

# ECOSWat – EbA Measures for the Sae-Or Reservoir



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# ECOSWat – EbA Measures for the Sae-Or Reservoir

## Document Information

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## 1 INTRODUCTION

Thailand has been struggling regularly with impacts of floods and droughts. Due to the 2011 flood and recent drought situations, water management became a priority on the national policy agenda.

In Thailand, flexible water management systems are not yet sufficiently implemented. Ecosystem-based adaptation (EbA) approaches are not yet fully recognised and established in water resources management. The potential of EbA for sustainable and cost effective measures are not well utilised and their values not well captured.

The Royal Irrigation Department (RID) of Thailand is currently conducting planning for a new reservoir and irrigation system within the Huay Yang Tributary Sub-Basin, that is located in the upper part of the River basin No. 17 (Tonle Sap River Basin). The Sae-Or Reservoir is planned as classical grey infrastructure dam by the RID. Two potential dam sites has been analysed by RID. For both reservoir locations, an Initial Environmental Evaluation (IEE) has been carried out. The IEE covered engineering, socio-economic, environmental, and economic criteria. Based on the chosen weighting factors, site 1 outscores site 2 in almost every aspect. Thus, RID has identified site 1 as appropriate project site.

SYDRO Consult has been commissioned by “Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH” to propose alternative or complementing Ecosystem-based adaption (EbA) measures for the planned reservoir and irrigation system. The study comprises

- a review of the proposed planning for the Sea-Or Reservoir,
- an onsite catchment and problem analysis,
- a consultation meeting with the local stakeholders,
- and the development and design of suitable EbA measures.

## 2 CLIMATE CHANGE AND ECOSYSTEM BASED ADAPTION (EBA)

The recently published fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013) states:

- Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.
- Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

According to Marks (2011) Thailand will likely be one of the most affected countries given its geography, economy and level of development. Figure 1 shows annual mean temperature in Thailand from 1981 to 2007 A.D. that rose by roughly 1°C during this time span. Based on analysis of a subset of models used for the 4th Assessment Report (AR4) of the IPCC the mean daily maximum temperature the Bangkok Metropolitan Region will increase between 1.2 to 1.9°C by 2050 (World Bank, 2009). The warming of the global climate system will have even stronger impacts on monsoon-driven climates as they prevail in Thailand (World Bank, 2009). Figure 2 shows annual rainfall in Thailand from 1951 to 2005 A.D. Both the number of rainy days and the level of precipitation have decreased. These findings are supported by several droughts in the recent years. Research prognoses a decrease in net amount of total precipitation with shorter duration of precipitation events, however combined with an increase in intensity in the form of storms and floods (Marks, 2011).

The impact of Climate Change on large precipitation patterns like tropical cyclones, the El-Niño Southern Oscillation, and the Asian monsoon are still uncertain. In 2015, El-Niño caused greatly reduced precipitation in Thailand, leading to critical water levels in large dams and affecting food production especially in Thailand's central plains. As Thailand is among the world's biggest food producers and rice exporters and as around 40% of the population is relying on rain fed agriculture for their livelihood, Climate Change will likely aggravate already existing water resources management problems. (Marks, 2011)

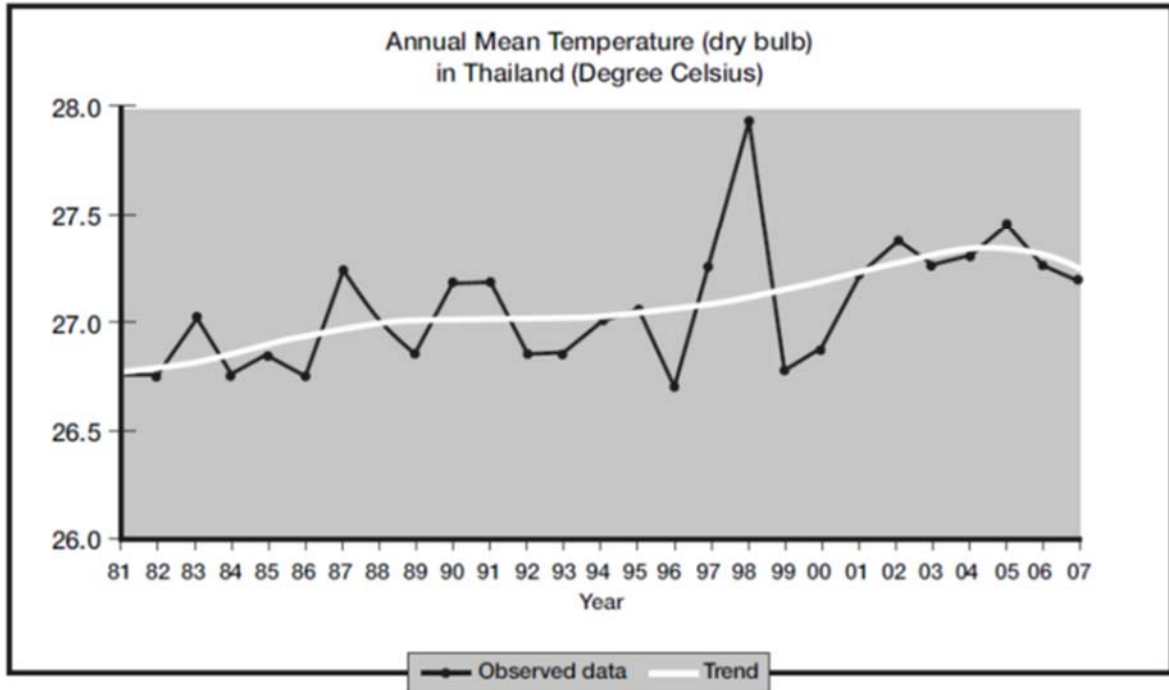


Figure 1: Annual Mean Temperatures in Thailand (Marks, 2011)

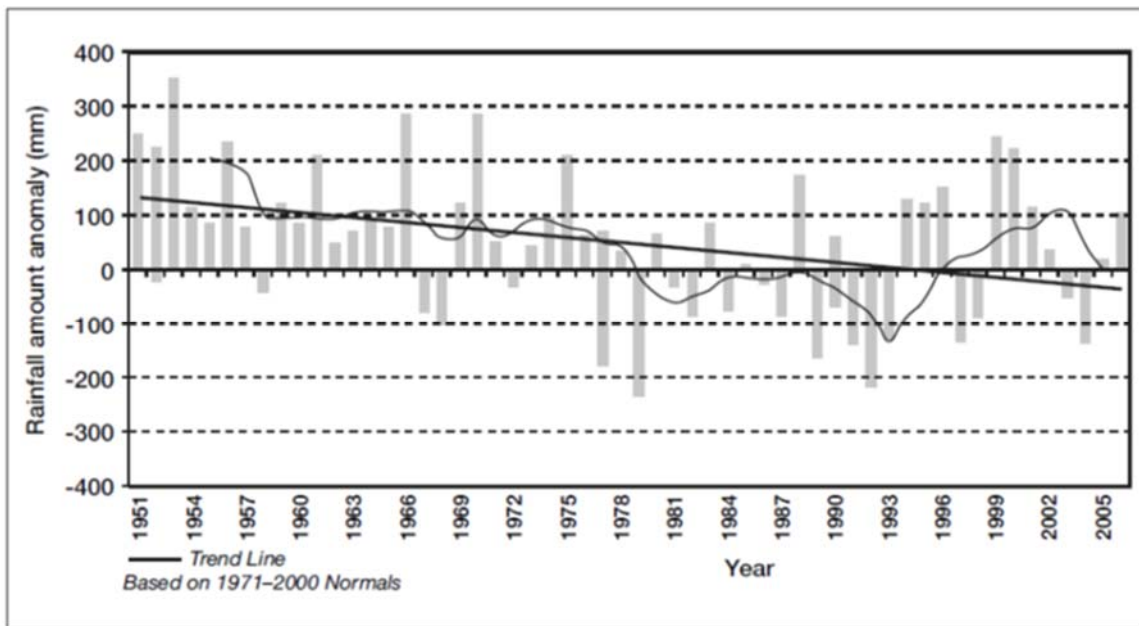


Figure 2: Annual Rainfall in Thailand (Marks, 2011)

The major impacts of Climate Change on Water Resources Management in Thailand can be classified into three major topics:

- **Increased Evapotranspiration:** A temperature increase together with a decrease of relative humidity will lead to higher (evapo-) transpiration.

- **Droughts and water resources competition:** A decline of overall precipitation will lead to a higher probability of severe droughts. Reduced water availability can increase competition between different users (Agriculture, Industry, Consumers, and Tourisms).
- **Floods/Landslides:** An increase of high intensity precipitation events can lead to more floods and landslides.

As Thailand is already experiencing more severe droughts and floods related to changing climate boundary conditions, it is obvious, that suitable adaption measures should be applied to ensure a sustainable water management in the future. To take appropriate action in order to prevent or minimize damage it is necessary to anticipate possible adverse effects of climate change for the given region. Generally, well-planned and early adaption actions save money, lives later and allows for an integrated and sustainable adaption plans.

There is a wide range of potential mitigation measures in the field of water resources management. Often, classical grey infrastructure measures like reservoirs, dams, weirs and flood control structures are applied. So far, dams provide for large parts of Thailand's energy production, irrigation water demand and flood control (Marks, 2011). However, these grey measures come with significant disadvantages and ecological damage, e.g. blocking migration routes, disrupting flood pulses, shrinking wetlands, decline of fish population, and shrinking of riverbank gardens (which are important riparian livelihoods in Thailand). Furthermore, these classic grey measures are not easily adaptable to changes in climate and water availability.

In adaption to climate change Ecosystem based Adaption gains more and more importance as robust and effective mitigation strategy. In a very simplified form, EbA means "Nature helps people adapt". The definition as given by the Convention on Biological Diversity (CDB) is:

- EbA uses biodiversity and ecosystem services in an overall adaptation strategy. It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to the adverse effects of climate change (CDB, 2009).
- EbA may include sustainable management, conservation and restoration of ecosystems, as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities (CDB 2010).

Well-functioning ecosystems enhance natural resilience to the adverse impacts of climate change. The resilience of these ecosystems leads to a reduced vulnerability of the local population. EbA can be an alternative to traditional actions such as infrastructure development or complement these traditional mitigation measures. Aside from protection against climate change effects, EbA also provides many benefits such as clean water, food, and other ecosystem services crucial for livelihood and human well-being. If designed appropriately they can also contribute to climate change mitigation by reducing emissions from ecosystem degradation or loss, and enhancing carbon sequestration. (WWAP, 2012) EbA measures aim at the conservation, rehabilitation and sustainable management of ecosystem, such as:

- Forest
- Water bodies
- Agriculture

As the general definition given by CBD above states, EbA uses biodiversity and ecosystem services in an overall adaptation strategy. Thus, EbA can be applied as standalone measures or supplement traditional grey infrastructure mitigation measures. In a wider definition, EbA comprises also topics

like environmental flows and (optimised) operation rules for water infrastructure. EbA measures should generally be part of an integrated water resources management.

One major advantage of EbA measures is, that these mitigation measures are by nature flexible and can (self-) adapt to future changes more easily than conventional measures. Given the uncertainty in the predictions of changing climate boundary conditions flexible approaches are naturally paramount. Aside of the benefits of EbA measures for humankind their implementation also strengthens or revitalizes the natural ecosystems. Thus, EbA measures are very suitable measures to ensure a sustainable and integrated management of water resources under the current challenges in the water sector. Furthermore, evidence suggest, that working with nature’s capacity can be a more efficient way of adapting than simply focusing on physical infrastructure (EC, 2009).

As EbA measures strengthen natural ecosystems, the implementation of one EbA measure normally provides several functions, benefits, and co-benefits. One disadvantage is the fact, that EbA measures often need more space to achieve the main objective compared to classical grey measures. However, seen from a sustainable perspective, more space for ecosystem is an indirect co-benefit for both the environment and humankind. Figure 3 gives a comparison between grey measures and EbA regarding stability and maintenance over time: Generally, EbA measure have a development phase, during which their stability and function is not yet fully developed. Once they reach their target state, there are often self-sustainable, keep their intended function without any further maintenance and provide their direct benefits and co-benefits over long time spans. Classical grey measures are normally fully functional directly after their implementation. After a certain time, often labelled as “life time” of the structure, they start to decay and can fail, sometimes stooping providing their function abruptly. EbA measures need more maintenance during the development phase but less maintenance in the end.

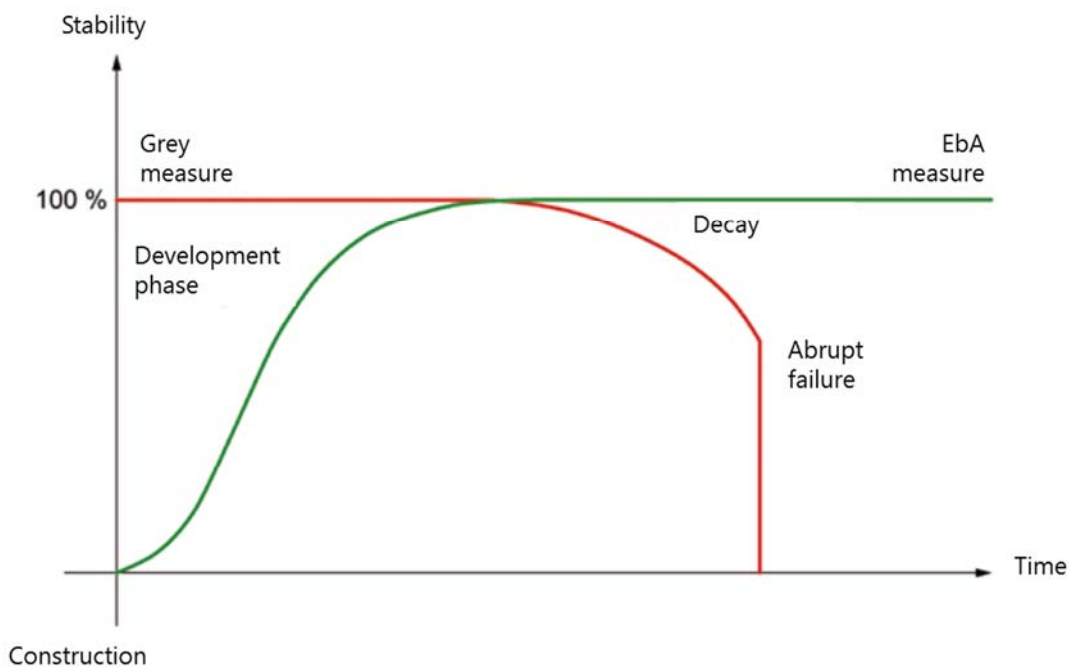


Figure 3: Comparison of grey measures vs. EbA measures (modified from LUBW, 2013)

Typically, upstream stakeholders conserve ecosystems and their services by applying land use types and cultivation practices that affect the ecosystems ability to provide adequate quantities and quality

of water at the right time (UNDP, 2003). The possible land use types can range managed forest over farmland and grazing land for livestock to natural forest and protected conservation areas. Cultivation practices that preserve basic ecosystems services of the catchment have different implications for the local stakeholders that should be compensated for by the beneficiaries of the ecosystem services (see Figure 4). Ecosystems conserved can provide, apart from water availability, the services of e.g. erosion control, climate regulation, water purification, and flood control. Beneficiaries of these services could be domestic water user, municipalities, and cities, hydroelectric power companies, fisheries (including aquaculture), recreation and tourism and the up- and downstream ecosystems as well (e.g. rivers, wetland, aquifers, coastal estuaries, mangroves, forests, floodplains).

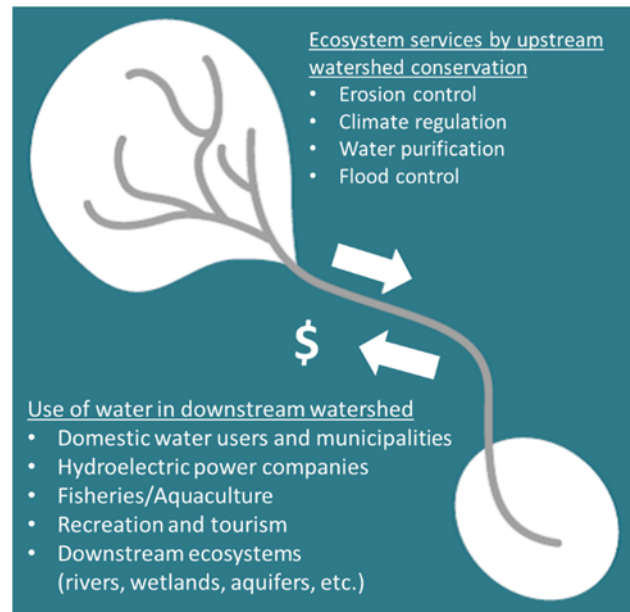


Figure 4: Transfer of benefits from ecosystem services from upstream catchment parts to downstream catchment parts (modified from UNDP, 2003)

### 3 GENERAL CATCHMENT ASSESSMENT

The planned Sea-Or reservoir and its accompanying irrigation system is located within the Huay Yang Tributary Sub-Basin, that is located in the upper part of the River basin No. 17 (Tonle Sap River Basin) in the East of Thailand (see Figure 5). The whole project is a Royal Initiative Project within the Wathanakorn District, Sa-Kaew Province.

The proposed location for the reservoir at Site 1, which was considered superior in the Initial Environmental Evaluation (IEE) by RID, is located in the upper catchment part of the Huay Yang Tributary sub-basin close to Pang Si Da National Park and mountain range. The Sae-Or reservoir will be located at UTM E=233265.193 N=1546971.908 and consist of a main dam, blocking the flow of the Khlong Pong Prathoon river and second dam at the East of the reservoir (Chang Kao Khan Dam). The reservoir will be accompanied by appurtenant structures and an irrigation system. The irrigation system will use both the existing Pong Pra Tun River and an irrigation pipeline network. An overview of the planned reservoir, the irrigation system and the accompanying structures is given in Figure 6. Main objectives of the project are the supply of water for agricultural purposes during the dry season and the prevention of floods during the rainy season (RID). The storage capacity of the planned Sea-or Reservoir is between 0.34 mil m<sup>3</sup> (minimum storage) and 2.57 mil m<sup>3</sup> (maximum storage capacity). The catchment area of the reservoir in the mountainous upstream area is 14.85 km<sup>2</sup>. The irrigation system is planned for an area of 7.6 km<sup>2</sup>.

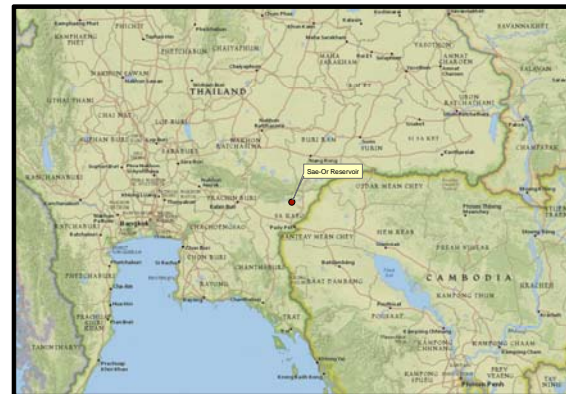
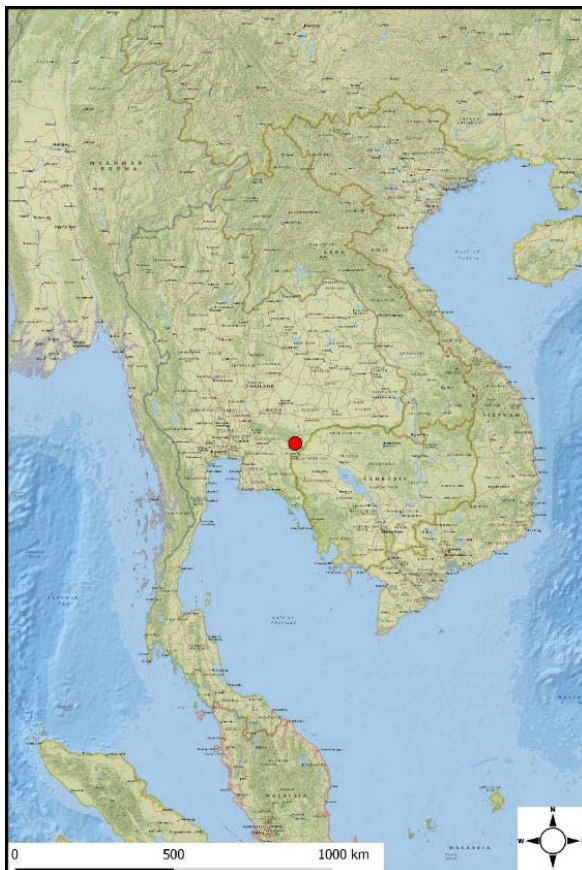


Figure 5: Location of the Sea-Or Reservoir

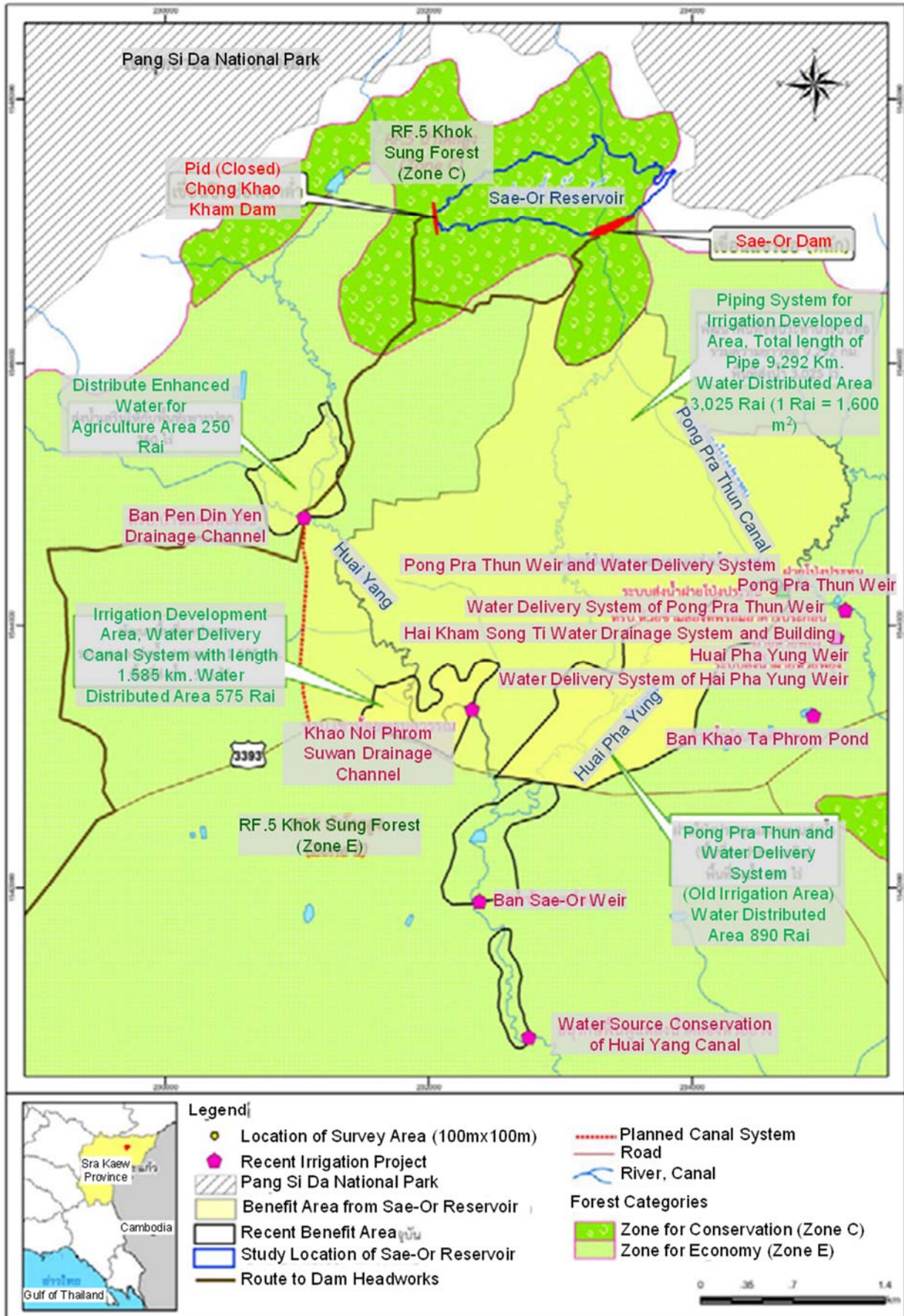


Figure 6: Overview of the Sae-Or project area (Source: RID)



### 3.1 Data, information, document resources

The catchment and problem assessment is based on documents, information and data that has been made available for SYRDRO Consult GmbH by the Royal Irrigation Department and some freely available data:

- Document: Executive Summary
- Document: Initial Environmental Evaluation (IEE)
- Basic GIS data (ESRI shapefiles)
- Field trip (conducted from June 22<sup>nd</sup> to June 24<sup>th</sup> with RID project team)
- Google satellite data/ Google hybrid data
- ESRI satellite data

### 3.2 Climate

The tropical, warm and humid climate of the project area is under the general influence of the Southwest and Northeast Monsoon, leading to a distinct dry and rain season. The rain season normally starts in May and ends in October, with high amounts of precipitation. Due to the close proximity of the Pang Sida National Park and the Phanom Dong Rak Mountain Range, precipitation is higher than normal in this region of Thailand.

