including Protected Area Estrada Parque de Praputanga	Pasture Agriculture	High	Medium	Low	Yes
E1. Ecosystem-based adaptation in aquifer recharge in the middle part of the Aquidauana river	Forest formation Savanna formation Grassland	High	Medium / High	Low	Yes

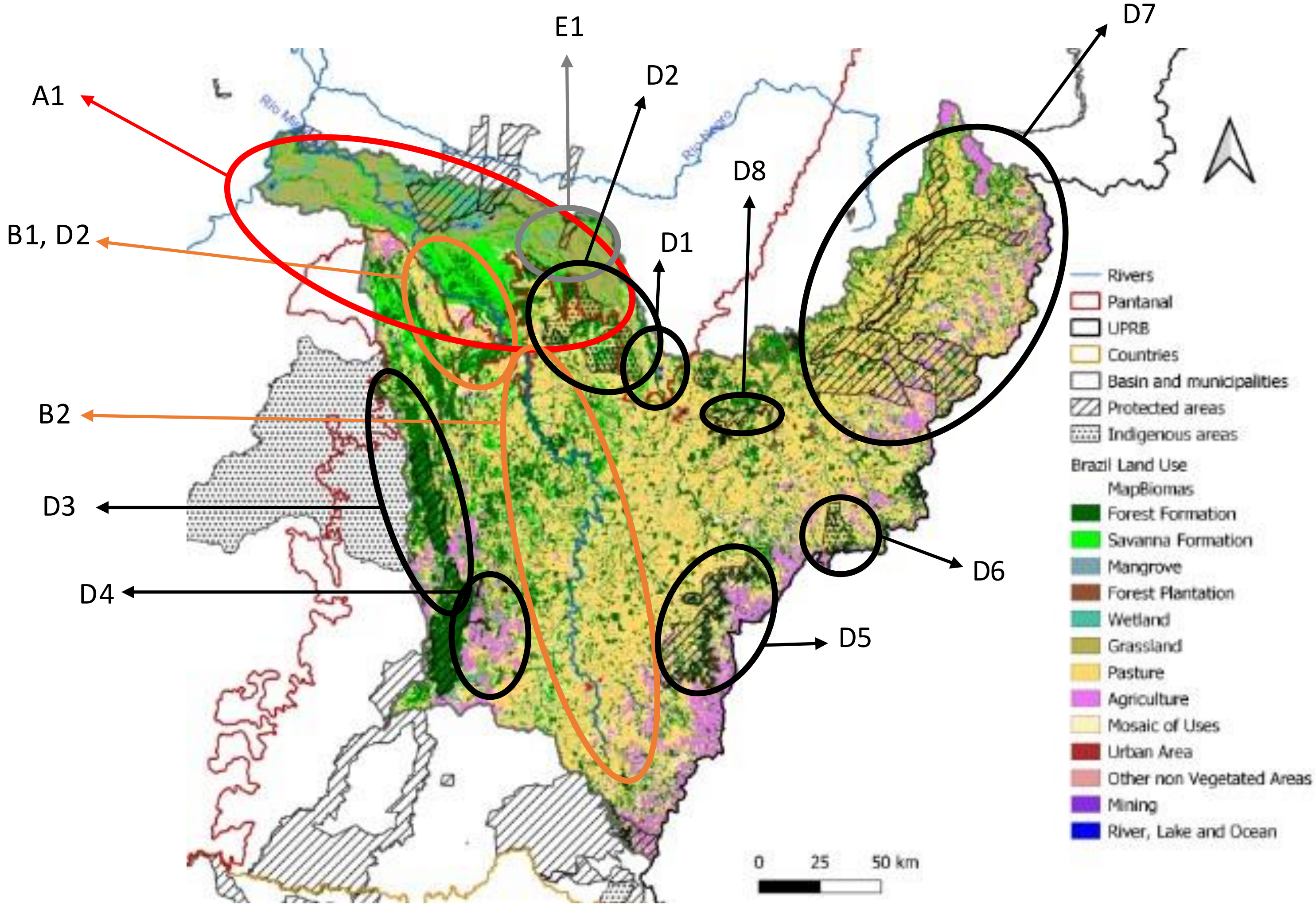

Figure 7-15 Potential locations of NbS opportunities in subbasin Miranda.

8 Conclusions and recommendations

The aim of this study was to scope NbS to address relevant challenges related to water security and navigation in the UPRB. NbS are actions to protect, conserve, restore, sustainable use and manage ecosystems and provide benefit to human well-being and the society. This study is the first stage of a NbS project cycle and focused on the questions: what is the water security and navigation challenge? and what are the most relevant NbS options? To scope NbS an informed approach was used and attention was paid to the ecosystem services, the landscape level processes and the site-specific context. As such, scoping NbS required to look at the UPRB as a whole system.

