

# The Effectiveness of Oxbow Lake Restoration as a Flood Reduction Nature-Based Solution (NbS) in the Kapuas River Basin, Indonesia

**Henny Herawati**

Department of Civil Engineering, Tanjungpura University, Pontianak, Indonesia  
hennyherawati@civil.untan.ac.id (corresponding author)

**Aji Ali Akbar**

Department of Environmental Engineering, Tanjungpura University, Pontianak, Indonesia  
Aji.ali.akbar.2011@gmail.com

**Eko Yulianto**

Department of Civil Engineering, Tanjungpura University, Pontianak, Indonesia  
ekoyulianto@civil.untan.ac.id

**Jajat Sudrajat**

Department of Agriculture Social Economic, Tanjungpura University, Pontianak, Indonesia  
jajat.sudrajat@faperta.untan.ac.id

**Budi Utomo**

Department of Urban and Regional Planning, Tanjungpura University, Pontianak, Indonesia  
utomobudi0205@teknik.untan.ac.id

**Yus Sholva**

Department of Informatics, Tanjungpura University, Pontianak, Indonesia  
sholvariza@untan.ac.id

**Entin Hidayah**

Department of Civil Engineering, Jember University, Jember, Indonesia  
entin.teknik@unej.ac.id

**Azmeri**

Department of Civil Engineering, Syiah Kuala University, Indonesia  
azmeri@usk.ac.id

**Juliastuti**

Department of Civil Engineering, Bina Nusantara University, Jakarta, Indonesia  
juliastuti@binus.ac.id

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**ABSTRACT**

The frequency and severity of flooding in the Kapuas River Basin are increasing. One possible mitigation strategy is utilizing oxbow lakes as natural retention ponds, but sedimentation has reduced their storage capacity. Oxbow lake restoration is a part of Nature-based Solutions (NbS), aimed at restoring the natural

functions of the floodplain ecosystem to reduce water runoff and create water reserves during dry seasons. This study offers a novel evaluation of oxbow lake restoration within a tropical floodplain system and provides a quantitative NbS assessment through integrated hydrological–hydraulic modeling. Hydrological modeling was performed using rainfall and field observation data to generate design rainfall and runoff. Hydraulic modeling was carried out with HEC-RAS 2D, utilizing terrain developed from a Digital Elevation Model (DEM) to simulate changes in storage capacity before and after restoration. The results demonstrate that reconnecting oxbow lakes to the main channel can reduce flood peaks by 12–18% and lower adjacent flood levels by up to 30 centimeters. The storage capacity of the Sinau, Jaras, and Selanyut oxbow lakes grew by 25–40% following dredging. Overall, incorporating NbS into river basin management offers an effective and sustainable way to reduce flood risk in the Kapuas River Basin. The findings provide valuable guidance for enhancing ecosystem-based flood resilience in this and other tropical regions.

**Keywords**–Oxbow lake; restoration; Nature-based Solutions (NbS); flood; flood mitigation; Kapuas River Basin

## I. INTRODUCTION

The Kapuas River, which is 1,143 km long, serves as a significant potential source of clean water for the community in West Kalimantan Province [1]. The Kapuas River Basin covers approximately 9.7 million hectares, with dominant land uses including peat swamp forest (34%), oil palm plantations (27%), and mixed agriculture (21%). The climate in this region is humid tropical, with an average annual rainfall of 3,500 mm and a bimodal pattern that peaks in March–April and October–November. Kapuas Hulu Regency is one of the regencies in the Upper Kapuas River area, and much of this region is designated as a conservation zone [2]. Rapid land-use changes in the Upper Kapuas River region have increased both the intensity and capacity of flooding [1]. This situation is further worsened by erosion caused by community activities around the Kapuas River [3, 4]. High levels of erosion and sedimentation decrease the number of temporary flood storage areas and reduce the capacity of water bodies to convey runoff.

