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List of acronyms and abbreviations

AWD	Alternate Wetting and Drying
BSL	Boeng Sneh Lake
CDRI	Cambodia Development Resource Institute
CFi	Community Fishery
CMD	Cambodian Mekong Delta
DEM	Digital Elevation Model
DTWG	District Technical Working Group
DWG-FSN	District Working Group for Food Security and Nutrition
ETa	Actual Evapotranspiration
FGD	Focus Group Discussion
FWUC	Farmer Water User Community
GEE	Google Earth Engine
HH	Household
IFReDI	Inland Fisheries Research and Development Institute
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
KII	Key Informant Interview
MOE	Ministry of Environment
MOWRAM	Ministry of Water Resources and Meteorology
PDAFF	Provincial Department of Agriculture, Forestry and Fisheries
PDWRAM	Provincial Department of Water Resources and Meteorology
PWO	Private Water Operator
RGC	Royal Government of Cambodia

Executive summary

A consortium of the International Water Management Institute (IWMI), WorldFish, CDRI and other national partners has worked with diverse stakeholders to develop a multi-stakeholder, collaborative governance model (District Technical Working Group, DTWG) to address water conflicts that threaten the ecological sustainability of Boeng Sneh Lake (BSL), which in turn threatens biodiversity, and a fishery that supplies local and wider households with high-quality animal protein and associated livelihoods and value-chains. A better understanding of the lake's hydrology and seasonal water storage capacity and abstraction is key information that can support objective decisions by the DTWG on water sharing and adaptive management during periods of especially high-water scarcity.

This working paper presents the results of a hydrological study by this consortium that examines the mounting hydrological stress and multi-sectoral governance challenges at BSL, Prey Veng Province—a vital freshwater wetland in the Cambodian Mekong Delta. Spanning 3,924 hectares and designated as the Toulpontalei – Boeng Sneh multiple-use area, the lake serves as a critical buffer for regional flooding and a lifeline for over 10,900 households. However, the system is currently traversing a trajectory of acute resource stress driven by intensified agricultural expansion and a changing climate.

The assessment utilises an integrated socio-hydrological framework, combining a systematic literature review, a decade of meteorological records (2014–2024), and three phases of intensive fieldwork in 2025. Technical innovations include a 121-point bathymetric survey used to create a high-resolution digital elevation model and the development of a Google Earth Engine web application for near real-time monitoring of lake surface area and volume. Qualitative insights were gathered through multi-stakeholder consultations with Farmer Water User Communities and Community Fisheries to verify irrigation boundaries, cropping intensity and schedule, and to understand adaptive farmer decision-making.

Key findings:

- **Hydrological instability:** Decadal climate analysis reveals a critical thermal peak in April (35.1°C), coinciding with minimum storage. Remote sensing confirms a progressive contraction of dry-season surface area, with 2024 recording the lowest extent in recent history. While wet season storage typically reaches 80–100 million m^3, recent dry seasons saw volumes collapse to extreme minima of 5–15 million m^3, well below the 27 million m^3 operational storage threshold (identified by PDWRAM based on historical bathymetric assessment) for supporting dry-season water supply and maintaining the lake's deep-pool ecological refugia.

- **The nexus conflict:** A multi-stakeholder mapping exercise demarcated the irrigation command area extending up to 13 km south of the lake and several kilometres in other directions from its boundary as dependent on the lake. The shift toward triple-cropping of short-duration rice and year-round vegetable cultivation has outpaced traditional institutional controls, creating a direct conflict between agricultural yield targets and the sustainability of capture fisheries, and of the lake's ecosystem as a whole.

- **Surging domestic demand:** Domestic water extraction from three Private Water Operator stations increases by up to 66.7 percent during the peak dry months, significantly exacerbating drawdown exactly when the system is most vulnerable.

- **Institutional transformation:** Fragmented sectoral management was historically ineffective given the multi-use nature of water, which demands collaborative water sharing arrangements to minimise trade-offs and avoid conflict. The pilot District Technical Working Group (DTWG) established in 2024 has served as a successful proof-of-concept as a platform to facilitate such multi-stakeholder coordination. This shift from sector-centric to a collaborative governance model has helped maintain adequate water for ecosystem functionality through improved water sharing amongst water users, thereby also improving water productivity and reducing conflict.

The assessment concludes that BSL's survival depends on transitioning to a data-driven Integrated Water Resources Management (IWRM) model. To safeguard the 27 million m^3 operational storage threshold, the paper proposes a trigger-based management matrix that maps specific actions—such as capping irrigation and adjusting planting calendars—to real-time lake volume. Key recommendations include formalising the DTWG into a permanent District Working Group for Food Security and Nutrition, completing monsoon bathymetric curves to refine level-storage relationships, and scaling this decentralised governance model to other critical wetlands across the Cambodian Mekong Delta.

The results of this study and resulting recommendations will be distilled into a format that the DTWG can use for decision-making, including locally appropriate methods of setting and monitoring minimum water levels in the BSL, that will ensure continued collaborative IWRM with minimal conflict. The work thus contributes significantly to the consortium's objective of demonstrating a replicable governance model and associated water management methodologies for more collaborative and integrated management of aquatic ecosystems in the Tonle Sap floodplain and Cambodia's part of the Mekong Delta to sustain floodplain biodiversity, the diverse food systems and associated livelihoods and build local adaptive capacity to climatic and other risks.

1. Introduction

Cambodia faces a persistent paradox in its management of water resources: abundance during the monsoon season followed by water scarcity during the dry months due to growing demands and basin alterations. This seasonal dichotomy is most pronounced in the floodplains of the Lower Mekong Delta, where freshwater wetlands like Boeng Sneh Lake (BSL) function as critical hydrological regulators (Arias et al. 2013).

BSL, also known as Boeng Pring, is a significant freshwater wetland in Prey Veng Province of Cambodia. The lake plays a crucial role in supporting extensive rice agriculture, community fisheries, and biodiversity, serving as a major water storage and ecological buffer that helps regulate seasonal flooding within the Cambodian Mekong Delta (CMD). The lake is vital for sustaining local livelihoods and maintaining the regional hydrological balance due to its large storage capacity and extensive floodplain connectivity (Sok 2026; IUCN 2021).

As part of the larger CMD, BSL and other floodplain ecosystems in the region face increasing challenges from competing water demands between agriculture and fisheries sectors locally (Arias et al. 2013; Chua et al. 2022; Sok et al. 2025). The integrity of the lake's ecological functions and its ability to sustain communities are threatened by altered water regimes stemming from broader regional hydrological shifts, climate change, and human interventions (Eyler and Kwan 2026; Västilä et al. 2010).

To address the challenges in managing BSL, WorldFish and the International Water Management Institute (IWMI) partnered with the Inland Fisheries Research and Development Institute (IFReDI) in 2024 to pilot District Technical Working Groups (DTWGs) in two districts: Ba Phnom in Prey Veng Province and Santuk in Kampong Thom Province. A form of multi-stakeholder platforms, these DTWGs brought together line agencies, local authorities, and Community-Based Organisations to transform how local institutions coordinate, plan, and respond to challenges associated with the management of key ecosystems like BSL towards multiple benefits.

One of the tasks of the DTWG for BSL in Ba Phnom District is to coordinate the activities between different water uses and users to ensure benefits are shared across the sectors while minimising the negative consequences. While the Mekong delta has become one of the best-studied deltas in the Global South (Schmitt and Minderhoud 2023), coordination at the local level is severely hampered by a lack of a knowledge base providing key hydrological insights for decision-making purposes (Tri et al. 2023). This assessment bridges this knowledge gap by thoroughly examining BSL hydrological conditions, water-use patterns, and existing management challenges, directly supporting the planning and decision-making of the DTWG.

Specifically, this hydrological assessment aims to build a key foundational knowledge base of BSL to enhance Integrated Water Resources Management (IWRM), fisheries, biodiversity conservation, and the efficient functioning of agricultural systems. By developing critical hydrological data and analytical tools, this study empowers the DTWG to make informed decisions on water allocation, particularly in mitigating dry-season extraction pressures and preserving ecological balance. Drawing on primary literature, secondary data analysis, and field data collection and verification, this document explores the lake's hydrology, water use, governance structures, and climate sensitivity.

This assessment is a multi-sectoral collaboration led by WorldFish and IWMI, in partnership with the Cambodia Development Resource Institute (CDRI) as the local expert in data collection and analysis. The BSL DTWG serves as the central platform for localised implementation, coordinating the research team's efforts in socio-institutional data collection.

To guide the empirical analysis and structure the findings of this working paper, three explicit, interconnected research questions are addressed:

- RQ1: What is the seasonal storage-volume relationship of BSL, and how has the dry-season surface water extent changed over the 2015–2025 period?
- RQ2: What are the current magnitudes and seasonal patterns of agricultural and domestic water abstraction around BSL, and how do they compare with the 27 million m^3 operational storage threshold established for dry-season water management?
- RQ3: How do local community-based institutions (such as FWUCs and CFis) perceive and respond to escalating water scarcity, and what decentralised governance mechanisms exist to support a trigger-based management framework?

