Modeling the Impact of Canal Blocking on Water Table Dynamics and Carbon Emissions in Drained Peatlands

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Peatlands are significant carbon sinks, storing vast amounts of organic carbon in their waterlogged soils However, when they are drained for agricultural or other land-use purposes, the natural hydrological balance is disrupted. This disruption allows the soil organic carbon to decompose, leading to peat subsidence and the release of carbon emissions into the atmosphere and waterways. Extensive drainage systems exacerbate this process, transforming peatlands from globally significant carbon sinks into one of the leading contributors of greenhouse gas emissions from the land-based sector[1].

With the backdrop of the ongoing climate crisis, there is no doubt a need to restore the hydrological function of our vast degraded peatlands, re-establishing higher groundwater levels, which consequently reduce greenhouse gas emissions. One way to do so is by canal blocking[2]. However, quantifying the effect of canal blocking properly at a meso-scale (landscape level) while considering the complex hydrological function is challenging. We extend the features of a previously built peat hydrological model[3] to simulate the impact of canal blocking on restoring the water table in drained peatlands.

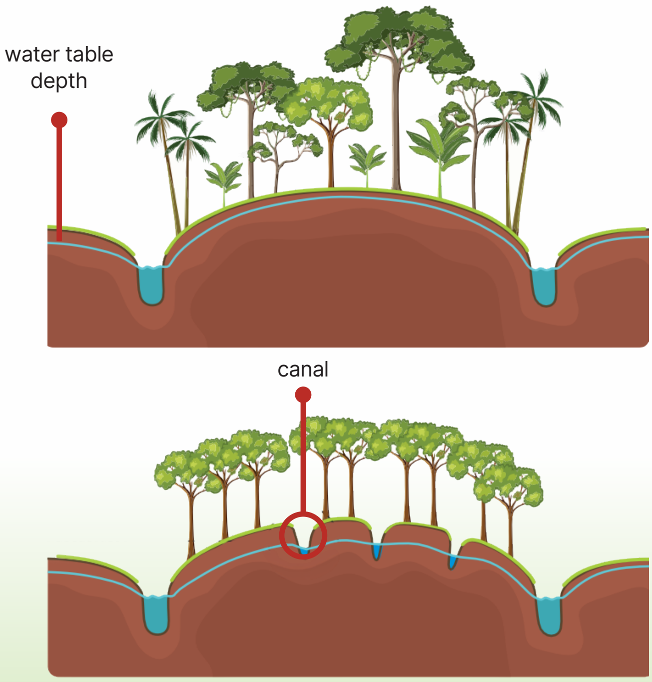


Figure 1. Illustration of a peat dome (above) and a drained peat dome that resulting in GHG emissions from peat decomposition (bottom)

Additionally, we analyse how these changes affect the reduction of greenhouse gas emissions from peat decomposition.

1 Dohong, A., et al., 2017. *Land use policy*, 69, pp.349-360.
2 Dohong, A., et al., 2018. Wetlands, 38, pp.275-292
3 Urzainki, et al., 2020. Biogeosciences, 17(19), pp.4769-4784.

Why do we need to simulate the effect of canal blocking?

- Canal blocking is a resource-intensive restoration activity for degraded peatlands. Computer simulations offer a cost-effective approach to estimate the potential impact of canal blocking before implementation (ex-ante), along with the associated costs and benefits.
- There is a lack of peat hydrological models that can simulate the effects of canal blocking at the meso-scale, i.e. a peat hydrological unit. The development and dissemination of such a tool can inform effective peatland restoration strategies.

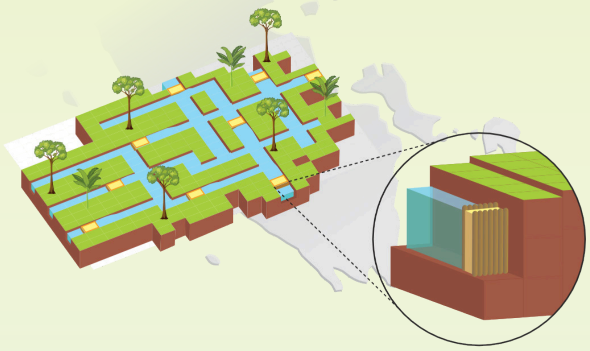


Figure 2. Illustration of multiple canal blocks placement within a network of canal in peatland

Who are the beneficiaries of the information produced using the model?