The resulting floods cause significant economic and social losses [5]. Therefore, it is necessary to develop mitigation measures to address these floods and reduce their impact. Besides flooding, drought is also an issue in the Kapuas River Basin, to the extent that it can trigger land fire disasters and lead to air pollution from smoke, as occurred in 2016. Controlling the destructive power of floods and droughts is one approach to managing current water resources [6]. Using NbS can help restore the environment to its natural state. Implementing NbS also improves flood resilience, especially in urban areas [7]. Oxbow lakes play a key ecological role in the floodplain system, acting as temporary water storage during floods and as a reserve water source during the dry season [8–10]. However, many oxbow lakes in the Kapuas River Basin are deteriorating due to sedimentation and the loss of their connection to the main river. As a result, this system's natural capacity to retain runoff water and decrease flood risk is decreasing. This condition requires a restoration approach that not only enhances physical capacity but also restores its ecological and hydrological functions [11].

NbS provides a strategic approach to tackle this challenge. NbS emphasizes the use of natural ecosystem processes and functions to support mitigation and adaptation to climate change, including flood risk management [12]. Implementing NbS efforts in the Kapuas River Basin through oxbow lake

restoration is believed to be a solution for flood control, so an analysis of its effectiveness should be conducted. This research evaluates the effectiveness of oxbow lake restoration in reducing flooding in the Kapuas River Basin using an NbS approach. It examines how reconnecting and restoring influences runoff reduction and enhances floodplain storage capacity. Although interest in NbS is growing, there are few quantitative studies measuring their success in tropical floodplain oxbows, especially regarding storage improvements and peak-flow reduction. This leaves a gap that this study aims to fill. The findings are expected to offer a scientific basis for more sustainable and informed water resource management in West Kalimantan.

## II. METHODS AND MATERIALS

### A. Location of Research

This research was conducted in Kapuas Hulu Regency, specifically in the upper part of the Kapuas River Basin. It took place at oxbow lakes, namely Sinau, Jaras, Selanyut, and their surroundings (Figure 1), which are located in North Putussibau Sub-district, Kapuas Hulu District, at coordinates 0°50'25.25" N – 112°53'10.91" E. The research area is situated on a slope of less than 15%. This research examines the relationships among runoff, land use, land cover, soil type, and topography to understand flood potential and analyze appropriate NbS for the oxbow lake after restoration.

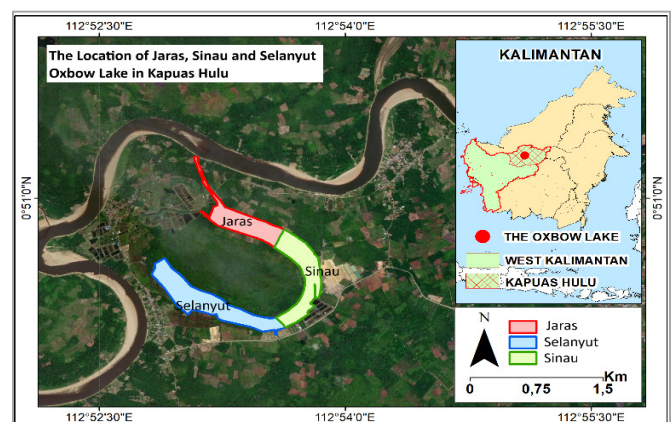


Fig. 1. Location of Jaras-Sinau-Selanyut Lake in Kapuas Hulu (Source: Google Earth. Image © 2024 Airbus) [13].

Figure 1 shows a satellite image of the Sinau, Jaras, and Selanyut oxbow lakes in the Upper Kapuas River, Kapuas Hulu Regency. These three oxbow lakes were selected as the study area because they have undergone sedimentation and changes in their connection to the main river channel. The approximate areas of each lake are Lake Jaras  $\pm 21.30$  ha, Lake Sinau  $\pm 27.20$  ha, and Lake Selanyut  $\pm 36.50$  ha. The conditions of the lakes are illustrated in Figure 2 (satellite image before restoration, Google Earth 2024) and Figure 3 (after restoration, Google Earth 2025) [13].