2. Review of the study area and context

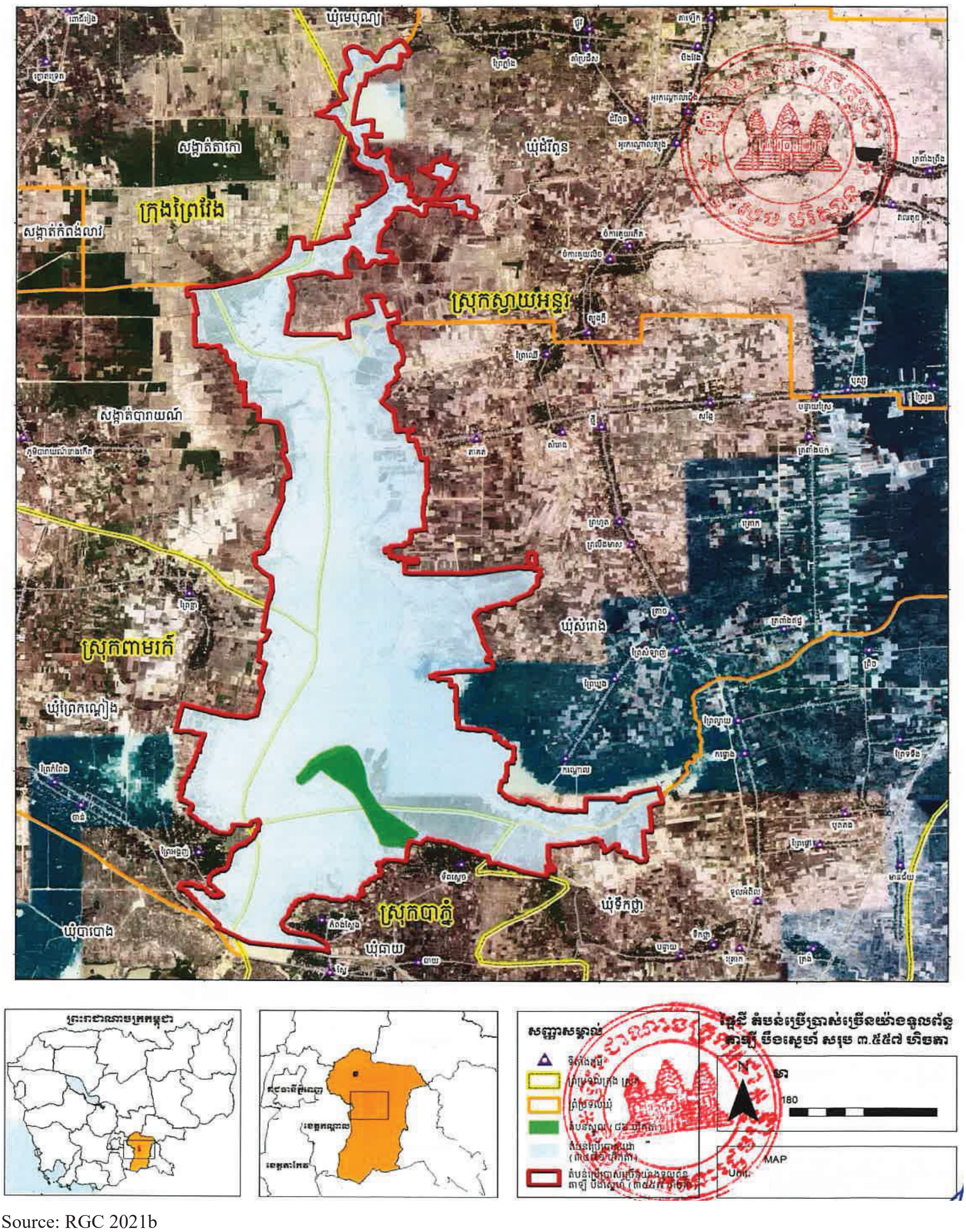
2.1. Hydrological regimes and vulnerability

BSL is recognised as one of Cambodia's largest freshwater wetlands, demonstrating considerable scale and ecological significance with an area of 3,924 hectares (Sok 2026). Its importance is formally recognised by the Royal Government of Cambodia (RGC), which designated the area as the Toulpontalei – Boeng Sneh multiple-use area (Figure 1) under Sub-decree No. 16 in 2021, covering 3,557 hectares (RGC 2021a). A primary function of BSL is its massive floodwater storage capacity, vital for regulating local and regional hydrology. Estimates suggest that the BSL is capable of storing between 80 and 89 million m^3 during the wet season (Sok et al. 2025; IUCN 2021). Crucially, BSL is a permanent water body that persists through both the dry and wet seasons, containing nine deep pools within its boundaries that provide essential dry-season sanctuaries for fish species to grow and reproduce (IUCN 2021).

BSL's hydrology is primarily driven by seasonal rainfall and wet-season inflows from the Mekong River through an interconnected canal and stream network linking the lake to the river to the north (Figure 2). This annual "flood pulse"—often referred to as the "beating heart" of the Mekong—facilitates fish migration, nutrient circulation, and the rejuvenation of floodplains (Eyler and Kwan 2026; Arias et al. 2013). While this flood pulse is fundamental to maintaining hydrological connectivity and ecosystem functioning throughout the Tonle Sap floodplain and the Lower Mekong Basin (LMB) (Eyler and Kwan 2026; Arias et al. 2013), it is undergoing a profound transformation due to upstream infrastructure development and climate change impacts (Västilä et al. 2010).

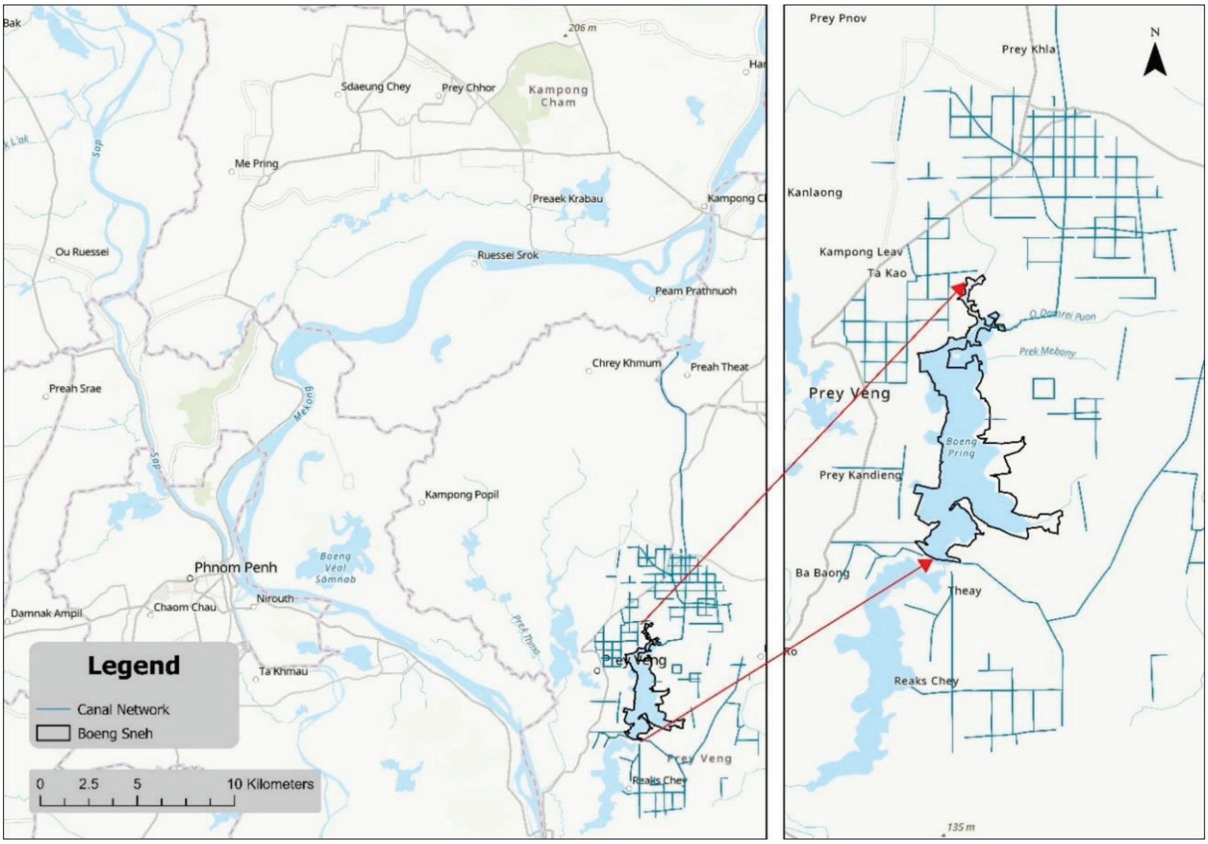
Recent studies indicate that these pressures are fundamentally altering the pulse, leading to higher minimum water levels in the dry season and reduced peaks in the wet season, which effectively decrease annual fluctuations and suggest a future of shorter, lower flood magnitudes (Chua et al. 2022; Arias et al. 2013). This regional hydraulic pressure establishes a baseline threat that exacerbates local problems; as the pulse weakens, BSL receives reduced replenishment, diminishing its connectivity to the larger system and intensifying local water extraction conflicts for rice farming and having a serious impact on the aquatic ecosystem (Sok 2026; Sok et al. 2025). Consequently, local governance strategies must now operate under a regime of rapidly declining predictability, demanding more sophisticated and adaptive climate-management approaches.

Figure 1: Map of the delineation and zoning of management areas in multiple-use areas of Toulpontalei Boeng Sneh



Source: RGC 2021b

Figure 2: Location of BSL and its hydrological connection to the Mekong River



Source: Authors

While the functional hydrology of BSL is well-understood through its integration into the larger Mekong system, detailed, locally relevant bio-physical data either remains difficult to access or is not available. Similarly, long-term water quality metrics are not detailed in available abstracts, despite the knowledge that agrochemical runoff serves as a major stressor (Sok 2026; Sok et al. 2025). Although researchers have collected large quantitative datasets involving BSL community fisheries and irrigation schemes (Sithirith and Sok 2024), specific details regarding sediment transport or long-term fluctuations are often not openly catalogued. This limitation is significant, as the scientific validation of ecological stress such as pollution levels from fertiliser use must rely heavily on qualitative findings from KIIs and FGDs regarding conflict and resource use patterns.