The tool can help the government in formulating a peat restoration and management plan, particularly for peat rewetting at the peat hydrological unit level. Plantations on peatland can simulate the ex-ante impacts of various alternative scenarios of canal blocking configurations on their land to meet certain regulations or good practices in maintaining water levels while ensuring viable crop or timber productivity.

How do we simulate the effect of blocking?

Model description:

- The model comprises two main components: a canal water level subroutine and a peat hydrological model. The canal water level subroutine calculates the canal water level (CWL) resulting from the construction of canal blocks at determined locations. This CWL then serves as an input into the peat hydrological model, which determines the water table depth (WTD) for the surrounding area[4].
- The CWL subroutine starts by using a Digital Elevation Model (DEM) to determine the initial water level in the canal network. To establish the baseline CWL, it subtracts a fixed offset (usually around 1.2 meters) from the DEM elevation. This initial step creates a starting point that represents natural canal water levels before any interventions.
- As canal blocks are introduced into the system, the CWL subroutine calculates their impact on water levels. Rather than directly using the physical height of the blocks, the subroutine uses a concept called the block head level. This level represents the elevation from the DEM to the top of the block, ensuring precise adjustments in water levels. When a block is placed in a canal pixel, the subroutine identifies the adjacent and upstream pixels that would be affected. It then raises the water level in these areas to match the block head level, simulating immediate changes in water flow dynamics within the canal network.

4 Urzainki, et al., 2020. Biogeosciences, 17(19), pp.4769-4784.

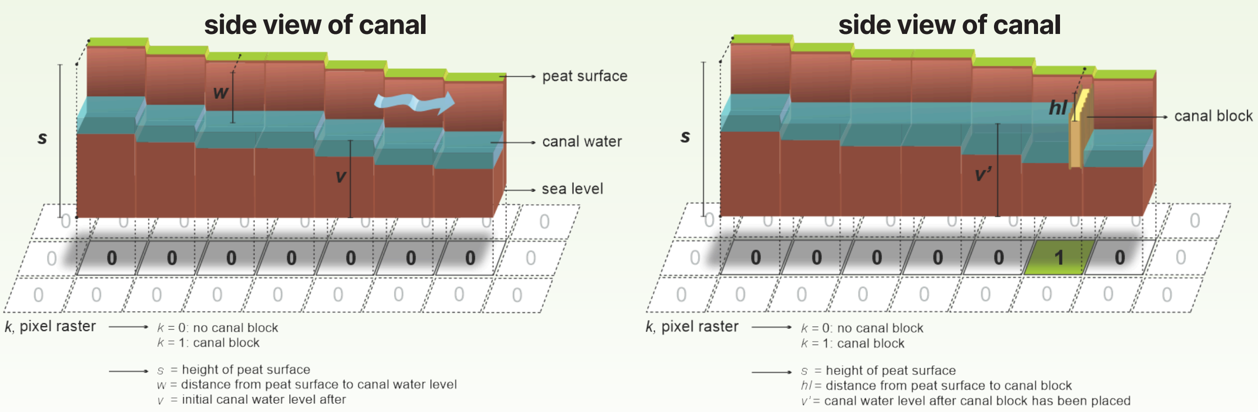


Figure 3. Schematic illustration of canal water level without and with a canal block

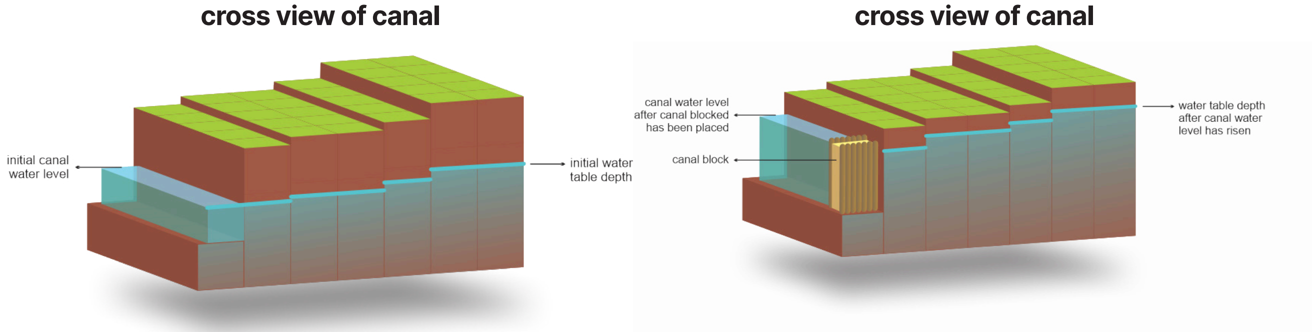


Figure 4. Schematic illustration of peat water table depth in the vicinity of a canal, without and with a canal block installed

