2026

Assessment of Watershed Management and Planning for Riparian Zone Restoration of BIPOSC Project North Sumatera

2nd Deliverable: Riparian Planning

Prepared by
Yudha Kristanto
Ardiansyah Putra Wardana

The riparian zone is a transitional area between terrestrial and aquatic ecosystems located along the banks of rivers, lakes, and other water bodies. Ecologically, this zone is characterized by fluctuating water levels, dominance of hydrophytic vegetation, and high biodiversity resulting from gradients in soil moisture and nutrients that are unique to this environment.
This area plays a critical role in:

- Maintaining water quality by filtering sediments, nutrients, and pollutants before they enter water bodies
- Controlling riverbank erosion through vegetation root systems
- Providing ecological corridors for wildlife and landscape connectivity
- Contributing to microclimate regulation by managing water, soil, and air temperatures through canopy shading
- Serving as a source of organic carbon input (leaf litter, coarse woody debris) for aquatic ecosystems
- Storing carbon for climate change mitigation

Pressure on riparian zones continues to increase, particularly in oil palm plantation landscapes such as the Bilah Watershed (DAS Bilah), making riparian restoration an urgent priority.

A. Mapping of Riparian Areas in the Bilah Watershed

One relevant approach to managing the Bilah Watershed is the implementation of riparian zones as part of Best Management Practices (BMP). Mapping the riparian zone in the Bilah Watershed has become increasingly urgent given existing conditions that show high pressure on riverbanks, particularly in landscapes dominated by oil palm plantations. The practice of planting crops right up to the river's edge has reduced the natural function of the riparian zone as a hydrological buffer, which should play a role in controlling surface runoff, stabilizing banks, and filtering sediments, nutrients, and agrochemical residues.

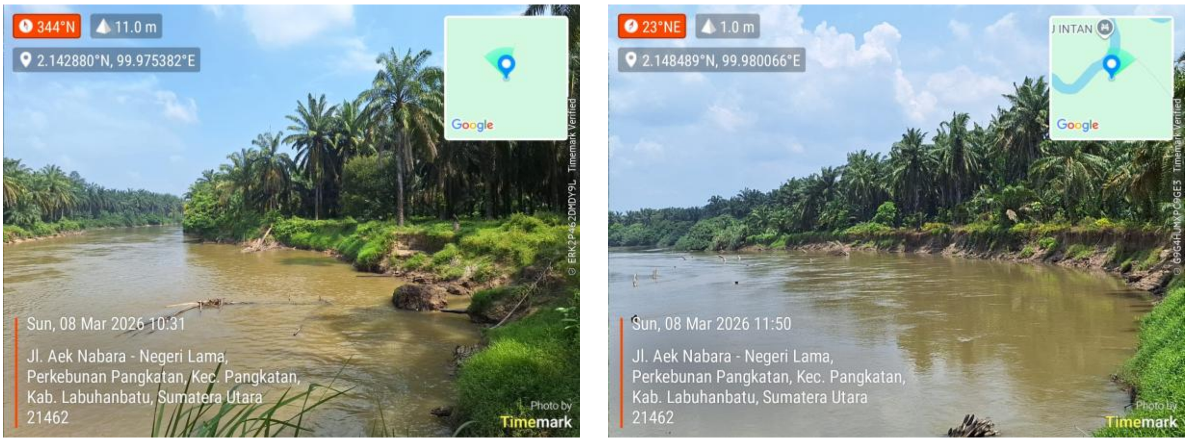


Figure 1: Oil palm planted up to river's edge and active erosion eroding farmers' land

This situation is compounded by the lack of bank-stabilizing vegetation, resulting in many river segments experiencing active bank erosion that erodes productive land and causes economic losses for farmers. Agricultural activities such as land clearing and drainage system modification also affect water flow patterns and increase vulnerability to erosion.

1. Identification of the Bilah Watershed Hydrological System

The Bilah Watershed (DAS Bilah) is part of the Barumun-Bilah watershed hydrological system located in the southeastern region of North Sumatra Province, playing a strategic role as a water management unit in Labuhan Batu Regency. Hydrologically, this watershed functions in controlling water flow distribution through key processes such as infiltration, percolation, and surface runoff, which collectively determine water availability and the stability of the flow regime throughout the year.

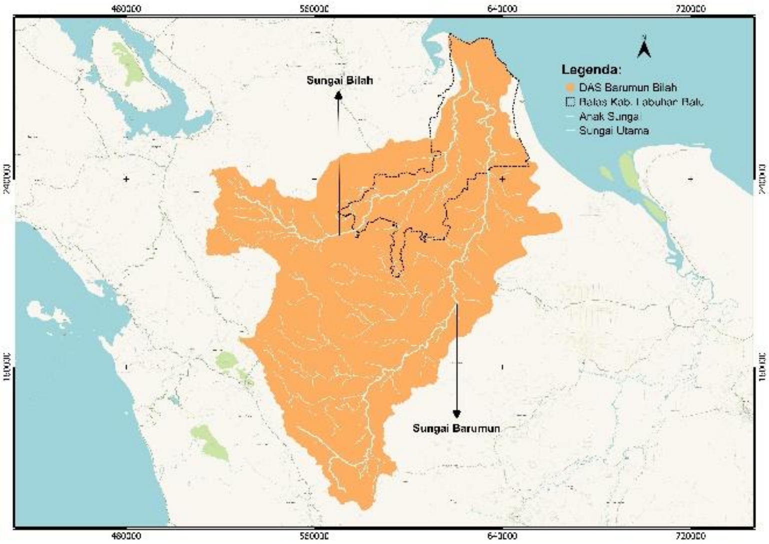
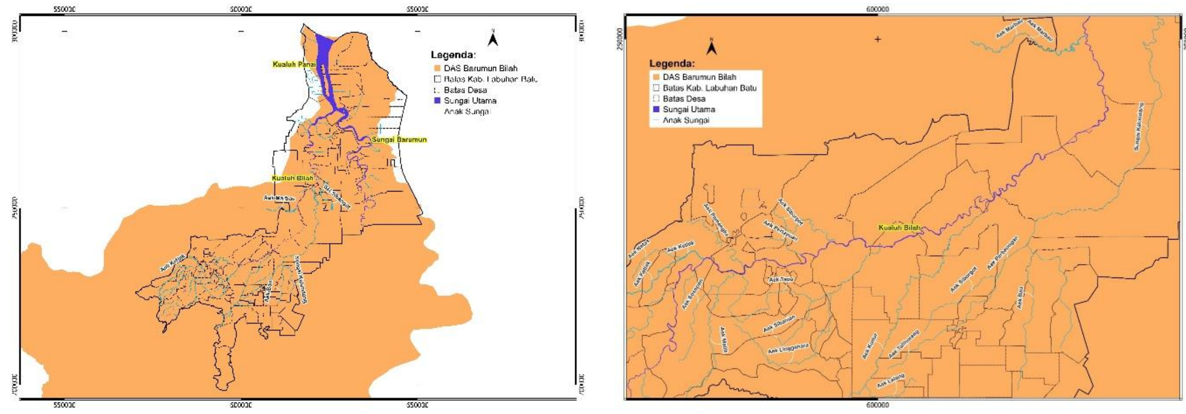


Figure 2: The Bilah Watershed within the Barumun-Bilah watershed system

The DAS Bilah also plays a role in maintaining ecological balance through its support for groundwater storage, erosion control, and water quality maintenance. However, intensive land-use change, particularly the conversion of forests to agricultural land and plantations, as well as vegetation degradation and other anthropogenic activities have caused a decline in the watershed's hydrological capacity. This has resulted in increased runoff coefficients, reduced infiltration, and greater variability in river discharge, which may ultimately increase the risk of hydro-meteorological disasters such as flooding during the rainy season and drought during the dry season.