Conclusions of this study are:

- There is limited literature available that describes the water-related challenges of the whole UPRB. Most of the literature focuses on challenges per country. This study presents a brief overview of the main water-related challenges for the UPRB and relates them to pressures on the basin impacting the availability, supply and quality of water, causing land degradation and erosion.
- Main water-related challenges can be grouped in 2 categories: i) Infrastructure developments affecting water availability, water supply and water quality; and ii) Land use and conversion due to economic activities. Infrastructure developments are related to energy generation, oil and gas distribution and navigation, in particular the Paraná-Paraguay Waterway. Economic activities causing land use conversion are livestock, agriculture and mining.
- Water-related challenges are different in the highlands and the Pantanal region, but intrinsically related. Water-related challenges in the highlands include the decrease in water production in headwaters, droughts, deforestation, increase in erosion and sediment transport, sedimentation of rivers, and alteration of natural regime of rivers. In the Pantanal the water-related challenges include alteration of the flood pulse, changes of water retention and infiltration, droughts and floods, deforestation, sediment transportation from the highlands, increase in erosion and sediment transport, alteration of the natural regime and water quality deterioration.
- These challenges have significant impacts on ecosystem services, as they disrupt the natural functioning of ecosystems and can lead to various ecological consequences. Relevant impacted ecosystem services within the scope of this study are water supply, erosion prevention, extreme events moderation, water purification and regulation of water flows.
- A simplified method that combines available georeferenced global data (GIS information) can be used to analyze the potential of water retention, runoff, infiltration and erosion in the whole UPRB and to identify potential locations and their land use that provide impacted ecosystem services. This method has limitations due to the resolution and validation of the global data. Additionally, it analyses the potential of locations to provide certain level of environmental processes based on recent information, but it does not analyze the dynamics of the processes in time.

- Developing an inventory of nature-based solutions for water challenges in the Pantanal and highlands region represents a visionary step towards sustainable water management and ecosystem conservation, protection, restauration, and management. With effective implementation and collaborative efforts, the inventory can serve as a blueprint for responsible water resource management that benefits both people and the environment.
  Categories of NbS in the inventory include actions on all ecosystems present in the UPRB, namely, management of intensive land use systems, floodplain management, restoration of rivers and lakes, rivers and lakes management, conservation of wetlands, forest restoration, conservation, and creation.
- Scoping NbS for the whole UPRB is complex as it requires specific and local knowledge of the environmental processes in the highlands and Pantanal, and in the subbasins. Understanding the local nuances and socio-economic interdependencies in the region are key to define NbS that not only fit the area in technical (environmental and ecological) terms, but also are applicable from a socio-economic perspective. WWF has over 20 years of experience in the region and works with a wide range of local partners and stakeholders. To enhance impact on a basin level, it is important to look at the whole UPRB. As the only international NGO present in all three countries of the basin, WWF has a unique position to facilitate the collaboration between countries and its offices. This was a challenge in the current project.
- Six areas were selected by WWF (2 per country) based on their own local knowledge, experience and enabling conditions for conservation efforts. For each one of the areas of interest a diverse number of NbS opportunities were selected based on the ecosystem present in the area and the potential for providing impacted services.
- The Highlands and the Pantanal are highly connected. Activities and interventions in the Highlands can have a huge cumulative impact on the Pantanal and surroundings.
- Most of the identified NbS opportunities relate to the conservation and protection of natural vegetation, including forest formation, savanna formation, grassland / herbaceous and other non-forest natural formation.
- Another opportunity for NbS is the restauration of natural vegetation in priority areas as riparian forest (in riverbanks, drainage network and paleochannels), headwaters, ecological easement, and connectivity areas. For them to have a real impact on the Pantanal, they would have to be major works and for that to happen, the participation of many state institutions is required. It was found that riparian forest is legislated in Paraguay and Brazil. In the case of Paraguay, this is not always implemented as the drainage network is not always clear.
- Conservation and sustainable management of wetlands (flooded forest and grasslands) also require attention. This includes for example improving the water connectivity in the floodplains by no cultivating the drainage network. Natural reservoirs for biodiversity are an opportunity to explore in these areas.
- Restauration of natural vegetation in pasture areas is not considered as an opportunity as these areas correspond to private productive areas or active communal areas and the owners of the land may not easily agree with changes in their economic activity.
- Reducing the impact of livestock in the basin requires sustainable practices and regenerative practices, including sustainable community livestock, livestock rotation, ecosystem-based management, silvopastoral practices, and soil restoration. Special attention has to be given to the implementation of these practices in protected areas and indigenous areas where livestock activities take place.
- Aquifers have an ecohydrological function for the entire UPRB. Therefore, natural aquifer recharge is a relevant NbS opportunity. The Adrian Jara aquifer and paleochannels in the Yrenda aquifer in Paraguay are relevant areas for infiltration. The Cuiabá basin is a strategic recharge site for the basin and defines the recovery of levels in the Paraguay River.
- The dialogue with the WWF local offices was very relevant as they had the local knowledge and could advise on the practically of the NbS options identified.