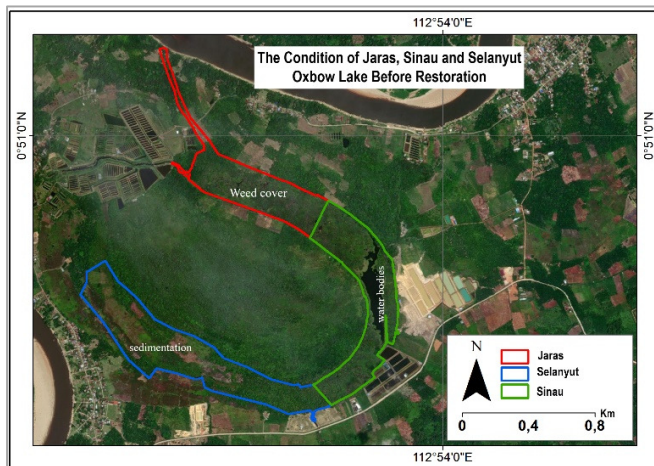


Fig. 2. Weed cover and sedimentation Jaras, Sinau and Selanyut Oxbow Lake before restoration (Source: Google Earth. Image © 2024 Airbus) [13].

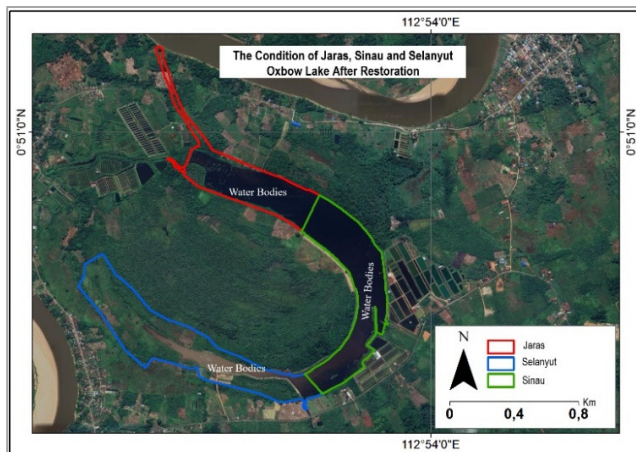


Fig. 3. Weed cover and other activities around Jaras, Sinau and Selanyut Oxbow Lake after restoration (Source: Google Earth. Image © 2025 Airbus, CNES/Airbus) [13].

Figure 4 presents the flood inundation modeling results using HEC-RAS software (RAS Mapper) for the area around the Kapuas River, especially in the Jaras, Sinau, and Selanyut oxbow lakes [14]. Blue shows flood-prone areas caused by runoff, with color intensity indicating different depths. The purple line marks the boundary of the main river channel analyzed. This map was generated by integrating hydrological data (river discharge) with a topographic model (DEM), enabling the spatial mapping of flood-prone areas. This

information is crucial for identifying high-risk areas, particularly in settlements and lowland agricultural areas. In addition, the legend in the lower right corner shows the elevation scale (low to high), which is used to interpret land height differences relative to the inundation potential. The results of this modeling serve as the basis for analyzing flood vulnerability and applying the NbS approach in the research area.

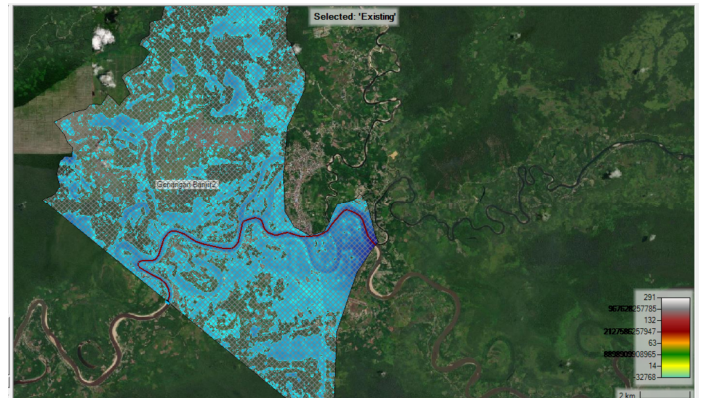


Fig. 4. Modeling results of restored oxbow lakes using HEC-RAS software [14] in the Upper Kapuas River (Background Image Source: Google Earth. Image © 2025 Airbus, CNES/Airbus) [13].