(a) (b)

Figure 3: Bilah River and its tributaries in Labuhan Batu Regency (a) and zoom-in of tributaries (b)

Based on the Indonesian Rupa Bumi Map (RBI), the river network system in DAS Bilah consists of the Bilah River as the main channel, supported by several identified and officially named tributaries. The Bilah River originates in Toba Regency, then flows through Labuhan Batu Regency before confluencing with the Barumun River and ultimately emptying into the Malacca Strait. The watershed includes tributaries such as Sungai Kundur, Sungai Ketiak, Sungai Pamengke, Sungai Merbau, and Sungai Kalundang, which play a role in maintaining flow dynamics and discharge continuity throughout the year. Administratively, the Bilah River flows through six sub-districts in Labuhan Batu Regency: Bilah Barat, Bilah Hilir, Panai Hulu, Pangkatan, Rantau Selatan, and Rantau Utara.

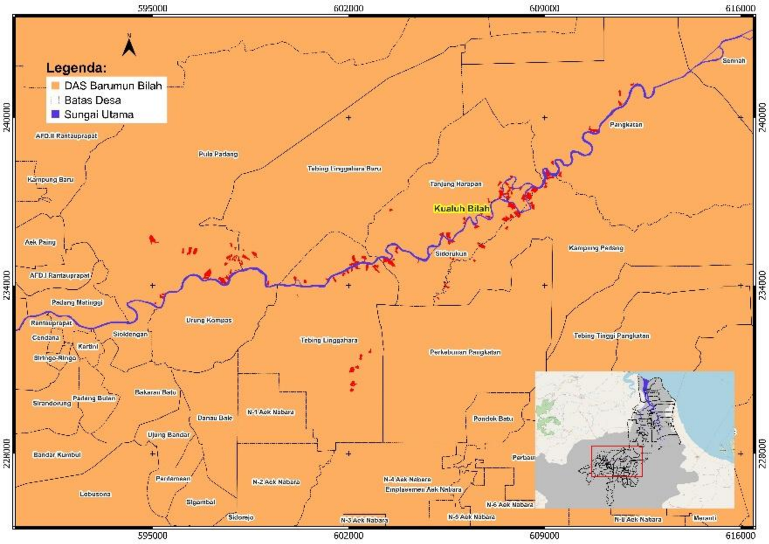


Figure 4: Villages in Labuhan Batu Regency traversed by the Bilah River

In addition to the main river, DAS Bilah also has many small channels that function as water collection points, generally less than 1 meter wide, as well as seasonal (intermittent) channels found mainly in the upper reaches. Although most of these channels are unnamed in RBI data, their presence remains important in the hydrological system, particularly in conveying water during rainfall events and maintaining connectivity between watershed sections.

2. **Determining Riparian Width in DAS Bilah**

The establishment of riparian zone width in DAS Bilah is guided by the principle of protecting riparian buffer functions and applicable regulatory requirements. In general, no new land clearing is permitted within the riparian zone, and areas that have experienced historical disturbance are required to undergo restoration. In management practice, the minimum riparian zone width is determined based on river scale, ranging from 0–5 m for streams, ≥5 m for small rivers, and ≥50 m for large rivers. Meanwhile, based on Government Regulation (PP) No. 28 of 2011 on Rivers, riparian buffer requirements outside urban areas are set at 100 m for large rivers and 50 m for small rivers.

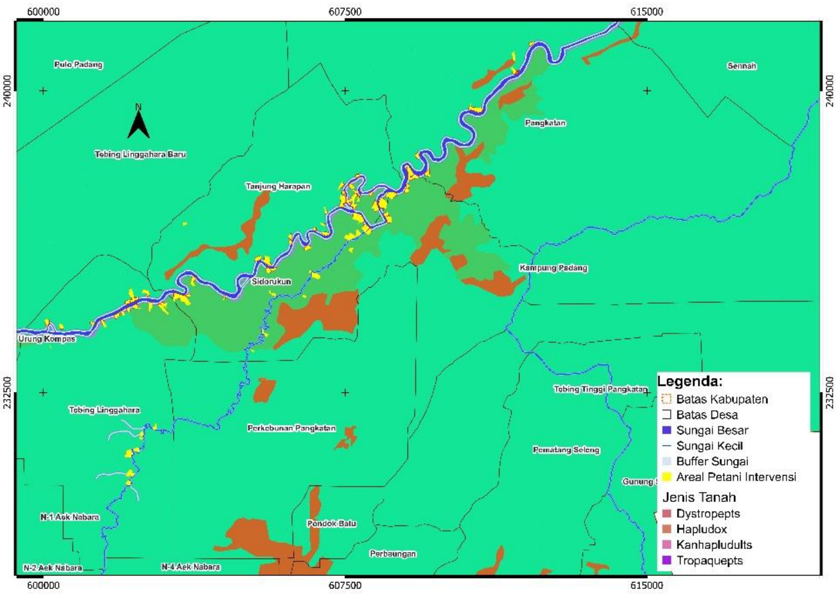


Figure 5: Riparian zones in DAS Bilah

Based on interpretation of the RBI map verified through field surveys, the Bilah River has an average width of approximately 50 m and can therefore be classified as a large river. River segments in Rantau Utara and

Rantau Selatan sub-districts fall within urban areas, while other segments are outside urban areas. Given these characteristics and an adaptive management approach, a minimum riparian zone of 50 m on each side of the river is recommended as the operational protection boundary. Given the Bilah River's length of approximately 136.61 km within Labuhan Batu Regency, the theoretical riparian area requiring management reaches approximately ±1,366.1 ha along the river corridor.