Recommendations of this study are:

- A next step towards a feasibility study of the identified NbS should be made to define a preferred strategy to address the water-related challenges in the areas of interest. Such a study should include the quantitative assessment of the impacts of the identified NbS options per area of interest, including costs and benefits profiles for prioritized NbS, under different climate and socio-economic scenarios. This study needs developing numerical models for understanding the dynamic of the environmental processes in space and time, including hydrology and sediment transport. Additionally, this study has to assess the enabling conditions for the implementation of identified NbS options.
- The feasibility study of identified NbS needs to have clear planning objectives that aligns with relevant planning instruments in the areas of interest (e.g., municipal spatial plans of land use, management plans of protected areas).
- Modelling the water resources system of the whole UPRB can support the understanding of the dynamics of the relevant biophysical processes in the basin and Pantanal. This information can be used as boundary conditions for the modelling activities of the areas of interest.
- Data collected and nomenclature need to be homogeneous in such an essential transboundary region. The Pantanal is located in three countries with different views, perspectives and data collection procedures.
- Make use of local data. Except for land-use, global data was used as information sources for parameters (as slope, roughness, saturated hydraulic conductivity) for the whole UPRB. This data has a lower resolution (e.g., precipitation and evapotranspiration data) and requires local validation.
- A hackathon[27] with students in collaboration with an university in an interesting opportunity to explore and assess different scenarios and solutions for the Pantanal and UPRB.
- Efforts to include stakeholders of the area (e.g., agriculture, landowners, and cattle grazing) are essential to implement conservation and restoration plans developed by the government. Without local stakeholders' participation, land use management, restoration, and conservation measures are challenging to implement and monitor.

[27] an event in which a large number of people meet to engage in collaborative modelling)

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A Land use categories per biome

A.1 Bolivia (source: MapBiomas Bolivia)

A.1.1 Forest

Chiquitano forest. The forests in this biome are characterized by the presence of numerous succulent plants, mostly thorny, the canopy is continuous and low with isolated emerging species, whose floristic composition and structure varies according to the edaphic and topographic conditions. The medium-high semi-deciduous forest with trees between 15-25 m high, which form a complex mosaic with other ecoregions such as the Cerrado and the Floodplain Savannahs.

Chaco forest. The Chaco Forest is distributed in the south of the country and is generally deciduous, microfoliate and thorny. It has a bushy tree canopy between 3 to 5 m high, with emergencies that reach over 10 m, with the presence of columnar cacti being frequent. The Chaco Forest develops on sediments of recent origin in well-drained red soils with rocky outcrops, characterized by hardwood trees, whose leaves are shed during the dry season.

Pantanal forest. Presents dense to semi-open forests and hydrophilic wooded savannahs (6-10 m). They are characterized by being semi-deciduous pluviseasonal. Low Chiquitano forests, transitional Chiquitano forests to the Pantanal, and subhumid forests with well-drained soils.

A.1.2 Non-forest natural formation: Countryside or herbal training

Chaco. It develops in plant formations in extremely xeric climates called savanna and that present shrub and tree elements that do not develop, on a continuous layer of herbs and/or are dominated by grasses.

Chiquiatano. Composed mainly of herbaceous species and open shrubby savannahs. The grass-herbaceous layer forms a continuous layer that generally does not exceed 1 m in height. Sclerophyllous chaparral and wooded savannas of Chiquitania on well-drained soils.

Marshland. Vegetation with a predominance of herbaceous strata, with the presence of isolated shrubs and stunted woody trees. The botanical composition is influenced by edaphic and topographic gradients.

A.1.3 Other non-forest natural formation

Chaco. It is made up of chaparral on very sandy soils, where the sands have covered the ground with silty and clayey sediments, deposited in the old alluvial plains. Wooded savannahs of the sandy areas of Chaco.

Chiquiatano. They are formed floristically by the Abayoy chaparrals, which mostly comprise broad elements of the Cerrado, followed by some floristic components of the Gran Chaco, characterized by its sandy soils. In addition, it presents bushes, bushes and low forests with frequent thorny bromeliads, cacti and xeromorphic ferns.

Marshland. It is made up of chaparral on very sandy soils, where sand covers the ground with silty and clayey sediments, deposited in the old alluvial plains, in transition zones between the Chaco and Pantanal biomes.

A.1.4 Flooded Forest

Chiquitano. It develops in the riverbed and floodplain of seasonal streams in the transition zone between the northeast of the Chaco and Chiquitania and a forest seasonally flooded by stagnant waters of the Chaco-Chiquitania transition. Low forest, with a dense canopy of 6-8 m. high, and emerging of 10-12 m, which develops in shallow depressions.