2.2. Ecosystem services and biodiversity under strain

BSL provides extensive ecosystem services critical to both human livelihoods and regional biodiversity, serving as a habitat for indigenous fish and a significant stopover for migratory waterbirds, including 53 species such as the Endangered Greater Adjutant (Leptoptilos dubius) and the Vulnerable Lesser Adjutant (Leptoptilos javanicus) (IUCN 2021). The lake's natural physical characteristics—its ecological infrastructure—which remains permanently wet, are vital for maintaining ecological resilience. In particular, its nine deep pools function as crucial dry-season refugia, which are analogous to fish refuges elsewhere in the LMD, enabling fish populations to survive the dry season and sustain four surrounding Community Fisheries (IUCN 2021). Furthermore, the lake's composition of approximately 20 percent aquatic vegetation and flooded forest alongside 80 percent open water provides the diverse micro-habitats essential for its complex food web (IUCN 2021).

The Sub-decree No. 16 issued by the RGC divides the Toulpontalei – Boeng Sneh multiple-use area into an 86-ha core zone for strict conservation and a 3,471-ha sustainable-use zone, with the intention of preserving the site's aesthetic, cultural, and biodiversity values for potential nomination as a Ramsar Site (RGC 2021b; IUCN 2021). While the sub-decrees explicitly promote the concept of co-management, the practical responsibility for the sustainable use zone is highly fragmented, as management is distributed among various sectoral ministries, including the Ministry of Environment (MOE), the Ministry of Interior (MoI), the Ministry of Land Management, Urban Planning and Construction (MLMUPC), the Ministry of Agriculture, Forestry and Fisheries (MAFF), and the Ministry of Water Resources and Meteorology (MOWRAM) (IUCN 2021).

Despite its official protected status, the BSL ecosystem is documented as "Under Strain" due to multifaceted pressures stemming from climate factors like droughts and human activities such as overexploitation, illegal fishing, and land encroachment (Sok 2026; Sok et al. 2025). A previous study emphasises that the most impactful local pressure is the intensification of dry-season rice farming, which necessitates high volumes of irrigation and the increased use of agro-chemicals (Sok 2026; Sok et al. 2025). This pursuit of agricultural yield is the primary driver of degradation by causing severe physical water stress and chemical pollution, thereby systematically undermining fishery productivity and natural resources (Sithirith et al. 2024a). Consequently, the dominant threat to BSL is rooted in a policy choice favouring high-input agriculture over the conservation of ecosystem services, suggesting that effective management must prioritise the regulation of agricultural inputs and water allocation (Sithirith et al. 2024a).

2.3. Water resource utilisation: The rice-fish nexus and emerging conflict

BSL is an indispensable resource that anchors the livelihoods of local communities, sustaining over 10,900 households by providing essential water for domestic use, agriculture, and fisheries (Sok et al. 2025). Given that rice and fish constitute the fundamental diet and primary income sources for Khmer society, the fate of wetlands like BSL is central to national food security (Sithirith et al. 2024b). Beyond these primary production sectors, the lake further supports the local economy through ancillary activities, most notably community-based eco-tourism, which diversifies the socio-economic value of the wetland.

Since 2015, the RGC has promoted increased rice production for export, leading to a widespread expansion of farming areas and a shift toward planting up to three rice crops annually. This intensification has created a high and often unsustainable demand for irrigation water, particularly during the dry season in the CMD (Sithirith et al. 2023). Management of this production is decentralised through Farmer Water User Communities (FWUCs), such as Damrei Puon's and Theay's FWUCs within the BSL area, which collectively manage significant agricultural land; these institutions focus on maintaining irrigation schemes and collecting water fees to sustain intensive dry-season farming (Sithirith et al. 2024a).

The primary cause of socio-ecological stress at BSL is a rising water-use conflict driven by direct competition between agricultural intensification and fisheries conservation. This conflict manifests through four documented mechanisms: hydrological fragmentation, where irrigation infrastructure blocks fish migratory pathways; water quantity depletion, as FWUCs pump water below the ecological thresholds required for a healthy fishery (De Silva et al. 2024); institutional opposition, where the conservation mandate of the four local Community Fisheries (CFis) directly clashes with the extraction mission of the FWUCs; and water quality degradation caused by increased agro-chemical runoff from intensive farming (Sithirith et al.

2024a). Ultimately, these two institutional frameworks operate with opposite objectives despite their shared reliance on the same hydrological system.

The persistent degradation of the traditional rice-fish system, compounded by governance failures and climate change, has resulted in severe socio-economic consequences, including increased production costs and high levels of household indebtedness (Sithirith et al. 2024b). This creates a governance failure cascade where sectoral institutional designs prioritise unchecked water extraction and pollution, leading to declining fishery productivity and increased social vulnerability (Sithirith et al. 2024a). When small-scale farmlands can no longer provide sufficient food for consumption, families are often forced to sell their land to settle debts, prompting a demographic shift as younger residents migrate to urban centres or overseas (Sithirith et al. 2024b). This underscores that the BSL conflict is an institutional failure that prioritises international rice export goals over the foundational food security and environmental resilience of the region (Sithirith et al. 2024b).

2.4. Institutional challenges and the evolution of governance

Cambodia's traditional approach to natural resource management has historically been characterised by a centralised, top-down, and strongly sectoral organisational structure, which frequently proved ineffective for managing shared, complex resources like BSL (Sithirith et al. 2024a). In the absence of a dedicated institutional mechanism for cross-sector coordination, management decisions often reflected the individual interests of surrounding communes rather than a shared, integrated approach, leading to overexploitation, internal competition, and rising water-use conflicts (Sithirith et al. 2024a). This systemic fragmentation resulted in a lack of effective coordination among key government agencies—such as the MAFF, the MOWRAM, and the MOE—while limiting meaningful involvement from local community stakeholders. Ultimately, this unbalanced environment favoured the politically and economically influential agricultural sector at the expense of long-term ecological sustainability (Sithirith et al. 2024a).

The 2021 designation of BSL as a multiple-use area through Sub-decree No. 16 and No. 17 represented an attempt to impose a formal governance structure by mandating "co-management" for the Sustainable Use Zone (RGC 2021a; RGC 2021b). However, this authority was diffused across numerous sectoral bodies, including the Ministries of Interior, Land Management, Agriculture, and Water Resources, which inadvertently formalised the administrative fragmentation that had previously inhibited effective governance. By assigning conservation to the MOE and resource extraction to agencies like MAFF and MOWRAM without a powerful, binding mechanism for integrated decision-making, the framework risked institutional paralysis. Consequently, the legal designation of BSL as a protected area was, by itself, insufficient to address the water-use conflicts and governance challenges observed at the local level (Sok et al. 2025).

Recognising these institutional gaps, the RGC pivoted in 2019 toward delegating the management of water, land, and the environment to the district level, leading to the formal establishment of the DTWG in May 2024 (Sok et al. 2024; De Silva et al. 2024). Piloted by WorldFish, IWMI, and the IFReDI, the DTWG serves as a platform for integrated and adaptive governance, bringing together representatives from all relevant sectors alongside Community-Based Organisations like Community Fisheries (CFis) and Eco-Tourism groups (De Silva et al. 2024). This collaborative approach has already demonstrated success by moving away from rigid sectoral views toward collective problem analysis, resulting in a consensus-based Management Plan (MP) that addresses five priority water-conflict issues (De Silva et al. 2024).

Furthermore, the DTWG process has explicitly empowered women in decision-making spaces, positioning this district-level delegation as a crucial case study for the entire CMD in mitigating resource conflict and enhancing climate resilience (Sok et al. 2024).

2.5. Knowledge gaps and contribution of this study

The existing literature provides a substantial foundation for understanding BSL as a hydrologically connected, ecologically significant, and institutionally complex wetland within the LMB. Prior studies have documented its flood storage capacity (Sok 2026; Sok et al. 2025; IUCN 2021), ecological importance for fisheries and migratory waterbirds (IUCN 2021), and the structural pressures arising from upstream hydrological alteration (Arias et al. 2013; Chua et al. 2022). Moreover, governance-oriented analyses have highlighted sectoral fragmentation, water-use conflict between FWUCs and CFis, and the emergence of district-level coordination mechanisms such as the DTWG (Sithirith et al. 2024a; De Silva et al. 2024).

Despite these advances, important knowledge gaps remain. Although basin-scale hydrological dynamics and change in the Mekong are well documented, its interaction with localised water allocation dynamics at BSL has not been systematically analysed within a unified socio-hydrological framework, leading water-use conflicts to be treated largely as institutional rather than hydrological–ecological issues. At the same time, key quantitative datasets including bathymetry, long-term water quality records, sediment dynamics, and abstraction volumes remain fragmented or insufficiently accessible, limiting evidence-based ecological threshold setting and adaptive planning. Governance studies highlight institutional fragmentation but provide limited examination of how district-level coordination mechanisms operationalise IWRM in practice. Finally, while the rice-fish nexus is widely recognised, the interaction between export-oriented agricultural policy, climate variability, and local ecological resilience remains underexplored, underscoring the need for a more integrated political–ecological analysis.

Against this backdrop, this study makes the following key contributions to the IWRM of BSL:

- It adopts an integrated socio-hydrological perspective that situates local water-use dynamics within the broader context of Mekong flood pulse alteration and climate variability.
- It systematically examines institutional interactions among FWUCs, CFis, and district-level coordination bodies to assess the evolving governance architecture surrounding BSL.
- It frames the lake not merely as an ecological site under pressure, but as a contested water allocation system where agricultural expansion, fishery sustainability, and climate resilience intersect.

By synthesising hydrological, ecological, and institutional dimensions within a single analytical framework, this study aims to advance understanding of how multiple-use wetlands in the CMD can transition toward more climate-resilient and IWRM pathways.

3. Methodologies

3.1. Systematic research design

This study systematically reviewed BSL research across four key thematic areas: hydrology, ecosystem health and biodiversity, water resource utilisation, and institutional governance. This comprehensive review was further enriched by integrated research, drawing from technical hydrological analysis and fieldwork conducted in Prey Veng, which included Key

Informant Interviews (KIIs) and Focus Group Discussions (FGDs). A significant emphasis in the reviewed literature was placed on qualitative, socio-institutional analysis, particularly concerning the Water-Land-Food Nexus and the institutional arrangements governing these resources. This provided a robust analytical framework for understanding the underlying causes of environmental degradation and social vulnerability within this critical wetland ecosystem. Recent research efforts, especially under the CGIAR Initiative on Asian Mega-Deltas, were instrumental in highlighting the fundamental conflict between intensified agricultural production, specifically dry-season rice farming, and the long-term sustainability of traditional capture fisheries.