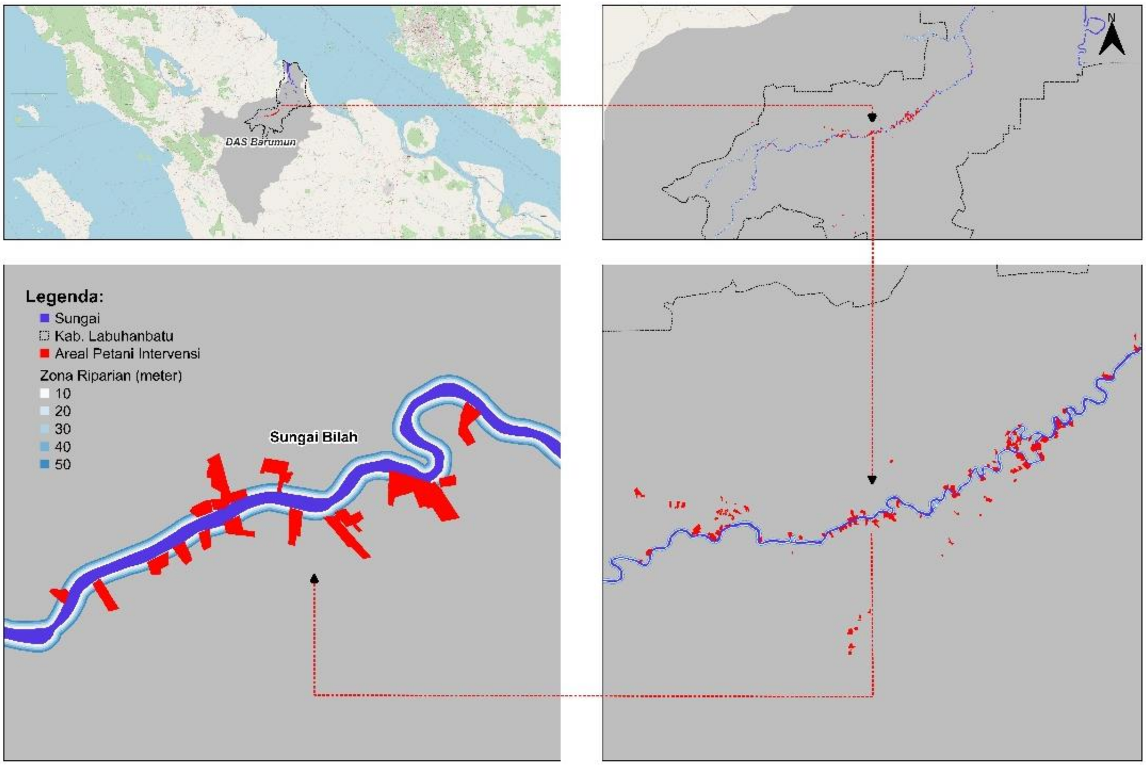


Figure 6: Zoom-in visualization of the riparian zone on the Bilah River

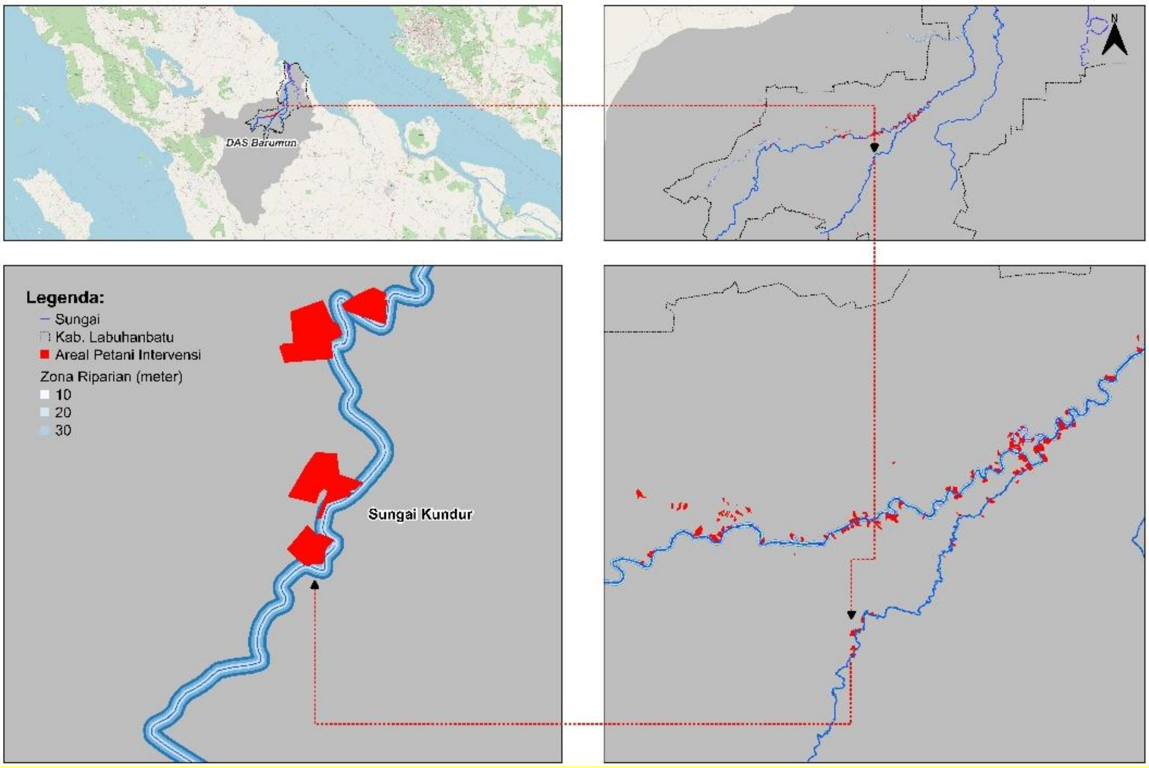


Figure 7: Zoom-in visualization of the riparian zone on the Kundur River

The Bilah Watershed's tributaries show considerable variation in width, so the riparian zone is determined using a general precautionary approach. Based on this approach, a minimum riparian zone width of 20 meters on each side of tributary channels is recommended to maintain bank protection, water quality, and aquatic ecosystem sustainability. For example, the Kundur River has a length of approximately 34.57 km within Labuhan Batu Regency, with a theoretical riparian area of approximately 207.42 ha.

A minimum buffer width of 10 m is considered effective for basic filtration functions, particularly for trapping sediments and pollutants, while a width of ≥30 m is needed to support more optimal ecological functions such as providing wildlife habitat and improving riparian ecosystem stability. For very narrow micro-channels (less than 1 meter) and limited-flow channels such as intermittent and dead streams, no specific riparian zone is designated, although these channels still require careful management to prevent disruption to the local hydrological system.

The mapping results were integrated with BIPOSC program intervention locations along the river corridor. Spatial analysis identified approximately 170 farmer plots totaling ±185 ha along the Bilah River banks, of which approximately 36.73 ha (about 20%) lies within the riparian zone. Along the Kundur River banks, the intervention area within the riparian zone was smaller, at approximately 4.55 ha (about 2% of total intervention area).

B. Riparian Design for DAS Bilah

Riparian zone design is a key step in ensuring that the ecological and hydrological functions of the river buffer zone can operate optimally within a plantation landscape. The design approach focuses not only on establishing zone width, but also on how the structure, composition, and condition of vegetation can respond to environmental pressures while supporting ecosystem recovery processes. Riparian zone design must therefore integrate threat management strategies that could reduce zone quality, as well as restoration interventions for degraded areas.

1. Existing Conditions

There are two main components in the riparian zone management program: managing threats to the riparian zone and restoring degraded areas with inadequate vegetation quality through rehabilitation programs. The condition of the riparian zone is the most important indicator for assessing whether the zone can effectively protect water quality, reduce bank erosion, and maintain biodiversity. Characteristics of an optimally functioning riparian zone include:

- High density of large trees and a closed canopy, providing shade, protecting soil, and supporting biodiversity
- Complex structure (diverse sizes, forms, and heights of vegetation) riparian areas also need small trees, shrubs, and ground cover vegetation
- High diversity of native tree and plant species
- High amounts of leaf litter and dead wood that important for reducing runoff and erosion and supporting terrestrial and aquatic biodiversity
- Low vegetation (grasses and ferns) between the forested riparian area and oil palm crops (outside the minimum riparian width) for filtering sediments and reducing nutrient and pesticide runoff before reaching the river

The existing condition of the riparian zone in the study area shows a high degree of degradation in both vegetation structure and ecological function. The riparian zone generally no longer has adequate vegetation cover, and on most river segments, oil palm has been planted right up to the river's edge. This indicates the absence of effective delineation and protection of the riverbank, so the boundary between the protected area and the cultivation area has become blurred.

The loss of the natural buffer zone directly reduces the area's capacity to dampen surface flow energy, filter sediments, and prevent nutrients and pollutants from entering the water body. In the long term, this not only affects water quality but also contributes to increased river sedimentation and declining hydrological function of the watershed overall.

Remaining riparian vegetation is very limited and does not form a complete structure. Only a few local species remain such as waru (Hibiscus tiliaceus), gelagah (reeds), bera-bera, and ara/beringin (locally known as 'snake food' or luwingan). However, their presence is scattered and insufficient to form a canopy or root system capable of stabilizing the riverbank.

Figure 8: Remaining riparian vegetation in DAS Bilah

Most of the area is dominated by open land, oil palm plantations, and even intensive horticultural cultivation with fertilizers and pesticides, increasing the risk of water contamination through surface runoff. Without a vegetative buffer, rainwater falling on the soil surface will easily carry soil particles, fertilizer residues, and other chemicals directly into the river, potentially causing eutrophication, increased water turbidity, and disruption of aquatic ecosystems.

From a geomorphological perspective, active erosion has been identified, particularly at river bends, indicating bank instability due to loss of vegetation protection and increased flow energy. Additional threats come from sand mining within the river, which may change the flow regime, including depth and discharge characteristics. Continuous extraction of riverbed material can cause an imbalance in the river's profile, accelerate bed degradation, and trigger bank failures in the surrounding area.

Pressure from agricultural and plantation activities in upstream areas further worsens hydrological conditions through extreme flow fluctuations. Discharge peaks during rainfall become higher and occur in shorter timeframes, increasing erosive energy downstream. Given this situation, natural regeneration is not recommended as a restoration approach due to the limited natural seed sources, absence of mature native trees, and lack of nearby natural forest to serve as a propagule source. Active restoration through planting is therefore the more relevant approach.