A.1.5 Flooded non-forest natural formations

Chaco. Floods are not very frequent; they occur every eight or ten years. The most affected areas are those located in mountain, downhill landscapes and river slopes.

Chiquitano. Vegetation that develops on heavy hydromorphic soils, clayey or silty, with poor internal drainage or even seasonally flooded, in alluvial plains and river valleys. Composed of hydrophytic savannahs with Cerrado mounds in Chiquitanía (*Pampas-termitero*), distributed in the southern and eastern areas, which are temporarily flooded to a variable degree depending on the topography.

Pantanal. Herbaceous vegetation with a predominance of grasses subject to permanent or temporary flooding (at least once a year) according to natural flooding pulses. Marshy areas generally occur on the margins of temporary or permanent lakes occupied by emergent, submerged or floating aquatic plants (e.g., curichis and marshes). Frequent and seasonal flooding area (3-4 months). Vegetation includes grasslands, grasses and herbaceous savannahs.

A.1.6 Pasture

Chaco. In the Bolivian Chaco, a new form of livestock exploitation is being implemented, characterized by semi-intensive management, called “sustainable community livestock” or new livestock, in communities where the sustainable and rational use of the forest and water are its main pillars, this accompanied by rigorous management of the livestock herd. It is characterized by the construction of shortcuts to provide water to livestock due to the scarcity of forage and water in the dry season. It also has cultivated grasses such as (fescue, brachiaria, ryegrass, etc.).

Chiquitano. The Chiquitano biome is historically a territory with a semi-extensive livestock or livestock vocation. This area is characterized by having planted pastures and, to a lesser extent, natural ones. Livestock rotation is practiced due to the lack of water. Currently it is an important area for the export of beef to international markets and domestic consumption.

Marshland. Cultivated pastures (brachiarias, fescue, ryegrass, etc.) and natural pastures, for livestock feed. The sown pastures are perennial and last 4 to 5 years.

A.2 Brazil (source: MapBiomas Brazil)

A.2.1 Forest Formation

Amazon. Dense Rainforest, Evergreen Seasonal Forest, Open Rainforest, Semideciduous Seasonal Forest, Deciduous Seasonal Forest, Wooded Savanna, Areas that have suffered the action of fire or logging, Forest resulting from natural succession processes, after total or partial vegetation suppression primary due to human actions or natural causes, with trees remaining from primary vegetation being possible. Bamboo forest (Acre).

Cerrado. Types of vegetation with a predominance of tree species, with the formation of continuous canopies (Mata Riparian, Mata de Galeria, Mata Seca and Cerradão) (Ribeiro & Walter, 2008), in addition to semi-deciduous seasonal forests.

Pantanal. Tall trees and shrubs in the lower stratum: Seasonal Deciduous and Semideciduous Forest, Forested Savanna, Forested Stepic Savanna and Pioneer Formations with fluvial and/or lake influence.

A.2.2 Savana formation

Amazon. Open plant formation with a more or less developed shrub and/or tree layer, herbaceous layer always present.

Cerrado. Savanna formations with defined arboreal and shrub-herbaceous strata (Cerrado Restricted Sense: dense Cerrado, typical Cerrado, thin Cerrado and rupestrian Cerrado).

Pantanal. Small tree species, sparsely distributed and arranged amidst continuous shrub and herbaceous vegetation. Herbaceous vegetation is mixed with erect and decumbent shrubs.

A.2.3 Flooded Forest

Amazon. Alluvial Open Rainforest established along watercourses, occupies the periodically or permanently flooded plains and terraces, which in the Amazon constitute physiognomies of floodplain forests or igapó forests, respectively.

A.2.4 Flooded Field and Swampy Area

Amazon. Lowland or grassland vegetation that is influenced by rivers and/or lakes.
Cerrado. Vegetation with a predominance of herbaceous stratum subject to seasonal flooding (ex. Campo Úmido) or under river/lacustrine influence (ex. Swamp). In some regions, the herbaceous matrix occurs associated with tree species from savannah formation (e.g., Parque de Cerrado) or palm trees (Vereda, Palmeiral).

Pantanal. Herbaceous vegetation with a predominance of grasses subject to permanent or temporary flooding (at least once a year) according to natural flood pulses. The woody element may be present on the grassland matrix, forming a mosaic with shrub or arboreal plants (e.g., cambarazal, paratudal and carandazal). Swampy areas generally occur on the banks of temporary or permanent lakes occupied by emerging, submerged or floating aquatic plants (e.g., marshes and baceiros). Areas with water surface, but difficult to classify due to the amount of macrophytes, eutrophication or sediments, were also included in this category.

A.2.5 Non-forest natural formations

This category includes countryside formations and rocky outcrop.