As mentioned outlined in Chapter 2 the warming of the global climate system will have stronger impacts on monsoon-driven climates, leaving the Sae-Or region potentially even more vulnerable than regions not influenced by monsoon-driven climates. Thus, flexible adaption measures, e.g. Environmental Based Adaption Measures.

### 3.3 Topography

The mountainous upstream catchments parts of the Phanom Dong Rak Mountain Range are significant steeper than the relatively flat parts of the downstream catchment parts of the Huay Yang Tributary sub-basin. Figure 7 shows the gradient of the Khong Pong Prathoon River. Directly downstream of the planned dam site location the river gradient decreases significantly. These change in topography is associated with agricultural land use presently existing directly downstream of the planned location of the main dam of the Sea-or Reservoir.

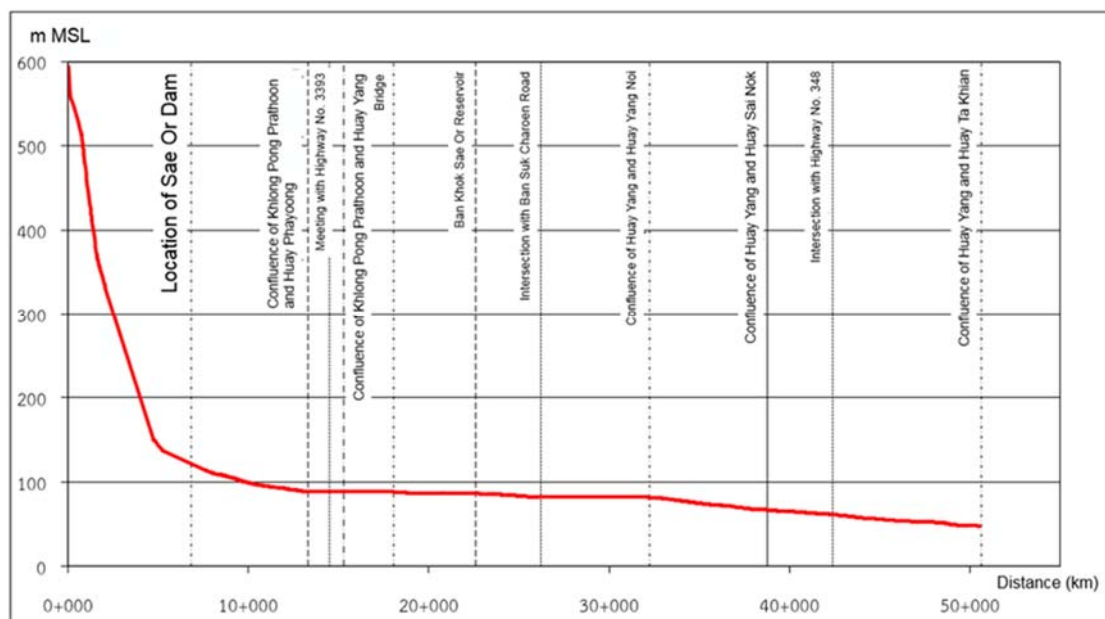


Figure 7: Profile of Khong Pong Prathoon from Upstream to Highway No. 3393 (Source: RID)

### 3.4 Land use

The catchment of the Khong Pong Prathoon River can be divided into two distinctive parts:

- The upper catchment part consists the Phanom Dong Rak Mountain Area and the Pang Si Da National Park Area. As shown in Section 3.3 and Figure 7 these upper catchment part is a relatively steep mountainous area, where natural rain forest prevails.
- The lower catchment part, starting at the proposed main dam location for the Sea-Or Reservoir is mainly used by agriculture. Currently, the local farmers grow cassava, maize, sorghum, sugarcane, jute, sesame, beans and rice. In some areas, fruit trees and some species of perennial trees are grown.

Five small villages are located in the project area. Several perennial and temporal streams are running through the catchment and subsequently, perennial lakes and temporary ponds can be found within the catchment. Figure 8 gives an overview of the land use and the water bodies within the catchment. The distinctive line between natural forest in the upper catchment part and farmland in the lower catchment part is clearly visible. The stream classification into perennial and intermittent streams is shown as taken from the GIS data provided by RID. Figure 9 gives an impression of the natural (rain) forest in the upper catchment part, an example of farmland and a water body in the lower catchment part is shown in Figure 10

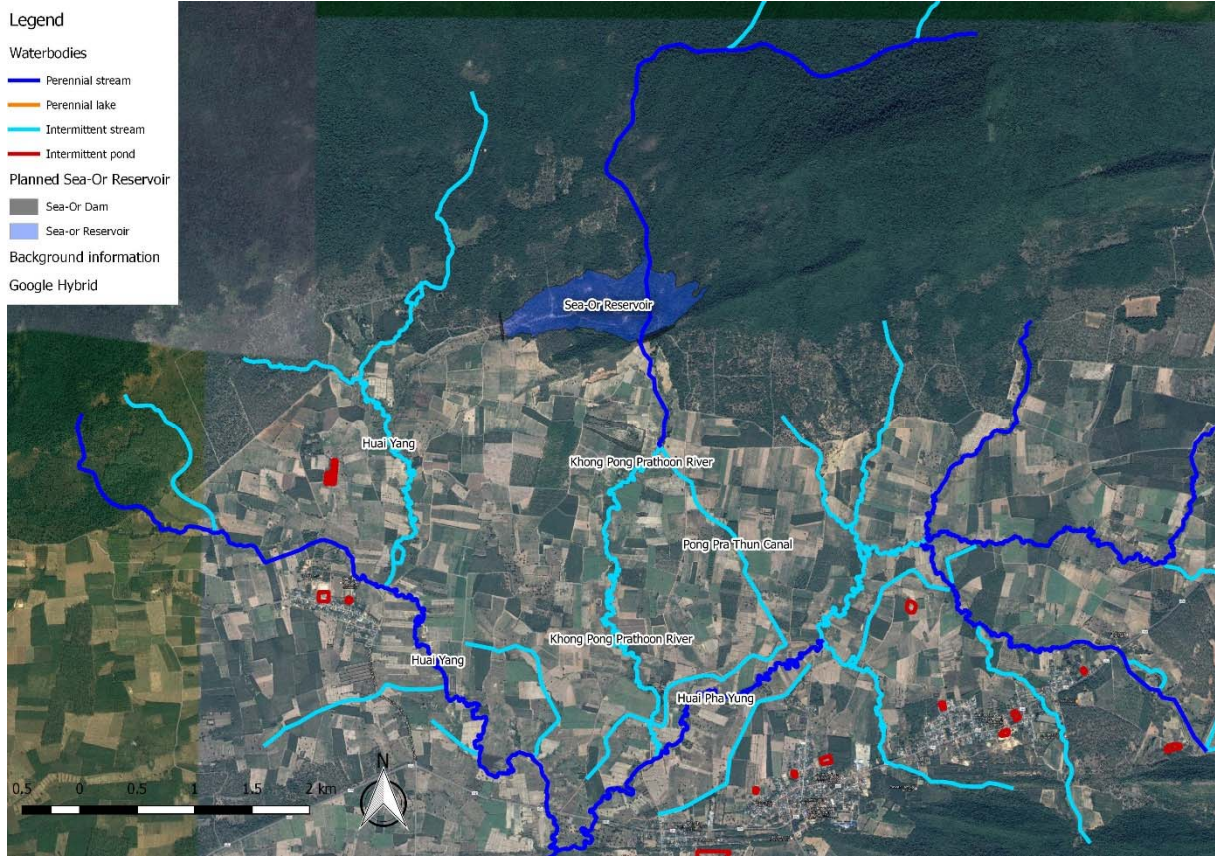


Figure 8: Land use of the Sea-Or project region



Figure 9: Natural (rain) forest in the upper catchment part



Figure 10: Agricultural used land with river stretch in background in the lower catchment part

### 3.5 Soils

As show in Figure 11, the soils in the project area (see Figure 6) belong to the soil series group 35: “Soil series group 35 consists of deep to very deep fine loam arisen from distributaries sediment or coarse mass parent material. The subsoil is sandy clay loam, brown, yellow or red in colour. The soil is deep; soil reaction is a very strong acid, with good to moderate drainage, but low fertility. Groundwater levels are deeper than 1.50 meters throughout the year. The pH of the soil is approximately 4.5 to 5.5. Examples of these soil series are Don Rai, Khorat, Satuek, Warin, Yasothorn, Dan Sai, and Mabbon. It is generally found is found in undulating areas up to foothill terrace, mainly with a slope of about 3 - 20% and partly with a slope of about 20 - 35%.” (LDD, 2016)

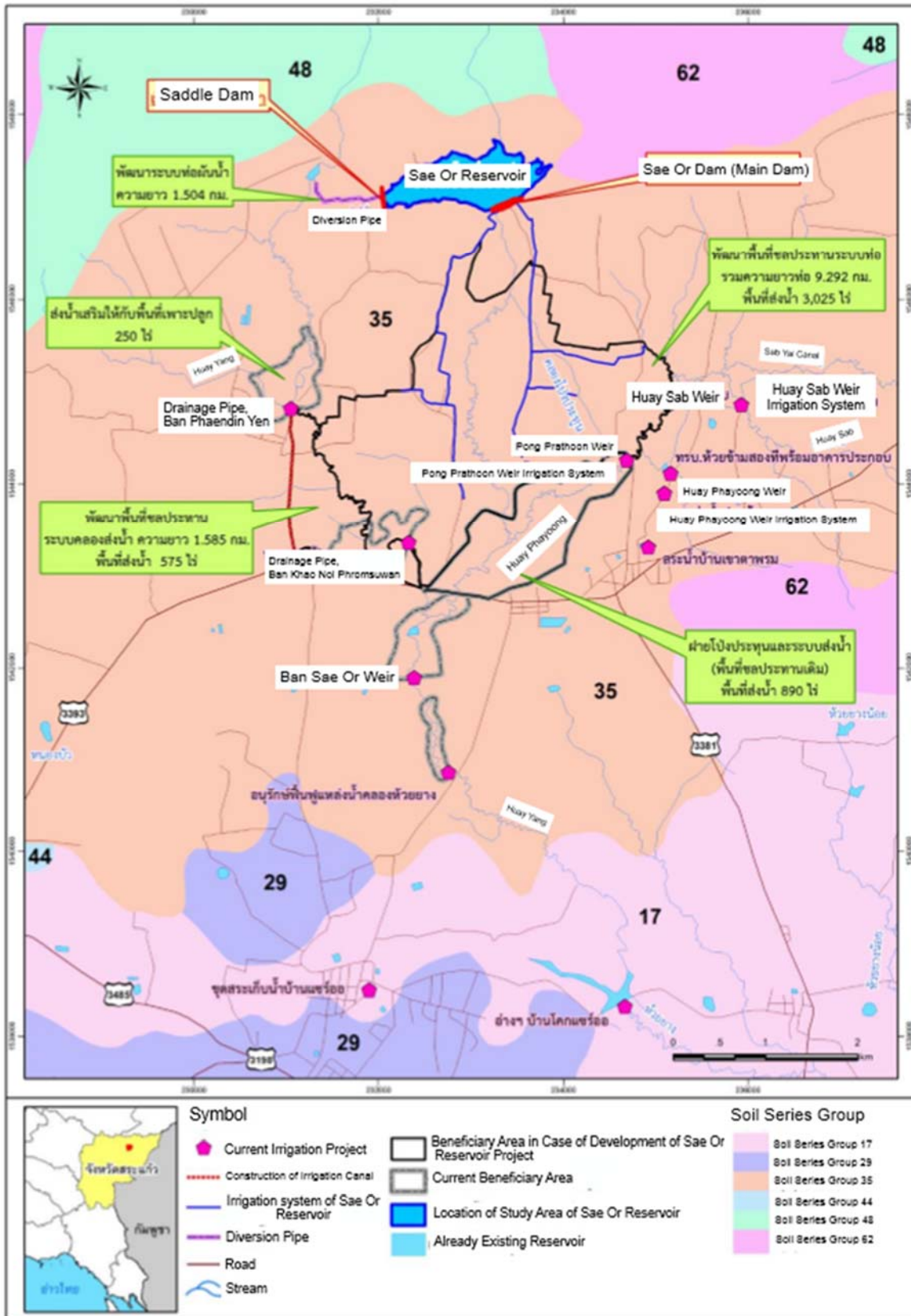


Figure 11: Soil series groups within the project area (Source: RID)

### 3.6 Water bodies

The Pont Prathoon River is the river in the project region that will be mainly affected by the planned Sea-Or Reservoir. The reservoir will block the natural flow in the river in order to store water in the rain season for irrigation purposes in the dry season. The planned dam will be located at the transition from the relatively steep mountainous catchment part in the upstream area and the relatively flat agricultural uses land in the downstream catchment area. Thus, a relevant amount of flow will be retained during the rainy season.

The Pont Prathoon River has no regular flow throughout the year. The flow conditions are characterized by quick increases and decreases of discharge strongly correlated to rainfall. Given the high discharge volumes and the flat topography, the river regularly overflows during the rainy season. In the dry season, the water level is generally low, often there are prolonged periods without any discharge and the riverbed dries out.

Figure 12 shows the water bodies within the project region and their classification into perennial, intermittent and ephemeral streams, lakes and ponds. Figure 13 shows a dried out river bed during the field trip in June 2016.

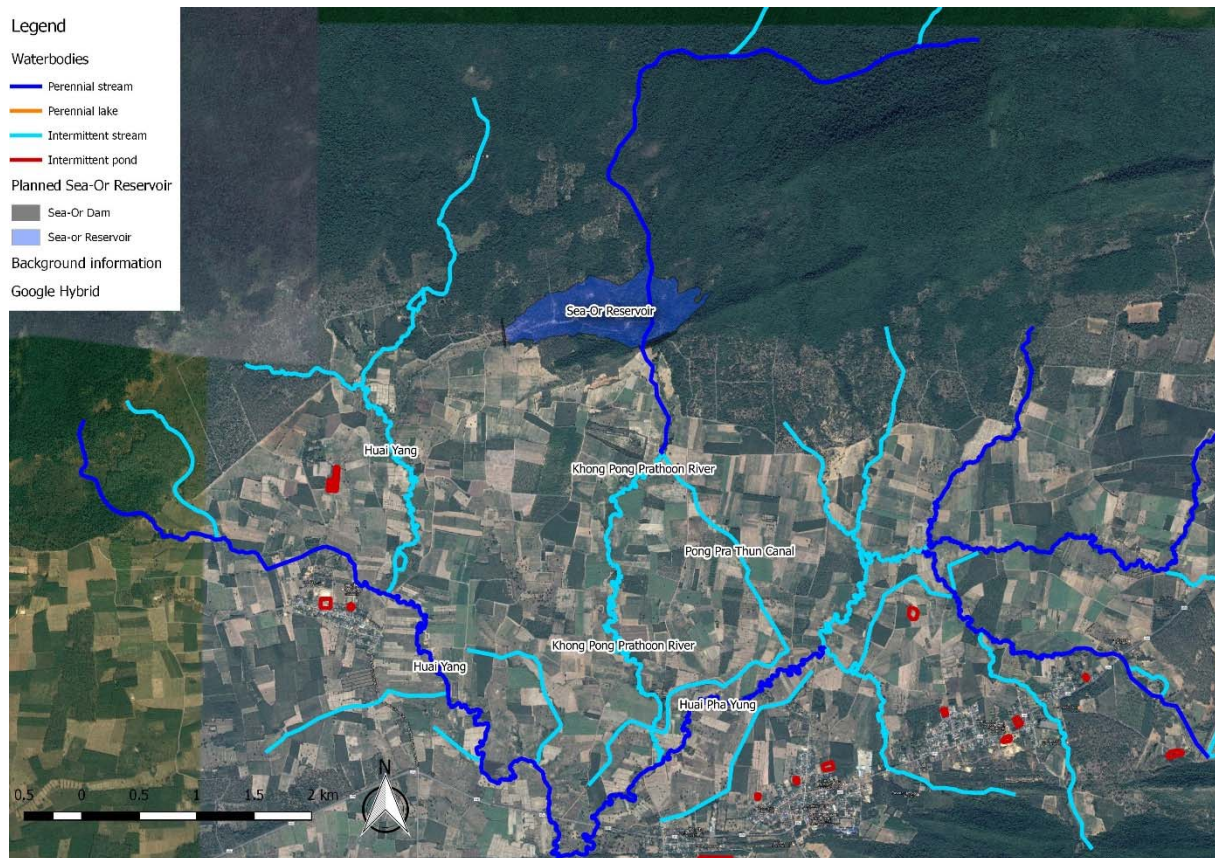


Figure 12: Water bodies and type of water body of the Sea-Or project region (Source: RID/ Google)



Figure 13: Dry riverbed

A good review about the importance of non-perennially flowing waters can be found in McDonough et al. (2011). The following paragraphs are mainly based on McDonough et al. (2011).

The flow regime is the most fundamental driver of physical, chemical, and biological processes in water bodies controlling among others morphology, substrate, temperature, flora and fauna habitat and the flux of energy and matter. According to the discharge conditions throughout the year, streams can be classified into

- perennial streams and
- temporary streams.

Perennial streams have flow throughout the year under normal circumstances (except years with severe drought conditions). In times without precipitation, perennial stream flow is fed by base flow. Temporary streams are water bodies that lack surface water flow during some periods of a year; this means they have periods of dry and wet conditions. They can be further distinguished into

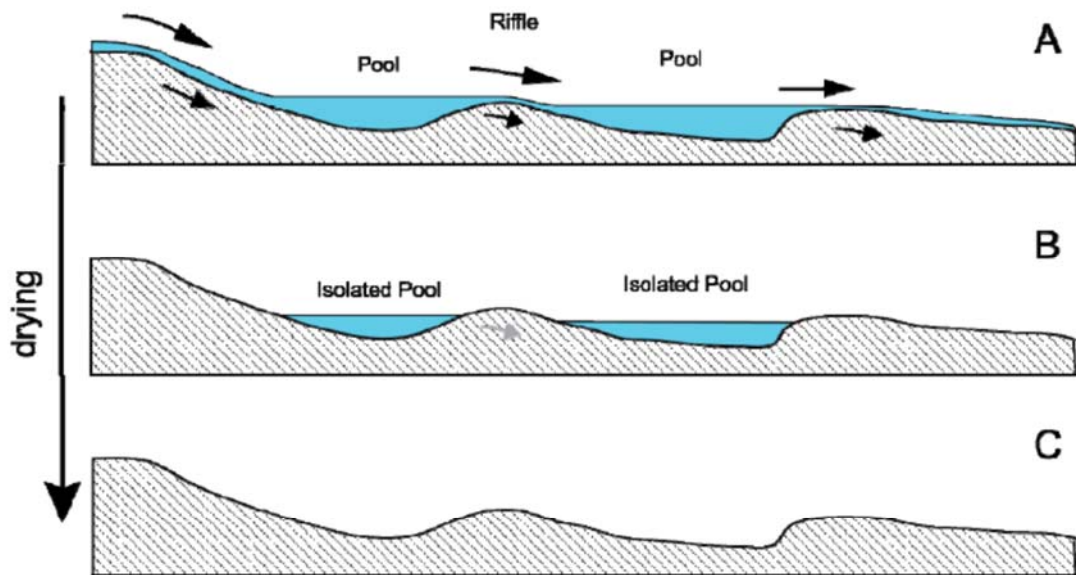
- intermittent streams and
- ephemeral streams.

Ephemeral streams are water bodies that only flow immediately during and after precipitation events. Their groundwater table is below the streambed, so they lack a base flow source. Intermittent streams flow during certain times of a year. Figure 14 shows examples for perennial, intermittent and ephemeral streams.



Figure 14: Examples of perennial, intermittent and ephemeral streams (Missouri Stream Fact Sheet, 2016)

In regions with distinct dry and wet seasons, the flow of intermittent streams strongly correlates to the dry and wet seasons, .e.g. they contain high discharges during the wet season and dry up during the dry season. The drying process of intermittent streams may vary along the river stretch and between different tributaries. Often, as water levels decrease, they dry up to a series of disconnected pools. Depending on the severity of drying, the pools may dry up and surface water will be lost entirely at the end of the dry season. The development of longitudinally isolated pools is especially common in climates and regions defined by strong seasonal wet and dry periods. A common drying process illustrates Figure 15.



Contraction of a stream reach under increasingly dry conditions. Arrows indicated surface and groundwater flowpaths. A) Surface hydrologic connectivity exists throughout the reach such that pools are connected via riffles. B) As drying persists, riffles dry and pools contract until they are geographically isolated. C) If drying persists long enough, all surface water may be lost to either groundwater reserves or evapotranspiration.

Figure 15: Drying process of a stream under increasingly dry conditions (McDonough et al. 2011)

Even though temporary streams do not contain surface flow throughout the year, they are among the most abundant and dynamic freshwater ecosystems on Earth and serve as important habitats for both flora and fauna. Temporary streams and their riparia are often the only places in the watershed with soil moisture levels necessary to support a substantial plant community. Thus, they are considered hot spots for plant diversity.