3.2. Secondary data collection

Secondary datasets were compiled to support hydrological assessment, spatial analysis, and agricultural water demand estimation. These included hydro-meteorological records (rainfall, temperature, relative humidity, evaporation, wind speed and direction, solar radiation), irrigation scheme documentation, spatial zoning maps, canal network maps, cropping calendars, and remote sensing products. Remote sensing datasets were processed to quantify seasonal variations in lake surface area, providing the foundation for storage volume estimation and hydrological assessment.

Data were obtained from authoritative institutions, including the MOWRAM and its Provincial Department (PDWRAM), the Provincial Department of Agriculture, Forestry and Fisheries (PDAFF), the RGC, and CGIAR-affiliated initiatives. Key datasets used in the hydrological assessment are summarised in Table 1 below.

Table 1: Data sources collected and used for hydrological assessment

Data	Description	Year/Period	Source
Weather Data	Hourly data at Prey Veng station, such as temperature, rainfall, evaporation, sunshine hours, relative humidity, solar radiation, wind direction, and speed	2014 - 2024	MOWRAM
Delineation and Zoning Map	Map of the delineation and zoning of management areas in the multiple-use area of Toulpontalei Boeng Sneh	2021	RGC – Sub-decree No. 17
Canal Network Map	Map of the main canal network in the Boeng Sneh irrigation system	-	PDWRAM
	Map of the canal network digitised using Google Earth Pro	-	-
Water Surface Area Map	Changes in BSL's water surface area from remote sensing data between February and June	2019 - 2024	Copernicus Sentinel-1
Evapotranspiration Map	Evapotranspiration in BSL and surrounding areas from remote sensing data between February and May	2024	USGS-Landsat
Cropping Calendar	Cropping calendar of wet- and dry-season rice and other vegetables in Ba Phnom District	2025	DTWG – Boeng Sneh

Source: Authors

3.3. Primary data collection

Primary data collection was conducted in three field phases between September and December 2025, combining technical measurements with participatory stakeholder engagement to bridge data gaps.

Phase I: Multi-stakeholder assessment (30 September – 3 October 2025)

The first field mission focused on qualitative data collection and institutional mapping. Activities included:

- **Site visits:** Direct inspection of irrigation schemes, pumping stations, and hydraulic infrastructure surrounding BSL to assess operational status and abstraction practices.
- **FGDs:** Conducted with members of the DTWG, Community Fisheries (CFis), FWUCs, Agricultural Cooperatives, farmers, and fishers. Discussions explored water access constraints, sectoral conflicts, seasonal extraction patterns, and adaptive strategies.
- **KIIs:** Held with village chiefs and district-level representatives to clarify governance mandates, coordination mechanisms, and institutional challenges.

Phase II: Bathymetric survey and storage estimation (21–24 October 2025)

Bathymetric data of the lake were collected during the second field mission to map the depth distribution and construct a Digital Elevation Model (DEM) of the lake. The field survey was executed by Commune Agricultural Officers and the WorldFish research team. A systematic 500 m grid was first established in QGIS using the Create Grid tool, defining 121 reference locations across the lake surface and seasonally inundated floodplain.

Depth measurements at each systematic grid point were taken manually by dropping a measuring rope tied to a heavy conical plumb weight from a boat until it reached the lakebed. To prevent the spatial smoothing of fine-scale topography and avoid underestimating the capacity of BSL's critical dry-season refugia, the systematic 500 m grid was supplemented by 19 targeted manual depth measurements taken directly within the physical boundaries of the nine known deep pools. The team sampled a few points per pool to capture the maximum and average depths of the lake. The 19 targeted deep pool depth measurements were combined with the 121 systematic grid points and interpolated in QGIS using the Raster Interpolation tool with the Inverse Distance Weighting (IDW) method to generate a high-resolution bathymetric DEM with a 10 m spatial resolution.

Phase III: Irrigation mapping and water-use verification (15–18 December 2025)

The third field mission addressed data gaps related to irrigation command areas, canal networks, cropping patterns, and water withdrawal volumes.

- **Institutional Coordination:** Technical meetings were held with PDWRAM to validate irrigation infrastructure mapping and refine command area delineation. Consultations with PDAFF focused on cropping schedules and agricultural water demand.
- **Field Verification and Community Consultation:** Water withdrawal data were collected from clean water supply stations. FGDs with approximately 20 FWUC representatives and farmers were conducted to verify irrigation boundaries, seasonal cropping intensity, and demand fluctuations.

3.4. Near-real-time monitoring system

3.4.1. Data preprocessing

Satellite data preparation was conducted using Sentinel-1 Synthetic Aperture Radar (SAR) imagery. Sentinel-1 was selected because radar data are independent of cloud cover and illumination conditions, enabling consistent monitoring of water bodies under varying weather conditions.

For the analysis, Sentinel-1 images were first filtered according to the selected temporal range corresponding to the study period. The filtered image collection then underwent standard pre-processing procedures, including geometric correction and radiometric calibration, to ensure spatial and radiometric consistency. Sentinel-1 normally provides a ~6-day revisit interval, but coverage was reduced after Sentinel-1B failed in December 2021 and was later restored with the launch of Sentinel-1C in December 2024. Accordingly, the analysis used all available Sentinel-1 observations during the study period.

Following preprocessing, the VV polarisation band was extracted for water surface detection. Water bodies typically exhibit low radar backscatter values, allowing them to be distinguished from surrounding land surfaces. A threshold-based classification method was applied to identify water pixels. From the historical Sentinel-1 images of BSL, a trial-and-error method was used to identify the backscatter values which can reliably differentiate between water surface and other land cover forms. In this approach, pixels with backscatter values lower than −15 dB were classified as water, while pixels with higher values were considered non-water.

This threshold was applied to each image within the filtered time series to generate binary water masks representing lake surface extent. The resulting masks were then compiled into a temporal stack of water surface maps, which were used to analyse variations in lake surface area throughout the study period.

3.4.2. Surface area

Lake surface area was estimated using the water masks derived from Sentinel-1 imagery. Since each pixel in the satellite image represents a known ground area based on the spatial resolution, the total water surface area can be calculated by counting the number of pixels classified as water within each mask. The number of water pixels was multiplied by the area represented by a single pixel to obtain the total water surface area for each observation. This process was applied to all images in the time series to generate a temporal record of lake surface area variations.

3.4.3. Volume calculations

Lake storage volume was estimated by integrating the monthly water masks with a bathymetric DEM of the lake. Both datasets were maintained at the same spatial resolution to ensure accurate pixel-level analysis. The water masks were spatially aligned with the bathymetric DEM so that each water pixel corresponded to a depth value from the bathymetry dataset. For each pixel, the water column volume was calculated by multiplying the pixel area by the corresponding depth value. The total lake volume was then obtained by aggregating the volume of all water pixels within the lake boundary. This analysis was also implemented using the Google Earth Engine platform, which allowed automated integration of satellite data and bathymetric information for large-scale spatial computation.

3.5. Operational storage threshold

To evaluate the hydrological status of BSL, this study adopted an operational storage threshold of 27 million m³ as a benchmark for interpreting seasonal storage dynamics. The threshold was elicited during an FGD with the DTWG held on 1 October 2025 at the Meanchey Community Collection Centre, in which a representative from PDWRAM participated.

During the discussion, the PDWRAM representative explained that this threshold originates from a joint bathymetric assessment conducted by MOWRAM and PDWRAM more than 30 years ago, which estimated the lake's storage capacity at approximately 65 million m³. This capacity was later increased to about 85 million m³ following the installation of an additional 30 cm crest on the spillway. Based on this historical assessment and long-term operational practice, PDWRAM has adopted approximately 27 million m³ as the minimum storage to be retained in the lake during the dry season.

This volume is considered necessary to support domestic and livestock water supply while maintaining the ecological function of the lake's nine deep pools as dry-season refugia. Accordingly, the 27 million m³ value is applied in this study as an operational management benchmark, rather than a formally derived ecological or hydrological threshold, to evaluate seasonal water availability and inform the trigger-based management framework.

3.6. Limitations and uncertainty

While this socio-hydrological assessment provides critical baseline data, several technical limitations and uncertainties must be acknowledged. First, the systematic 500 m spacing of the bathymetric grid was relatively coarse compared to BSL's localised deep pools (some as small as 4 ha), presenting a risk of under-sampling their high-gradient topography and smoothing fine-scale features during spatial interpolation. Although this was mitigated by combining the systematic grid with targeted manual measurements of the nine pools (as detailed in Section 3.3), the resulting 10 m DEM remains subject to localised interpolation uncertainties in transition zones between the flat floodplain and the steep pool depressions.

Second, the agricultural and domestic water abstraction analyses are constrained by data reporting limitations. The monthly domestic clean water extraction rates presented in Table 5 rely on historical billing records, estimated capacities, and self-reported operational logs from Private Water Operators (PWOs) rather than inline, continuous digital flow meters. This introduces potential under- or over-estimation of actual withdrawals, compounded by system leakage or unmetered bypasses. Furthermore, no systematic water quality monitoring datasets (e.g., dissolved oxygen, turbidity, or nutrient loading) were available; agricultural runoff and chemical pollution impacts are therefore inferred qualitatively from stakeholder testimonies during FGDs and KIIs.

Third, significant hydro-climatological and remote sensing data gaps exist within the ten-year monitoring period (2015–2025). Gaps in daily meteorological records from the Prey Veng weather station between September 2021 and April 2023 fell below the 75 percent completeness threshold and were excluded, directly limiting the reliability of the long-term precipitation-drawdown coupling trends shown in Figure 7. In parallel, the hardware failure of the Sentinel-1B satellite from December 2021 to December 2024 reduced the Sentinel-1 revisit frequency from approximately 6 to 12 days. However, because this study was designed to derive one representative water surface extent per month, the reduced revisit frequency did not materially affect the monthly water surface mapping or the resulting storage estimates.