- The peat hydrological model uses the Boussinesq equation, a partial differential equation (PDE) common in groundwater flow modeling. This model considers various factors that influence water table depth (WTD), such as specific yield (Sy) and transmissivity (T). Specific yield refers to how much water is released per unit decline in hydraulic head, while transmissivity describes how easily water moves through the peat layers. These parameters are crucial for accurately predicting water movement and retention in the peatland environment.
- To solve the Boussinesq equation, numerical methods like the finite volume method are employed. This approach discretizes the domain into a grid and iteratively computes changes in hydraulic head over time. Boundary conditions, including constant head values at the domain edges and canal pixels, ensure realistic simulation outcomes. The model begins simulations from fully saturated conditions and then progresses through periods of dry weather to mimic natural hydrological cycles.
- Ultimately, we can evaluate the ex-ante impact of different scenarios of canal block placements on the increase in canal water levels and the peat water levels in the vicinity. This evaluation can then be further used to estimate the impact on emission reduction and potentially the associated costs of building and implementing the canal blocks.

A Case Study from Our Project Site

Sugihan Lumpur peat hydrological unit (PHU) is a peatland area bordered by the Sugihan River network in the north and the Lumpur River in the south. Administratively, it is located in the regencies of Banyuasin and Ogan Komering Ilir (OKI). This peatland covers a total area of 633,762 hectares, which constitutes 30.3% of the total peatland area in South Sumatra. Based on its designated functions, the peatland in Sugihan Lumpur is predominantly used for conservation purposes (60%, or 380,256 hectares) and for cultivation purposes (40%, or 253,506 hectares). The various commodities produced from the peatland in Sugihan Lumpur PHU

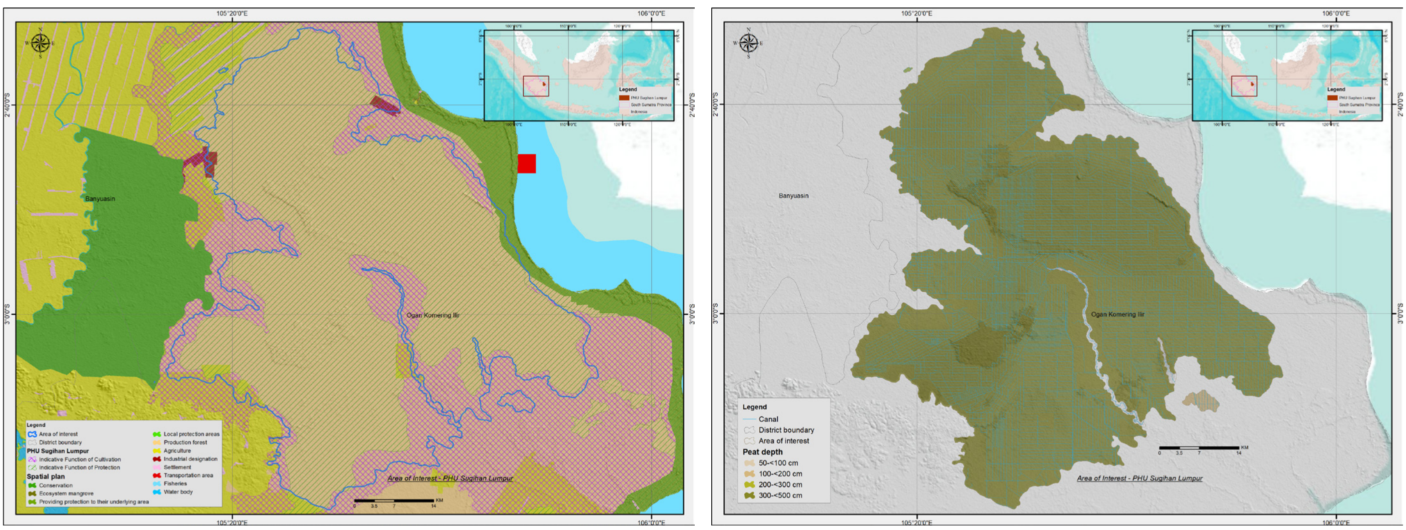


Figure 5. Spatial plan (left) and canal distribution (right) in PHU Sugihan Lumpur