The account for a significant proportion of the total number, length, and discharge volume of the world’s river. Furthermore, temporary streams build connectivity corridors between the watersheds



they drain and the river networks to which they are periodically connected. Despite the periodic drying process and the absence of surface flow, they are linked hydrologically and ecologically to their watersheds and downstream perennial water bodies.

Even in absence of surface flow, temporary streams may contain hyporheic flow paths that serve as habitat refuge from drying, zones of biogeochemical processing, and hydrologic connections to downstream waters. Especially macroinvertebrate taxa can survive in the hyporheic refuge areas during the dry season where they can resist desiccation. In the wet season, it is possible for them to re-colonize adjacent river stretches subsequently.

Given the temporary nature, intermittent and ephemeral have been “historically neglected” by scientists and society (McDonough et al. 2011). Therefore, they have been understudied compared to continuously flowing perennial streams. Often, they are poorly mapped and faced with numerous anthropogenic disturbances, such as:

- Water abstraction
- Livestock grazing
- Land clearing
- Agriculture
- Channelization
- Damming
- Loss of riparian vegetation/ floodplain connectivity
- Climate change

With respect to climate change and prolonged dry seasons with no or little precipitation, temporary streams may become even more temporary. A proper recognition, management and protection of temporary streams, especially under changing climate boundaries, is crucial.

Figure 16 to Figure 18 show impressions of the upper part of the Pont Prathoon River during the dry season (field trip in June 2016). The images clearly show that the Pont Prathoon River does form the longitudinally disconnected pools typical for climates and regions with strong seasonal wet and dry periods. It is also apparent, that even in stretches without visible pools the remaining soil moisture and invisible hyporheic flow paths serve as important flora refuge habitats. Therefore, the pool structures and the adjacent regions with remaining soil moisture and plant life also serve as important refuge habitat for different fauna species during the dry season. Similar conditions have been identified throughout the river stretches within the catchment during the conducted field trip in June 2016.



Figure 16: Pool within Pont Prathoon River during dry season (June 2016)



Figure 17: Dry and wet parts of riverbed in Pont Prathoon River during dry season (June 2016)



Figure 18: Pools are places within the Sae-Or watershed with soil moisture levels necessary to support a substantial plant community (June 2016)

## 4 IDENTIFICATION OF MAJOR CHALLENGES

The selection, design and implantation of EbA measures required a comprehensive assessment of the current challenges within the catchment. Furthermore, challenges for existing ecosystems introduced by the planned reservoir had to be included into the assessment before developing an integrated EbA concept for the Sea-Or Reservoir project.

### 4.1 Droughts and floods

Trigger for the planning of the Sea-Or Reservoir by the Royal Irrigation Department of Thailand was the reporting of drought problems by local stakeholders (farmers) to the Royal Initiative Project Bureau. According to a meeting with the local stakeholders of the Sae-Or catchment conducted during the field trip of RID and SYDRO in June 2016 (see Figure 19) the amount of river/canal water is low during the dry season, causing water shortage. The water shortage leads to a decrease of crop productivity. Given the fact, that agriculture is the major source of income within the Sea-Or region, the decrease of crop harvests is threatening the livelihood of the local stakeholders. Local villagers reported that the drought problems increased during the last three years with shortened rain periods. In 2016, the drought problem started in May and was still present in June, as the rainy season had not yet started again.



Figure 19: Consultation with local villagers during field trip

Most parts of the project area is relatively flat (see Figure 7). During the rainy season large amounts of water flows over the river/channel embankments onto the adjacent agricultural areas. These flooding can potentially cause damage. However, local stakeholders reported during the field trip (see Figure 19) that floods are a minor problem with only 1-2 days of flooding per year, causing no significant damage to crops and farmland. Thus, floods can be considered an only minor problem within the catchment.

## 4.2 Erosion

Aside from the natural land use in the steeper upper catchment part, where natural forest still prevail, the catchment area downstream of the planned dam site is heavily altered by anthropogenic uses. Mostly, the flatter catchment area is characterized by a patch of different agricultural areas (cf. Section 3.4). Farmland account for ca. 80% of the total catchment area downstream of the planned reservoir.

Soils on arable land are often bare or with only minor plant cover. Existing furrows are often created in flow direction. Thus, the arable land is extremely erosion prone, especially during high intensity rainfalls.

Figure 20 gives an example of farmland without any plant cover. The furrows are created in the direction of the general slope. Eroded soils are thus directly transported into the receiving water body. Figure 21 shows, that erosion is actually taking place. The photo was taking during the dry season. Figure 22 gives an impression of the amount of eroded soils that will probably washed into the adjacent river stretch during the next strong precipitation event. The evaluation of the erosion problem should take into account that all photos were taken during the field trip in June 2106 in the dry season. Thus, during the rainy season with much more intense precipitation the amount of eroded soils will be significantly higher. Figure 23 shows the beginning formation of an erosion gully. A fully developed erosion gully is depicted in Figure 24. The plants are part of the river embankment directly adjacent to the farmland with bare soils, a trapping of eroded sediments is not taking place, and all eroded material will be washed directly into the receiving water body.

The erosion problem within the downstream areas of the Sea-Or catchment is not limited to agricultural areas alone. Figure 25 shows erosion patterns from a minor road within the farmland area. As with the farmland, the road is not plant covered or fixed in any way. The small road drainage channel on the right hand side of the road transport both water and eroded sediments directly into the receiving water body, any form of sediment retention is not in place.



Figure 20: Bare soils with no plant cover and furrows in flow direction on a stretch of farmland



Figure 21: Erosion of fertile soils from farmland following the furrows in flow direction



Figure 22: High amount of eroded soils



Figure 23: Beginning formation of an erosion gully



Figure 24: Fully developed erosion gully (river on left hand side, farmland on right hand side)



Figure 25: Erosion from road with the farmland area

Buffer strips along the exiting river/canal stretches are generally missing. The farmland reaches right until the riverbanks (see Figure 26). At different locations, soils from arable land have been even to stabilize river embankments (Figure 27), hindering a natural river development and wasting fertile soils.

The problem of heavy soil erosion from the arable land and small roads into the receiving water body is further aggravated by the fact that the predominant Soil Series Group 35 (see Section 3.5) has low fertility. Thus, different types of fertilizers (compose fertilizer, animal manure, mixed green manure, Chemical or liquid LDD fertilizer) need to be applied (LDD, 2016). The use of fertilizers to enhance crop productivity has been confirmed by the RID project team for the project region. These fertilizers will be washed into the river together with eroded soil, impacting the water quality of the receiving water body.





Figure 26: Agriculturally used land reaching right until the river embankment



Figure 27: Stabilization of river embankment with fertile soil

### 4.3 Water body degradation

The water bodies within the Sea-Or region are heavily degraded in huge proportions of their total length. As shown in Figure 28 stretches of rivers have been shaped into canals, the river in these stretches does not have naturally shaped cross sections any more.

The river/canal embankments are very steep and seldom covered by plants, leaving them very erosion prone. During floods, the river will cut and erode (outer) banks, as there are no stabilizing roots or other structures in place. As shown in Section 4.2, farmers counteract the loss of arable land by refilling eroded parts with fertile soils from the farmlands (see Figure 27).

Often, there are man-made embankments that are considerably higher than the adjacent farmland, hindering a natural spreading of water during flood events. The embankments are made from fertile soils and are often bare without any plant cover. Figure 29 shows an example of a river stretch formed into a canal cross section, embankments without any erosion protection and with a height hindering a natural spread of flood pulses. The condition of the river embankments leave them extremely erosion prone, heavy erosion patterns of the embankments could be observed (see Figure 30 for an example).

At several locations, the anthropogenic altering of the water bodies including their embankments have cut off (former) natural river branches, which is illustrated in Figure 31.

Several concrete weirs are located throughout the catchment within the rivers and canals (see Figure 32, Figure 33, and Figure 34). They have all been funded as Royal Initiative Projects in order to support the livelihood of local villagers. Even though, some of the weirs are equipped with adjustable gates there were fully closed during the conducted field trip. The weir shown in Figure 33 has no gate structures at all. Thus, these weirs block the natural flow patterns totally. Only during high discharge events, water will be transported over the weirs to downstream areas. Aside from disrupting flood pulses (discharge disruption), they are also blocking migration of aquatic species (ecological disruption) as fish passages or bypasses could generally not be found.

The biggest weir structure (cf. Figure 34) has been accompanied by a shaped backwater area. The river stretch within the backwater area has been significantly widened, forming a small reservoir for storing water in the rainy season. Aside from its water storage function, the small reservoir acts as mini-wetland in the dry season, where surface water is still available in sufficient amounts to provide habitat for both aquatic flora and fauna. Figure 35 gives an impression of the backwater area and the wetland during the dry season (June 2016) including its vegetation with water lilies.

In the upper part of the Pont Prathoon River, several small weirs build with natural materials could be found during the field trip. They have been built by local villagers to store small amounts in water for its use within the dry season (Figure 36). As they are often washed away by flood events during the rainy season, the small weirs are rebuild at different locations every year.



Figure 28: Water body shaped into a canal



Figure 29: Dikes along the embankment, embankment with bare soils



Figure 30: Erosion of river embankments



Figure 31: Cut off natural river course



Figure 32: Concrete weir (with gates)



Figure 33: Concrete weirs (without gates)



Figure 34: Big weir with shaped backwater area



Figure 35: Widened backwater area with wetland (in dry season)



Figure 36: Small weir build within the natural water body by local villagers

#### 4.4 Forest degradation

The Royal Irrigation Department (RID) examined two potential site locations for a reservoir in the upper catchment area of the Pont Prathoon River (see Chapter 1). The location of Site 1 is indicated in Figure 6, the second potential dam site is located further downstream. Table 1 shows the technical details of the two potential dam site locations.

Site 1 is located in the steeper upstream catchment part, the planned dam will block the Pont Prathoon River between two existing hills right at the border of the Zone C forest area (Figure 37). The active storage volume of the reservoir at Site 1 will be ca. 2.6 mil m<sup>3</sup>. The reservoir area will stretch mainly into a Zone C forest area, ca. 61 ha of forest would need to be cut within the reservoir area. Given the high amount of (rain) forest that Thailand already has lost in the last decades, any further deforestation should be generally avoided.

Site 2 is located further downstream where the catchment topography is more flat. Natural hills for building a dam are not present at this location. It would be necessary to build a long earth dam. Due to the inferior topography for building a reservoir, the active storage volume would be ca. 0.39 mil m<sup>3</sup> (Source: RID). The reservoir area at site 2 would be located mostly within the farmland of the catchment, only 0.32 ha of Zone C forest would be affected (Source: RID).

An Initial Environmental Examination carried out by the Royal Irrigation Department of Thailand (Source: RID) states, that Site 1 outscores Site 2 in almost every aspect. Table 2 gives an overview of the comparative analyses, the variables considered and the weighting factors used for the site selection. The different potential reservoir locations differ especially in the amount of storage water (see above) and the beneficiary area. Both values are significantly greater for Site 1. The topics “3.3 Impacts on farming area in reservoir” and “3.4. Impacts on transport routes in reservoir” have been categorized into the major category “Environmental”. However, these topics should probably be sorted into the major category “Economic” as both the loss of farmland and necessary detours mostly have economic consequences.

Given the strong decline in slope (cf. Section 3.3) downstream of the mountains headwater area of the catchment, Site 1 is rather optimal for storing a relatively huge amount of water within the catchment. A similar value of active storage value seems rather impossible with a reservoir in the flatter downstream area of the Pont Prathoon River. It is assumed that the water shortage for irrigation purposes within the planned project area and the resulting storage volume of ca. 2.6 mil m<sup>3</sup> was estimated reliably based on current and future water demand.

**Table 1: Technical details of the two reservoir site locations (Source: RID)**

Description	Unit	Site 1	Site 2
1. Headwork site			
Location	-	Ban Kaonoi Promsuwan, Sae Or Sub-district, Wattana Nakorn District	Ban Kaonoi Promsuwan, Sae Or Sub-district, Wattana Nakorn District
Coordinates	-	E = 233265.193 N = 1546971.908	E = 232982.788 N = 1545497.935
2. Hydrological characteristics			
Reservoir size	km <sup>2</sup>	14.85	16.35
Average annual runoff	Million m <sup>3</sup> /year	4.03	4.35
3. Reservoir storage capacity			
Minimum pool level	MASL	+107.20	+97.00
Normal pool level	MASL	+112.00	+100.00
Crest level	MASL	+113.80	+102.60
Dead storage	Million m <sup>3</sup>	0.34	0.01
Active storage	Million m <sup>3</sup>	2.57	0.39
Reservoir surface area at minimum pool level	Rai	137.94	13.70
Reservoir surface area at normal pool level	Rai	455.21	147.90
4. Reservoir structure			
Type	-	Zone type	Zone type
Crest height	M	11.05	6.60
Crest width	M	8.00	8.00
Crest length	M	350.00	420.00
Dam slope gradient – upstream	-	1 : 3.0	1 : 3.0
Dam slope gradient – downstream	-	1 : 2.5	1 : 2.5
5. Farming area			
Rainy season	Rai	4740	2095
Dry season	Rai	898	130
6. Construction cost	Million baht	317.80	220.19
Dam and spillway	Million baht	209.77	160.19
Irrigation system	Million baht	108.03	60.00



Table 2: Comparison of potential reservoir locations (Source: RID)

Variable	Score composition	Project development option					
		Site 1			Site 2		
		Description	%	Score given	Description	%	Score given
1. Engineering							
1.1 Storage capacity vs. average runoff	9.80	58.06%	80	7.84	8.79%	20	1.96
1.2 Conveyance efficiency	7.60	Pipeline network	100	7.60	Pipeline network	100	7.60
1.3 Flood mitigation (100-year return period)	7.60	7.25%	50	3.80	< 50%	25	1.90
<b>Total score</b>	<b>25</b>			<b>19.24</b>			<b>11.46</b>
2. Socio-economic							
2.1 Beneficiary area	15	4,470	100	15.00	2,095	60	9.00
2.2 Local need	15	65.6%	75	11.25	<25%	25	3.75
<b>Total score</b>	<b>30</b>			<b>26.50</b>			<b>12.75</b>
3. Environmental							
3.1 Loss of national park	9.80	No impact	100	9.80	No impact	100	9.80
3.2 Loss of forest reserve area	9.80	379 rai	40	3.92	2 rai	80	7.84
3.3 Impacts an farming area in reservoir	7.70	195 rai	60	4.62	164 rai	60	4.62
3.4 Impacts on transport routes in reservoir	7.70	No impact	100	7.70	No impact	100	7.70
<b>Total score</b>	<b>35</b>			<b>26.04</b>			<b>29.96</b>
4. Economic							
4.1 Construction cost vs. beneficiary area	5.60	62,744 bht/rai	40	1.76	105,103 bht/rai	20	0.88
4.2 Construction cost vs. storage capacity	4.40	123.66 bht/m <sup>3</sup>	60	2.64	569,52 bht/m <sup>3</sup>	20	0.88
<b>Total score</b>	<b>10</b>			<b>4.40</b>			<b>1.76</b>
<b>Overall score</b>	<b>100</b>			<b>75.93</b>			<b>55.93</b>

Given the results of the site comparison within the IEE, Site 1 was identified by RID as an appropriate option for infrastructure development. All further planning for the Sea-Or Reservoir including the IEE has been carried out for Site 1. Thus, the reservoir location at Site 1 was taken for granted within this project.

Figure 37 shows the location of the planned Sea-Or Reservoir at Site 2, the two dam structures and the classification of forest types according to the classification of Thailand’s Royal Forest Department. The reservoir area is located within a mostly undisturbed natural forest, classified as Zone-C forest. Figure 38 shows the current status of the forest at the planned reservoir location; Figure 39 shows the area at the dam site.

According to the “Forest Management in Thailand” manual (Ongprasert, n.d.), Zone-C forest type deserves a high level of protection and the allowed land use within areas classified as Zone-C forest is limited to

- conservation forest,
- protected and natural forest,
- class 1 watershed areas,
- national parks,
- wildlife sanctuaries,
- forest parks,
- non-hunting areas,
- biosphere reserves,
- and minimal human activities.

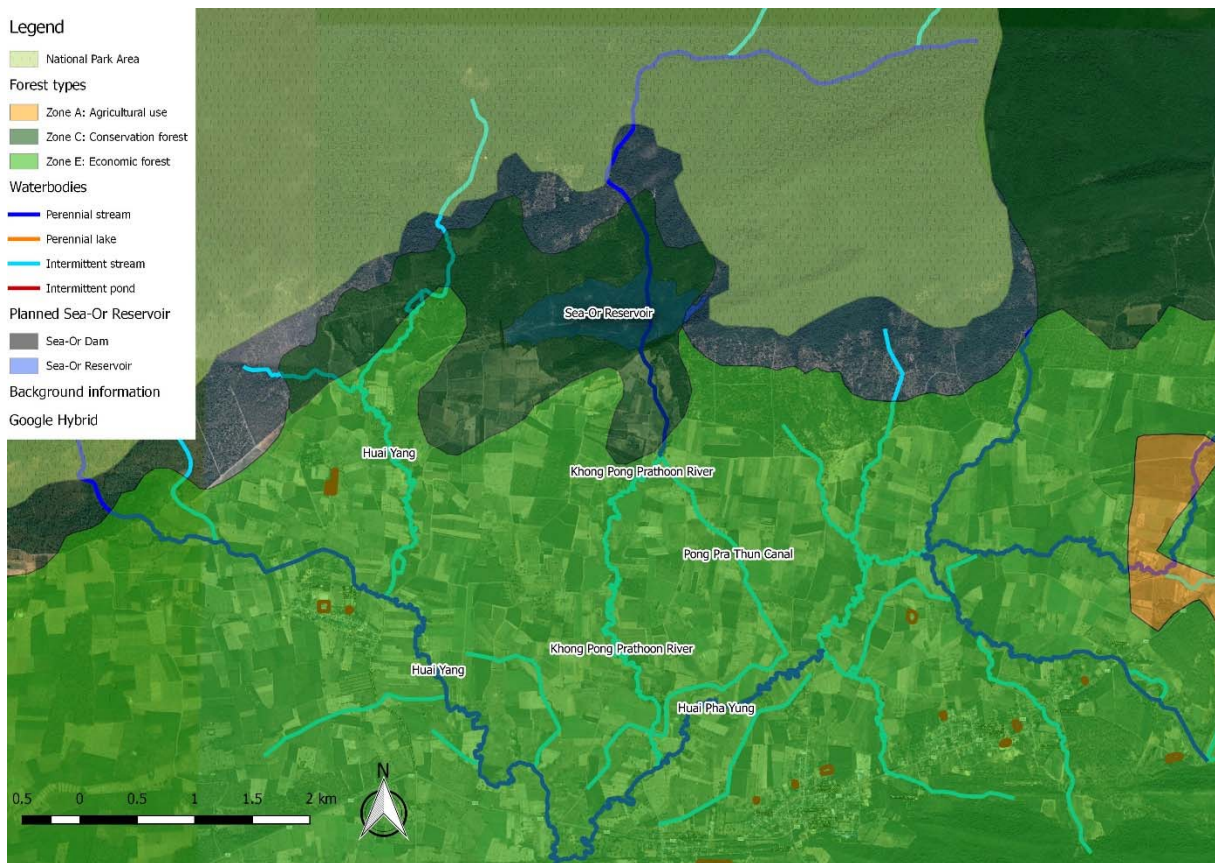


Figure 37: Reservoir location and forest types



Figure 38: Undisturbed natural forest at the reservoir site; Hills of Hanom Dong Rak Mountain Range in the background



Figure 39: Area at the dam site

As mentioned above, the building of the reservoir will lead to a direct loss of 0.61 km<sup>2</sup> of Zone-C forest. However, Figure 37 shows, that farmland is already under current circumstances moving into the protected area of mostly undisturbed natural forest as farmers apparently try to increase their area for crop production. Thus, the preservation of the natural forest in the headwater of the catchment is already at risk without building a reservoir, probably due to the high development pressures of local farmers, who rely on agriculture for their livelihood.

The endangerment of the natural forest in the headwater area is further exacerbated by the fact, that there is currently no transition zone between the Zone-C forest and the farmland. The arable land stretches already right to the border of the forest. Furthermore, Local farmers are allowed to let their cattle graze with-in the Zone C forest.

## 4.5 Conclusion

The identified major challenges within the Sea-Or catchment can be grouped into two main categories.

- Challenges for the local farmers
- Challenges for the catchments ecosystems.

Table 3 gives a summary of the identified challenges in Sections 4.1 to 4.4.

**Table 3: Major groups of challenges within the Sea-Or catchment**

Major challenges for local farmers	Major challenges for catchments ecosystems
<ul style="list-style-type: none"> <li>- Water shortage during dry season</li> <li>- Decrease of crop productivity</li> <li>- Agriculture is major income</li> <li>- Threatened livelihood</li> </ul>	<ul style="list-style-type: none"> <li>- High proportion of agricultural land use</li> <li>- Loss of natural forest</li> <li>- Heavily degraded water bodies</li> <li>- Erosion</li> </ul>
<b>⇒ Not enough water</b>	<b>⇒ Degrading ecosystems</b>

The trigger for the planning of the Sea-Or Reservoir by the Royal Irrigation Department was the reported water shortage for irrigation purposes by local farmers. This challenge is strongly related to the high proportion of farmland on total catchment size, which leads to degrading ecosystems in form of deforestation, degradation of natural water bodies and high losses of fertile soils and high amount of erosion. Unfortunately, the different impacts on the catchments ecosystems interact and mutually reinforce.

As acceptance by local stakeholders is crucial for maintaining ecosystems and their service in a sustainable way, mitigation measures need to address both the water shortage problems of the local farmers and the degradation of the catchments ecosystems in an integrated concept.

## 5 PROPOSED EBA CONCEPT

As concluded in Section 4.5, both the location of the planned Sea-Or Reservoir and its active storage size was taken as set within this analysis. Due to the catchment topography, the construction of a mid-size reservoir is only possible at the location determined by the RID. EbA measures alone cannot replace a reservoir with an active storage volume of 2.7 million m<sup>3</sup>. Thus, the EbA concept proposed constitutes of measures as compensation and accompanies the planned water infrastructure (reservoir and irrigation system).

The planned Sea-Or Reservoir will block the natural flow of the Khlong Pong Prathoon River. Thus, the focus of the EbA concept was based of the catchment of the Khlong Pong Prathoon River from directly downstream of the dam location until its confluence with the next river.

For watershed development and EbA implementation particularly, some basic guidelines or rules should be followed for successful und sustainable planning and implementation processes. GIZ (2015) list, among others, the following points to be observed:

- **Participation:** Stakeholder communities need to be actively involved in all stages of planning, implementation, management, and maintenance. This is a continuous process rather than a one-off exercise.
- **Building upon local experience, strength and proven success:** Local knowledge is essential to improving existing technologies, to adapting new ones and to managing natural resources and other measures.
- **Inclusiveness:** Watershed development planning and implementation should follow a holistic approach, which considers the entire watershed.