Finally, formal uncertainty bounds for the estimated lake storage volumes were not quantified in this study due to the lack of continuous field calibration data and the complexity of propagating errors from the bathymetric DEM and satellite-derived water extent. Consequently, the reported storage volumes should be regarded as best-estimate values, and no quantitative uncertainty range is provided. Future work should incorporate field measurements and uncertainty analysis to quantify the confidence of the volume estimates.

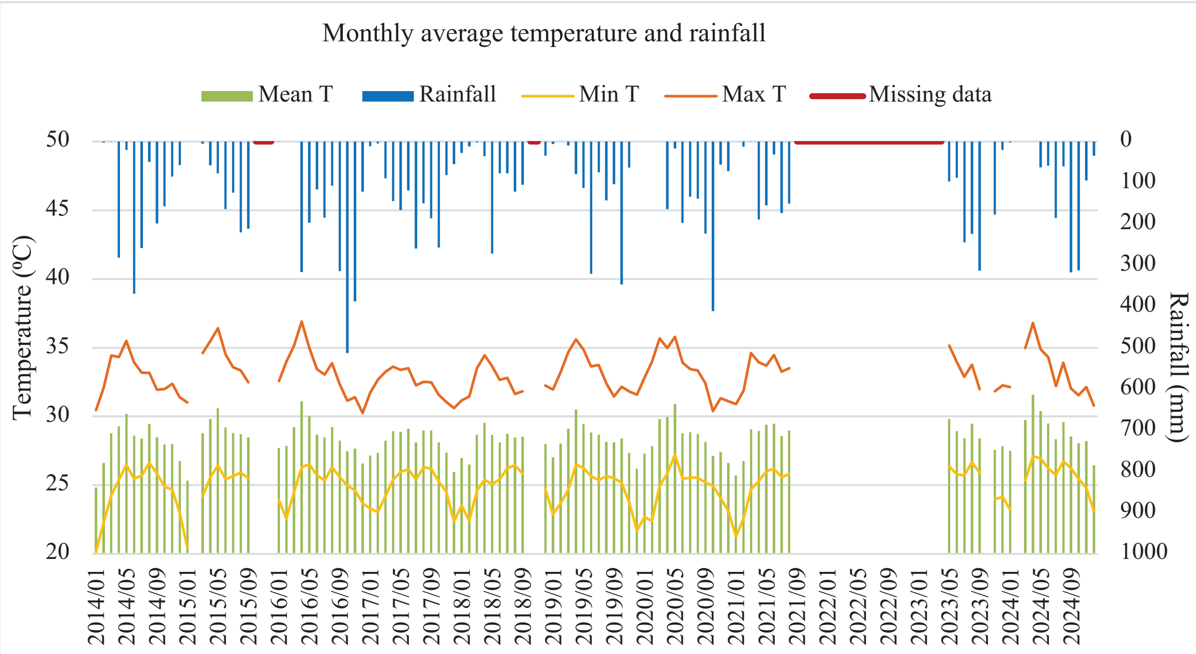
4. Hydrological characteristics of BSL

4.1. Climatological trends

Hourly weather data for the Prey Veng station (11.48888969, 105.3319016), the closest weather station to BSL, covering the period 2014–2024, were obtained from MOWRAM. The dataset includes air temperature, rainfall, evaporation, sunshine duration, relative humidity, solar radiation, wind direction, and wind speed. The raw hourly observations were cleaned and aggregated into daily, monthly, and annual datasets. Notably, there are substantial data gaps, particularly for the years 2015, 2021, 2022, and 2023. During the data aggregation process (hourly to daily, daily to monthly, and monthly to yearly), only periods with at least 75 percent data completeness were included in the calculations.

Figure 3 illustrates the monthly average temperature (maximum, minimum, and mean) together with monthly rainfall in Prey Veng. The chart also highlights substantial data gaps from September 2021 to April 2023, during which hourly observations did not meet the 75 percent completeness threshold required for inclusion in the monthly dataset. For the periods with available data, the monthly mean temperature ranges from approximately 25°C to 31°C, with the coolest conditions typically occurring in December–January and the warmest in April–May. Monthly average maximum temperatures remain between about 30°C and 37°C, while monthly average minimum temperatures range from 20°C to 27°C. This consistently high thermal regime likely contributes to elevated evapotranspiration rates and hydrological stress within the BSL system.

Figure 3: Monthly average temperature and rainfall in Prey Veng from 2014 to 2024



Note: There are substantial data gaps, particularly between 2021 and 2023, where the 75 percent completeness threshold was not met. Source: MOWRAM

Rainfall exhibits a pronounced seasonal pattern, with lower totals during the dry season (generally December to April) and substantially higher totals during the wet season (May to October). Peak monthly rainfall commonly occurs between August and October, with several months exceeding 300–500 mm. Considerable interannual variability is also evident, as some wet-season months receive markedly higher rainfall than others.

Table 2 presents the average monthly meteorological data, characterising a distinct monsoonal cycle where maximum temperatures peak in April at 35.1°C, coinciding with the highest daily sunshine duration of 10.0 hours and the end of a prolonged dry period. Rainfall patterns show an extreme contrast, with the lowest precipitation occurring in February at 4.5 mm before surging to a peak of 332.9 mm in October, which also records the highest mean relative humidity at 83.0 percent. Humidity is at its lowest in March at 70.6 percent, while minimum temperatures reach their lowest average in January at 22.4°C. Wind speeds remain relatively stable throughout the year, varying only slightly from a minimum of 1.5 m/s in October to a maximum of 2.1 m/s in August. Collectively, these variables define a period of intense thermal and evaporative demand from February to May, which drives the rapid seasonal drawdown of BSL's hydrological systems.

Table 2: Average monthly climate variables at Prey Veng from 2014 to 2024

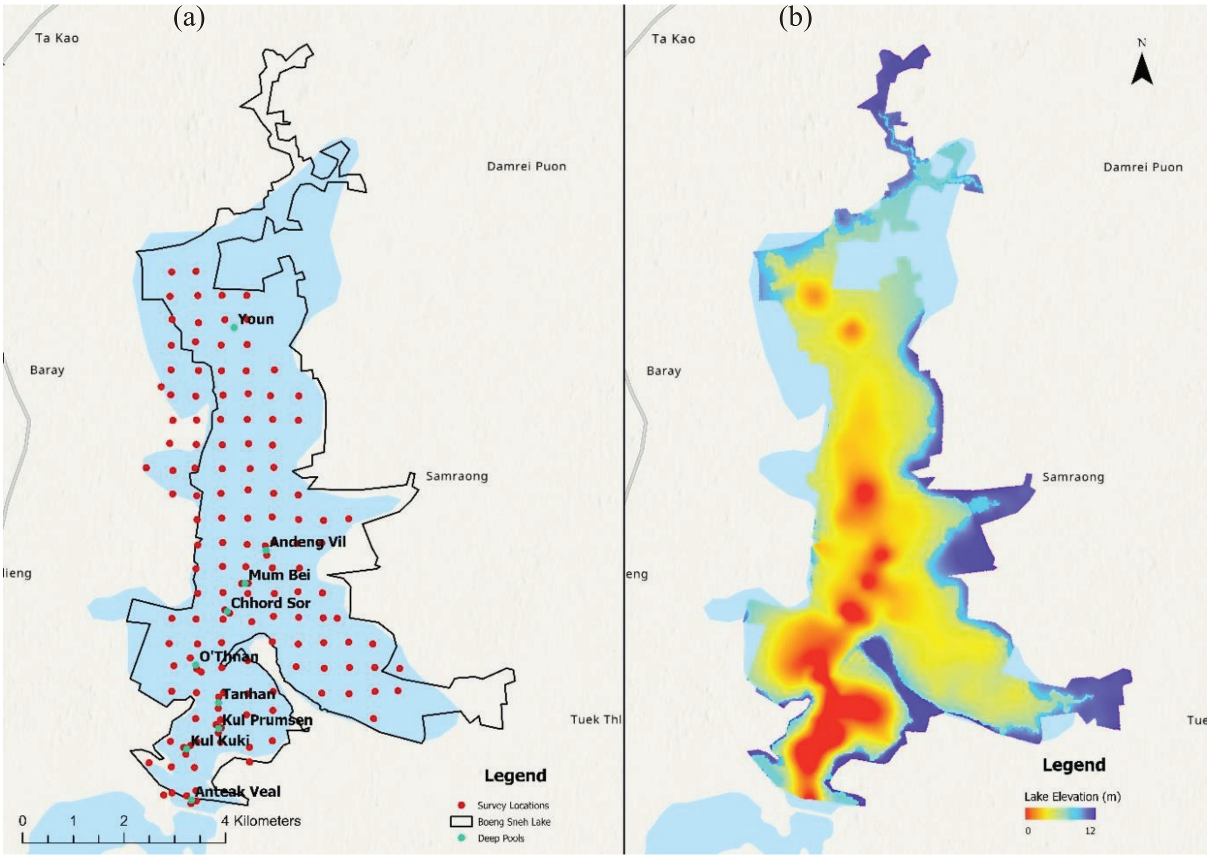
Variables	Unit	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T (max)	°C	31.6	32.8	34.5	35.1	34.8	33.8	33.0	33.1	32.1	31.5	31.7	31.3
T (min)	°C	22.4	22.7	24.6	25.9	26.3	25.8	25.6	26.2	25.8	25.1	24.3	23.2
Rainfall	mm	5.3	4.5	12.0	141.0	117.6	154.0	171.4	136.5	219.1	332.9	134.8	49.2
RH (mean)	%	71.9	71.0	70.6	73.2	77.5	78.3	76.1	80.2	82.1	83.0	80.1	75.0
Wind Speed	m/s	1.7	1.7	1.9	1.8	1.6	1.8	2.0	2.1	1.8	1.5	1.7	2.0
Sunshine Hour	hour/day	9.1	9.5	9.9	10.0	9.7	9.4	9.4	9.4	9.3	9.2	9.1	8.9

Note: Averages are calculated using available data for each month from 2014–2024, excluding the 2021–2023 gap where the 75 percent completeness threshold was not met. Source: MOWRAM

4.2. Bathymetry and ecological refugia

The section presents the results of water-level measurements conducted at BSL from 21–24 October 2025 by Commune Agricultural Officers and the WorldFish research team. Measurements were collected at 121 systematic locations across the lake (including both the official lake boundary and surrounding floodplain areas), supplemented by 19 targeted measurements within the nine deep pools, to characterise the lake's bathymetry (Figure 4a). The water elevation data obtained from the measurement was then developed into the DEM, which illustrates the varying topography of the lake. Presented in Figure 4b, the lake is characterised by a deep central basin (red to yellow), surrounded by progressively shallower margins (green to purple). The extensive shallow peripheral zones indicate areas that become hydraulically connected to the main lake as water levels rise during the wet season. As water levels decline, these higher-elevation floodplain areas are the first to become disconnected and dewatered, leaving the deeper central "spine" of the lake and its deep pools as the primary remaining water bodies during the dry season.