2. **Determining Priority Areas**

From a morphological perspective, most agricultural land along the Bilah River banks lies on flat to gently sloping topography, which is generally very supportive for cultivation. However, the key distinguishing feature is the presence of riverbanks that directly border the agricultural land and the river. These banks form a transitional zone that is geomorphologically more dynamic than the flat area above, because they are directly exposed to river hydrological processes.

On low-slope floodplains, bank stability is not solely determined by slope angle but is heavily influenced by hydromorphological factors such as flow velocity, discharge fluctuations, and erosion-sedimentation dynamics, particularly on the outer side of river bends. In this context, riparian vegetation is a key factor determining bank resistance to erosion. The root systems of vegetation increase soil cohesion and strengthen bank structure, while the canopy helps absorb rainfall energy and reduces surface flow velocity before it reaches the river.

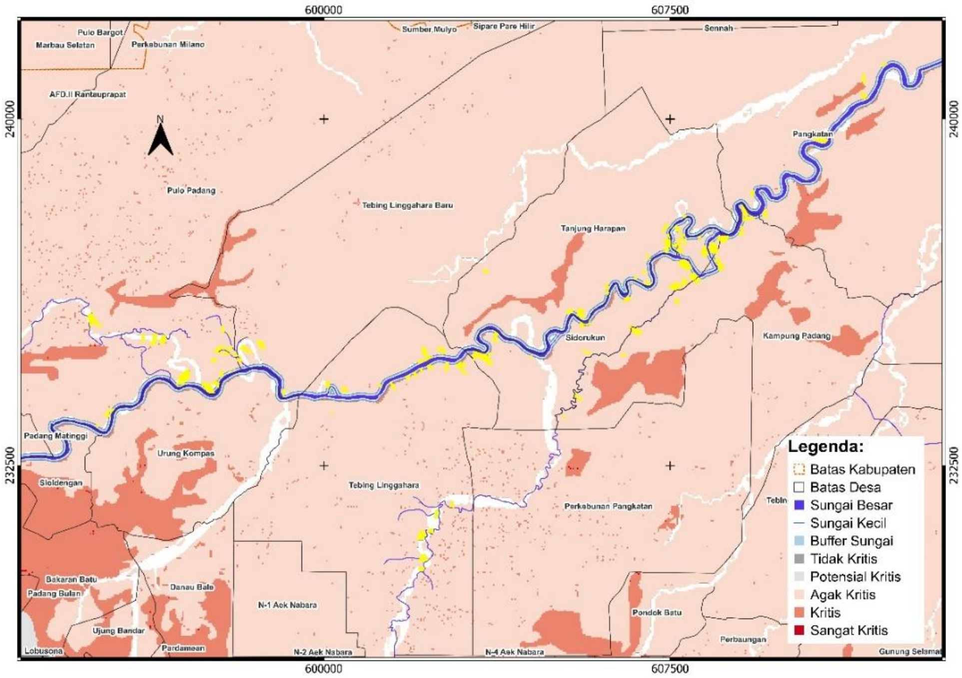


Figure 9: Land criticality levels along the Bilah River

Based on land criticality classification, most of the area falls into the 'moderately critical' category, indicating that land quality degradation has occurred and may develop into more serious damage if not controlled promptly. At the section where flow meets the bank, particularly at unprotected bends without vegetation cover, erosion can progress into more intensive bank erosion and trigger local landslides.

Figure 10: Active erosion on outer bend and sedimentation on inner bend

Geomorphologically, the river system in Labuhan Batu Regency is in the lower zone of the Barumun-Bilah watershed system. On meandering rivers, flow energy distribution is not uniform along bends. When water flows around a bend, flow velocity increases on the outer side, generating greater hydraulic pressure against the bank, triggering bank erosion. On the inner side, velocity decreases, allowing sediment deposition to form point bars.

Based on these spatial positions, several priority plots for riparian restoration demonstration plots located on the outer bend of the river are identified as follows:

Table 1: Priority Demonstration Plots Located on the Outer Bend of the River

No	Name	Location
1	Ahmat Syarip Siregar C dan A	Tanjung Harapan, Pangkatan
2	Ahmat Syarip Siregar A	Tanjung Harapan, Pangkatan
3	Nur Rahayu	Kampung Padang, Pangkatan
4	Juita Ningsih	Kampung Padang, Pangkatan
5	Rosmah Hasibuan	Kampung Padang, Pangkatan
6	Yatino A	Tanjung Harapan, Pangkatan
7	Bahsan Pohan B	Tanjung Harapan, Pangkatan
8	Delhi Munthe	Kampung Padang, Pangkatan
9	Samsul Bahri Munthe	Kampung Padang, Pangkatan
10	Maslan A dan B	Kampung Padang, Pangkatan
11	Maulana Rahmat Hasibuan	Kampung Padang, Pangkatan
12	Jamaludin	Kampung Padang, Pangkatan
13	Reinisa	Kampung Padang, Pangkatan
14	Suparmin	Tanjung Harapan, Pangkatan
15	Nyono	Kampung Padang, Pangkatan

Field verification shows contrasting erosion vulnerability levels based on river geomorphological position and riparian vegetation condition. On relatively straight river segments, erosion tends to be more controlled due to more even flow energy distribution, as observed on Ibu Murni's and Pak Usup's land in Tebing Linggahara village, where no significant bank erosion was found and sedimentation was even occurring.

In contrast, on meandering segments, particularly on the outer bend, erosion vulnerability increases significantly. On Mr. Ahmad's and Suparmin's land, erosion has developed into bank failures causing partial land loss. The situation is worsened by the absence of riparian vegetation, with some banks planted with oil palm, whose root systems are relatively less effective at strengthening bank structure than native riparian vegetation.

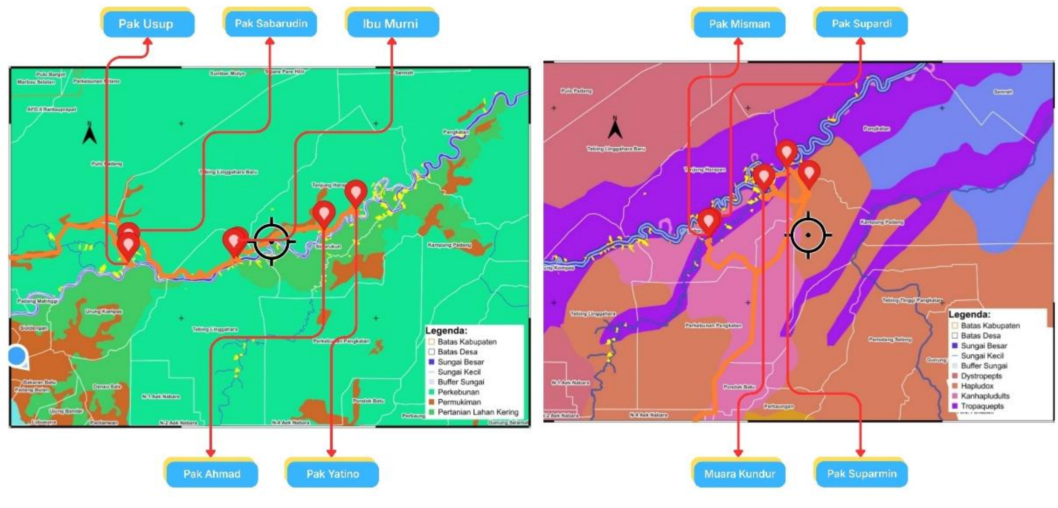


Figure 11: Field survey locations

However, the presence of riparian vegetation—even if not fully optimal—still plays an important role in dampening erosion impacts, even in meander areas that are naturally more vulnerable. This is evident on Pak Yatino's land, which is also located on a river bend but retains vegetation cover such as luwingan, waru, ferns, and gelagah. This combination of vegetation, particularly through its root systems and ground cover, can reduce flow energy reaching the bank and increase soil cohesion.