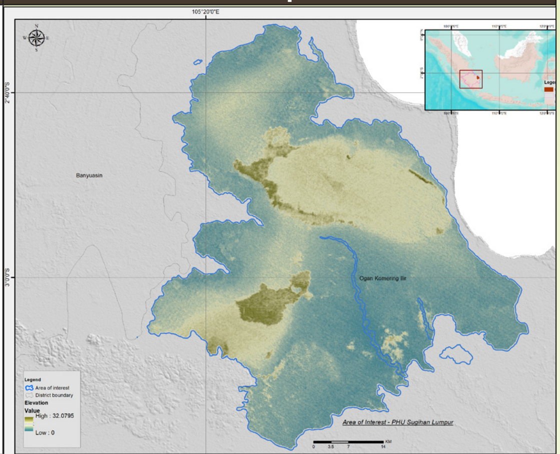
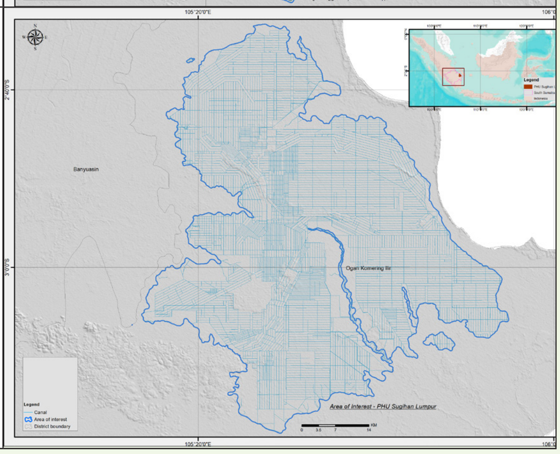
include swamp buffalo, fish, purun, edible-nest swiftlets, and rice[5]. Sugihan Lumpur PHU has been designated as one of the priority peatland areas in South Sumatra[6]. This designation is based on several criteria: peat thickness (≥ 3 meters), the presence of legally protected species, cultural heritage protection areas, and peatland ecosystems located within protected and conservation forest areas. The total area of concession permits for IUPHHK with the highest fire risk in Sugihan Lumpur PHU in 2023 is 54,867.47 hectares[7]. In 2018, BRG prioritised peatland restoration activities in five PHUs and Sugihan Lumpur is included[8].

More than half of the allocated production forest area in South Sumatera is located in the Sugihan River – Lumpur River PHU, covering an area of 468,000 hectares[9]. This situation highlights a significant factor contributing to the numerous forest plantation industries around this PHU.

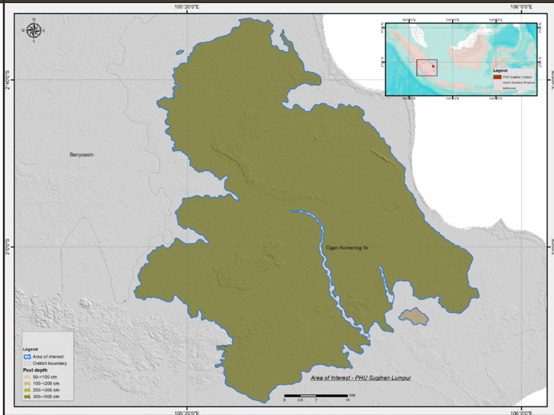
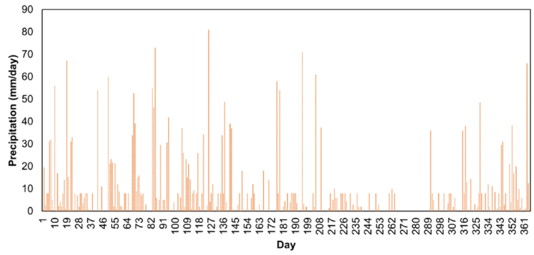
The areas of HGU, HTI, and KPH in the Sugihan Lumpur PHU are 4,286 hectares, 464,086 hectares, and 73,423 hectares, respectively. Looking at the South Sumatra PHU units, in 2015, this Sugihan Lumpur became a PHU with the largest burned area with 189,113 hectares (42% of the cultivation function of the PHU and 33% of the protection function of the PHU). Restoration efforts have been undertaken in this area. In the restoration plan for 2019-2023, the area of restoration rewetting actions in the Sugihan Lumpur PHU is 370,842 hectares, with details as follows: 6,730 hectares through canal backfilling, 226,048 hectares through canal blocking and water management improvements, and 138,064 hectares through water pumping. The Sugihan River–Lumpur River PHU has the highest number of canal blocks in South Sumatra, totaling 1,877 points.