Figure 4: Lake elevation measurement points, including the nine deep pool locations (a) and the lake DEM (b)



Source: Authors

The lake has a maximum depth of 5.10 m, a minimum depth of 0.50 m, and an average depth of 2.33 m across measured points (Table 3). These values indicate moderate depth variation, suggesting that while certain parts of the lake retain significant water levels, other areas are relatively shallow, reflecting natural heterogeneity in basin morphology and possibly localised sedimentation.

Table 3: Max, min, and average depths of BSL, measuring at 121 different locations

No.	Measurement	Value
1	Maximum Depth (m)	5.10
2	Minimum Depth (m)	0.50
3	Average Depth (m)	2.33

Source: Authors

Table 4 details the sizes and average depths of nine deep pools within BSL. Eight of the nine deep pools each cover an area of 4 hectares, while the remaining pool spans 7 hectares. Collectively, the nine deep pools occupy about 1 percent of the total BSL area. The pools have average depths ranging from 3.80 to 5.95 meters. The Tanhan deep pool is the deepest, averaging 5.95 meters, while the Youn deep pool is the shallowest at 3.80 meters. Several other pools, including Kul Prumsen (5.90 m) and Kul Kuki (5.50 m), also maintain substantial depths, suggesting their importance as potential dry-season water refuges for aquatic biodiversity and local water use.

Table 4: Sizes and average depths of deep pools within BSL

No.	Name of Deep Pool	Latitude	Longitude	Size (ha)	Average Depth (m)
1	Andeng Vil	11.425441	105.39640	4	4.40
2	Anteak Veal	11.381125	105.38316	4	4.97
3	Chhord Sor	11.414593	105.38952	4	5.00
4	Kul Kuki	11.390187	105.38233	4	5.50
5	Kul Prumsen	11.393827	105.38798	7	5.90
6	Mum Bei	11.419576	105.39267	4	4.25
7	O'Thnan	11.405105	105.38395	4	5.40
8	Tanhan	11.398410	105.38798	4	5.95
9	Youn	11.465032	105.39074	4	3.80

Source: Authors

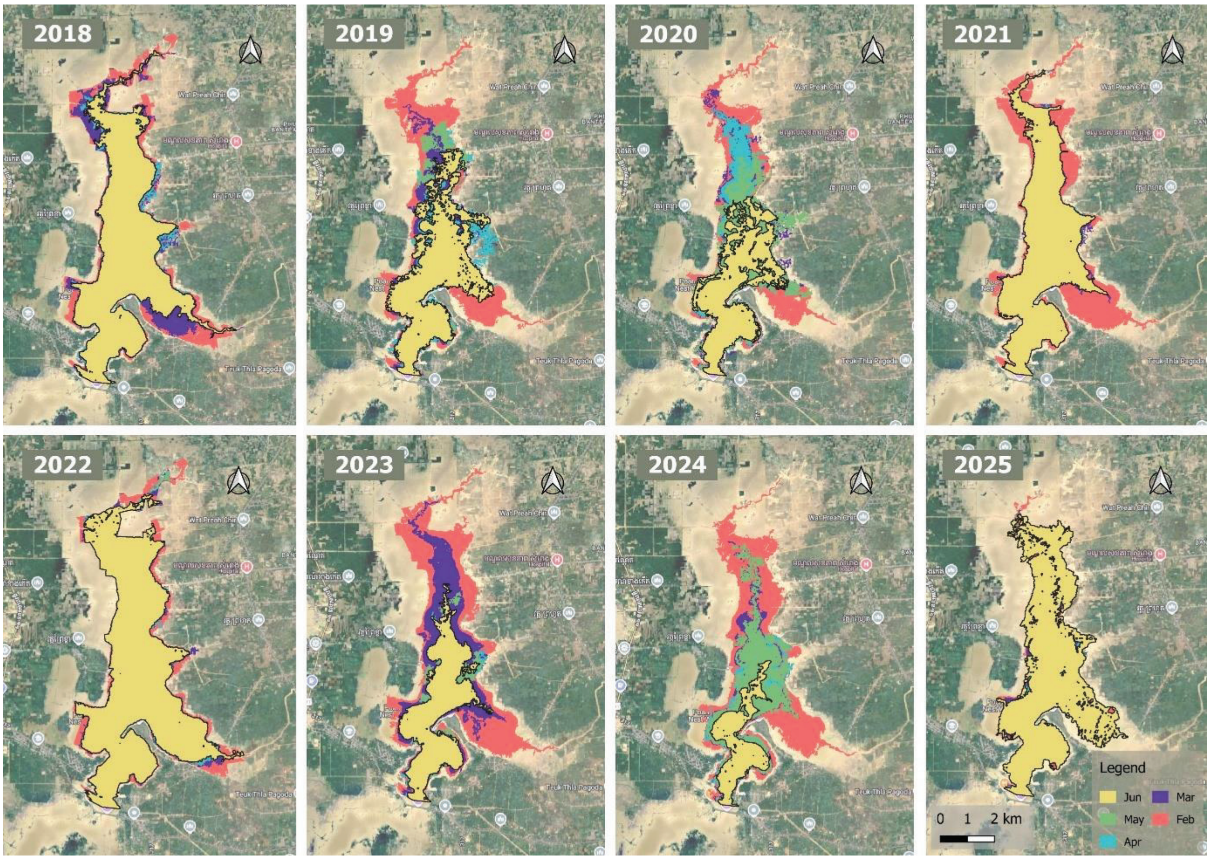
4.3. Lake morphometry and surface-volume relationship

Figure 5 illustrates the seasonal variation and interannual changes in the water surface area of BSL between February and June for the years 2018–2025, derived from remote sensing analysis. The classified satellite imagery shows a progressive contraction of open water areas from February toward June each year, corresponding to the transition from the mid-dry to early wet season.

Over the years, the extent of the lake's surface area has shown considerable interannual variability. In 2019, 2020, 2023, and 2024, the lake exhibits smaller and more fragmented water bodies as early as February, indicating reduced water retention capacity. The surface area continues to decline sharply toward June, reaching its minimum extent in 2024. In contrast, 2018, 2021, 2022, and 2025 display substantially larger inundated areas, likely associated with above-average rainfall or delayed dry-season drawdown—although this could not be confirmed due to missing rainfall data between 2021 and 2023. Overall, the observed decline in dry-season surface area throughout the analysis period suggests increasing hydrological stress, likely driven by lower or absent rainfall, elevated evapotranspiration between February and June, and intensified water extraction for irrigation purposes.

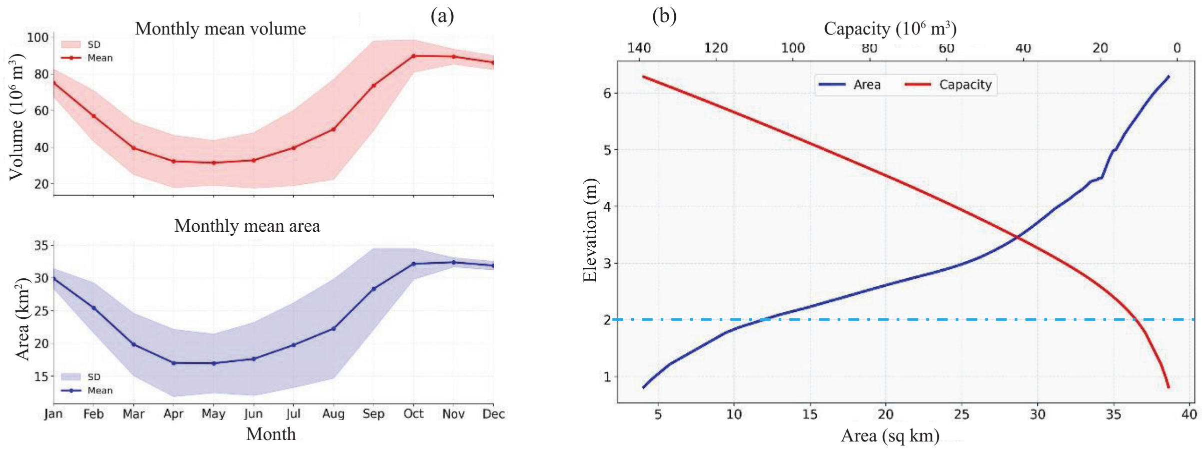
The monthly volume and area plots indicate a pronounced seasonal drawdown, with water storage reaching its minimum in April–May (Figure 6a). During this period, mean lake volume declines to just above 30 million m^3, while the surface area contracts to approximately 17 km^2. In contrast, both volume and area increase sharply during the wet season, peaking around October–November. The relatively large standard deviation during these peak months highlights considerable interannual variability, reflecting the influence of the Mekong flood pulse.