Countryside formation in the Amazon biome describes Savanna, Parque Savanna (Marajó), Estépica Savanna (Roraima), Grassy Woody Savanna, Campinarana, for regions outside the Amazon/Cerrado Ecotone. And for regions within the Amazon/Cerrado Ecotone, there is a predominance of herbaceous stratum. In the Cerrado biome, countryside formations with a predominance of herbaceous stratum (dirty field, clean field and rupestrian field) and some areas of savannah formations such as the rupestrian Cerrado. In the Pantanal biome, vegetation with a predominance of graminoid herbaceous stratum, with the presence of isolated shrubs and stunted woody plants. The botanical composition is influenced by edaphic and topographic gradients and by pastoral management (livestock). Patches of invasive exotic vegetation or forage use (planted pasture) may be present, forming mosaics with native vegetation.

Rocky outcrops in the Amazon and Cerrado biome with rocks naturally exposed on the earth's surface without soil cover, often with partial presence of rupicolous vegetation and high slope.

B NbS Inventory

MANAGEMENT OF INTENSIVE LANDUSE SYSTEMS

NbS name	Type	Description	Ecosystem	ES	Scale	Highlands or lowlands	Potential location
Crop rotation	Ecosystem management	Crop rotation increases infiltration capacity and reduces runoff, preventing erosion. It also minimizes evapotranspiration and contribute to increase soil nutrients and efficient water use.	Intensive land-use systems	Erosion prevention, water purification	Basin, local	Highlands	It's a solution to be implemented in highly eroded areas in the Highlands with high sediment transportation that impact areas in the Pantanal (e.g., Corumbá, Miranda bordering the Chaco region, Cuiabá basin bordering highland/Pantanal, areas with high soy and corn production).
Strip cropping	Ecosystem management	Strip cropping contouring ploughing conserves the soil and creates ridges that retain water, like natural dams, preserving soil strength, retaining soil moisture and preventing erosion. Certain layers will absorb minerals and water from the ground more effectively than others. However, with strong strips on the soil, water flow is slowed down, and a weaker soil receives the necessary water and minerals, increasing its fertility.	Intensive land-use systems	Erosion prevention	Basin, local	Highlands	It's a solution to be implemented in the highlands, areas with high slopes (e.g., Corumbá, Miranda bordering the Chaco region, Cuiabá basin bordering highland/Pantanal, areas with high soy and corn production).
Terraces	Ecosystem management	The implementation of terraces decreases runoff and control erosion. The adoption of soft terraces, which are typically traditional used in terraces, also increases water infiltration, soil moisture and soil productivity.	Intensive land-use systems	Erosion prevention	Basin, local	Highlands	

Securing land tenure rights increasing natural resources resilience	Ecosystem management	Securing land tenure rights and increasing natural resources resilience work towards reducing topsoil erosion and land degradation.	Intensive land-use systems	Erosion prevention	Landscape, basin	Highlands and Lowlands	Applicable to areas with organic production of livestock and sustainable agriculture. Also securing indigenous lands rights.
Transferring rights for traditional land management practices	Ecosystem management	Bringing back sustainable land management practices such as traditional nomadic grazing systems, through transfer of land management rights to local communities and indigenous groups.	Intensive land-use systems	Moderation of extreme events (drought and flood), water flow regulation	Local	Highlands and Lowlands	Applicable to areas with organic production of livestock and sustainable agriculture. Also securing indigenous lands rights.
Target ponds/wetland creation to trap sediment/pollution runoff in farmed landscape	Ecosystem management	Constructed field wetlands are an edge-of-field option for reducing the landscape's loss of sediment and nutrients and for diffuse pollution mitigation. Their design and depth can vary (i.e., shallow, or deep), but they are usually unlined ponds excavated along runoff pathways or in naturally wet hillslope hollows.	Intensive land-use systems	Erosion prevention, water purification	Local	Highlands	Areas in the highlands susceptible to produce water and farmed areas
Payment for Ecosystem services	Ecosystem management	PES schemes provide incentives (monetary or otherwise) to landowners or farmers in exchange for sustainable land use practices (agriculture, forestry, etc.). The objective is that those who benefit (e.g., a water utility) from environmental services (e.g. better water quality in a river) should pay for their provision (e.g. for better pesticide and fertilizer use management or for preservation of the forest cover) to those, usually upstream, who can provide them (e.g. farmers or landowners), in order to ensure their continued production" (UNESCO)	Intensive land-use systems	Water supply	Local	Highlands and Lowlands	Agricultural areas, production water areas and retention water areas are especially benefited from this measure.