On the Kundur River tributary, land conditions also show serious degradation, particularly with active erosion on meandering segments lacking riparian vegetation cover, as observed on Mr. Misman's and Mr. Supardi's land. Poor conditions are also found at the downstream confluence where the Kundur River meets the Bilah River, where oil palm has been planted close to or even within the confluence zone—a geomorphologically complex area with higher and less stable hydraulic dynamics.

3. Three-Zone Design for Riparian Management

Science-based riparian vegetation design generally adopts a three-zone approach first developed by Welsch (1991) and later adapted in guidelines by FAO (2018) and USDA (2012). This approach is designed to optimize hydrological, ecological, and management functions in an integrated manner through systematic spatial arrangement. The riparian zone is divided into three main zones: the lower bank, upper bank, and grass strip (outer buffer zone).

Table 2: Riparian Zone Division

Parameter	**Zone A: Core Riparian Zone**	**Zone B: Stand Buffer Zone**	**Zone C: Outer Buffer Zone**
Distance from river edge	Small river: 0–5 m Large river: 0–15 m	Small river: 5–20 m Large river: 15–50 m	Small river: >20 m Large river: >50 m
Primary function	Prevent bank erosion through dense root systems; stabilize bank structure; provide microhabitat for aquatic organisms; slow current velocity at river edge	Intercept surface runoff before it enters the river; filter sediments, nutrients, and pollutants; provide shade to stabilize water temperature; serve as wildlife habitat corridor	First filter of rainwater runoff from land; capture sediments, fertilizers, and pesticides; reduce surface flow velocity; transition zone between land and river ecosystems
Vegetation typology	Native riparian trees, amphibious herbs, reeds (gelagah)	MPTS with medium to tall canopy (dominant)	Shrubs, ground cover / cover crops
Priority species	Ficus spp., Barringtonia spp., Pandanus spp., Salix tetrasperma	High-value MPTS	Vetiveria zizanioides
Permitted activities	No cultivation; passive monitoring only	Limited selective timber harvesting (non-clear-cut); fruit harvesting	Cover crop management
Regulatory reference	PP 38/2011, RSPO, HCV Standard	PermenPU 28/2015, FAO Buffer Guidelines 2018	GIZ ILA Framework, Wilmar NDPE Policy 2019
Priority monitoring	Canopy cover, root density, active bank erosion	Vegetation cover %, sediment interception, stand biomass	Soil infiltration, surface runoff, invasive weed invasion

The lower bank is the zone closest to the river body and is directly influenced by flow dynamics. This zone has a high flooding frequency due to water level fluctuations, particularly during discharge increases or seasonal flooding. Soil conditions are generally moist to saturated. Vegetation suitable for this zone must be flood-tolerant with strong, deep root systems to increase soil cohesion and stabilize bank structure. This zone is recommended to have a width of approximately 0–15 meters from the river's edge. No productive crop planting is permitted in this zone under any circumstances—violations can be categorized as major non-conformance findings in RSPO or ISPO audits. All naturally growing volunteer trees must be retained, unless they are invasive alien species (IAS).

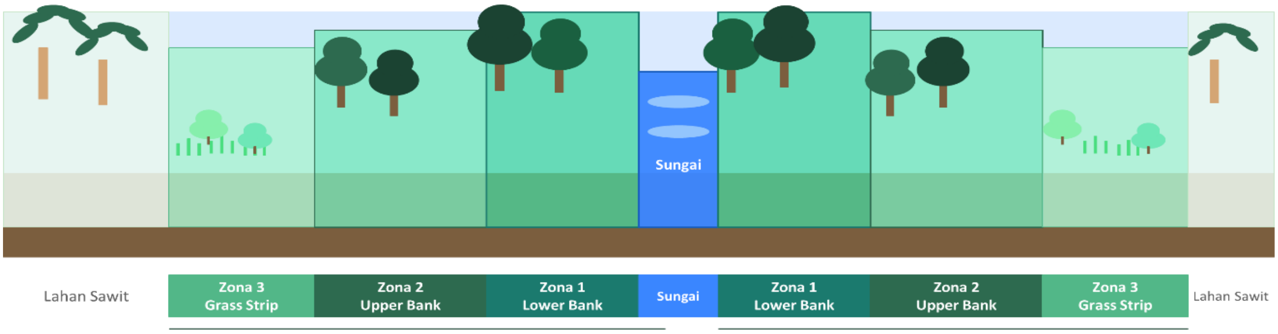


Figure 12: Illustration of the three riparian zones

The upper bank zone functions as a buffer area between the river body and the surrounding land. This zone is less frequently flooded due to its higher elevation, so soil conditions tend to be more stable although still relatively moist. Vegetation in the upper bank generally has a more complex layered structure consisting of trees, shrubs, and ground cover. Its ideal width generally ranges between 20–40 meters, depending on biophysical conditions and surrounding land-use pressures.

The third zone is the grass strip, the outermost part of the riparian zone, functioning as a transition zone between the river ecosystem and land-use areas such as agriculture or settlements. This zone is generally not flooded except during major floods, and is dominated by low vegetation such as grasses and ground cover plants. Although located on the outer edge, this zone is critically important as a first filter for surface runoff from land.

4. Plant Species Selection

Species selection for riparian planting must be based on key criteria supported by scientific studies and Best Management Practices (BMP) standards. Ignoring these criteria is often the main factor causing low survival rates and failure to achieve restoration objectives in the long term.

Table 3: Plant Species Selection Criteria

Criterion	**Description and Scientific Justification**
Native/local species	Absolute priority for species naturally distributed in the region/bioregion. Native species have evolutionary adaptation to local hydrology, soil, and climate (Maginnis & Jackson, 2007)
Flood/waterlogging tolerance	Species must survive seasonal waterlogging. Measured through aerenchyma root or adventive root adaptation (Kozlowski, 1997)
Strong root system	Deep (taproot) and extensive lateral roots prioritized for bank stabilization. Root:shoot ratio >0.5 preferred (Shields et al., 2008)
Rapid early growth	Pioneer species with fast growth (>1 m/year) needed for quick coverage and early erosion protection. Can be combined with long-term climax species
High ecosystem value	Prioritize species with wildlife food/habitat value (frugivory, nesting sites). HCV 1–2 species receive highest selection scores

Seedling availability	Availability of seeds/seedlings from local sources (regional nurseries, local BPTH) strongly considered for cost efficiency and genetic adaptability
Free of invasive species	Must not be on IUCN IAS, KLHK, or regional invasive species lists. Acacia nilotica, Chromolaena odorata, and Lantana camara must be avoided
Multifunctional/agroforestry	For Zone C and farmer incentives, consider species offering economic products (fruit, timber, MPTS) without sacrificing primary riparian functions

ZONE A: Core Riparian Zone Species (0–5 m / 0–15 m from river edge)

This zone is closest to the river and must be dominated by obligate riparian species, which is species that have physiologically adapted to waterside conditions. The planting approach here is enrichment planting, with the primary principle of retaining all existing natural vegetation. Recommended species must tolerate waterlogging and have strong root systems that firmly grip the soil.