## B. Methodology

This study employed an observational, spatial-comparison approach to evaluate how oxbow-lake restoration affects inundation extent and water-surface levels. The procedures included three stages: data collection and processing, inundation mapping using HEC-RAS 2D, and field validation [14].

### 1) Data Collection and Processing

Primary data included field surveys, hydrometric observations, and documentation of lake conditions before and after restoration. Secondary data comprised rainfall records, land cover, DEM, soil information, river morphology, and historical flood observations. All datasets were processed to refine the DEM, delineate lake boundaries, and illustrate pre- and post-restoration topography.

### 2) Model Development

This research did not perform full hydrodynamic simulations. HEC-RAS 2D was used to generate water-surface and inundation maps based on a fixed water level derived from field observations. The HEC-RAS parameters listed in Table I refer to the settings used for inundation mapping, not comprehensive hydraulic modeling.

### 3) Model Validation

Model outputs were validated qualitatively by comparing simulated inundation patterns with field observations, including actual wet-season water coverage, flow directions, and lake connectivity. Validation focused on ensuring consistency between the spatial patterns produced by HEC-RAS and the observed conditions around the oxbow lakes.

TABLE I. PARAMETER HEC-RAS MODELING

Parameter	Value	Source
HEC-RAS version	6.3.1	USACE [14]
Simulation Type	2D unsteady	Model Setup
DEM	30 m	BIG
Manning n (main channel)	0.030–0.035	Field survey
Manning n (floodplain)	0.045–0.070	Vegetation survey
Time step	1–5 s	Courant stability
Boundary conditions	Upstream hydrograph; normal depth downstream	HEC-RAS / field

TABLE II. PARAMETERS FOR THE FLOOD HYDROGRAPH CALCULATION IN UPPER KAPUAS RIVER 1

Parameter	Value	Unit	Source
Area	9890.03	km <sup>2</sup>	Catchment Map
Ct	1.40		Trial and error within the range of values 0.75-3
Cp	1.20		Trial and error within the range of values 0.9-1.4
L	195.73	km	Catchment Map
Lc	130.49	km	Catchment Map
tp	29.397	hour	Calculation
te	5.345	hour	Calculation
Tp	29.897		Calculation
qp	0.112	m <sup>3</sup> /sec/mm/km <sup>2</sup>	Calculation
Qp	28.200	m <sup>3</sup> /s	Calculation
λ	0.085		Calculation
α	0.067		Calculation
x	0.033		Calculation
y	0.013		Calculation
Q	0.370	m <sup>3</sup> /s	Calculation

III. RESULTS AND DISCUSSION

A. Flood Hydrograph

Hydrologically, rainfall patterns in the Upper Kapuas River are quite consistent across all rainfall stations. The annual rainfall consistently exceeds 3,500 mm, and the region experiences a predominantly wet climate, with wet months possibly lasting up to 10 months each year. This results in the downstream Kapuas River area receiving large amounts of rainfall and runoff, reducing the effective storage capacity of water bodies downstream. The flood hydrograph in Figure 5 is based on rainfall analysis using the Snyder–Alexeyev synthetic unit hydrograph method from data between 2013 and 2023, as shown in Table II. The discharge data for various return periods are shown in Figure 6. The hydrograph for the 2023 rainfall event was used as inflow data for the HEC-RAS hydraulic simulation.

B. Flood Modeling Using HEC-RAS 6.3.1

The results of the water availability calculation, shown as a flow hydrograph in the restored oxbow lakes (Sinau, Jaras, and Selanyut) in the Upper Kapuas River, which serve as the inflow to the hydraulic model in 2023, are presented in Figure 7. Meanwhile, the rainfall data for 2023 is shown in Figure 8.