EbA measures can be divided into four sectors:

- **Agriculture** (e.g. intercropping)
- **Urban** (e.g. green roofs)
- **Forest** (e.g. land use conservation)
- **Hydro-Morphology** (e.g. re-meandering)

Different benefits can be expected from EbA implementation in the different sectors, some example benefits are given below:

- **Agriculture EbA:** Slowdown of runoff, increase of infiltration, reduction of erosion, filtration of pollutants
- **Urban EbA:** Slowdown and storage of runoff, increase of evapotranspiration, flood risk reduction, aesthetic and cultural values
- **Forest conservation:** Storage and slowdown of runoff, increase of evapotranspiration, increase of infiltration, reduction of pollutant sources, interception of pollutants, reduction of erosion, biodiversity preservation
- **Hydro-Morphology:** Slowdown of discharge, interception of pollutants, reduction of erosion, creation of aquatic and riparian habitats, natural biomass production, biodiversity preservation

A dam and reservoir construction does have significant impacts on the affected ecosystem, such as altering of timing and quantity of river flows; changes in water temperature, nutrient and sediment transport; reduction of delta replenishment and the blocking of migrations of fish and other aquatic life (CAP NET, 2016). Thus, the EbA concept developed and described in the following Sections aims at

mitigation a further degradation of the ecosystems within the Khlong Pong Prathoon River that will be mainly affected by the reservoir. However, a transfer of the suggested EbA measures to other part of the Se-Or region is easily applicable.

Together with the grey measure of the Sea-Or reservoir, the EbA concept is not to be seen as a standalone solution but as complimentary measure together with the reservoir planning conducted by the RID. Given the heavily degraded water body within the project area, it is concluded that the reservoir within the forest type C zone could be an option, if it is complemented by comprehensive EbA measures regarding the remaining forest and the degraded water body.

The combined approach is supposed to bring benefits to both human stakeholders within the catchment and its ecosystems:

- The problem of water shortage during the dry season for the local farmers will be addressed by the reservoir construction and the storage of water in the rain season for irrigation purposes in the dry season.
- The loss of natural forest (Zone C forest) will be counter measured by a graded forest edge (EbA sector: Forest conservation).
- The degraded water body of the Khlong Pong Prathoon river will be addressed by river rehabilitation measures (EbA sector: Hydro-Morphology) and environmental flows from the reservoir.
- A (riparian) buffer strip will mitigate the impact of the farmland and the related erosion problems (EbA sector: Agriculture).

As there are only five smaller villages within the overall catchment, EbA's from the urban sector have not been within the scope of this project.

## 5.1 Forest edge development

Headwater areas are important source areas for streams and crucial for downstream ecosystems of catchments. Forests, especially natural forest in headwater areas are good for both water quality and quantity. They are also very important for erosion control. The destruction of natural forest and its ecosystem services will lead, among others, to a loss of

- wood and non-wood products: e.g. biomass based energy,
- climate regulation: e.g. C-sequestration,
- pollution control,
- soil protection and formation: e.g. erosion control,
- nutrients cycling,
- Biodiversity protection,
- water regulation and supply,
- recreation,
- and disturbance regulation.

As shown in Section 4.4, the natural forest in the upstream catchment area (Zone-C forest) is already today under major pressure as farmland is moving into it at great speed. The building of the Sea-Or reservoir will contribute to a further loss, as its location is within the Zone-C forest. Given the catchment topography, an alternative reservoir site location with comparable storage volume could not be found.

To hinder any further degradation of the natural forest it is suggested use the planned reservoir as nucleus for a sustainable forest protection. This is supposed to be achieved by the implementation of

a forest edge zone, stretching from the main dam of the planned Sea-Or Reservoir to the adjacent water bodies of the Khlong Pong Prathoon river to the West and East along the Zone-C forest respective the Pang Si Da National Park Area.

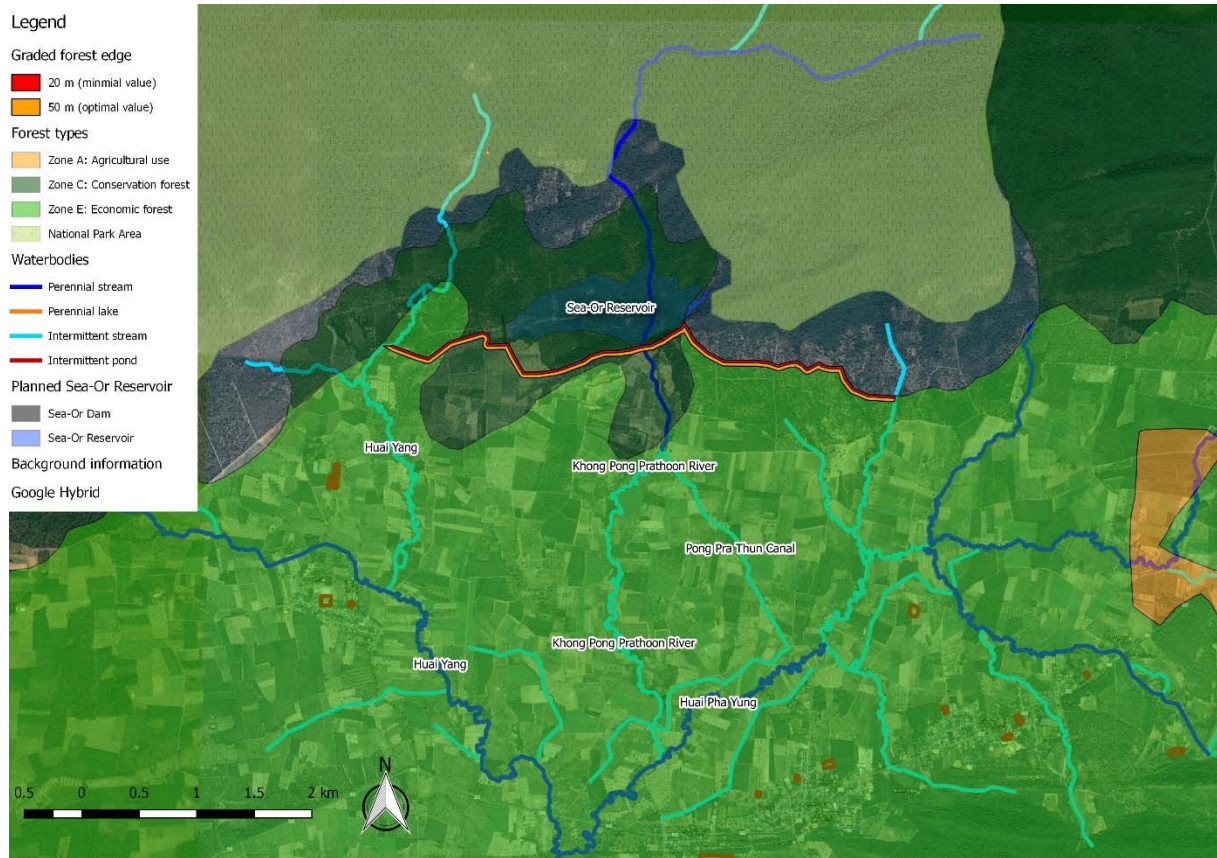


Figure 40: Forest edge zone stretching from the two dam locations of the Sea-Or reservoir to the adjacent water bodies of the Khlong Pong Prathoon river

Forest edges are physical vegetation structures (Wiström, 2015): They form transition zones between a forest and a more open land cover. Natural forest edges are dynamic and often change their position and structure. A forest edge is developed, where the natural succession of the forest is stopped by stress or disturbances. This creates a transition between the forest and non-forested areas, a process that can be either natural or man-made. Based on the origin and upholding of the forest edge, three classes of forest edges can be defined (Wiström, 2015):

- Natural forest edge,
- Maintained forest edge,
- Regenerating forest edge.

For the Sea-Or catchment, upholding the natural forest succession is man-made, as forested areas have been and are cut down to gain more farmland. If the forest edge is restricted in its movement, e.g. agricultural land use, the external stressor will fix the horizontal position of the forest edge. A forest edge that is permanent for a longer period of time is called a “stationary forest edge” (Wiström, 2015).

Figure 41 shows different structures of forest edges, ranging from abrupt edges at the top to graded forest edges at the bottom. Graded forest edges are forest edges that are increasing in height from the periphery (i.e. the farmland) to the interior of the forest (i.e. the natural forest mostly undisturbed forest within the Zone-C forest area). The schematic overview in Figure 41 also shows that species

richness fundamentally increases in graded forest edges. Graded forest edges provide important ecosystem services:

- Biodiversity
- Filter and barriers (for sediments, nutrients and pollutants)
- Shelter, Habitats, Corridors (for both flora and fauna)
- Visual qualities

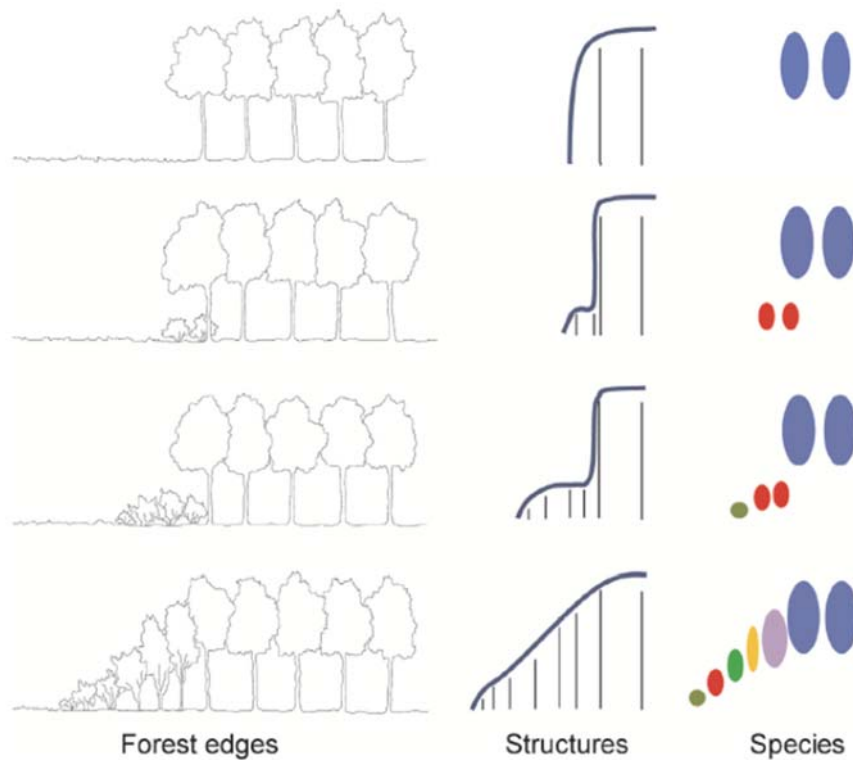


Figure 41: Schematic figure of some different forest edges, their structures and species groups ranging from abrupt forest edges in the top to graded forest edges in the bottom (Wiström, 2105).

A study by Sritongchuay (2014) for the Krabi province in Thailand showed, that the provision of different microhabitats, e.g. trees and shrubs of graded forest edges, attract different groups of avian seed dispersers. They found both a greater species richness and a higher number of seeds beneath shrubs and trees than compared to grassy areas. Fruiting trees in forest restoration areas proved so-called “stepping stones” for birds within fragmented forest ecosystems and potentially attract greater numbers of seed dispersers. According to the study, birds spend significant amounts of time both in intact forest as well as in open, non-forest habitats. Thus, seeds of forest trees are naturally dispersed into deforested habitats.





Figure 42: Potential seed disperses of Thailand in graded forest edges (Bulbus, flowerpecker)

In heavily anthropogenic altered catchments, especially with high amounts of urbanization, graded forest edges are rare as certain conditions are necessary for their development (Wiström, 2105):

- Natural succession of forest into old fields (“advancing edge phenomena”)
- Cultural landscapes with moderate disturbances, where for example low-intensity grazing supports the development of edge zones with a graded profile
- Locations with specific intrinsic environmental gradients, such as moisture gradients and soil depth gradients

There are two distinct ways to establish a graded forest edge. One is the dense planting of intimate mixtures, aiming at the restoration of as much of the site’s original and structural diversity as possible. However, a subsequent colonisation from outside is still necessary, and one major drawback is, that a planted forest edge is rather expensive. Figure 43 shows the initial planting within the area intended for the graded forest edge, the different species mixture is shown on the two left images. The right image shows the grade forest edge after 10 years, when the initial planting has been superimposed with the subsequent colonisation from the natural forest.

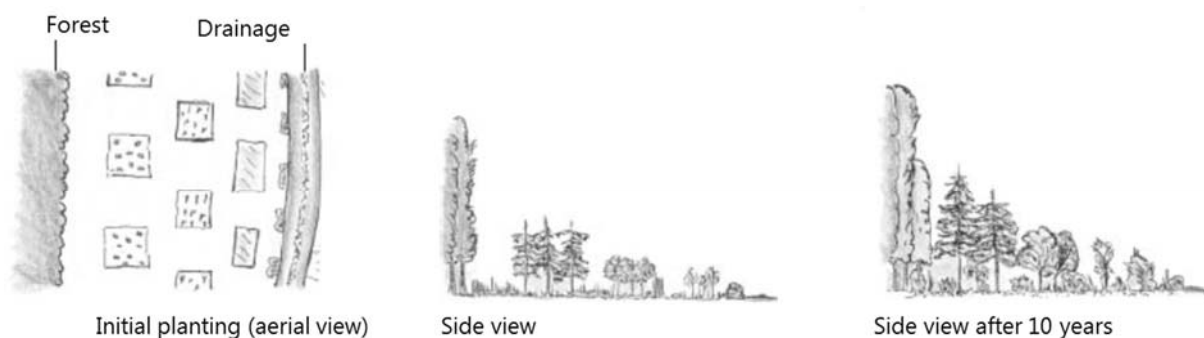


Figure 43: Forest edge development by intense initial planting of intimate mixtures and development after 10 years (Costa 2001)

The second way to establish a (graded) forest edge is the process of natural succession. Removing disturbances or stress regimes, forest edges will advance forward and reclaim the non-forested land. Many heavily degraded forest ecosystems have shown to be able to recover from disturbances and degradation, if pristine flora and fauna is still present at the site or in the region. The original plants and animals will act the source of new colonists. However, they must be able to move across the landscape, at least via so-called “stepping stones” of still intact habitats. Furthermore, the soils must

have been remained in appropriate conditions for shrubs and trees and any intrusion of pest or weed species needs to be controlled rigorously.

The current circumstances within the Sea-Or catchment are rather ideal for the development of the proposed forest edge buffering the mostly undisturbed natural forest in the steeper headwater area of the catchment from the progressing farmland use in the flatter areas of the catchment. Natural forest still exist in the upper reaches of the catchment. The transition from steeper to flatter topography provide the needed intrinsic environmental gradients necessary for the process of natural succession. Thus, the process of natural succession will take place, if the disturbances and stress regimes (agricultural use, cattle grazing, etc.) are removed at the forest border.

Figure 44 shows the target state of the proposed forest edge: The grey areas mark the existing and mostly undisturbed forest. The natural forest will be followed by a graded forest edge with a depth ranging from 20 meter (minimum value) to 50 meter (optimal value), compare with red line in Figure 44. The depth of the shrub area (darker green areas in Figure 44) is supposed to be greater than 10 meter. The following herbaceous fringe (light green area in Figure 44) also needs a minimal depth of at least 10 meter. The specific form of the forest edge may alter between different locations and is depended on the process of natural succession and potential management interventions.

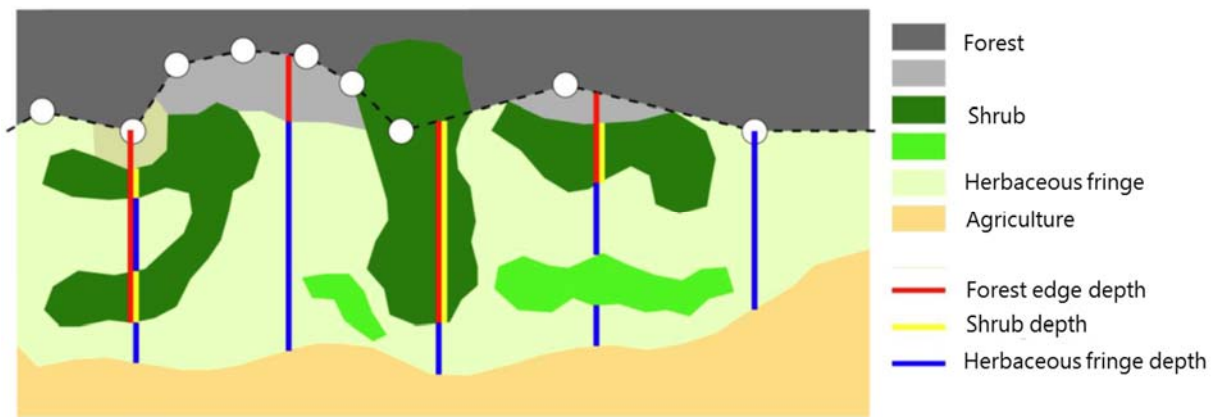


Figure 44: Target state of the proposed graded forest edge (modified from ZAHW, 2015)

Figure 45 and Figure 46 show conceptual managements interventions during the development phase of a graded forest edge. The red lines in Figure 45 show the threshold heights of shrubs and trees, species higher than the threshold heights will be cut. In Figure 46 the concept of a functional species control is shown: Red species will be cut to develop and maintain a graded forest edge.

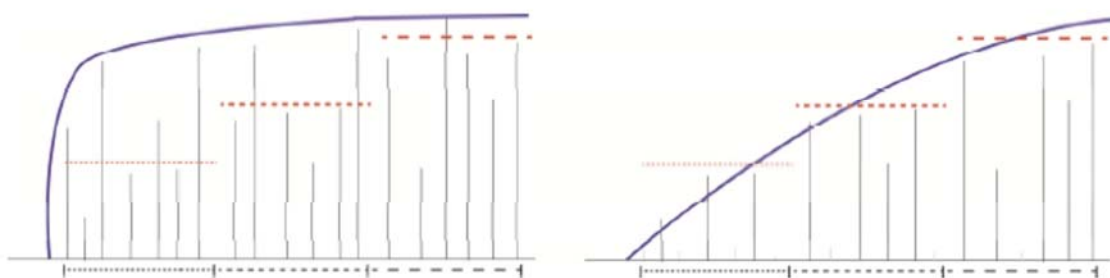


Figure 45: Threshold heights for the development of a graded forest edge (Wiström, 2015)

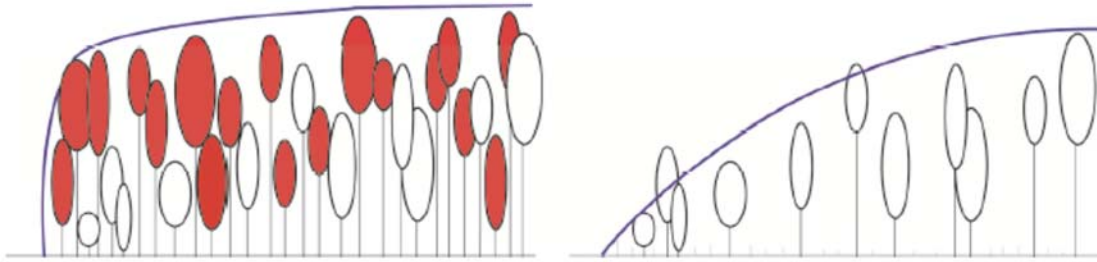


Figure 46: Species control during the development of a graded forest edge (Wiström, 2015)

The proposed graded forest edge will be followed by a drainage structure where it meets the farmland. The drainage structure will provide several functions:

- Drainage of water
- Sediment and erosion control
- Visual demarcation

The drainage structure will provide a visual demarcation and a distinctive border between the forest area of the catchment and the agricultural uses area. No agricultural use should be allowed behind the drainage structure, which will be especially important during the development phase of the graded forest edge.

Aside from the distinctive border, the structure will drain water stemming from the steeper catchment part of the forested area in the direction of nearby rivers or ponds. Where it is possible by natural topography, the flow will be directed to nearby rivers, thus supporting natural flow conditions within the water bodies. Where topography hinders the discharge into natural water bodies, artificial ponds will be created for local water retention and storage. Water in the ponds will increase groundwater infiltration, the natural water cycle will be sustained and soil moisture will be increased. This effect will be especially beneficial during the dry season, where water is typically rare.

Within the rainy season and during high precipitation events the drainage structure will also trap sediments eroded in the steeper headwater area. Furthermore, as the flow is retained and diverted within the drainage structure, the erosion of arable soils by high runoff volumes will be hindered.

Figure 47 gives a schematic overview of the proposed forest edge together with the accompanying drainage structure. Suitable plants should stabilize the drainage channel. An example of the design of the drainage channel at locations with steep gradients is given in Figure 48.