Establishing a water fund	Ecosystem management	A Water Fund uses in-kind compensation mechanisms to, for example, encourage farmers to adopt agricultural best management practices, restore riparian buffers, install efficient irrigation and reforest. These in-kind compensation packages include water pans, capacity building and training around agricultural production, seeds, equipment, and livestock such as dairy goats. The water fund can also focus on reducing sediment from unpaved rural roads	Intensive land-use systems	Water supply	Local	Highlands and Lowlands	Areas exploited for agriculture, mining and livestock raising are possible to implement this measure
Windbreaks	Creation of ecosystem	Windbreaks are linear plantings of trees and shrubs designed to provide economic and environmental benefits such as creating a more beneficial condition for soils, crops, livestock, wildlife, and people. Non-wind-related benefits of windbreaks include shade for livestock and wood and non-timber forest products. Some types of windbreaks can be implemented, such as control soil wind erosion, increase crop yields, and increase bee pollination and irrigation and pesticide effectiveness.	Tropical-subtropical Forest Shrublands & shrubby woodlands Savannas and grasslands	Erosion prevention, water purification	Local	Highlands	

FLOODPLAIN MANAGEMENT

NbS name	Type	Description	Ecosystem	ES	Scale	Highlands or lowlands	Potential location
Floodplain restoration and management	Restoration of ecosystem	Floodplain restoration comprises a series of measures that can be applied at different scales, ranging from afforestation to the modification of the main channel. The main objective of these solutions is to reconnect the floodplain to the main waterway, to reduce and mitigate the risks of flooding. Floodplains in many places have also been separated from the river by dikes, berms or other structures designed to control the flow of the river. Restoring floodplains can also bring various co-	Floodplain	Erosion prevention, water purification, water supply and water flow regulation	Landscape, basin	Lowlands	This measure can be implemented in areas that retain water in the lowlands but are affected by activities upstream.

		benefits, such as increase soil water retention, evapotranspiration and infiltration and reduce erosion.					
Meadows and pastures for flood storage, increased water retention in the landscape and runoff attenuation	Ecosystem management	Replacement of some areas of arable land for establishing rooted vegetation such as pastures and meadows. These areas can provide good conditions for the uptake and storage of water during temporary floods.	Floodplain	Erosion prevention, water purification	Local	Highlands	Water retention areas

RESTORATION OF RIVERS AND LAKES

NbS name	Type	Description	Ecosystem	ES	Scale	Highlands or lowlands	Potential location
Reconnection of oxbow lakes and similar features for flood control	Restoration of ecosystem	Reconnecting an oxbow lake or ancient meander with the river is a measure to improve water retention during floods. It consists in removing terrestrial lands between both water bodies (i.e., the river and the old meander), favoring the lateral connectivity and diversification of flows.	Lakes, rivers and streams	Water flow regulation	Local	Lowlands	Especially applicable to water retention areas.
Removal of Dams and other longitudinal barriers	Restoration of ecosystem	Dams and other transversal barriers are obstacles crossing the river section and causing discontinuities for sediment and fauna. Removing them consists in destroying all the obstacles, restoring the slope and the longitudinal profile of the river, therefore allowing re-establishment of fluvial dynamics, as well as sedimentary and ecological continuity.	Rivers and streams	Moderation of extreme events (drought and flood), water flow regulation, erosion prevention	Basin	Highlands	This measure can be implemented especially in the areas in the Cuiabá River basin, which has a lot of PCHs implemented.
Re-meandering to control the river flow and increase sedimentation	Restoration of ecosystem	River re-meandering consists in creating a new meandering course or reconnecting cut-off meanders, therefore slowing down the river flow. The new form of the river channel creates new flow conditions and very often also has a positive impact on sedimentation	Rivers and streams	Erosion prevention, water flow regulation	Local	Highlands and Lowlands	Especially applicable to upstream river areas in the Highlands

Planted embankment mat	Restoration of ecosystem	Combination of mats with vegetation layers alongside rivers/channels that slow down water velocity and promote sedimentation. It increases water infiltration, retention, filtering and connectivity of rivers.	Rivers and streams	Erosion prevention, water purification, water supply and water flow regulation	Local	Highlands and Lowlands	
Restoration or reconnection of seasonal streams	Restoration of ecosystem	Restoring and reconnecting seasonal streams with the river consists of favoring the river's overall functioning by restoring lateral connectivity and diversifying flows to these seasonal streams for better water retention during floods. Seasonal streams provide essential ecosystem services to society, including flood control and irrigation. The abundance and distribution of seasonal streams, and their natural intermittent flow regimes, are being altered by climate change, water abstraction and inter-basin transfers.	Rivers and streams	Moderation of extreme events (drought and flood), water flow regulation	Local	Highlands and Lowlands	Areas with interrupted flows - it's a good measure to be implemented as part of the free flow rivers project.
Riverbed material restoration	Restoration of ecosystem	Re-naturalization consists in recovering the nature-like structure and composition of the bed load, in particular the equilibrium between coarse and fine sediment. The main objective is to control erosion on slopes and riverbanks providing this type of sediment.	Rivers and streams	Erosion prevention, water purification, water supply and water flow regulation	Local	Highlands and Lowlands	This measure is especially applicable in areas impacted by siltation from hydroelectric plants
Bank protection measures	Restoration of ecosystem	1) near bank gravel bars acting as breakwaters, 2) off-bank timber piling acting as wave protection walls. Principle of both measures: "The working principle of the structures is based on the dissipation and reflection of the kinetic wave energy to an extent that the remaining energy behind the breakwaters can be reduced to a reasonable level."	Rivers and streams	Erosion prevention, water flow regulation	Local	Highlands and Lowlands	
Removing or reducing the height of embankments	Restoration of ecosystem	This results in: allowance of more riverbank dynamics, side-arms to be reconnected	Rivers and streams	Erosion prevention, water flow regulation	Local	Highlands and Lowlands	
Restoration of lowland rivers	Restoration of ecosystem	Restoring permanent lowland rivers with boulders, gravel, logs and branches for effective catchment management.	Rivers and streams	Water supply	Local	Lowlands	