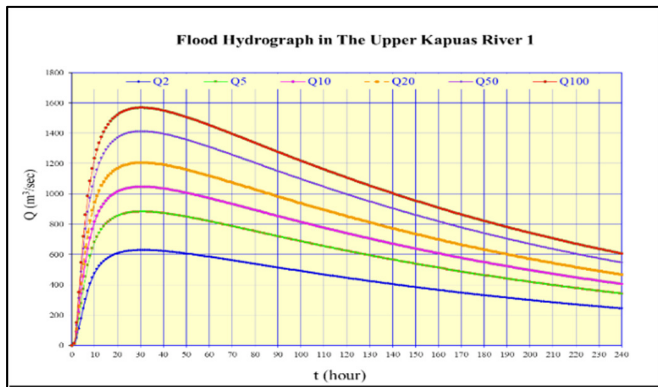


Fig. 5. Flood hydrograph in the Upper Kapuas River 1.

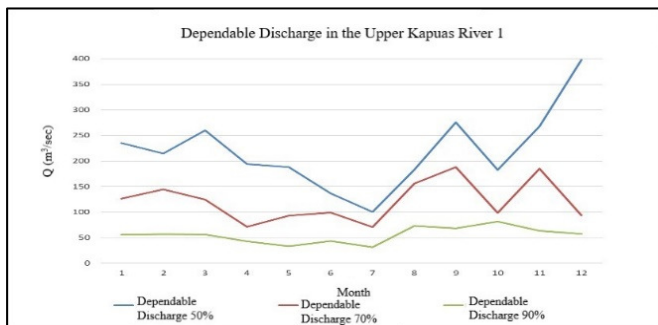


Fig. 6. Dependable discharge for various probability percentages in the Upper Kapuas River 1.

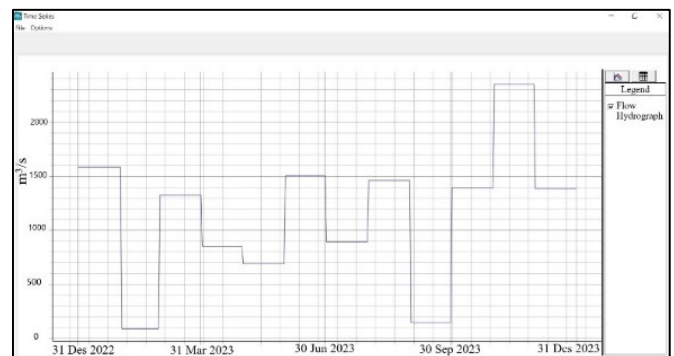


Fig. 7. Inflow data in the form of water availability (flow hydrograph) for the Year 2023 used as input for HEC-RAS software.

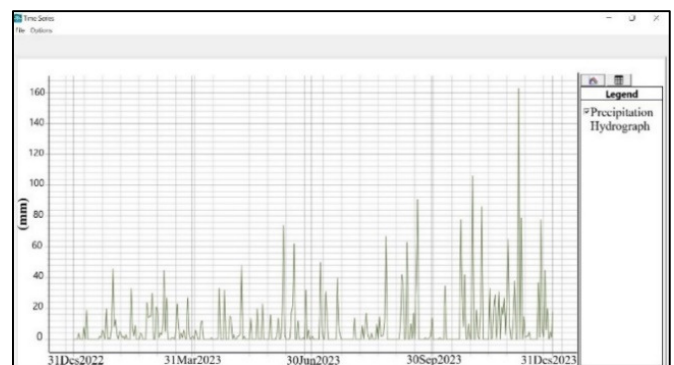


Fig. 8. Input data for HEC-RAS software, consisting of 2023 rainfall data.

### C. Magnitude of Flood Reduction by Utilizing Oxbow Lakes

Oxbow lake restoration through sediment dredging and riparian revegetation effectively increases water retention capacity. Hydrological simulations indicate that the water storage capacity of the studied oxbow lakes (Sinau, Jaras, Selanyut) increased by an average of 25–40% after dredging. The inundation distribution using the HEC-RAS Mapper software is depicted in Figure 9. The blue color, with varying intensity, indicates flood depth, with darker blue indicating deeper inundation. From these results, it is evident that inundation predominantly occurs in the floodplain along the Kapuas River, especially in low-lying areas with limited storage capacity. From the modeling results, it is known that restoration efforts in the oxbow lakes can reduce flooding, resulting in a difference in flood water surface elevation of approximately 30 cm.