Data and parameters

The model requires several types of data to run, as described in the table below:

No	Data	Format	Description	Description
1	Elevation map	TIFF	A digital elevation model (DEM) map for the entire study area	
2	Peat canal network map	TIFF	A raster map of the canal network and the adjacent natural river network within the study area.	

5 ekosistem:khg_sungai_sugihan_-_sungai_lumpur [WikiGambut]
6 BRG: Kriteria Gambut yang Direstorasi di Sumatera Selatan, Bukan hanya
7 PowerPoint Presentation (pantaugambut.id)
8 (PDF) Laporan Kinerja Gambut Sumsel 2018 (researchgate.net)
9 Pemulihan Ekosistem Gambut untuk Provinsi Sumatera Selatan yang Sejahtera: Rencana Restorasi Ekosistem Gambut

No	Data	Format	Description	Description
3	Peat depth and soil type map	TIFF	A raster map of the peat type and the thickness of the peat layer throughout the study area.	
4	Daily precipitation	.xlsx	An Excel file containing daily precipitation data for the simulation period.	
5.	Model configuration	.YAML	The YAML configuration file defines a peat hydrological model scenario, specifying parameters such as simulation duration, canal block placements, hydrological settings, CO_2 emission coefficients, paths to data input files, and tracking points for monitoring water table depth in drained and undrained areas.	

Results

The model is capable of simulating variations in the depth of the water table, with its dynamics primarily influenced by rainfall patterns. Additionally, the model can illustrate how peat canal drainage impacts the water table, allowing for a comprehensive understanding of the hydrological system's response to such interventions.

We ran simulations to examine the impact of canal blocking across multiple scenarios, differentiated by the number of dams and the water level control relative to the surface. We then estimated the CO_2 emissions using a peat emission factor from Deshmukh et al., 2023.

The simulation reveals that the scenario with the highest number of dams and the lowest water level control from the peat surface results in the greatest CO_2 emission reduction. Specifically, the scenario with 200 dams and a water level 0.2 meters from the surface achieves the highest reduction, amounting to 45,423 tons of CO_2 equivalent annually compared to the baseline.

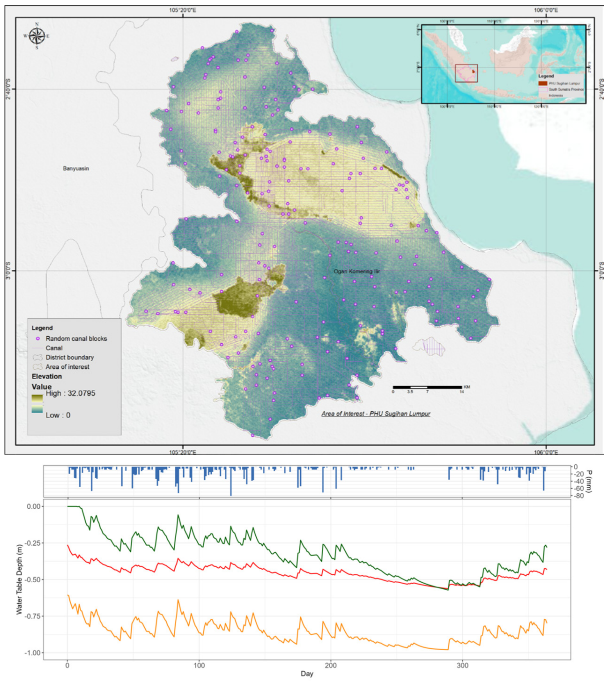
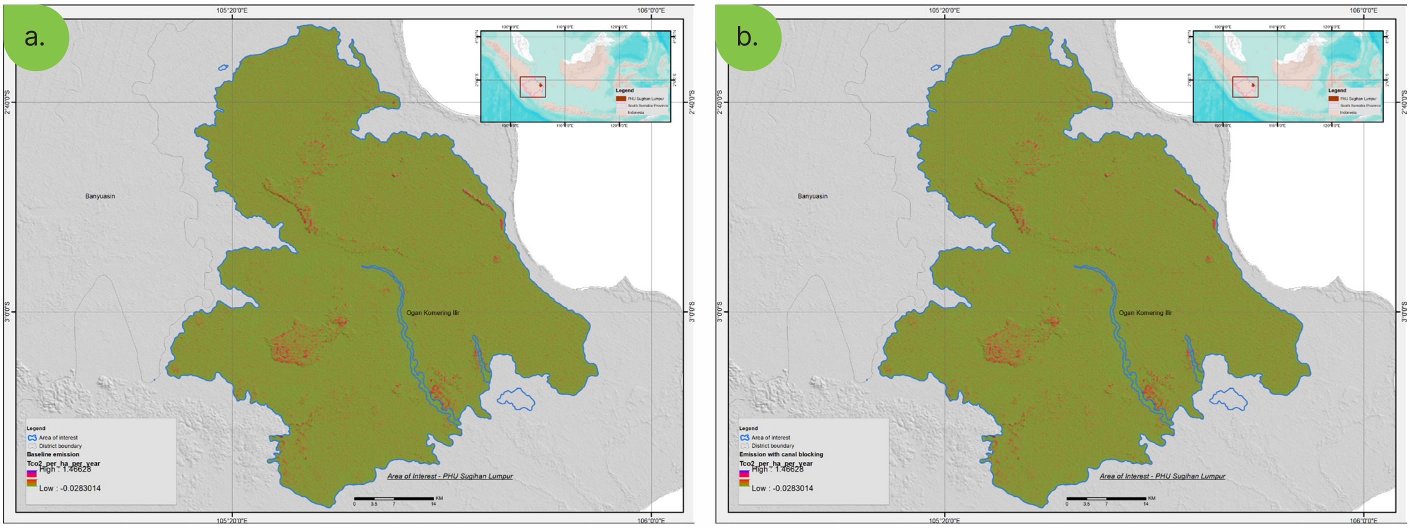