Figure 5: Changes in BSL surface area between February and June from 2018 to 2025



Source: Authors

Figure 6: Monthly BSL surface area and storage volume (a) and their relationships with water elevation above the lakebed (b)



Note: Shaded bands in (a) represent ±1 standard deviation (SD). The blue dashed horizontal line at 2 m in (b) indicates the floodplain connectivity threshold; 0 m corresponds to the lowest point of the lakebed.

Source: Authors

The relationships between lake capacity, surface area, and water elevation are distinctly non-linear (Figure 6b). The curves show that both storage capacity and surface area increase gradually at lower water elevations, followed by a more rapid expansion as water levels rise beyond 2 m. This behaviour reflects the transition from the confined lake basin to the surrounding floodplain. Beyond this threshold, small increases in water elevation correspond to substantial gains in area and volume until overbank spilling occurs. These relationships support the use of satellite-derived surface area as a practical proxy for estimating lake storage, particularly in data-scarce conditions, and provide a useful basis for informing irrigation planning and water allocation.

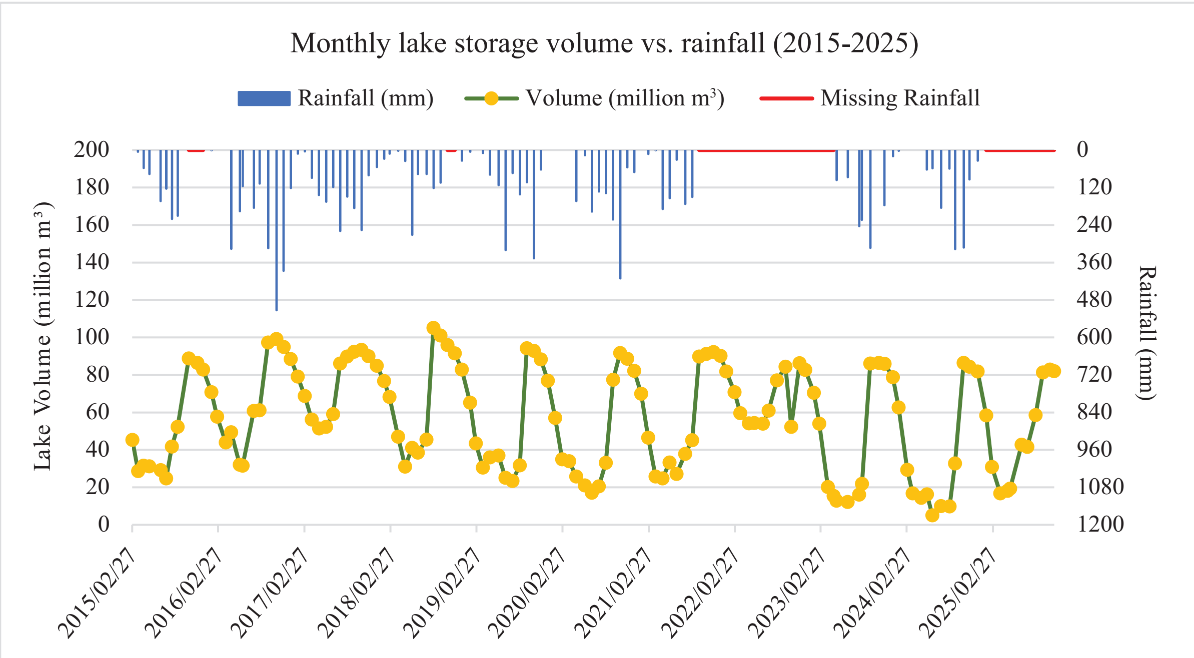
4.4. Seasonal storage pattern

Figure 7 illustrates a strong seasonal coupling between rainfall at Prey Veng station and the storage capacity of BSL, showing that volume typically peaks between September and November at 80–100 million m^3, when cumulative rainfall and Mekong floodplain connectivity replenish the system. This is followed by a rapid drawdown during the February–June period, which corresponds with the thermal and evaporative peak seen in earlier meteorological data—specifically the April temperature maximum of 35.1°C and the extreme rainfall scarcity during January and March.

While the lake historically retained 20–35 million m^3 during the dry season, the results show that storage declined to approximately 5–15 million m^3 in 2023 and 2024. These extreme lows fall well below the 27 million m^3 operational storage threshold adopted in this study based on institutional practice derived from historical MOWRAM–PDWRAM bathymetric assessment and confirmed through stakeholder consultation. This threshold represents the minimum dry-season storage maintained to support domestic and livestock water supply while sustaining the ecological function of the lake's nine deep pools as dry-season refugia.

Interannual variability is pronounced and has direct management implications, with weaker or delayed rainfall years exhibiting lower peak storage and earlier drawdown, while wetter years maintain higher volumes into the early dry season.

Figure 7: Monthly lake storage volume changes against rainfall from 2015 to 2025



Source: Authors and MOWRAM

5. Water consumption and management

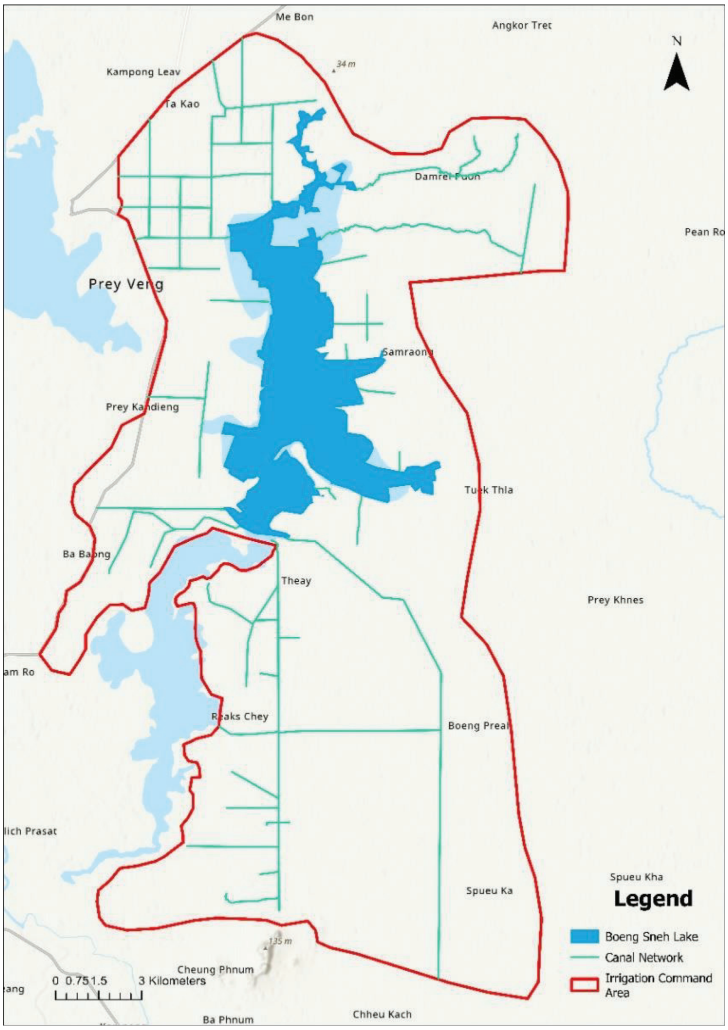
5.1. Agricultural water-use

5.1.1. Irrigation command area

A definitive irrigation command area boundary, demarcated in red line as shown in Figure 8, was established during a multi-stakeholder consultation on December 17, 2025. This delineation was facilitated by representatives from six local FWUCs surrounding the lake: Domrey Poun (North-east), Theay (South-east), Roung Domrey (South), Ba Boang (South-west), Prek Kandieng (West), and Toul Skea (North-west). By cross-referencing PDWRAM canal network maps with localised operational knowledge, the FWUC representatives identified the specific agricultural blocks under their authority that rely on BSL for dry-season irrigation supply.

The defined irrigation command area extends up to 13 km south of BSL and several kilometres in other directions, measured from the lake boundary. This verified boundary represents a critical technical achievement for the DTWG, as it provides the spatial baseline required for future estimation of irrigation water requirements and determination of equitable water allocation quotas during periods of intense dry-season drawdown. The major canal network shown in Figure 8 (depicted as blue lines), obtained from the PDWRAM in Prey Veng, underpins this spatial analysis; originally available in PDF format, the network was digitised using Google Earth.

Figure 8: Digitised irrigation canal network (green lines) and verified irrigation command area boundary (red line) supplied by BSL