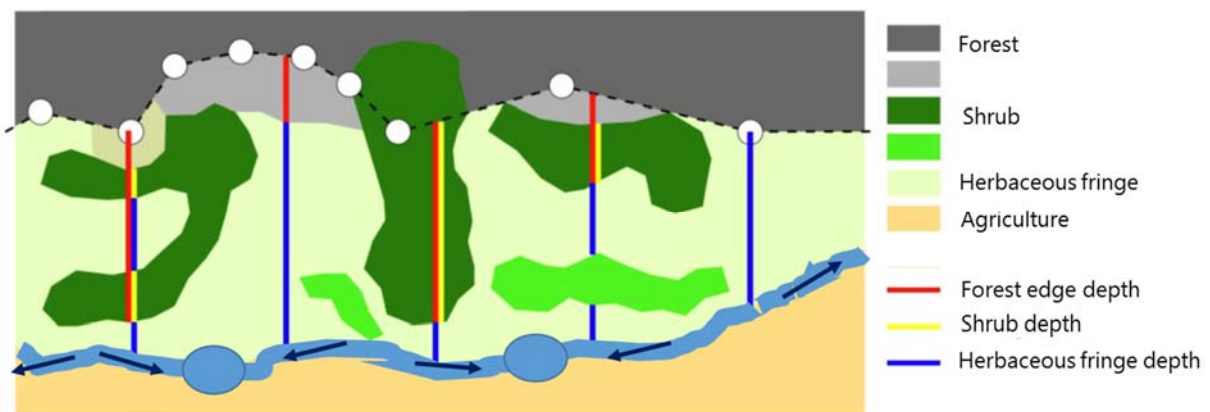


Figure 47: Drainage structure for water & erosion management at the end of the graded forest edge (modified from ZAHW, 2015)

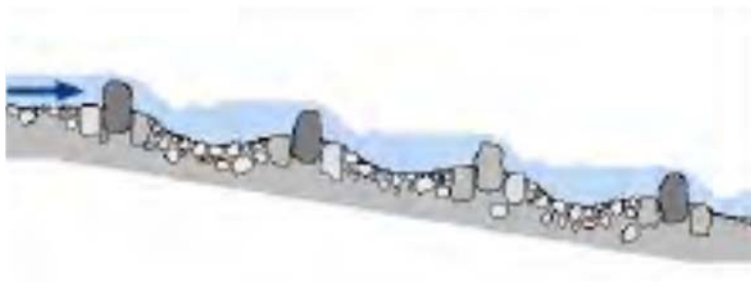


Figure 48: Pool structure to avoid erosion of the drainage channel at steeper sections (DWA-M509, 2014)

Aside from the protection of the Zone-C forest area in the upstream catchment area of the Sea-Or catchment, the EbA measure also provides several co-benefits for the local stakeholders:

- Protection of the headwaters hydrological cycle and thus a water availability in quantity and quality within the future
- Local water retention and storage providing additional water sources during the dry season
- Groundwater infiltration that could be potentially used
- Sediment retention and discharge retention, protecting soil losses from the adjacent farmlands

During the development phase of the forest edge, a rigorous monitoring and, if necessary, maintenance of the graded forest edge is crucial. The overall rate of any forest restoration is also depending on management input. Figure 49 shows three different development scenarios (Lamb and Gilmourm, 2003):

- **A:** With an extensive site preparation and a large number of planted species at the beginning, the forest edge will develop rather rapidly, weeds will be excluded more naturally and the necessary microclimate will be recreated fast. Thus, the colonisation with further species will be facilitated.
- **B:** Less or no initial planting will lead to a longer timeframe for the succession process and the development of the graded forest edge. Until the forest edge has not reached the safety threshold, from which on it will be mostly self-sustainable, it will be exposed to a longer period of risk from disturbances such as wildfires or grazing.
- **C:** If the forest edge development is left unaided are showing an even longer time until a self-sustaining state (safety threshold) is reached. If external disturbances, such as grazing, wildfires or sporadic logging are happening to often an unaided forest edge may never reach a

self-sustaining state

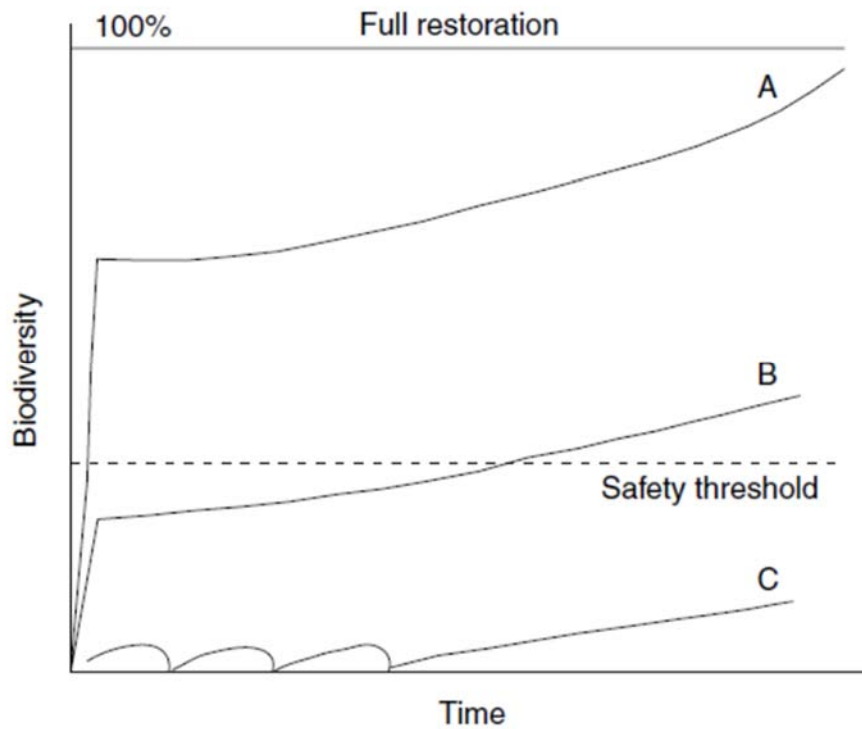


Figure 49: Rate of recovery of biodiversity (Lamb, 2003)

Lamb (2003) gives a good indicator for monitoring the success of reforestation programs: “A crucial element for the success of any restoration program is whether the local community is involved in its development and desire its success. The extent to which the community continues to be actively involved in a project is thus an important indicator of its likelihood of success. Public knowledge about ecological issues and the ability this provides the community to respond to changes in the forest condition is another aspect of community involvement.

A more scientific based approach to monitor the development of the graded forest edge is shown in Figure 50. The number of species of different groups of both flora and fauna in the newly developed forest edge can be compared to the respective number of species in the original ecosystem. This monitoring approach is depending on the existence of undisturbed sites near the project area to act as reference. For the Sea-Or region and its mostly undisturbed forest area in the headwater catchment areas, these reference conditions do still exist.

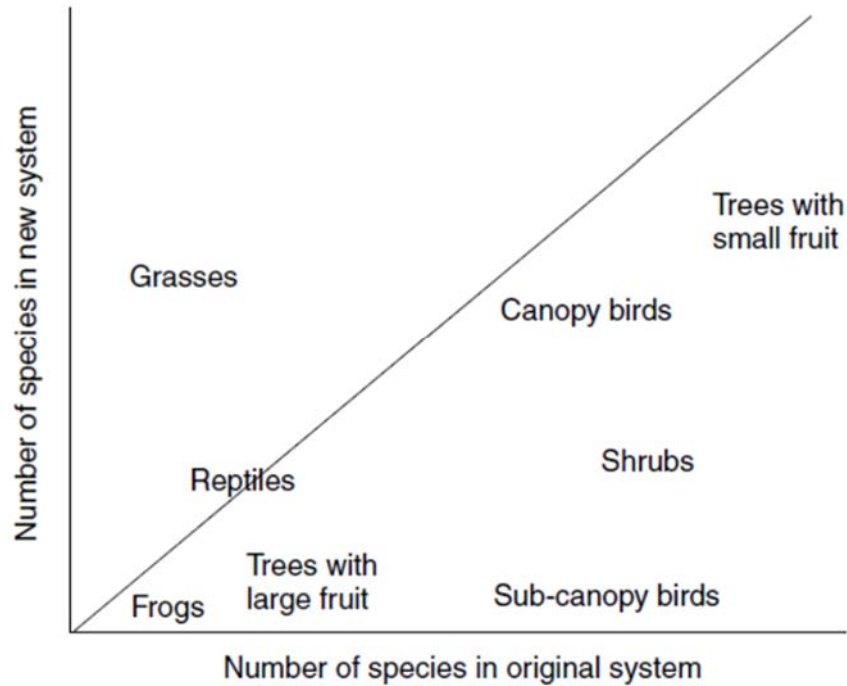


Figure 50: Monitoring of forest edge development (Lamb, 2003)

For a successful implementation of the EbA measure “Graded forest edge” it is crucial, that and further (illegal) deforestation is prevented within the Zone-C forest aside from the logging necessary for the reservoir. Existing deforested areas in the headwater area of the catchment should be reforested.

## 5.2 River rehabilitation

Although the water bodies within the overall catchment area are already heavily degraded, areas worth of protection can still be found. One example is the river stretch directly located at main dam location of the planned reservoir, as shown in Figure 51. The river bottom and the adjacent soils retain enough soil moisture to sustain different species of plants also during the dry season. The morphology of the water body at this location is diverse. However, as shown in Section 4.3, huge parts of the Khong Pong Prathoon River and water bodies in the catchment surroundings are heavily degraded.



Figure 51: River stretch at the dam location with natural vegetation

River restoration generally modifies a degraded river reach with uniform, monotone cross sections and bare riverbanks into a diversified section with natural structures within the riverbed and vegetated riverbanks. The aim is to develop a variation in morphology, flow velocities, bank shapes and vegetation. Potential EbA measures for river rehabilitation are:

- **Streambed Naturalization:** “Streambed (or riverbed) represents the floor of the river, including each riverbank. In the past, riverbeds were artificially reconstructed, therefore modifying flows and decreasing fauna habitat and vegetation diversity. Those modifications were aiming at flood prevention or supporting changes of agricultural practices for example. This has led to uniformed flows in the rivers and often having effect of reducing travel time along the river. Streambed re-naturalization consists in removing constructions in the riverbed and on riverbanks, then replacing them with vegetation structures, in order to avoid these damages and restore biodiversity. The re-naturalization of riverbeds and banks could have a high impact on the erosion process. Stabilisation techniques are among the main measures to be implemented. The maximum impact is reached when the stabilisation technique restores the vegetation cover and the naturalness of the banks. Most of the time, techniques use plants for bank stabilization. According to their degree of complexity, these techniques can be grouped into two categories: Bank re-naturalization is a stabilisation technique used to correct mild erosion problems and that does not require a high degree of expertise to be implemented. Plant engineering is defined as the techniques combining the principles of ecology and

engineering to design and implement slope, bank and bank stabilisation works, using plants as raw materials for making vegetable frames”. (NWRM, 2015)

- **Re-Meandering:** “A river meander is a U-form taken by the river, allowing it to decrease water velocity. In the past, rivers have been straightened by cutting off meanders. Many rivers have been straightened and channelized to, for example, facilitate speed up the drainage of water and control/limit the riverbed movements. Channelizing was also a way to gain land for cultivation. 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 has a positive impact on sedimentation and biodiversity. The newly created or reconnected meanders also provide habitats for a wide range of aquatic and land species of plants and animals.” (NWRM, 2015)
- **Restoration and reconnection of seasonal stream:** “Seasonal streams or intermittent rivers are rivers for which surface water ceases to flow at some point in space and time. They comprise a large proportion of the global river network and are characterized by dynamic exchanges between terrestrial and aquatic habitats. These habitats support aquatic, semi-aquatic, and terrestrial biota. 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. Despite their values and ongoing alterations, seasonal streams are chronically under-studied and protective management is inadequate. Restoring and reconnecting seasonal streams with the river consists in, therefore favouring the overall functioning of the river by restoring lateral connectivity, diversifying flows and ensuring the proper functioning of these seasonal streams for a better water retention during floods.” (NWRM, 2015)
- **Natural bank stabilization:** “Riverbank represents both natural and artificial terrain following the river flow. In the past, many artificial banks were built with concrete or other types of retention walls, therefore limiting rivers’ natural movements, leading to degradation of the river, increased water flow, increased erosion and decreased biodiversity. River bank renaturalisation consists in recovering its ecological components, thus reversing such damages and especially allowing bank to be stabilized, as well as rivers to move more freely. Nature-based solutions such as bioengineering are preferable, but civil engineering has to be used in case of strong hydrological constraints.” (NWRM, 2015)
- **Riparian buffer strips** “are areas of natural vegetation cover (grass, bushes, and trees) at the margin of fields, arable land and water courses. They can significantly reduce the amount of water infiltration and slowing surface flow; they therefore promote the natural retention of water. They can also significantly reduce the amount of suspended solids, nitrates and phosphates originating from agricultural run-off. Buffer strips can be sited in riparian zones, or away from water bodies as field margins, headlands or within fields (e.g. beetle banks). **Hedges** across long, steep slopes may reduce soil erosion as they intercept and slow surface run-off water before it builds into damaging flow, particularly where there is a margin or buffer strip alongside.” (NWRM, 2015)

Different stages of river rehabilitation are shown in Figure 52. The upper sketch shows a heavily degraded water body. The river stretch has been fully straightened, it is very monotone, the flow is uniform and there is almost no vegetation at the embankments and the adjacent areas of the river. Riparian buffer strips do also not exist. The lower sketch shows an ideal version of a rehabilitation



project. Natural morphology and flow diversity is restored, the river has more room for its development and there is a distinct riparian buffer strip before the farmland begins.

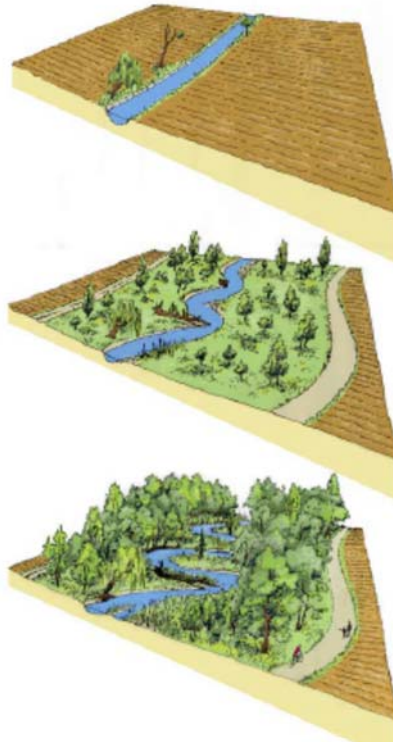


Figure 52: Schematic view of different stages of river rehabilitation (LAWA, 2006)

Even though huge parts of the Pont Prathoon River are heavily degraded, it seems unlikely to rehabilitate it in its total length, as it would require the transformation of huge amounts of farmland and probably be rather expensive. It is also assumed, that the acceptance of such an EbA measure, which is crucial for the successful implementation of EbA measures (cf. Chapter 5), would be difficult to achieve. The proposed EbA concept for river rehabilitation thus consists of a concerted combination of:

- Riparian buffer strip/filter strip
- River Rehabilitation at distinct locations following the “String of pearls” concept
- Embankment stabilization

### 5.2.1 Riparian buffer strip/ Filter strip

Riparian buffer strips or smaller filter strips main function is the protection of surface water from impacts related to human land use. These vegetated buffers are complex ecosystems and provide food and habitats for unique plant and animal species. Even though they are relatively easy to implement, buffer or filter strips are most effective means for the protection of outstanding resource values:

- Water quality
- Hydrology
- Unique species and natural communities
- Watershed ecosystem function

If buffer strips are not in place, huge amounts of eroded sediments from areas with human land use are directly delivered into receiving water bodies. As elaborated in Section 4.2, this impact is especially

strong, if intensively used farmland and the respective fertilizer application is in the vicinity. Aside from the sediments itself, huge amount of nutrients and fertilizers are attached especially to the finer sediment grain sizes and are washed into the river stretches together with the sediment wash-off. Within the water body sediments and attached nutrients and pollutants

- increase turbidity,
- impact the water quality
- narrow the cross section widths,
- and can provide substrate for invasive plants.

Vegetated buffers between farmland and water bodies

- stabilize streambanks and
- stop or slow down the sediment-laden runoff including nutrients and pollutants.

The protection of water bodies from impacts from human land use is especially important in headwater streams, as smaller headwater streams have normally greater land-water interaction than in more downstream catchment areas. Even temporary streams can serve as important sources of sediments and pollutants to the river. Thus, the temporary nature of the Pont Prathoon River and its location in the headwater of the Huay Yang Tributary Sub-Basin makes a protection from impact of human land use very important, also for water bodies further downstream influenced by the discharge of the Pont Prathoon River. Downstream buffer have less impact, if polluted water from upstream river stretches is already contained in the flow. The shading effect of vegetated buffer strips and its positive effect on water temperature is also more effective in smaller streams.

For being effective, riparian buffer strips should constitute a dominant feature along a river rather than having only few scattered spots in place. Narrow buffers are already effective measures for sediment trapping, more extensive buffers are better at transforming nutrients and pesticides. Recommendations for buffer trips vary widely in a range from 10 to 30 meters and more as listed in Table 4.

Table 4: Recommended widths of buffer/filter strips for vegetation, reptiles/amphibians, mammals, invertebrates, and fish (Fischer & Fischenich, 2000)

Authors	State	Width	Benefit
<b>Vegetation</b>			
Spackman and Hughes (1995)	Vermont	≥ 30m	Needed to capture >90% vascular plant species
Brososke et al. (1997)	Washington	≥ 45m	...buffers at least 45m wide on each of the stream are needed to maintain an unaltered microclimatic gradient near streams (but could extend up to 300m in other situations)
<b>Reptiles and Amphibians</b>			
Burbrink, Phillips, and Heske (1998)	Illinois	100-1000m	Wide (>1000m) areas of riparian habitat did not support greater numbers of species of reptiles and amphibians than narrow (<100m) areas.
Rudolph and Dickson (1990)	Texas	≥ 30m	“We recommend retaining streamside zones of mature trees at least 30 m wide and preferable wider when forest stands are harvested. Zones

			this wide will benefit amphibians, reptiles, and other vertebrates.”
Semlitsch (1998)	Eastern U.S.	≥ 165m	To maintain viable populations and communities of ambystomatid salamanders, attention must be directed to the terrestrial areas peripheral to all wetlands; maintaining the connection between wetlands and terrestrial habitats will be necessary to preserve the remaining biodiversity of our remaining wetlands.
Buhlmann (1998)	South Carolina	≥ 135m	Aquatic turtles (e.g., chicken turtle [ <i>Deirochelys reticularia</i> ]) may spend a greater proportion of a year in terrestrial habitat (e.g., buffer strips adjacent to wetlands) than in the wetland where they would have been predicted to occur.
<b>Mammals</b>			
Dickson (1989)	Texas	≥ 50m	The minimum of streamside management zones that will maintain gray squirrel ( <i>Scurus carolinensis</i> ) populations is about 50 m.
<b>Invertebrates</b>			
Erman, Newbold, and Roby (1977)	California	≥ 30m	Maintain background levels of benthic invertebrates in streams adjacent to logging activity
<b>Fish</b>			
Moring (1982)		≥ 30m	Increased sedimentation from logged, unbuffered stream banks clogged gravel streambeds and interfered with salmonid egg development. Buffer strips at least 30 m wide allow eggs develop normally.

Widths at the lower end of the possible spectrum protect the physical and chemical characteristics of water bodies from impact of human land use. Buffer sizes at the upper end are more suitable for maintaining ecological integrity. However, with little space available, a smaller setback can be a compromise. Minimum requirement throughout the published literature are vegetated riverbanks. Rather than ignoring temporal streams completely, a compromise would be to create a smaller setback. The recommendable filter strip width is also a function of the slope of the catchment. Table 5 gives estimates for effective filter widths and different slope classes.

Table 5: Recommend filter strip width as function of slope (modified from UMA, 2013)

Slope [%]	Filter strip width [ft / m]
0	50 / 15
10	90 / 27
20	130 / 40
30	170 / 52
40	210 / 64
50	250 / 76
60	290 / 88
70	330 / 101
80	370 / 113
90	410 / 125
100	450 / 137

Wider buffer strips allow for a more diverse planting of different plant species, e.g. grassland, shrubs and trees. Figure 53 shows an example of a buffer strip that starts with a stretch of grassland at the farmland side and different species of shrubs and trees. Table 6 gives an overview of different plant species categories and their efficiency regarding sediment trapping, filtration of sediment born nutrients, microbe and pesticides, filtration of soluble forms of nutrients and pesticides, flood conveyance, reduction of stream bank erosion. The overview shows, that grass has high to medium efficiency for almost all functions. Only for stream bank stabilization, shrubs and trees do outperform grassland due to deeper and more stable roots.



Figure 53: Example of a buffer strip (HMuKLV, 2014)

Table 6: Removal efficiency of different plant types (Hawes and Smith, 2005)

Function	Grass	Shrubs	Trees
Sediment trapping	High	Medium	Low
Filtration of Sediment born Nutrients, Microbe and Pesticides	High	Low	Low
Soluble forms of Nutrients and Pesticides	Medium	Low	Medium
Food Conveyance	High	Low	Low
Reduce Stream Bank Erosion	Medium	High	High

The topography of the Pont Prathoon River catchment has relatively steep slopes upstream of the planned reservoir but flat slopes downstream of the dam location. Thus, the farmland is almost completely located in the flat area of the catchment.

For the flat slopes within the project region (cf. Section 3.3) and the temporary nature of the water bodies (cf. Section 3.6) the following recommendations are given for the EbA measure “Riparian buffer strip/ filter strip:”

- Filter strip as wide as possible along the whole Pont Prathoon River.
- Reduction of minimum width to three meters of grassland on both riversides; where this is not possible, at least vegetated riverbanks should be enforced.
- Synergetic combination of the measure with the EbA measures “String of pearls” concept (cf. Section 5.2.2) and “Embankment stabilization” (cf. Section 5.2.3).

Figure 54 shows the location and extension of the proposed filter strip for the Pont Prathoon River.

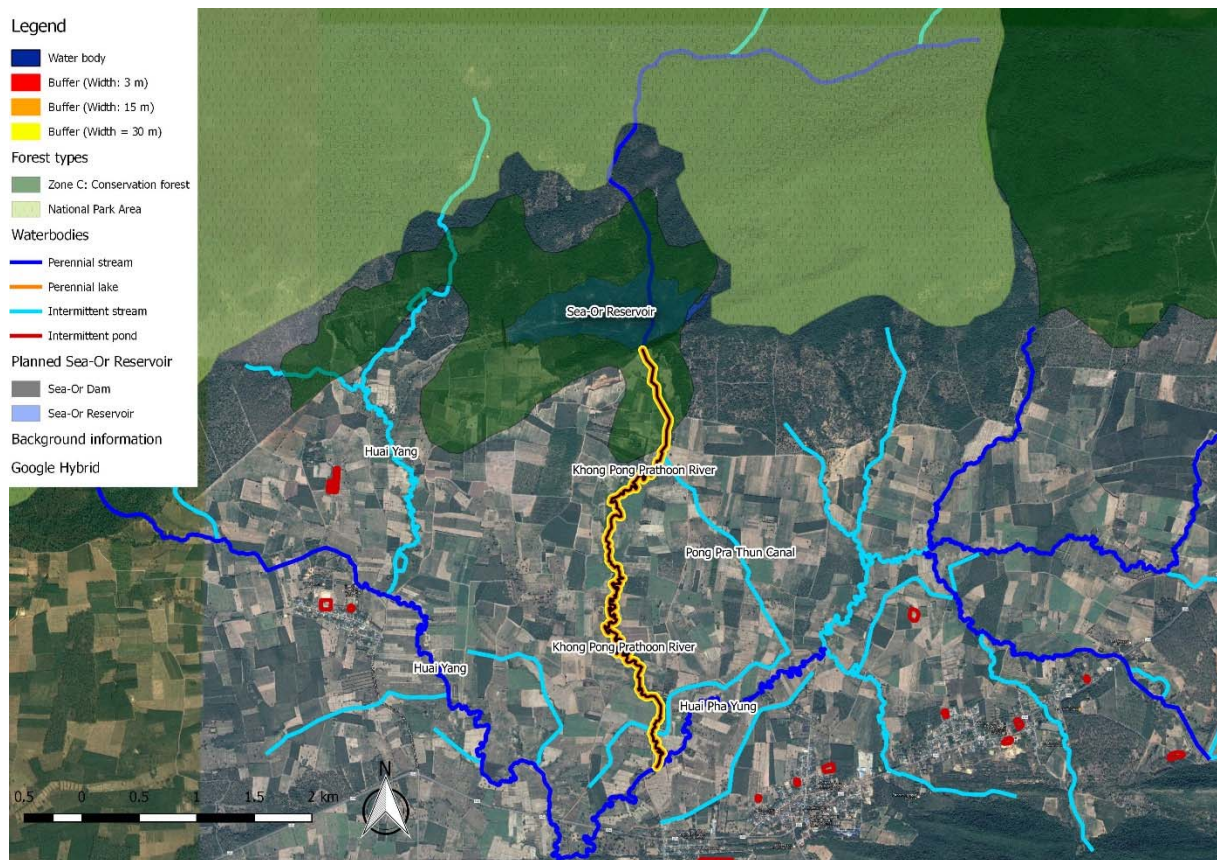


Figure 54: Overview of the EbA measure "Riparian buffer strip/ filter strip"

Aside from protection, the receiving water from agricultural impacts the riparian buffer strips/ filter strips will imply several direct co-benefits for the local farmers: The loss of soils (cf. Section 4.2) will be significantly improved. Thus, fertility of the farmland will be preserved and the need of fertilizers will be reduced. The riparian buffer strip will also provide habitats for different kind of parasite eaters that could potentially protect the farmland corps from parasite losses.