CONSERVATION OF WETLANDS

NbS name	Type	Description	Ecosystem	ES	Scale	Highlands or lowlands	Potential location
Maintain and enhance natural wetlands	Conservation of ecosystem	Existing, relatively intact ecosystems are the keystone for conserving biodiversity and securing different services provided by wetland ecosystems. Restoration is a complementary activity that, when combined with protection, can help achieve overall improvements in a greater percentage of a territory's waters bodies and their multiple functions.	Natural wetlands	Moderation of extreme events (drought and flood), water flow regulation, erosion prevention	Landscape, basin	Lowlands	This solution can be implemented in Pantanal areas with permanent and herbaceous wetlands and its surroundings, already affected by agriculture and livestock expansion. Highlight areas are the ones adopting organic livestock creation and agriculture measures that also have pieces of lands in the lowlands.

RIVERS AND LAKES MANAGEMENT

NbS name	Type	Description	Ecosystem	ES	Scale	Highlands or lowlands	Potential location
Diverting and deflecting elements	Ecosystem management	Disruptive and diverting elements such as single rocks and tree trunks are placed in the riverbed with the primary objectives of redirecting and deflecting the current and initiate water dynamics. The elements can be placed near the riverbank or in the middle of a river, depending on the desired effect.	Rivers and streams	Erosion prevention	Basin, local	Highlands and Lowlands	Areas with high sediment accumulation, riverbanks eroded and areas with flow alteration.

Innovative rive training and stabilization structures	Ecosystem management	For example a notched closure structure or dike.: "that includes an open section within the structure to allow continuous passage of river flow, thereby maintaining aquatic habitat with sufficient flushing in the secondary channel." or for example a series of chevron training structures: "These structures utilize the river's energy to maintain navigable depths in the main channel, divert some flow from the main channel towards the wet bank line, and deposit sediment downstream of the chevrons for increased environmental diversity in the reach, which ultimately reduces future dredging requirements. In addition, these structures can be made more sustainable by using local materials to construct them"	Rivers and streams	Erosion prevention	Basin, local	Highlands and Lowlands	Especially applicable to areas with high levels of dredging (along the waterway).
Replacing groynes	Ecosystem management	This results in: reduction of riverbed erosion, restoration of natural shoreline, better fish passage	Rivers and streams	Erosion prevention, water purification	Local	Highlands and Lowlands	
Multi-stage ponds to treat wastewater	Ecosystem management	Implementing multi-stage ponds to treat wastewater before discharging directly it to rivers. Multi-stage wetlands are combinations of different treatment wetland (TW) designs, such as vertical flow (VF), horizontal flow (HF), as well as free water surface (FWS) wetlands which are connected in series. When the available area is limited, recirculation can also be considered. The main field of application is the removal of nutrients (total nitrogen, phosphorus) to comply with stringent effluent standards as well as enhanced disinfection for water reuse	Rivers and streams	Water supply	Local	Highlands and Lowlands	
Implementing transboundary water governance approach in the borders between Bolivia, Paraguay and Brazil	Ecosystem management	Establish agreements and institutional arrangements, such as river basin organizations between countries, that can offer an important means by which to manage transboundary waters in an equitable and sustainable way.	Rivers and streams	Water supply	Landscape	Lowlands	Areas bordering Brazil-Paraguay, Brazil-Bolivia, Bolivia-Paraguay