Table 4: Plant Species for Zone A (Lower Bank)

Local Name	Scientific Name	Family	Stratum	Primary Function	Flood Tolerance
Ara/beringin (Fig)	Ficus racemosa	Moraceae	Canopy (15–25 m)	Stabilization, wildlife habitat, fruit for fauna	Very high
Pulai sungai	Alstonia scholaris	Apocynaceae	Canopy (15–20 m)	Shade, timber, bird habitat	High
Bintangur sungai	Calophyllum soulattri	Calophyllaceae	Canopy (12–20 m)	Stabilization, fruit, waterside shade	Very high
Pangi/Barringtonia	Barringtonia racemosa	Lecythidaceae	Sub-canopy (5–12 m)	Phytoremediation, wildlife fruit, waterside	Very high
Pandan sungai	Pandanus helicopus	Pandanaceae	Large herb (2–4 m)	Bank stabilization, herpetological habitat	Very high (inundated)
Tropical willow	Salix tetrasperma	Salicaceae	Small tree (5–10 m)	Bank bioengineering, adventive roots	Very high
Gelagah (river reed)	Phragmites karka	Poaceae	Herb (2–4 m)	Sediment filter, waterbird habitat	Very high
Kayu apu (water lettuce)	Pistia stratiotes	Araceae	Floating herb	Nitrogen & phosphorus phytoremediation	Obligate aquatic
Waru sungai	Hibiscus tiliaceus	Malvaceae	Sub-canopy (5–10 m)	Rapid stabilization, multipurpose	Very high

ZONE B: Stand Buffer Zone Species (5–20 m / 15–50 m)

This zone functions as the primary surface runoff filter while still allowing limited integration with agroforestry systems. Species composition is prioritized on woody plants with tall canopies, deep root systems, and effective shading capacity. Functionally, this zone acts as a buffer between the river body and surrounding land use areas.

Table 5: Plant Species for Zone B (Upper Bank)

Local Name	Scientific Name	Family	Stratum	Primary Function	Economic Value
Mahogany	Swietenia macrophylla	Meliaceae	Canopy (25–35 m)	Shade, high-value timber, carbon sink	High (timber)
Teak	Tectona grandis	Lamiaceae	Canopy (25–30 m)	Premium timber, deep roots, carbon sink	Very high (timber)
Sengon Laut (Albizia)	Paraserianthes falcataria	Fabaceae	Fast canopy (25 m)	N fixation, rapid coverage, pulpwood	Medium (timber)
Dadap (Coral tree)	Erythrina fusca	Fabaceae	Sub-canopy (8–15 m)	N fixation, livestock feed, riparian border	Medium (feed)
Bungur (Pride of India)	Lagerstroemia speciosa	Lythraceae	Canopy (10–20 m)	Stabilization, aesthetics, honeybee habitat	Low–medium
Johar (Siamese cassia)	Cassia siamea	Fabaceae	Canopy (10–20 m)	N fixation, shade, bank pioneer	Medium
Wild rambutan	Nephelium sp.	Sapindaceae	Canopy (10–18 m)	Wildlife fruit, biodiversity habitat	Low (ecology)
Kemiri (Candlenut)	Aleurites moluccanus	Euphorbiaceae	Canopy (15–20 m)	MPTS, food, oil, shade	High (MPTS)
Gamal/Gliricidia	Gliricidia sepium	Fabaceae	Small tree (5–10 m)	N fixation, green manure, living fence	Medium

ZONE C: Ground Cover Species

Zone C serves as the outermost buffer belt, absorbing surface runoff from cultivation areas before it reaches the riparian zone closer to the river. Vegetation design here emphasizes full ground coverage to reduce splash erosion and increase soil infiltration capacity.

Tabel 1 Spesies tanaman untuk zona C (grass strip)

Vetiver / Vetiveria zizanioides	Ground cover grass	High anti-erosion, deep roots to 3 m, sediment filter	20–30 cm between clumps	Slope bioengineering
Akar wangi (vetiver synonym)	Ground cover grass	Same as vetiver; widely used locally in Java	20–30 cm between clumps	Slope bioengineering
Bahia grass / Paspalum notatum	Ground cover grass	Rapid coverage, moderate shade tolerance	Broadcast seeding	Suitable for moist areas
Desmodium / Desmodium rensonii	Cover legume	N fixation, living mulch, forage source	50 cm rows	Common in ICRAF agroforestry systems

Mucuna / Mucuna bracteata	Cover legume	Super-fast coverage, high biomass, weed suppression	2×2 m planting points	Standard ground cover for sustainable palm oil
Bamboo (Betung) / Dendrocalamus asper	Bamboo clump	Bank stabilization, MPTS (bamboo shoots), lateral filter	5×5 m clumps	Strongly recommended for steep banks
Lamtoro / Leucaena leucocephala	Border small tree	N fixation, feed, erosion control, fuelwood	2×2 m living fence	Avoid seeded varieties in conservation areas

Based on field surveys along the river corridor in DAS Bilah, several plant species were identified as naturally occurring riparian vegetation. These species demonstrate important ecological functions in preventing bank erosion, slowing surface flow, and supporting habitat for aquatic and terrestrial organisms.

Table 7: Local Plant Species Found in the Riparian Zone

Local Name	Scientific Name	Habit	Riparian Role	Recommended Zone
Gelagah	Saccharum spontaneum	Herb	Pioneer riparian grass with dense fibrous root system; highly effective at holding soil and strengthening vulnerable bank structure; high tolerance to temporary flooding	Zone 1 (Lower Bank): Very suitable on frequently flooded lower banks
Waru	Hibiscus tiliaceus	Tree	Riparian tree tolerant of moist to waterlogged conditions; strong root system for bank stabilization; dense canopy for shade and rainfall energy reduction	Zone 1 (Lower Bank): Suitable for riverbank planting due to flood tolerance and soil strengthening
Bera-bera / Kersen	Muntingia calabura	Tree	Fast-growing tree with wide canopy; fruit provides food source for birds and small animals, contributing to biodiversity in the riparian corridor	Zone 2 (Upper Bank): Suitable as buffer vegetation to reduce surface runoff and increase vegetation cover
Luwingan / Ara Sungai	Ficus racemosa	Tree	Fig tree common in riparian ecosystems; strong root system; fruit is important food for birds, bats, and primates, supporting biodiversity corridor function	Zone 1 (Lower Bank): Tolerates moist conditions; strengthens bank stability
Mahogany	Swietenia mahagoni	Tree	Hardwood tree used in rehabilitation activities; wide canopy reduces rainfall intensity reaching soil; increases vegetation cover in buffer zone	Zone 2 (Upper Bank): More suitable in relatively drier zones; not tolerant of prolonged waterlogging
Pakis sayur (vegetable fern)	Diplazium esculentum	Herb	Fern common in moist riparian areas; fibrous root system helps hold soil; functions as understory vegetation maintaining soil moisture	Zone 3 (Grass Strip): Serves as boundary between oil palm plantation and riparian zone

Figure 13: Waru plant (left) and luwingan (right)

Table 8: Practical Guidelines for Developing Riparian Plants in the Field

Plant	Propagation Method	Planting Distance	Simple Planting Method
Gelagah	Clump or rhizome	0.5–1 m	Plant clumps directly at river edge
Waru	Seeds or stem cuttings	4–6 m	Plant seedlings on riverbank
Bera-bera / Kersen	Seeds	5–6 m	Transfer nursery seedlings to field
Luwingan / Ara Sungai	Seeds or suckers	6–8 m	Plant seedlings or natural suckers
Mahogany	Seeds	6–8 m	Transfer nursery seedlings
Pakis sayur (vegetable fern)	Rhizome or suckers	0.5–1 m	Plant rhizomes directly in moist soil

5. Planting Protocol

The riparian planting protocol is developed with reference to ecological restoration standards developed by the Society for Ecological Restoration International (2004), adapted to the characteristics of Indonesia's humid tropical climate, and integrating principles for tropical forest restoration success formulated by Shono et al. (2007).