### 5.2.2 River rehabilitation with “String of Pearls” concept

As already outlined in the introduction to the proposed EbA concept (cf. Chapter 5) a complete rehabilitation or re-naturalization of the Pont Prathoon River is not a realistic option. The proposed EbA measure to restore a basic functionality of the river and its ecosystem serviced thus bases on the connection of so several rehabilitated areas (also called “pearls”) by stepping-stones suitable for different aquatic species groups.

The rehabilitated areas are stretches, where a full rehabilitation of the river, its embankment and adjacent areas is carried out. These areas will be connected by short so-called “stepping-stones” consisting of:

- Short sections with near-natural morphologic conditions
- Structural elements (roots, plants, deadwood)
- Possible integration with needed river bank stabilization (protection of arable land)

Figure 55 gives a schematic overview of the “String of pearls” concept. The blue marked areas are the rehabilitated areas (“Pearls”). The lighter marked areas are the non-rehabilitated areas in between. If these non-rehabilitated areas are too long (second light area), stepping-stones provide refuge habitats for aquatic animals so that they can reach the next river section with good morphologic status.



Figure 55: Schematic layout of the "String of pearls" concept with stepping-stones (LANUV, 2011)

It is important, that the “pearls” of the proposed rehabilitation concept be not too far away from each other. Figure 56 shows the proposed locations of the three pearls:

- The first pearl or source pearl will be located right below the dam structure of the Sea-Or reservoir. The status of the Pont Prathoon River at this location and further downstream is already quite good now (cf. Figure 51 and Figure 57). The length of the source pearl sets the maximal length of the river stretches in between the different “pearls”. Given the good status of the river in its current condition, it is crucial to maintain this status during the construction of the dam site and the reservoir to keep its ecological diversity. After the rehabilitation of the other “pearl” structures, further downstream, aquatic animals can repopulate these stretches using the stepping-stones in between.
- The second local for a rehabilitation area, see Figure 57 for a detailed view, is located at the second potential dam site examined in the IEE report by the RID. The location is relatively close to the source pearl, some meandering of the river is visible in its current state. Furthermore, within a questionnaire conducted by RID, local farmers expressed their willingness to give up farmland for the potential building of the reservoir. Thus, acceptance for given up farmland for the EbA measure of “river rehabilitation” in combination with irrigation water from the reservoir further upstream should be reachable.

- The third pearl was chosen at a location that, based on the available satellite data, already shows a diverse morphology (cf. Figure 57). Some cut-off former river branches are visible. Thus, the river rehabilitation will be possible with comparatively low effort.
- The last rehabilitation area is located at the confluence of the Pont Prathoon River with the following river (cf. Figure 57). Here, a floodplain and wetland construction is proposed, which will be an especially valuable “pearl”. Located at the end of the Pont Prathoon River, it will complete the river rehabilitation. Forming the contrasting pearl to the longer source pearl, aquatic life will also repopulate the Pont Prathoon River from this downstream area, using the two pearl measures and several stepping-stones in between.

Figure 58 shows a possible cross section of the rehabilitated pearls. In contrast to the degraded water bodies found within the catchment, the sketch shows a natural layout of a river cross section with varying morphology and areas with different flow regimes:

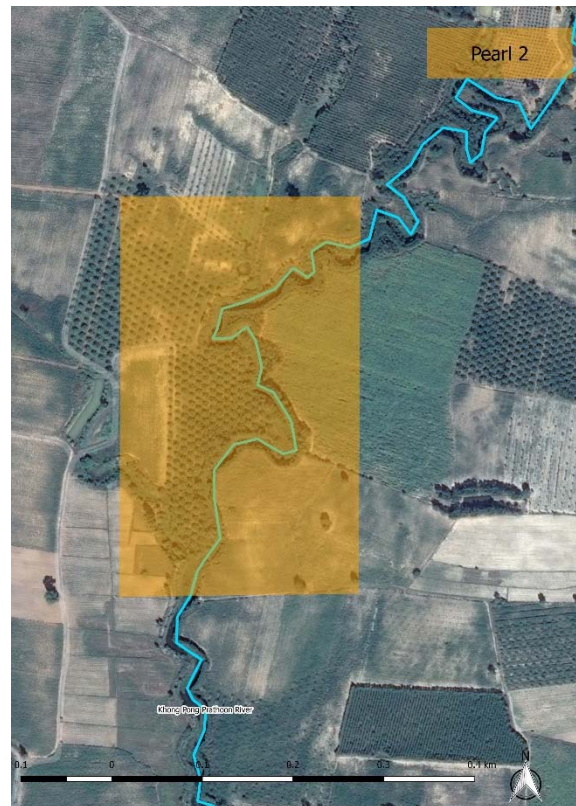
- In the middle of the cross section, the permanently submerged (during the season when the river contains flow) riverbed (1) is shown, that contains discharge at average water levels.
- This main riverbed is followed by lower terraces (2), characterized by very wet conditions, that form transition zones between the riverbed and the riverbanks.
- The riverbanks (3) are elevated terraces, but still frequently submerged by normally occurring flood events.
- The riparian zone (buffer strip) of the flood section (4) is only flooded during some events per year. Due to their permanent vegetation, these zones offer good conditions for effective water infiltration and slowing surface flow.
- The riparian zone is followed by the adjacent farmland that will be flooded only during extreme flood events.

Given the high degree of diversity of morphology, discharge conditions and plant species within the different sections of the cross sections, the rehabilitated areas will provide habitats for different aquatic species. The widened river cross section will lead to reduced flow velocities during peak events, the different plant and the corresponding hyporheic zones under the riverbed and the terraces are providing important refuge habitats for different aquatic species both during high discharge events and during low discharge events. The increased water infiltration in these areas will provide soil moisture conditions that can still sustain aquatic life during the drought conditions of the dry season.

The reduction of flow velocities, the increased water storage due to the widened cross section together with the increased groundwater infiltration is of particular importance for the Pont Prathoon River that is of temporary nature (cf. Section 3.6). The pearl structures will support the building of pools that still contain some water during the dry season and these pools will act as habitat refuge during drought periods. Both flora and fauna can remerge from these refuge habitats in the rain season, when the whole river stretch will contain discharge again.



Figure 56: Location of the rehabilitated areas of the "String of pearls" concept





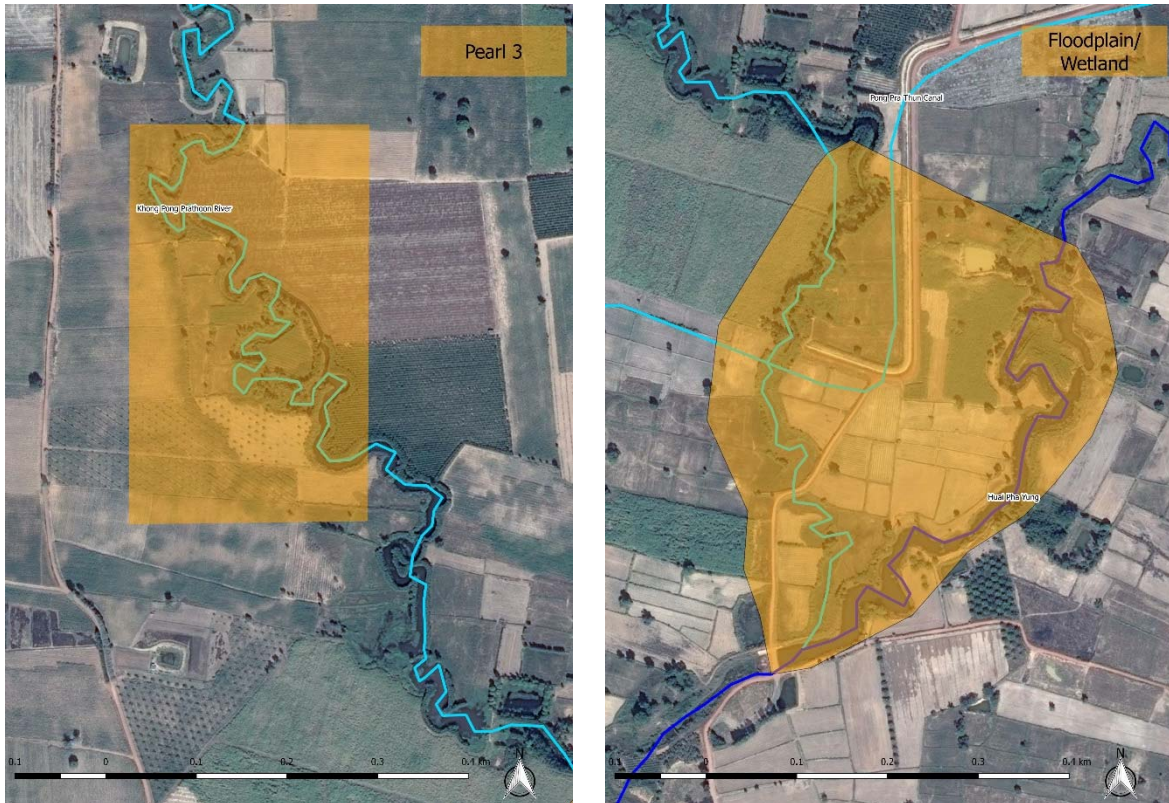


Figure 57: Detailed view of the four different rehabilitation areas

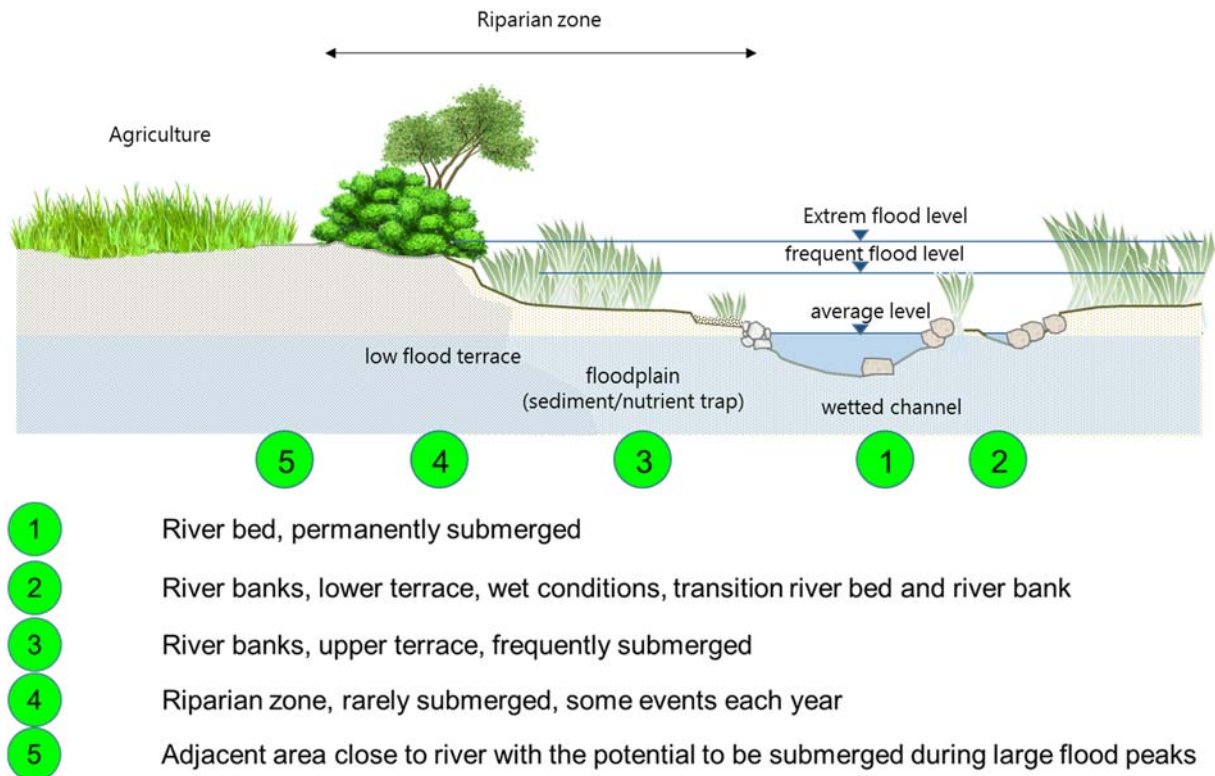


Figure 58: Schematic cross section of the rehabilitated river stretches

The construction process of the three rehabilitation areas is depending on the detailed assessment of their current status (Recommendation: Drone flights) as, in principle, two different methods of implementation can be distinguished:

- Direct shaping of the cross section and planting of appropriate plant species in the different zones of the cross section.
- Building initiating structures within the riverbed and let nature do its work.

The first method should be used, when the current cross-section and morphology is very uniform. Thus, the rehabilitation process will be accelerated. Furthermore, the desired target state of the rehabilitated areas can be defined a priori and constructed more or less exactly as intended (see for example a cross section in Figure 59). This is especially useful, if space is limited but several different zones within the cross section (different habitat for different species) are desired.

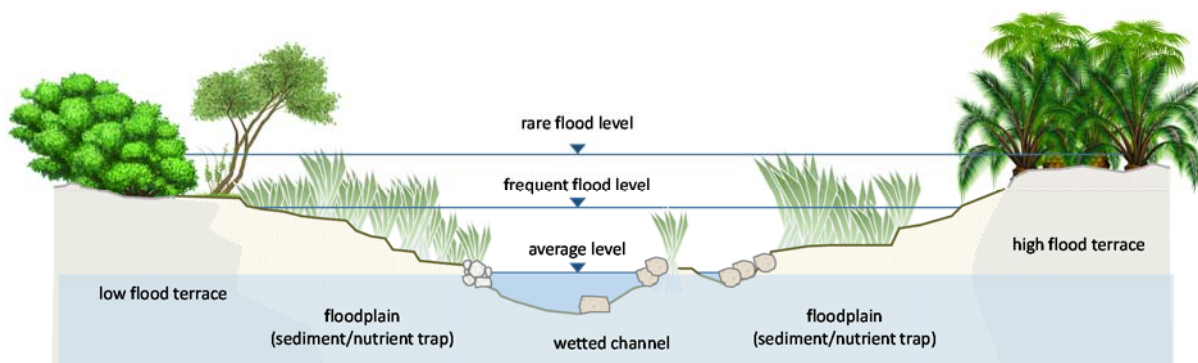


Figure 59: Predefined cross section for direct shaping of a rehabilitation stretch

The second method can be applied, if there is already some variety in the morphology of the respective river stretch. Initiating structures, e.g. dead wood and tree roots from the cutting process within the reservoir area, can be used to start a natural riverbed development. Naturally, this process will take more time. Figure 60 gives an example of the natural river development that will take place after initiating structures are applied. As with the direct construction, several different zones will build. However, in contrast to the direct building even more diverse cross sections and terrace structures will be the target state.

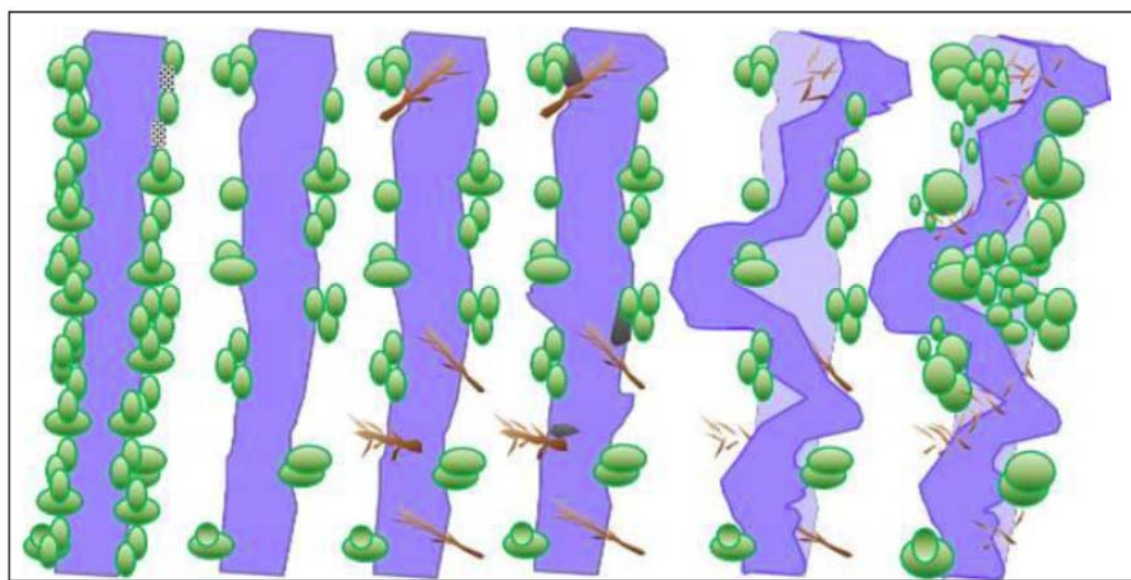


Figure 60: Development of a river rehabilitation area with initiating structures (Hugo 2012)

To protect the adjacent farmland from bank erosion and loss of farmland by uncontrolled river development, the second method can be accompanied by the construction of so-called sleeping

embankments. Figure 61 shows an example of a sleeping embankment structure. If the natural river development needs to be stopped at a certain river width, a sleeping embankment can be constructed. Once the natural development has reached the sleeping embankment, any further widening of the cross section is hindered by the stabilizations structures (plant, rocks) of the sleeping embankment. One major advantage of the sleeping embankment method is that the plants have one or several years to develop sufficient root depths and stability before the eroding force of flood pulses needs to be withstand.

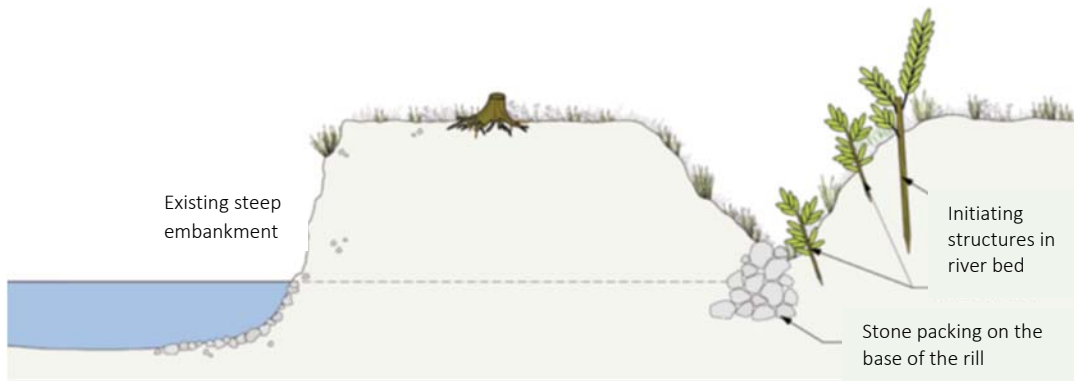
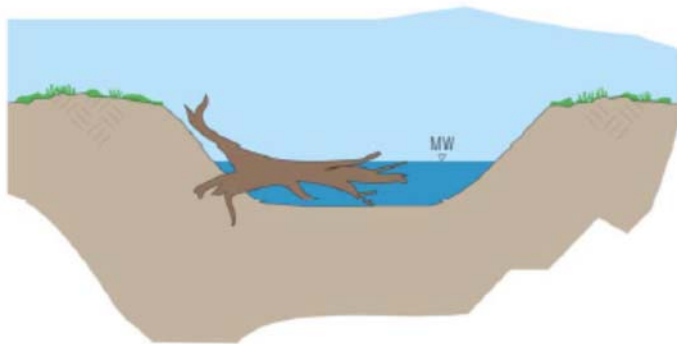


Figure 61: Sleeping embankment to protect adjacent farmland in river rehabilitation areas (modified from LUBW, 2013)

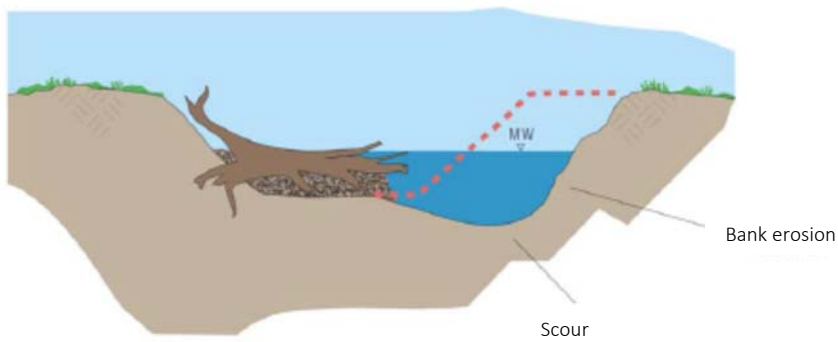
If the distance between two rehabilitated areas is too long to be overcome by aquatic life directly, so called “stepping-stones” need to be provided. Stepping-stones are local structures that provide areas of reduced flow velocities and mini-refuges for aquatic life in order to recover before moving further up- or downstream. Examples for the construction of stepping-stones are given in Figure 62 and Figure 63.

Cross section

Start:



Development:



Aerial view

Development:

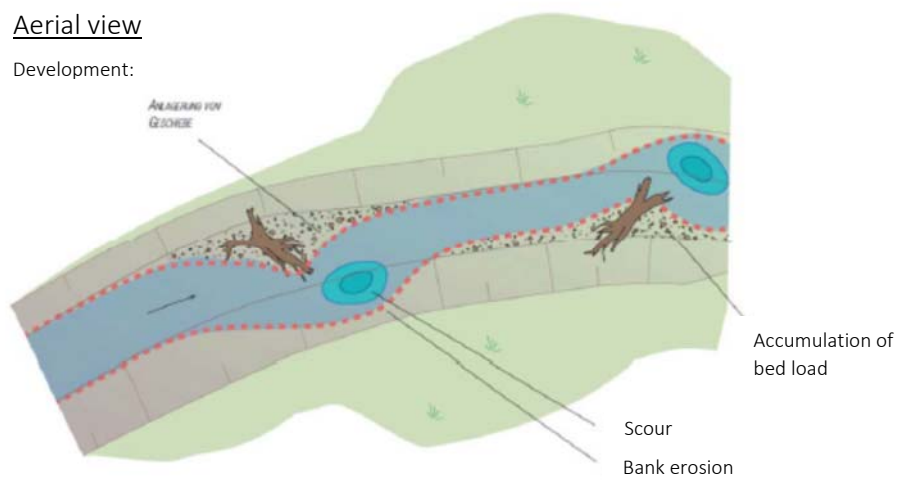
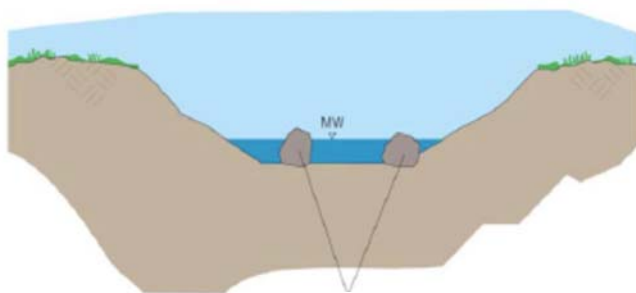


Figure 62: Wooden stepping-stones (LWRP, 2003)

Cross section

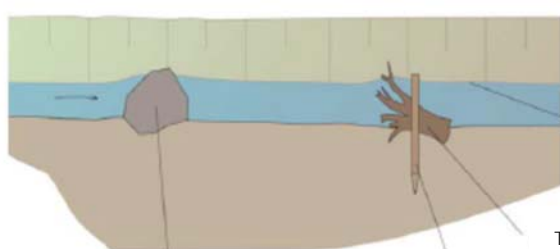
Method:



Stepping-stones

Longitudinal section

Method:



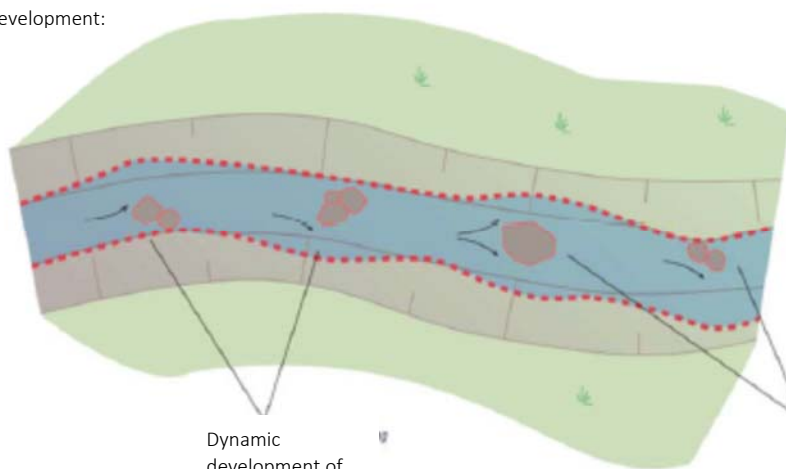
Area with reduced flow

Stepping-stone

Tree stump  
Securing by stakes

Cross section

Development:



Dynamic development of the riverbed

Area with reduced flow behind the stones

Figure 63: Stepping-stones (LWRP, 2003)

5.2.3 Embankment stabilization

To encourage the necessary acceptance and active participation of local stakeholders with the construction and maintenance of the proposed EbA measures for river rehabilitation an indirect co-benefit should be stressed. Especially the construction of the buffer strip (cf. Section 5.2.1) will contribute to stable river embankments. Situations as depicted in Figure 27, where fertile soils are eroded by the river or used for embankment stabilization will be reduced significantly. As shown in in Table 6, embankment stabilization is mainly achieved by shrubs and trees. Where only a small filter

strip of grassland will be possible due to space restriction, the planting of vetiver grass could be a solution for embankment stabilization. Figure 64 shows an example of embankment stabilization by stem sets.