Living revetment	Creation of ecosystem	The replication of natural conditions, in this case the vegetation, stabilizes the soil, protects the river zone from erosion and slowdowns water velocity. It also fosters natural processes, such as filtering, storage and infiltration.	Intensive land-use systems	Erosion prevention	Basin, local	Highlands	It can be implemented in areas with intense use in the Highlands. For example, areas with intensive livestock raising and agricultural areas close to rivers.
Revetment with cuttings	Restoration of ecosystem	Revetment with cuttings consists in covering high eroded areas with high slopes with trees (able to root) and brushwood (not able to root) or with any simple and local available materials. The installation and fixation on embankment will protect against erosion. It increases hillside stabilization, water infiltration, retention and filtering.	Intensive land-use systems	Erosion prevention	Local	Highlands	Especially applicable to upstream river areas in the Highlands (e.g., livestock raising).
Rock reuse	Restoration of ecosystem	Removal of rocks from the bottom of the river. Reuse these rocks to stabilize riverbanks or outside the riverbank to create a habitat for aquatic species.	Rivers and streams	Erosion prevention, water flow regulation	Local	Highlands and Lowlands	Very applicable to highly eroded riverbanks areas

FOREST RESTORATION

NbS name	Type	Description	Ecosystem	ES	Scale	Highlands or lowlands	Potential location
Forest landscape restoration as a priority policy	Restoration of ecosystem	Forest Landscape management tools such as agroforestry, silviculture, natural forest restoration and protective riparian forest for improving livelihoods and hydropower capacity	Tropical-subtropical Forest Shrublands & shrubby woodlands Savannas and grasslands	Moderation of extreme events (drought and flood), water flow regulation, erosion prevention	Landscape	Highlands	
Replenishing groundwater through reforestation	Restoration of ecosystem	Increase of the forest area of a water catchment to mid-term gains in groundwater and water supply. The activities include reforestation of native species and establishment of pits and	Tropical-subtropical Forest Shrublands & shrubby woodlands	Water supply, erosion prevention, water flow regulation	Basin, local	Highlands and Lowlands	This measure can be implemented closer to water recharge and water production areas with high levels of impact.

		earthen dams to retain water while the trees grow.	Savannas and grasslands Subterranean freshwater				
Reuse of local large woods	Restoration of ecosystem	This wood can be used for the construction of wooden constructions to influence the stream and sediment transport. Such as wooden pile dikes, palisades and training structures.	Tropical-subtropical Forest Shrublands & shrubby woodlands Savannas and grasslands	Moderation of extreme events (drought and flood)	Basin, local	Highlands and Lowlands	Wood transported in the Paraguay river can be used.

FOREST CONSERVATION

NbS name	Type	Description	Ecosystem	ES	Scale	Highlands or lowlands	Potential location
Maintenance of forest cover in headwater areas	Conservation of ecosystem	Conserving and protecting headwaters is crucial for river and streams functioning and productivity as well as to keep downstream ecosystems healthy. Headwaters are relevant areas for water production, where precipitation contributes most for surface and groundwater. Maintaining forest cover in the headwater areas is important to water availability, improve soil infiltration capacity and slope stabilization, tackling erosion and potential landslides.	Tropical-subtropical Forest Shrublands & shrubby woodlands Savannas and grasslands	Water supply, erosion prevention, water flow regulation	Landscape, basin	Highlands	This measure can be implemented in areas that produce water located in the Highlands.
Protect forests from clearing, degradation, logging, fire and unsustainable levels of non-timber resource extraction	Conservation of ecosystem	This activity comprises the range of legal, governance, and social instruments to ensure that forests are not harvested at levels higher than their increment rate, leading to forest clearance.	Tropical-subtropical Forest Shrublands & shrubby woodlands Savannas and grasslands	Erosion prevention	Landscape, basin	Highlands	This measure can be implemented in forest areas, deforested areas, and other areas of the Pantanal and Highlands.

FOREST CREATION

NbS name	Type	Description	Ecosystem	ES	Scale	Highlands or lowlands	Potential location
Targeted planting for "catching" precipitation	Creation of ecosystem	Land use change and associated deforestation at a large scale may lead to significant weather and rainfall patterns. Targeted afforestation is a measure to combat drought and desertification processes.	Tropical-subtropical Forest Shrublands & shrubby woodlands Savannas and grasslands	Moderation of extreme events (drought and flood)	Landscape, basin	Highlands and Lowlands	Areas that could benefit from this measure are farm properties inside the basin that are willing to create preserved areas and areas that have become dryer over the years due to land use change.
Windbreaks	Creation of ecosystem	Windbreaks are linear plantings of trees and shrubs designed to provide economic and environmental benefits such as creating a more beneficial condition for soils, crops, livestock, wildlife, and people. Non-wind-related benefits of windbreaks include shade for livestock and wood and non-timber forest products. Some types of windbreaks can be implemented, such as control soil wind erosion, increase crop yields, and increase bee pollination and irrigation and pesticide effectiveness.	Tropical-subtropical Forest Shrublands & shrubby woodlands Savannas and grasslands	Erosion prevention, water purification	Local	Highlands	

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