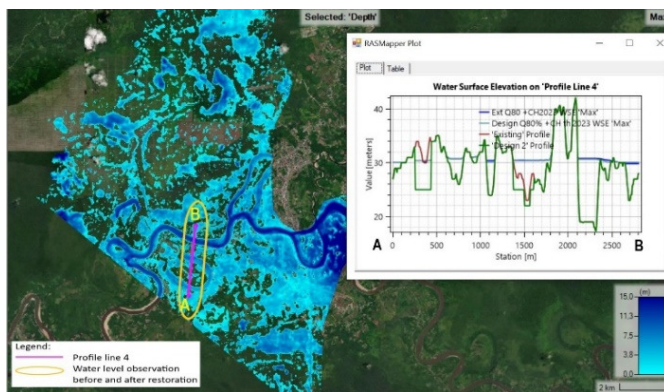


Fig. 9. RAS mapper in HEC-RAS application showing water level after the restoration of oxbow lakes (Sinau, Jaras, and Selanyut) in the Upper Kapuas River.

The impact on flooding is quite significant: the peak discharge in the main river decreased by 12–18% during extreme rainfall (with a return period of 5–10 years). This shows that the oxbow lakes act as effective natural retarding basins. Additionally, riparian revegetation slows surface runoff, allowing more water to infiltrate the soil before reaching the river. A study in Iowa supports these findings, showing that restored oxbow lakes absorb 35–76% of agricultural runoff nitrogen while also reducing flood peak discharge [15]. Similar research in the Citarum indicates that oxbow restoration can reduce the extent of flood inundation in the Bojongsoang area [16]. This confirms that restoring the storage capacity of oxbow lakes is an NbS strategy that not only reduces flood risk but also enhances water quality and aquatic ecosystems.

Besides lowering the water surface elevation, oxbow restoration can also decrease the extent of flood inundation. This conclusion was drawn from modeling across different terrains: the current condition (before restoration) and the planned condition (after restoration), where using the same input data yielded different flood-overflow results. The difference before and after restoration is shown in Figures 10 and 11. These simulation results confirm that the current conditions remain highly vulnerable to flooding. Low-lying areas around the river are especially prone to inundation during

a large flood discharge. Therefore, nature-based solutions (NbS) are necessary, such as restoring the natural retention function of oxbow lakes. With restoration, oxbow lakes can hold some of the runoff, significantly lessening the depth of flooding in settlements and productive lands. Overall, Figure 11 shows that the NbS approach, especially through the use of oxbow lakes, can improve the adaptive capacity of the Upper Kapuas River area to manage recurring flooding while also preserving the health of the aquatic ecosystem.



Fig. 10. Extent of inundated area before restoration in Oxbow Lakes (Sinau, Jaras, and Selanyut) using HEC-RAS modeling.



Fig. 11. Extent of inundated area after restoration in oxbow lakes (Sinau, Jaras, and Selanyut) using HEC-RAS modeling.

## IV. CONCLUSION

This research evaluated the effectiveness of oxbow lake restoration as a Nature-based Solution (NbS) for flood reduction in the Kapuas River Basin. The study involved field surveys, hydrological data collection, and hydrological modeling using the Snyder–Alexeyev hydrograph method, along with hydraulic modeling with HEC-RAS 2D to assess changes in storage capacity, inundation areas, and water levels before and after restoration. Model validation was performed with field-based restoration activities and flow observations to ensure that the simulation results aligned with actual conditions. The findings indicate that restoring oxbow lakes can increase water retention capacity by 25–40%, decrease peak flood discharge by 12–18%, and reduce flood heights around the lakes by about 30 cm. These improvements directly show a decrease in inundation area and water levels in the surrounding region, highlighting the hydrological benefits of

reconnecting and dredging oxbow lakes in an area that receives over 3,500 mm of annual rainfall. Since no previous studies have specifically quantified the hydrological effects of oxbow restoration in this basin, this research provides new evidence of how Nbs-based restoration can aid flood mitigation, enhance local water availability, and strengthen ecosystem functions. Overall, the results confirm that oxbow lake restoration offers a practical and effective strategy for enhancing the Kapuas River Basin's resilience to flooding and heavy rainfall.

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