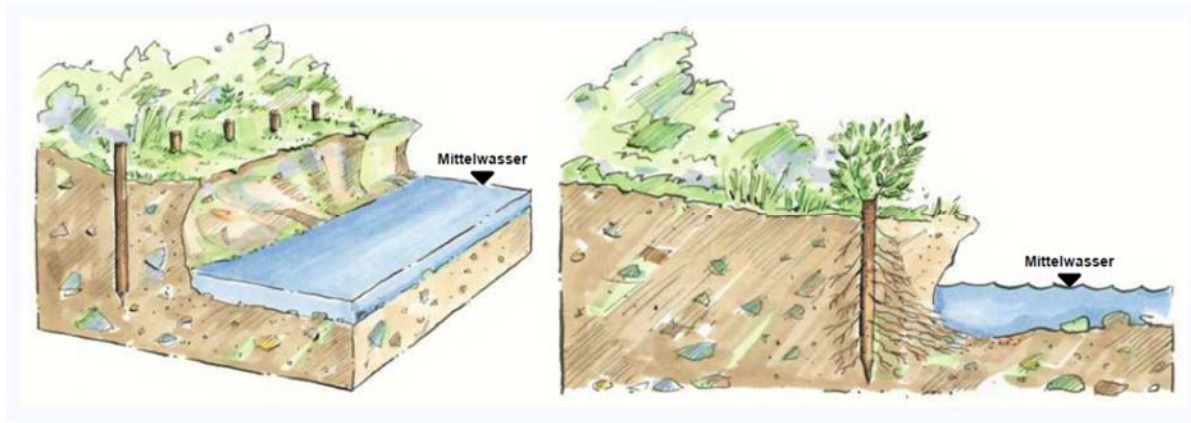


Figure 64: Embankment stabilization by stem sets (LUBW, 2013)

### 5.3 Floodplain/ Wetland construction

Floodplains and wetlands provide unique ecosystem services such as

- flood control,
- groundwater replenishment,
- shoreline stabilisation and storm protection,
- sediment and nutrient retention and export,
- water purification,
- reservoirs of biodiversity,
- wetland products (extensive agricultural use)
- cultural values,
- recreation and tourism,
- climate change mitigation and adaptation.

**Wetlands:** “According to the Convention on Wetlands (1971), a wetland is an area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters. It provides water retention, biodiversity enhancement or water quality improvement. Wetland restoration and management can involve: technical, spatially large-scale measures (including the installation of ditches for rewetting or the cutback of dykes to enable flooding); technical small-scale measures such as clearing trees; changes in land-use and agricultural measures, such as adapting cultivation practices in wetland areas. They can improve the hydrological regime of degraded wetlands and generally enhance habitat quality. Creating artificial or constructed wetlands in urban areas can also contribute to flood attenuation, water quality improvement and habitat and landscape enhancement.” (DWRM, 2015)

**Floodplains:** “A floodplain is the area bordering a river that naturally provides space for the retention of flood and rainwater. Floodplain soils are generally very fertile and they have often been dried-out to be used as agricultural land. 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. They have also been covered by legacy sediments. Major floodplains roles have thus been lost, due to land drainage,

intensive urbanization and river channelization. The objective is to restore them, their retention capacity and ecosystem functions, by reconnecting them to the river.” (DWRM, 2015)

Floodplains and wetlands develop automatically in plain landscape without human activities. They require flood pulses with raising and receding water levels occupying a certain space depending on the slope and characteristics of the terrain. In areas without regarding floodplains as valuable and no proper land use planning, floodplains are drained, utilized and occupied with settlements and infrastructure. Therefore, settlements and infrastructure are exposed and vulnerable to inundation, which in turn calls for flood protection and control.

Within the heavily modified water bodies of the Sea-Or catchment, natural floodplains and wetlands could not be identified. The straightening of river stretches, their conversion into canals, embankment with small dikes and the intensive agricultural use (cf. Section 4.3) have disconnected the water body from its surroundings, hindering any floodplain or wetland development.

The construction of floodplains and wetlands need several prerequisites. The riverbed needs to be widened to facilitate the creation of diverse river channels and a meandering process. Landscaping and river rehabilitation must ensure a connectivity of the floodplain or wetland with the main river. Regular flooding is crucial. Thus, flood paths need to be established ensuring sufficient overflows. Different flow paths enhance the diversity of flow regimes and provide opportunities for different water-related plant and the development of wetland areas. Agriculture is not necessarily banned from floodplains but require crops adapted to the specific hydrological conditions and an adjusted farmland management (i.e. extensive agriculture and no fertilizer or pesticide application).

Figure 65 gives a schematic view of a floodplain/wetland construction. The main river channel is diverted into two branches. Within the floodplain, further diversion of flow takes place. Two cross-sections are shown in Figure 66. Different terrace heights and ground structures ensure zones of different water levels, vegetation and micro-habitats.

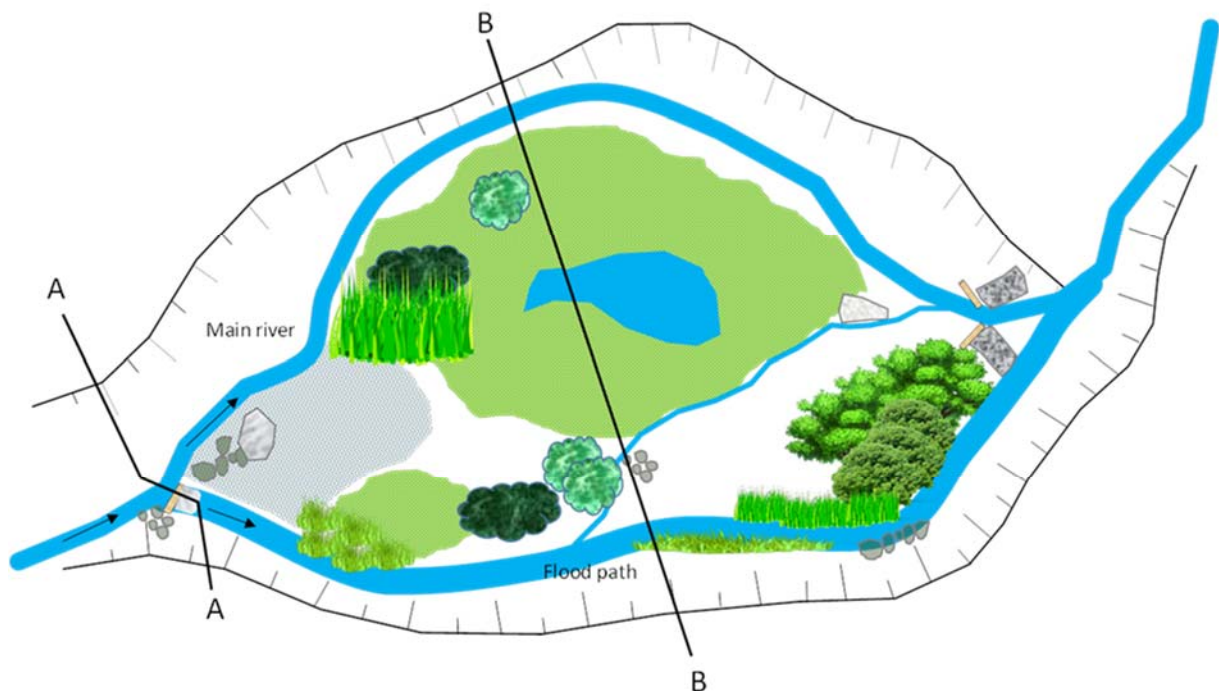


Figure 65: Schematic view of a constructed floodplain/wetland (Ariel view)

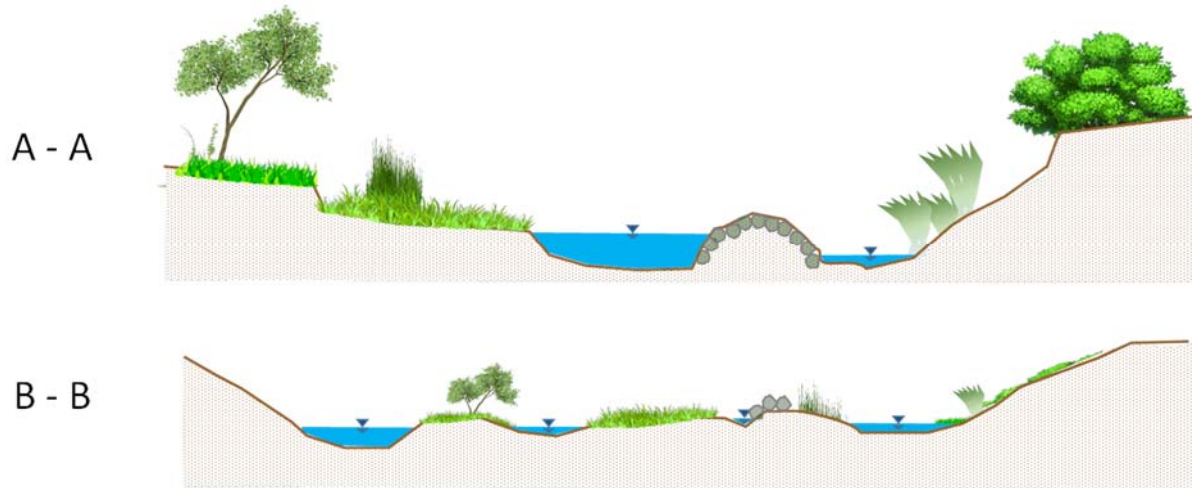


Figure 66: Schematic view of a constructed floodplain/wetland (Cross sections)

Figure 67 shows a real world example of a floodplain from Germany. Impressions of the floodplain are shown in Figure 68. During flood events, water is diverted from two river branches into the floodplain and on old river section is reactivated during such events. Control structures at the inlet and outlet of the floodplain allow for a detailed management of flow volumes and water levels within the area. An adjusted landscaping leads to different flooding intervals for different areas of the floodplain:

- Zone 1 is a nature conservation area and regularly flooded. Any human use is prohibited within this area.
- Zone 2 is an area that is less regularly flooded than Zone 1. However, flood events and respective water levels will still reach this zone regularly. Part of the area is used for conservation purposes. In other parts, extensive agriculture is allowed.
- Zone 3 is flooded seldom. Extensive agricultural use is allowed within the whole Zone-3 area. However, fertilizer and pesticides are strictly forbidden in this zone as well.

If farmers experience heavy loss of earnings due to frequent crop destruction by flood events, downstream beneficiaries that are protected from floods by means of the floodplain provide compensation payments (cf. Chapter 1).



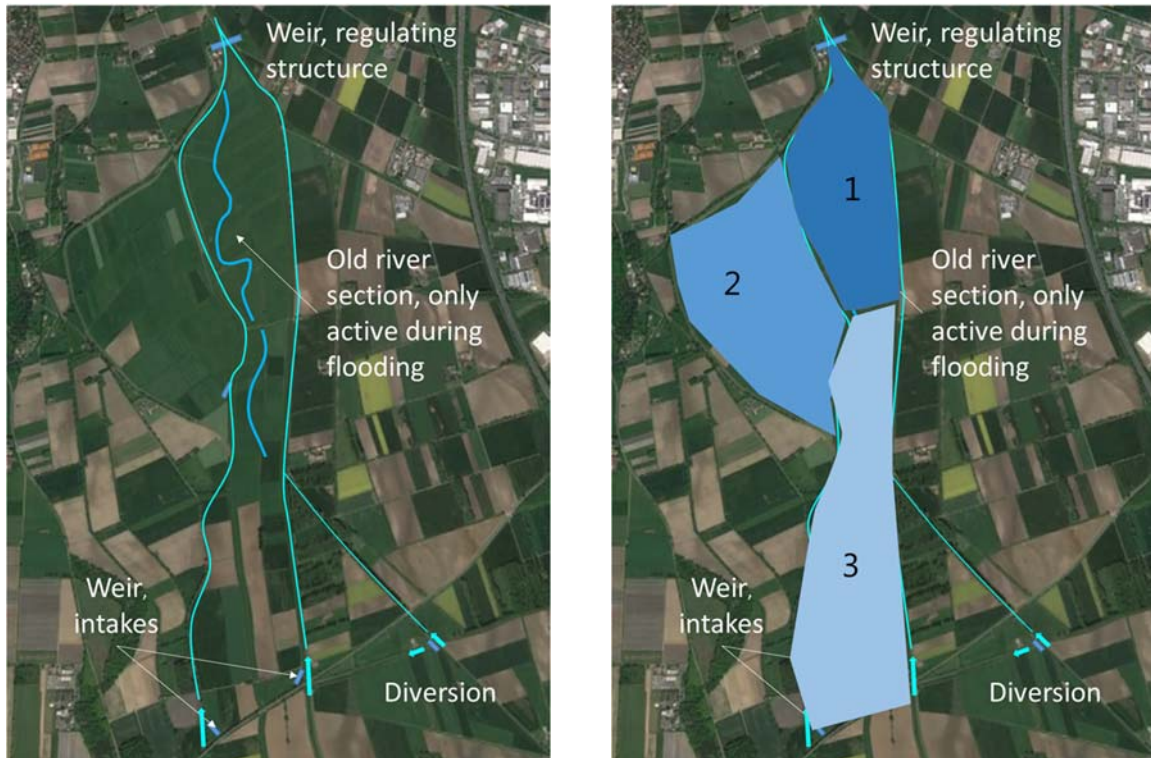


Figure 67: Floodplain example (Germany)



Figure 68: Floodplain example (Germany) - Photos

The proposed location for the floodplain and wetland construction has already been shown in Figure 56, as the floodplain/wetland will act as one of the rehabilitated areas within the “String of pearls” concept (cf. Section 0). The location was identified based on satellite images of the catchment. At the confluence of the Pont Prathon River with the Huai Pha Yung River, see Figure 69.

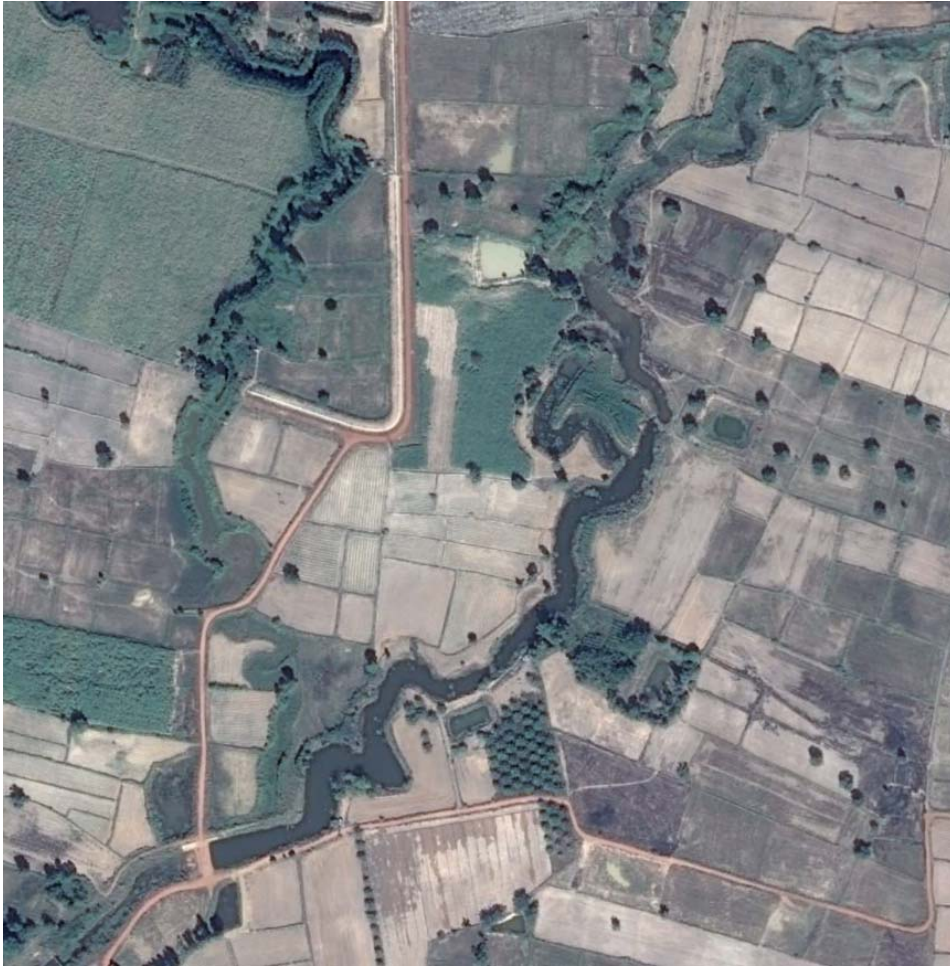


Figure 69: Proposed location of the floodplain

The proposed location was chosen based on several reasons:

- It is located at the end of the Pont Prathon River. The “Source pearl” that will be located directly downstream of the Sea-Or Reservoirs dam structure will provide important habitat structures at the upstream reach of the Pont Prathon River. The floodplain/wetland will provide respective habitats at the downstream end of the river.
- The floodplain/wetland will store water released by the reservoir.
- The water quality of the Pont Prathon Rivers outflow will be enhanced by the purification functions provided by the floodplain/wetland. This is of special importance, as a small intermittent lake and an area of “Water Source Conservation of Huai Yang Canal” can be found downstream of the confluence.
- An existing weir structure within the Huai Yang Canal can be used. Currently, the weir structure (see Figure 33) is not equipped with any control structures, blocking flood pulses and migration routes totally. With its integration into the floodplain/wetland, control structures and bypass modules could be implemented (see Section 5.4.3 for details).
- Both the Pont Prathon River and the Huai Yang Canal show basic variety in morphology and cross section in their current state, providing a good starting point for the construction of a floodplain/wetland.

- Located at the confluence of the Pont Prathhon River with the Huai Yang Canal, the floodplain/wetland will receive discharge and flood pulses from both tributaries. Possible water shortages in one inflow can be potentially compensated by the other inflow.

A preliminary design of the proposed floodplain/wetland is shown in Figure 70. The EbA measure will stretch from the confluence of the two rivers to a cross section further upstream, where the distance between the two rivers is short. At the upstream end of the floodplain/wetland, a vegetated buffer consisting of shrubs and trees will build a barrier to the adjacent farmland. Several structures will divert flow from the main river channels into the floodplain at certain water levels. With the floodplain/wetland, different surface heights will be shaped, leading to the formation of several flow channels and temporarily flooded pools. Roughly, one third of the floodplain/wetland area is intended for a restricted area, where human activity is forbidden. Within the remaining area of the measure, extensive agriculture will be allowed, which will potentially greatly benefit from the increased soil moisture due to the water storage and infiltration function of the measure. If necessary, embankments will be created. Several piezometers and a water gauge level with automatic readings will be used to monitor soil moisture, groundwater infiltration and flow regime.