Table 9: Spatial Design and Planting Density by Zone

Design Parameter	Zone A	Zone B	Zone C
Canopy tree spacing	3×3 m (enrichment)	4×4 m – 5×5 m	3×3 m (pioneer)
Sub-canopy spacing	2×2 m – 3×3 m	3×3 m	2×2 m
Minimum species composition	≥5 different species	≥4 different species	≥3 species + 1 cover crop
Native species proportion	100% obligate native	≥70% native, max 30% non-invasive exotic	≥50% native/naturalized
Planting pattern	Random/cluster	Contour strip/strip planting	Rows parallel to contour
Target canopy cover (5 years)	≥70% cover	≥60% cover	≥80% ground cover
Plant distance from water edge	0–0.5 m (herbs); 0.5–2 m (trees)	Directly after Zone A	Directly after Zone B
Seedling density per ha	600–1,100 seedlings/ha	400–625 seedlings/ha	1,000–1,600 seedlings/ha (incl. cover crop)

a. Land Preparation

The initial stage begins with control of invasive weeds, particularly Chromolaena odorata and Mikania micrantha, conducted manually or using selective herbicides at minimal doses, at least two weeks before planting. On the lower bank zone (Zone A), land clearing must not use mechanical methods such as bulldozers but must be done selectively and manually to minimize disturbance to soil structure and remaining natural vegetation. Planting holes are made approximately 40×40×40 cm for trees and 20×20×20 cm for shrubs or ground cover plants, prepared at least two weeks before planting to allow soil oxidation. Each planting hole is amended with 2–3 kg of organic matter such as compost or bokashi to improve soil fertility. Chemical fertilizers with high nitrogen content must be avoided near water bodies to prevent eutrophication risk.

b. Seedling Standards

Seedlings used in restoration activities must come from verified seed sources such as BPTH, certified nurseries, or community nurseries that have undergone a validation process. Minimum recommended seedling heights are 30–50 cm for canopy tree species and 20–30 cm for sub-canopy plants and shrubs. Seedlings must be in healthy condition, free from pests and diseases, with good root systems that are not circling, and not overly compacted growing media. Before field planting, seedlings must undergo an acclimatization (hardening off) process for at least two weeks.

c. Optimal Planting Time

Planting should be conducted at the beginning of the rainy season, approximately October-November in Java and November–December in Sumatra. when soil moisture is sufficient but before major flooding occurs. Planting during peak dry season (generally July–September) should be avoided unless supplemental irrigation is available. Planting proceeds in stages by zone, starting from Zone A (closest to the river), then Zones B and C, to provide initial bank protection from the earliest stage of restoration.

d. First-Year Maintenance (Critical Phase)

The first year is the most critical phase for restoration success, requiring intensive maintenance activities. Gap filling (replanting) is carried out approximately two months after planting to replace dead plants, with a target survival rate of at least 80% by the end of the third month. Weed control and soil loosening are conducted at least three times in the first six months, within a 50 cm radius from the plant stem to reduce competition. Application of organic mulch (straw, sawdust, or dry leaves) 5–10 cm thick around plants is strongly recommended to maintain soil moisture. At locations experiencing micro-erosion, planting holes need to be reinforced using wooden or bamboo stakes to prevent further damage from rainwater splash or surface flow.

6. Monitoring and Evaluation

The riparian zone monitoring program is designed to ensure that planting and rehabilitation interventions proceed as planned, and to detect early any constraints or deviations requiring corrective action. The system references the RSPO Monitoring & Evaluation Framework (2020) and GIZ Biodiversity and Ecosystem Services Monitoring Guidelines, integrating ecological monitoring (vegetation cover, biodiversity, erosion, water quality) and agronomic monitoring (individual plant growth, soil health).

Table 10: Monitoring Indicators for Riparian Restoration Target Achievement

Indicator	Measurement Method	Frequency	Target (Year 5)
Plant survival rate	Individual census per monitoring plot (20×5 m transect)	Monthly (Year 1); Quarterly (Years 2–5)	≥75% of seedlings planted
Vegetation cover %	Canopy cover estimation (densiometer / hemispherical photo)	Semi-annually	Zone A: ≥70%; Zone B: ≥60%
Average height and DBH	Direct measurement per target tree individual	Annually	Average growth >0.8 m/year for pioneer species

Biodiversity	Shannon-Wiener Index H' (flora); Point count for birds (fauna)	Annually	H' flora ≥1.5; at least 3 waterbird species detected
Active bank erosion	Erosion pin measurement + standardized photos per segment	Quarterly	≥50% reduction in active erosion from baseline
Water quality (TSS and nutrients)	Water sampling upstream-downstream of restoration segment; APHA methods	Semi-annually (rainy and dry seasons)	≥40% TSS reduction from baseline

The monitoring period is set at 5 (five) years from the first planting, with higher monitoring intensity in Year 1 to ensure plant establishment success. After Year 5, monitoring continues in a long-term maintenance scheme with frequencies adjusted based on final evaluation results. All monitoring data is documented in a field database and reported periodically, including georeferenced photo documentation, tabular measurement data, spatial vegetation cover maps (for annual reports), and specific actionable follow-up recommendations.

Data management uses a spatial database (GIS) containing buffer zone shapefiles, plant distribution points by species, and water quality sampling locations. This database must be updated annually and reported to management and relevant certification bodies. If deviations from targets are found (low survival rate, water quality standards not met), a Corrective Action Plan (CAP) must be prepared within a maximum of 30 days from the finding.

a. Plant Survival Rate

Survival rate is the proportion of living plants compared to the total number of seedlings planted at program start. Measurement uses individual census methods in 20×5 m monitoring plots systematically placed in each riparian zone. Monthly monitoring in Year 1, reducing to quarterly in Years 2–5. A minimum target survival rate of 75% in Year 5 is the success threshold. If survival rate falls below 60% in two consecutive monitoring periods, a cause evaluation and immediate replanting are required.

b. Vegetation Cover (Canopy Cover, Height, and Diameter)

Vegetation cover percentage is measured using canopy cover estimation with a spherical densiometer or hemispherical photography. Targets differ by zone: Zone A (0–10 m) targets minimum 70% cover; Zone B (10–50 m) targets minimum 60% by Year 5. Tree growth is monitored through total height and DBH measurements on permanently marked target trees, annually by the same team. Minimum growth target of 0.8 m/year applies to pioneer species (waru, gelagah, young mahogany). Climax species have separate growth targets based on species-specific literature data.

c. Biodiversity

Biodiversity monitoring covers two groups: (1) flora, using the Shannon-Wiener Diversity Index (H') from vegetation transects; and (2) fauna, using point count methods for avifauna at fixed points along the riparian corridor. A flora H' target of at least 1.5 in Year 5 indicates a sufficiently diverse plant community. A target of detecting at least 3 fauna species per taxon reflects recovery of riparian habitat function for water-dependent species.

d. Active Bank Erosion

Bank erosion measurement uses erosion pins—iron/bamboo rods driven perpendicular into the bank at representative points. Pin position changes relative to the soil surface are measured quarterly to calculate active erosion rates. Standardized photo documentation is conducted simultaneously with consistent photo points (GPS coordinates recorded). A target of 50% reduction in active erosion from baseline is expected by Year 5 as the riparian plant root systems develop.

e. Soil Health

Soil samples are taken from depths of 0–20 cm and 20–40 cm at representative points in each zone. Parameters analyzed include soil organic carbon, total nitrogen, available phosphorus, available potassium, Cation Exchange Capacity (CEC), and base saturation. Analysis is conducted at an accredited laboratory. Improvement of all parameters from baseline indicates successful restoration of soil ecosystem function.

f. Water Quality

Water quality sampling is conducted at two points: one upstream and one downstream of the restoration segment. Sampling twice per year—once during peak rainy season (capturing maximum sediment load) and once during peak dry season. Key parameters: Total Suspended Solids (TSS) as a sediment load proxy, and nitrogen and phosphorus concentrations as indicators of nutrient contamination from surrounding agricultural areas. A TSS reduction target of 40% from baseline indicates that riparian vegetation cover is effectively functioning as a sediment filter.