Figure 6. 200 dam placements over the canal network within the Sugihan-Lumpur PHU (left) and the corresponding simulated water table depth (right).

Scenario Name	No of dams	Dam Water Level (from the surface)	CO_2 emission reduction (Mg/yr) towards baseline
Scenario 1	100	0.4 m	14,711
Scenario 2	100	0.2 m	22,204
Scenario 3	200	0.4 m	28,572
Scenario 4	200	0.2 m	45,423



It is important to note that scenarios with the same number of canal blocks can have varying impacts on canal water levels and water table depths due to differing configurations. By carefully considering the spatial allocation of these blocks, we can maximize the emission reduction per unit of cost invested in canal blocking.

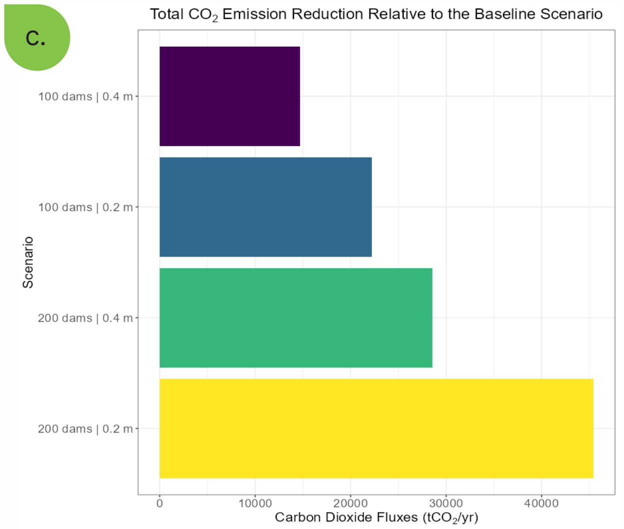


Figure 7. a) Baseline emissions b) Emission with canal blocking c) Emission reduction graph estimated using the emission factor from Deshmukh et al., 2023.

Current Limitations

- Simplified GHG peatland fluxes, excluding methane emissions.
- Identical canal and canal block specifications.
- Ignoring land cover/land use variations in Ks (saturated hydraulic conductivity), which can influence drainage resistance.

Way forward

- Incorporate existing land use and socio-economic factors into the model when designing canal blocking allocations to achieve optimal meso-scale impacts at the least cost.
- Research the impact of land cover types on key parameters, such as Ks (saturated hydraulic conductivity).
- Consider varying the size and specifications of canals based on actual conditions, including dam designs adapted to the size and availability of canals.
- Calibrate and validate simulated results using groundwater levels monitored at several sites, discharge measurements in the main river, and flooding patterns derived from remotely sensed radar images.

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