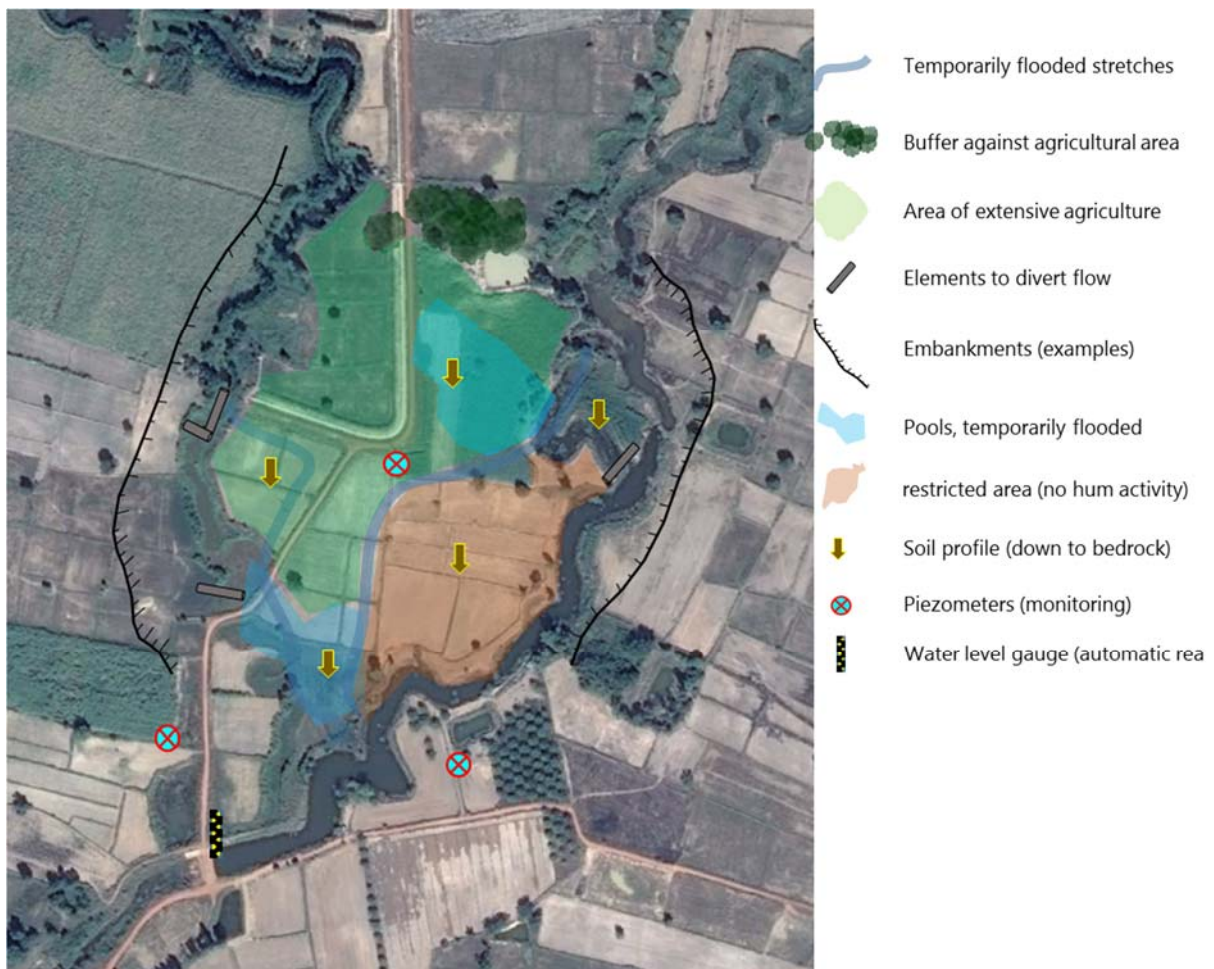


Figure 70: Preliminary design of the proposed floodplain/wetland

The preliminary concept of landscaped elements needs verification and further adaptation by means of

- Digital Elevation Model (DEM)
- High Resolution Images (HighRes Images)
- Water level duration curve
- Contour map of groundwater table

- Plant inventory
- In situ soils

For the final design of the floodplain/wetland measure, the following steps are suggested:

1. Installation of water level gauge
2. Drone flight for DEM and HighRes-Images
3. Soil profile sampling
4. Calculations
  - Release rules from dam 1 must be determined prior to any calculation
  - Infiltration and groundwater recharge
  - Evaporation
5. Landscaping
  - Relocation of road outside floodplain
  - Backwater calculation
  - Zoning plan
  - Embankments
6. Installation of piezometers

#### 5.4 Integrated management and accompanying measures

Aside from the EbA measures described in detail, the concept should be accompanied by several other measures to ensure its overall function and long-term sustainability.

The temporary Pont Prathhon River and especially the rehabilitated river stretches and the floodplain/wetland hey require rather natural flow regimes with flood pulses (raising and receding water levels, high flow and low flow periods, different flow velocities, different gradients of flow regime change, etc.). Thus, the outflow of the planned Sea-Or Reservoir needs to provide environmental flows for the Pont Prathhon River (see Section 5.4.1).

Given the strong interaction of the different land uses in the catchment, an integrated water resources management should be implemented. Section 5.4.2 outlines basic principles of an integrated water resources management for the Sea-Or region.

Several weirs are currently blocking flow and migration routes of aquatic life. Even though most of them are equipped with control structures, the field trip showed, that the control structures not used regularly. Bypass solutions for aquatic life are missing. Section 5.4.3 outlines basic ideas about the enhancement of weirs to ensure biological consistency.

Section 4.2 outlined the major impact of current agricultural practices on erosion and affecting river morphology and water quality. Major EbA measures to counteract the farmland impact on receiving water quality have been outlined in Section 5.2.1 (Buffer/filter strip) and Section 0 (Rehabilitated river stretches). Further possible EbA measures to reduce the impacts of agriculture on the ecosystem within the Sea-Or region are given in Section 5.4.4.

##### 5.4.1 Environmental flows

Environmental flows are not natural flows but water left in river ecosystem to maintain healthy ecosystems. Environmental flows can be defined as “Quantity, timing, and quality of water levels required to sustain freshwater ecosystems and the human livelihoods and well-being that depend on these ecosystems.” (Le Quesne et al. 2010). It is important to take downstream ecosystems, such as the planned floodplain/wetland, the small intermittent lake and the “Water Source Conservation of Huai Yang Canal” area into account. During the rainy season, this is probably easy to achieve, as there

will be enough water available. However, the provision of environmental flows will be of particular concern at the beginning and end of the rain season and during the dry season. Especially the discharge stemming from precipitation events with low intensity during the dry season should not be totally stored within the reservoir. A sufficient amount of the discharge should be drained into the river to provide water for the aquatic life in the rehabilitated river stretches and the floodplain/wetland.

The provision of environmental flows needs an assessment of the per-reservoir flow regimes. This should be conducted by the determination of the Indicators of Hydrologic Alteration (IHA), see The Nature Conservancy (2009) for details. Daily flow values are analyzed for 33 different parameters to gain information about five subgroups of flow characteristics:

- Magnitude of monthly water conditions
- Magnitude and duration of annual extreme water conditions
- Timing of annual extreme water conditions
- Frequency and duration of high and low pulses
- Rate and frequency of water condition changes

The reservoir operation rules for the Sea-Or Reservoir should be developed in a way that the Indicators of Hydrologic Alteration change as less as possible and that specific flow regimes in the river body can be provided at certain times to sustain different aquatic life (i.e. reproduction periods). Thus, operating structures to control reservoir outflow, e.g. sluice gates, low-pressure outlets, vales, need to be implemented into the design. Given that the main purpose of the reservoir is water storage for irrigation purposes, this requirement calls for the optimization of multi-purpose reservoir rules.

#### 5.4.2 Integrated water resources management

An Integrated water resources management, often also called River basin management plan (RBMP) should address the following topic (EC, 2012):

- It needs to include quantitative data on water demand and availability including better forecasting of water availability and consumption. Data should also be transparent, revealing uncertainties, time spans, and sources. In drought-prone areas, drought uncertainties and variations (e.g. of the water availability) should be considered in the RBMP's baseline and not be interpreted as unexpected natural climate extremes.
- Widening the scope of current economic instruments is necessary to ensure that they provide incentives for sustainable water abstraction and use. Where there are currently no tariffs, they need to be put in place; consumption based water tariffs need to be promoted; the role of abstraction charges and taxes needs to be expanded so that the environmental and resource costs are internalised into the water users decisions.
- Ensuring that new economic development is coherent with the water availability is the basis for long-term sustainability, and specific attention on land use is required. This re-emphasises the need for proper integration between RBMPs and other economic and physical planning processes.

Most of the weirs within the Sea-Or region are equipped with gates, so that an environmental operation (e.g. environmental flows) could in principle be possible.

Aside from the reported prolonged dry season and respective water shortages during the last three years reported by local stakeholders, the actual water demand within the catchment was not transparently comprehensible by means of the available data. A reliable estimation of current and future water demand should be the basis for all further planning efforts.

Furthermore, it seems that the water use is currently not managed at all. During the field trip conducted, several locations could be found, where farmers pumped water from small depletions in the riverbed, storage areas behind the weirs (Figure 71), or small man-made ponds next to the river stretch (Figure 72) onto adjacent agricultural areas.

At present, farmers are used to apply rain-fed agriculture, which leads to water supply problems during the dry season. Given the high proportion of farmland on total land use, it should be evaluated, if the water demand of current agricultural practice can be supplied in a sustainable way under future climate boundary conditions. With a new reservoir, there is a big incentive to switch from rain-fed agriculture to irrigation water provided by the reservoir. This could lead to inefficient irrigation practices if no training for local stakeholders is provided. Exploiting more and more water resources only directs to consume more water without questioning efficiency. Anyhow, given that agriculture is the major source of income, a successful transition to a sustainable and coordinated land use and water resources management should and cannot be made against the local stakeholders (cf. Chapter 2).

The planning of a reservoir within a Zone-C forest area close to the Pang Sidas National Park involves, aside from the local stakeholders, different regulative authorities of Thailand:

- Royal Irrigation Department (Reservoir and irrigation planning)
- Royal Initiative Project Bureau (Weirs along the river and planned Sea-Or Reservoir)
- Royal Forest Department (Forest Zone C Protection and Management)
- Department of National Parks, Wildlife and Plant Conservation (National Parks)
- Office of Natural Resources and Environmental Policy and Planning (Overall environmental policies)
- Department of Agriculture (Crop and fertilizer regulations, Food production, Incentives)

The planning process seems to be not well coordinated between the different authorities. One indicator of the necessity to a more jointly project planning and handling is the fact, that the Royal Forest Department and the Office of Natural Resources and Environmental Policy and Planning are opposing the status quo of RID's planning. Another indicator is the uncoordinated building of concrete weirs build by the Royal Initiative Project Bureau. The weirs are disrupting the rivers and are not part of an overall water resources management strategy including the planned reservoir and irrigation system.



Figure 71: Unmanaged water extraction by a farmer from a pond behind weir



Figure 72: Small water storage pond next to the river

#### 5.4.3 Biological consistency of longitudinal barriers

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. (NWRM, 2015)

The existing small and concrete weirs within the receiving water bodies of the Sea-Or catchment serve the important function of water storage. Therefore, a total removal is contradictory to the overall aim of increased water storage possibilities. Rather, to ensure biological consistency bypass solutions

should be implemented: The natural flow regime should be undisturbed during low and normal flow conditions and water would only be stored in the backwater area of the weirs when a certain amount of discharge is exceeded (water storage in parallel connection).

#### 5.4.4 Agricultural EbA measures

Aside from the implementation of buffer strips between farmland and water bodies as outlined in Section 5.2.1 two other EbA measures for the agricultural sector can be suitable for both agriculture itself and to reduce the impacts of agriculture on the catchments ecosystems:

- **Green cover** (including cover crops or catch crops) “refers to crops planted usually on arable land, to protect the soil, which would otherwise lie bare against wind and water erosion. Green cover crops also improve the structure of the soil, diversify the cropping system, and mitigate the loss of soluble nutrients” (NWRM, 2015)
- **Intercropping** “is the practice of growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade. Numerous types of intercropping, all of which vary the temporal and spatial mixture to some degree, have been identified: mixed intercropping, row cropping, relay cropping, etc.” (NWRM, 2015). As crops cover more soil, intercropping also has high benefits regarding reduction of soil erosion and sediment delivery.

## 5.5 Conclusion

Figure 73 gives an overview of the integrated concept of the Sea-Or Reservoir and EbA measures outlined in the Sections 5.1 to 5.3.

The Sea-Or Reservoir will address the water shortage during the dry season reported by the local stakeholders. Location, size and design of the reservoir as planned by the RID was taken as set within the scope of this project.

The EbA measures suggested address the major challenges for ecosystems as identified in Chapter 4 in an integrated and coordinated manner.

The protection of the natural headwater forest by the implementation of a graded forest as buffer between the forest and farmland will supply the Pont Prathhon River with a natural flow regime. The long river rehabilitation stretch downstream of the proposed Sea-Or Reservoir will serve as important habitat for different plant animal species. At the downstream reach of the Khong Pong Prathoon River, the floodplain/wetland construction has similar functions, providing even more diverse flow regimes and habitats. Movement of aquatic life will within the longitudinal direction of the water body will be fostered by the two rehabilitated river stretches (Pearl 2, Pearl 3) and the stepping-stones in between. The riparian buffer strip/filter strip, minimizing the impacts of the adjacent farmlands on the receiving water body, will counteract a degradation of the rivers water quality.



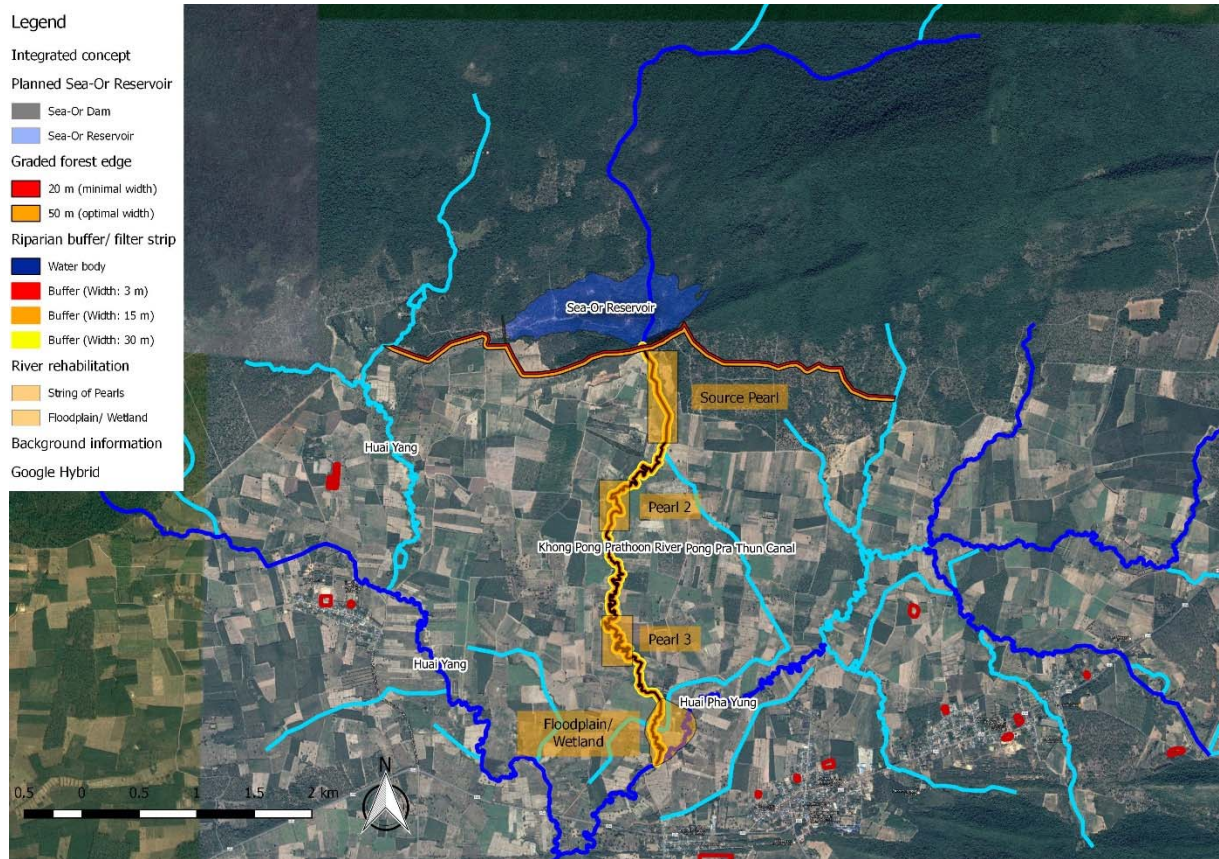


Figure 73: Integrated concept of the Sea-Or Reservoir and EbA measures

All proposed EbA measures are located within or at the border of the planned irrigated area (cf. Figure 6). In contrast to the transfer of benefits from upstream areas to downstream areas and potential compensations vice versa as depicted in Figure 4, the local stakeholders in the Sea-Or catchment are benefitting both from the reservoir and the co-benefits EbA measures directly. Figure 74 illustrates that both the EbA measure implementation itself and the benefits of the EbA measures are directly situated within the catchment of the Pont Prathoon River catchment. Naturally, downstream areas will benefit from the implementation of the proposed EbA concept, too. Aside from the direct co-benefits of the EbA measures, a proper implementation and maintenance of the proposed EbA concept will also ensure that the local stakeholders will have functioning ecosystems and their services available in the future, even if climate change should further increase and reduce the water availability within the catchment.

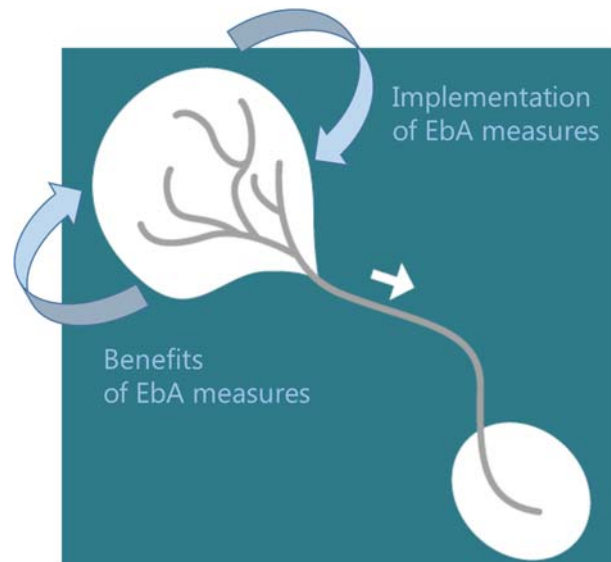


Figure 74: Benefits of the proposed EbA measures (modified from UNDP, 2003)

## 6 SCENARIO ANALYSIS

In Chapter 2 it was outlined, that EbA measures could be applied as standalone measures or supplementing traditional grey infrastructure measures. The integrated concept for the Sae-Or catchment as summarized in Section 5.5 consists of a combination of the grey infrastructure measure of the Sea-Or Reservoir and appropriate EbA measures.

In principal, the Sea-Or Reservoir and the EbA measures proposed in Chapter 5 could be implemented separately. Four different implementation scenarios can be distinguished:

1. **Baseline scenario**
  - No reservoir
  - No irrigation system
  - No EbA measures
2. **Reservoir, Irrigation system**
  - Sea-Or Reservoir
  - Irrigation system
  - No EbA measures
3. **EbA measures**
  - No reservoir
  - No irrigation system
  - EbA measures
4. **Reservoir, Irrigation system, EbA measures**
  - Sea-Or Reservoir
  - Irrigations system
  - EbA measures

The “Baseline scenario” represents the current status of the catchment, if nothing is done. The scenario “Reservoir, Irrigation system, EbA measures” refers to the proposed concept of this study. Possible implementation scenarios in between are “Reservoir, Irrigation system”, where the classical grey measures would not be accompanied by EbA measures for maintain the catchments ecosystems, and the scenario “EbA measures”, where no reservoir and irrigation system would be build and the reported problem of water shortage would not be addressed.

For the four different scenarios, the potential development of the catchment in the future can be estimated:

### 1. Baseline scenario

Water shortage during the dry season will lead to reduced crop yields from the farmland areas of the catchment. As agriculture is the major income source for the local stakeholders, their livelihood will be threatened. The degraded ecosystems within the catchment will not be improved. Rather, a further degradation seems possible, as farmers will probably continue to log tress within the Zone-C forest in order to gain more farmland or as alternative income source. Possibly, the use of fertilizer and pesticides will be increased to gain as much crop yield as possible in periods with enough water (rainy season). Erosion will remain at high levels, impacting the receiving water bodies and contribute to the loss of fertile soils. Thus, the status of the receiving water bodies and soil fecundity will further degrade.

The scenario could be described as **lose-lose scenario**, both for the local stakeholder and for the ecosystems of the Sea-Or catchment.

## 2. Reservoir, Irrigation system

The water shortage during the dry season reported by the local stakeholders will be mitigated by the construction of the Sea-Or Reservoir and the corresponding irrigation systems (cf. Figure 6). Thus, as irrigation water will be available in the dry season, increased crop yields can be assumed. The livelihood of local farmers will be improved. The increased availability of water could be an incentive for the cultivation of more water demanding crops and for a waste of water. As no EbA measures will be implemented, the ecosystems of the Sea-Or catchment will further degrade. Given the already quite degraded current status, a tipping point might be reached in the future, where the ecosystems of the catchment may collapse.

The scenario could be described as **win-lose scenario**: local farmers are (at least temporarily) winning, the catchments ecosystems are losing.

## 3. EbA measures

Within this scenario, the focus is only on enhancing the degraded ecosystems of the Sea-or catchment. The degradation of the ecosystems will be stopped and their status will be significantly improved. However, the water shortage for agricultural purposes during the dry season will not be mitigated. As agriculture is the major income source within the region, people's livelihood will be threatened. The acceptance of this scenario by the local stakeholders seems unlikely. The implemented EbA measures will probably not be maintained by the local stakeholders. Without proper maintenance, the implemented EbA measures will probably lose their effects over time. In the long run, a degrading of the catchments ecosystems needs to be assumed.

The scenario could be described as a **lose-win scenario**: the catchments ecosystems are (temporarily) winning, the local stakeholders are losing.

## 4. Reservoir, Irrigation system, EbA measures

The water shortage during the dry season reported by the local stakeholders will be mitigated by the construction of the Sea-Or Reservoir and the corresponding irrigation systems (cf. Figure 6). Thus, as irrigation water will be available in the dry season, increased crop yields can be assumed. The livelihood of local farmers will be improved. Aside from irrigation water, the reservoir will also need to provide water for environmental flows and the floodplain/wetland. Thus, a strong incentive for a spare use of irrigation water will exist, counteracting the potential of wasting water and cultivating more water demanding crops. The degradation of the catchments ecosystems will be stopped. The acceptance of the EbA measures by local stakeholders is assumed to be high, especially as the EbA measures do have direct co-benefits for the farmers. Thus, it is likely, that local stakeholder will take ownership of both the reservoir and the EbA measures, ensuring a proper maintenance of the EbA measures. In the long run, a significant improvement of the catchments ecosystems is likely.

The scenario could be described as win-win scenario as both the local stakeholders and the environment will benefit from the combined implementation of grey and EbA measures.

Given the results of the scenario analysis, the combined implementation of the Sea-Or Reservoir with its irrigation systems and the proposed EbA concept seems to be most promising to improve both the likelihood of local stakeholders and the status of their natural environment.

## 7 SUMMARY

Thailand is affected by climate change (cf. Chapter 2): Local stakeholders within the Sea-Or region reported increased water shortage problems for agricultural purposes during the yearly dry season. Thus, the Royal Irrigation Department (RID) conducted the planning of a reservoir and irrigation system (cf. Chapter 3). Several major challenges for the Sea-Or catchment could be identified (cf. Chapter 4):

- Water shortage for irrigation purposes during the dry season, threatening the livelihood of local farms.
- Loss of natural forest both due to farmland intruding into the forest area and the planned reservoir.
- Very high proportion of farmland use within the catchment.
- Heavy erosion, resulting in loss of fertile soils and affecting receiving water bodies.
- Heavily degraded water bodies.

To counteract these challenges, a concept for Ecosystem based Adaption measures was developed (cf. Chapter 2 and Chapter 5), consisting of

- Forest edge development,
- River rehabilitation,
- Floodplain/Wetland construction,
- Integrated water management and accompanying measures.

The EbA measures proposed constitute measures as compensation and accompany the planned water infrastructure (Sea-Or Reservoir and irrigation system). The measures are in line with the mitigation measures from IEE report but more comprehensive and with a stronger focus on ecosystem restoration.

Based on a scenario analysis (cf. Chapter 6), a combination of grey measures (Sea-Or Reservoir and Irrigation system) and EbA measures could be identified as most promising to improve both the likelihood of local stakeholders and the status of their natural environment in the long run.

The proposed EbA concept focusses on the Khong Pong Prathoon River and its catchment as it will be most affected by the planned reservoir. Furthermore, the benefits of increased volumes of irrigation water provided by the reservoir and the irrigation system will be mainly with the catchment of the Khong Pong Prathoon River, which makes the acceptance of the EbA measures by the local stakeholders very likely.

However, the EbA measures described in Chapter 5 are easily transferable to other catchment within the region facing similar challenges.

## 8 REFERENCES

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