Immediate corrective action is required if any of the following conditions are detected in two consecutive monitoring periods:

- Survival rate falls below 60%: Evaluate cause of mortality, conduct replanting, and if necessary, revise species selection
- Bank erosion rate increases >20% from baseline: Evaluate geotextile condition, consider adding mechanical reinforcement structures, and accelerate vegetation cover in problem segments
- Downstream TSS consistently exceeds baseline: Investigate new sediment sources upstream or areas lacking vegetation cover, and reinforce planting in critical zones
- Vegetation cover stagnates or declines: Evaluate inhibiting factors (competitive weeds, herbivory, drought) and adjust maintenance intensity

Farmers and local communities are actively involved as citizen scientists in the monitoring program, particularly for routine observations such as seedling conditions and extraordinary events (flooding, bank failures, pest attacks). Simple training is provided to partner farmers using simplified field recording forms. Farmer involvement in monitoring not only increases observation frequency and coverage, but also builds a sense of ownership toward the program.

7. Budget Plan for the Riparian Demonstration Plot

The riparian demonstration plot budget plan is prepared to provide a comprehensive overview of financing needs for the implementation of riverbank planting and rehabilitation. The unit area used is 100 m × 50 m (equivalent to 1 hectare) of land at the riverbank. Costs can be adjusted proportionally based on the actual length of each farmer's land. All figures are indicative estimates that may vary depending on field conditions, local material and labor prices, and the level of intervention required at each site.

The RAB covers four main work components:

- Plant Seedling Procurement: Includes amphibious grass seedlings (gelagah, river pandanus, vetiver, betung bamboo), waru/fig seedlings, hardwood tree seedlings (mahogany, petai), MPTS seedlings (durian, avocado), and buffer grass seedlings (vetiver, turnera)
- Land Rental and Labor: Covers 1-year land rental and all labor components from land clearing, planting, fertilization, maintenance, monitoring, and replanting
- Agricultural Inputs: Procurement and application of organic fertilizer three times per planting cycle
- Civil Engineering Works: Installation of bank-reinforcing geotextile and installation labor as structural intervention to directly prevent bank erosion

Table 11: Summary of RAB Cost Components for Riparian Demonstration Plot per 1 Ha

No.	Cost Component	**Estimated Cost (IDR)**
A	Vegetation / Plant Seedlings	IDR 6,522,500
B	Land Rental and Labor	IDR 8,500,000
C	Agricultural Inputs (Organic Fertilizer)	IDR 13,556,250
D	Civil Engineering Works	IDR 35,750,000
	TOTAL ALL (Vegetation + Civil Engineering)	IDR 64,328,750
	TOTAL REVEGETATION (without civil engineering)	IDR 28,578,750

Of the total budget of IDR 64,328,750, the largest portion is civil engineering works (IDR 35,750,000 or approximately 55.6%), covering geotextile procurement and installation. The pure revegetation component (without civil engineering) is IDR 28,578,750, covering all planting activities, labor, and agricultural inputs.

Table 12: Detailed RAB for Riparian Demonstration Plot – All Zones (Unit: 100 m × 50 m / 1 Ha)

Component	**Unit**	**Quantity**	**Unit Price (IDR)**	**Total (IDR)**
A. VEGETATION / PLANT SEEDLINGS				
Amphibious grass seedlings (gelagah, river pandanus, vetiver, bamboo, etc.) – 1 row, 1×1 m spacing	clumps	110	—	—
Waru/Ara/Luwingan seedlings – 1 row, 2×2 m spacing	trees	55	—	—
Hardwood tree seedlings (mahogany, petai, etc.) – 3×3 m spacing, 6× palm row count, 110% for replanting	trees	92	15,000	1,380,000
MPTS seedlings (fruit trees: durian, avocado, etc.) – 3×3 m, 7 per 2 palm rows, 110% for replanting	trees	269.5	15,000	4,042,500
Buffer grass seedlings (vetiver, turnera, etc.) – 1 row, 1×1 m spacing	clumps	110	10,000	1,100,000
B. LAND RENTAL AND LABOR				
Land rental	ha/year	1	5,000,000	5,000,000
Labor: Waru and gelagah cuttings	person/day	2	100,000	200,000
Labor: Land clearing (10 workdays)	person/day	10	100,000	1,000,000
Labor: Planting hole preparation and stakes (2 workdays)	person/day	2	100,000	200,000
Labor: Planting and base organic fertilization (5 workdays)	person/day	5	100,000	500,000
Labor: Monitoring and replanting (2 workdays)	person/day	2	100,000	200,000
Labor: Maintenance and monitoring – 2nd and 3rd fertilization (3×2 workdays = 6)	person/day	6	100,000	600,000
Labor: 2nd and 3rd manual weeding (4×2 workdays = 8)	person/day	8	100,000	800,000
C. AGRICULTURAL INPUTS				
Organic fertilizer – 5 kg per planting hole, 3 applications	kg	5,422.5	2,500	13,556,250
D. CIVIL ENGINEERING WORKS				
Bank reinforcement geotextile – 100 m × 5 m (one-time at start)	m^2	550	35,000	19,250,000
Installation labor + site clearing	m^2	550	30,000	16,500,000
TOTAL ALL (VEGETATION + CIVIL ENGINEERING)				64,328,750
TOTAL REVEGETATION ONLY				28,578,750

The table above presents complete details of all riparian demonstration plot cost components covering Zones 1, 2, and 3 in an integrated manner. The base unit is 100 m × 50 m (1 ha). For land with different dimensions, all cost components can be multiplied by the appropriate area conversion factor. Seedling components without unit price (marked '—') are seedlings sourced from the land and easily propagated, so no procurement cost is charged. If they must be purchased, procurement costs need to be added. Unit prices for seedlings and labor refer to average prices at the local level and should be adjusted if there are significant differences at the implementation site.

a. Seedling Procurement and Agricultural Inputs

Seedling procurement focuses on species with strong ecological functions matching the riparian zoning design. Hardwood tree seedlings (mahogany, petai, etc.) are calculated based on 6 times the number of existing palm rows with a 110% replanting factor to anticipate initial seedling mortality. MPTS seedlings (durian, avocado, etc.) are calculated at 7 units per 2 palm rows with the same replanting factor. Amphibious grass seedlings (gelagah, river pandanus, bamboo) and waru/fig seedlings are not priced in this RAB as they are assumed to be available from community nursery programs or obtained from nature in an environmentally friendly manner.

Organic fertilizer is applied 3 times per planting cycle at 5 kg per planting hole per application. With approximately 361 planting points (hardwood trees + MPTS + buffer grasses), total organic fertilizer requirements reach 5,422.5 kg at IDR 2,500/kg, giving a total fertilizer cost of IDR 13,556,250. Organic fertilizer is chosen to avoid chemical contamination of the water body, consistent with riparian zone management principles.

b. Land Rental and Labor

Land rental is set at IDR 5,000,000/ha/year as compensation for farmer land owners willing to include their land in the demonstration plot program. Labor components cover all activity stages:

- Waru and gelagah cuttings (2 workdays): Preparation and vegetative propagation
- Land clearing (10 workdays): Weed and plant residue clearing before planting
- Planting hole preparation and stakes (2 workdays): Preparation of planting points and seedling position markers
- Planting and base fertilization (5 workdays): Planting seedlings with first organic fertilizer application
- Monitoring and replanting (2 workdays): Checking seedling conditions and replacing dead seedlings
- Maintenance and 2nd & 3rd fertilization (3×2 = 6 workdays): Follow-up organic fertilization twice a year
- 2nd and 3rd manual weeding (4×2 = 8 workdays): Manual weeding twice a year

c. Civil Engineering Works

The civil engineering component is a structural intervention to physically reinforce the riverbank using geotextile. Installation is carried out once at the start of the program on a 100-meter-long bank with 5-meter width (550 m² total). Costs cover two items:

- Geotextile procurement: IDR 35,000/m² × 550 m² = IDR 19,250,000. Geotextile functions as mechanical bank reinforcement before the vegetative root systems are strong enough to support the soil structure
- Installation labor and site clearing: IDR 30,000/m² × 550 m² = IDR 16,500,000. Covers labor for geotextile installation and bank area clearing before installation

The civil engineering component is optional if the riverbank condition is already relatively stable, in which case, the revegetation component alone (Total Revegetation: IDR 28,578,750) is sufficient.