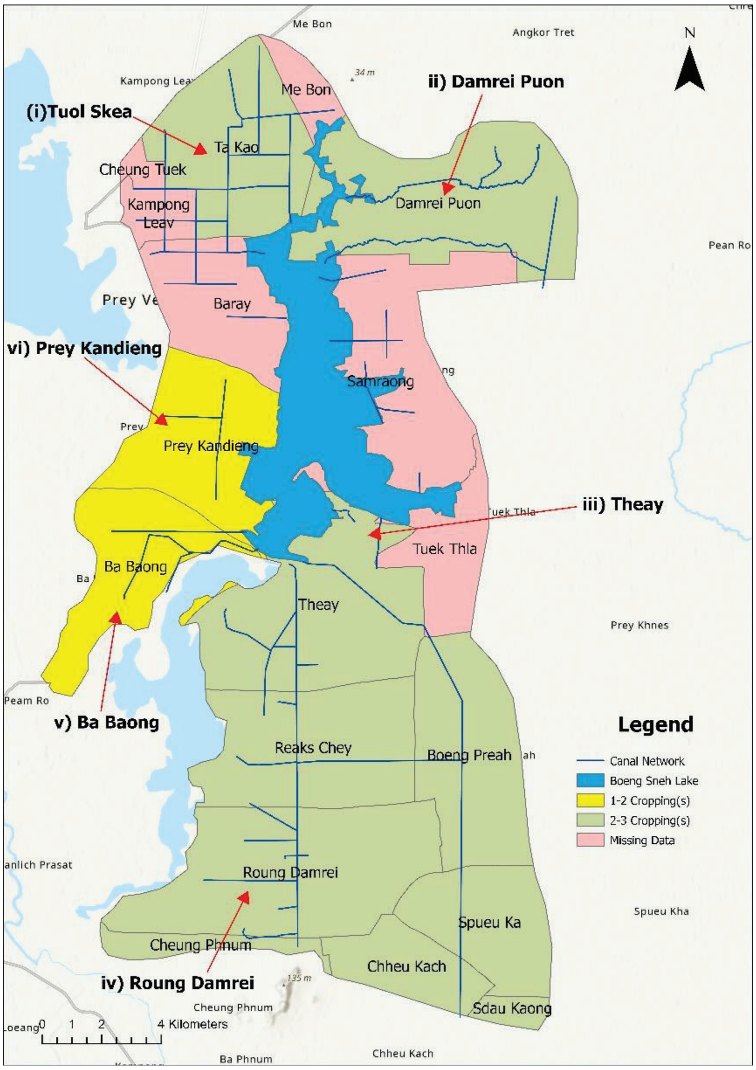


Source: Authors

5.1.2. Cropping intensity

The cropping intensity map around BSL (Figure 9) reveals a distinct spatial pattern in agricultural intensity. Areas with 1–2 croppings per year (light yellow) are concentrated mainly on the western (Prey Kandieng) and southwestern (Ba Baong) sides of the lake, which correspond to floodplain zones that are regularly inundated during the wet season; as a result, cultivation in these areas is largely limited to the period after floodwaters recede. In contrast, 2–3 croppings per year (dark yellow) dominate much of the land to the north (Tuol Skea), northeast (Damrei Puon), and south (Theay and Roung Damrei irrigation schemes) of the lake, forming larger and more continuous zones that closely follow the canal network, reflecting more reliable access to irrigation water and enabling intensive multi-season farming. The lake itself serves as a central water source within this system, while small, scattered areas of missing data do not alter the overall pattern, which underscores that the lower cropping intensity in the western and southwestern floodplain areas is primarily constrained by seasonal inundation rather than by the absence of agricultural land or irrigation systems.

Figure 9: Spatial distribution of cropping intensity in agricultural areas receiving water from BSL, particularly during the dry season



Source: Authors

5.1.3. Cropping calendar

Figure 10 illustrates the cropping calendars of the irrigation scheme and farm areas around BSL that use water from the lake for irrigation, particularly in the dry season.

i) **Tuol Skea:** The cropping calendar for the Tuol Skea irrigation scheme in the northern part of BSL reflects an intensified rice-based system dominated by short- and medium-duration varieties. The 1st short-duration dry-season rice crop of about 1,193 ha is cultivated from May to August at the onset of the monsoon. In parallel, a medium-duration rice crop spanning roughly 511 ha extends from May to mid-October. The 2nd short-duration rice crop of approximately 2,211 ha is grown from September to December, followed by the 3rd short-duration rice crop of the same area (2,211 ha) relying on residual wet-season storage.

ii) **Damrei Puon:** The cropping calendar for the Damrei Puon irrigation scheme, located in the northeastern part of BSL, shows a diversified rice system combining short-, medium-, and long-duration varieties. The 1st short-duration rice crop, covering approximately 256 ha, is cultivated from May to August. In parallel, a medium-duration rice crop of roughly 150 ha extends from May to September, while a long-duration crop covering approximately 21 ha spans May to November, relying mainly on rainfall throughout the wet season. The 2nd short-duration crop of around 256 ha is grown from September to December, followed by the 3rd short-duration crop of about 599 ha from January to April, relying on irrigation water from the lake.

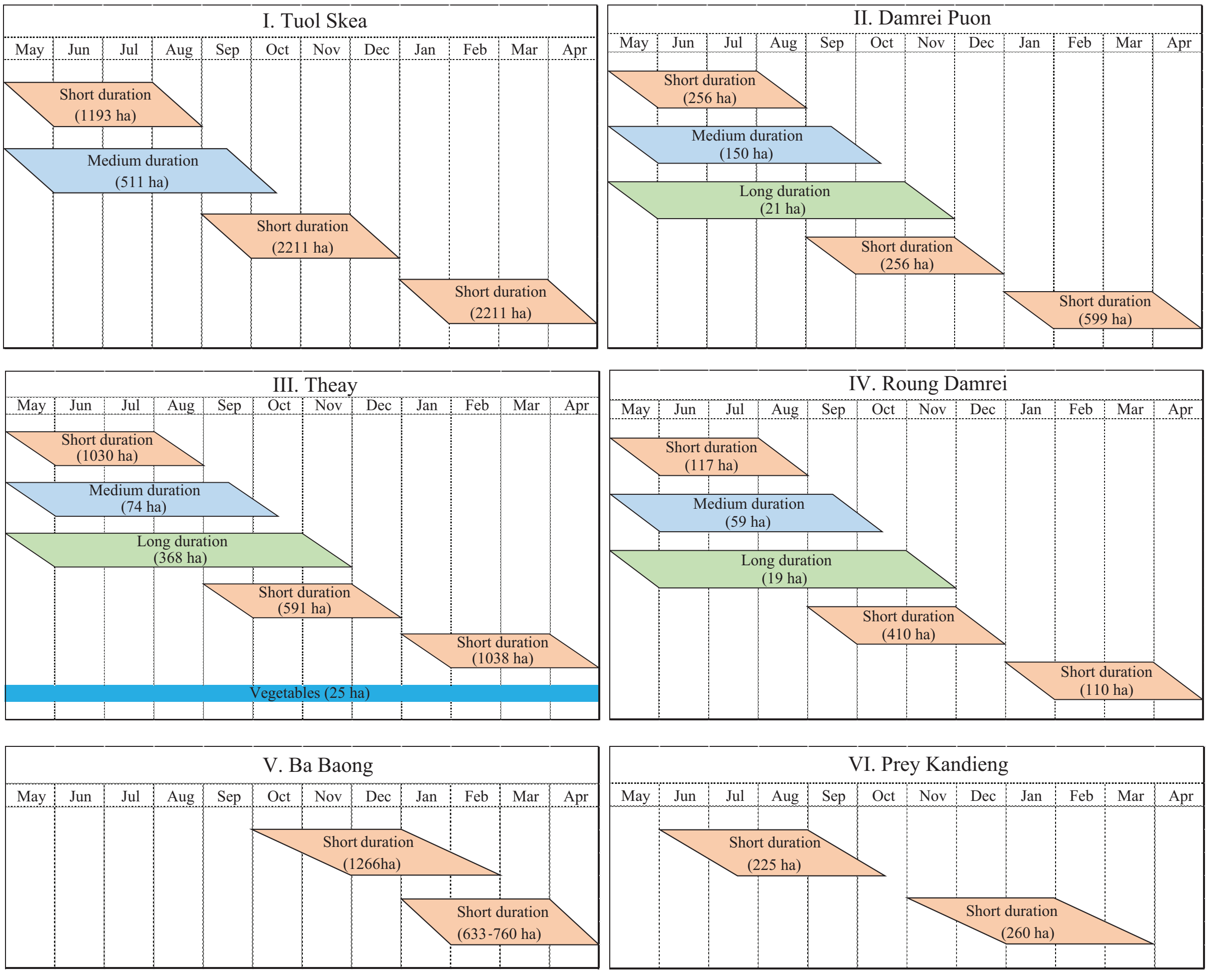
iii) **Theay:** The cropping calendar for the Theay irrigation scheme, located in the southern part of and next to the lake, reflects an intensified and diversified agricultural system combining rice and vegetable production. The 1st short-duration dry-season rice crop, covering approximately 1,030 ha, is cultivated from May to August. In parallel, a medium-duration rice crop of roughly 74 ha extends from May to September, while a long-duration rice crop covering approximately 368 ha spans May to November, relying primarily on wet season rainfall. The 2nd short-duration crop of around 591 ha is grown from September to December, followed by the 3rd short-duration crop of about 1,038 ha from January to April, relying on irrigation water from the lake. In addition to rice, a mix of vegetable cultivation (~25 ha), particularly water convolvulus/water spinach, occurs throughout the year, maintaining continuous water demand.

iv) **Roung Damrei:** The cropping calendar for the Roung Damrei irrigation scheme, located in the southern part of and further from the lake, follows an intensive triple-cropping system focused on short-duration varieties. The 1st short-duration crop of about 117 ha is cultivated from May to August, utilising early rainfall and supplemental irrigation. In parallel, a medium-duration rice crop of roughly 59 ha extends from May to mid-October, while a long-duration rice crop covering approximately 19 ha spans May to November, relying primarily on wet season rainfall. This is immediately followed by the 2nd short-duration crop of about 410 ha from September to December, sustained by monsoon rains and supplementary irrigation. The 3rd short-duration crop (~110 ha) is grown from January to April, relying on irrigation water from the lake.

v) **Ba Baong:** The cropping calendar for the Ba Baong irrigation scheme, located in the southwestern part of BSL, is characterised by a single/double-cropping cycle. The 1st short-duration crop of about 1,266 ha begins in October/November and reaches harvest by January/February. It is followed by the 2nd short-duration crop of approximately 633-760 ha cultivated from January to April, relying extensively on the primary and secondary canal networks to extract water from the lake.

vi) Prey Kandieng: The cropping calendar for the Prey Kandieng irrigation scheme, located on the western side of BSL, follows a single/double-cropping cycle synchronised with the lake's seasonal pulse. The 1st short-duration crop of about 225 ha is sown in June/July and harvested by September/October, established through rainfall and supplementary irrigation. The 2nd short-duration crop of about 260 ha spans from November/December to February/March, relying on irrigation water from the lake.

Figure 10: Cropping calendars of irrigation schemes and farmlands taking water from BSL



Note: i) Tuol Skea (north), ii) Damrei Puon (northeast), iii) Theay (southeast), iv) Roung Damrei (south), v) Ba Baong (southwest), and vi) Prey Kandieng (west).

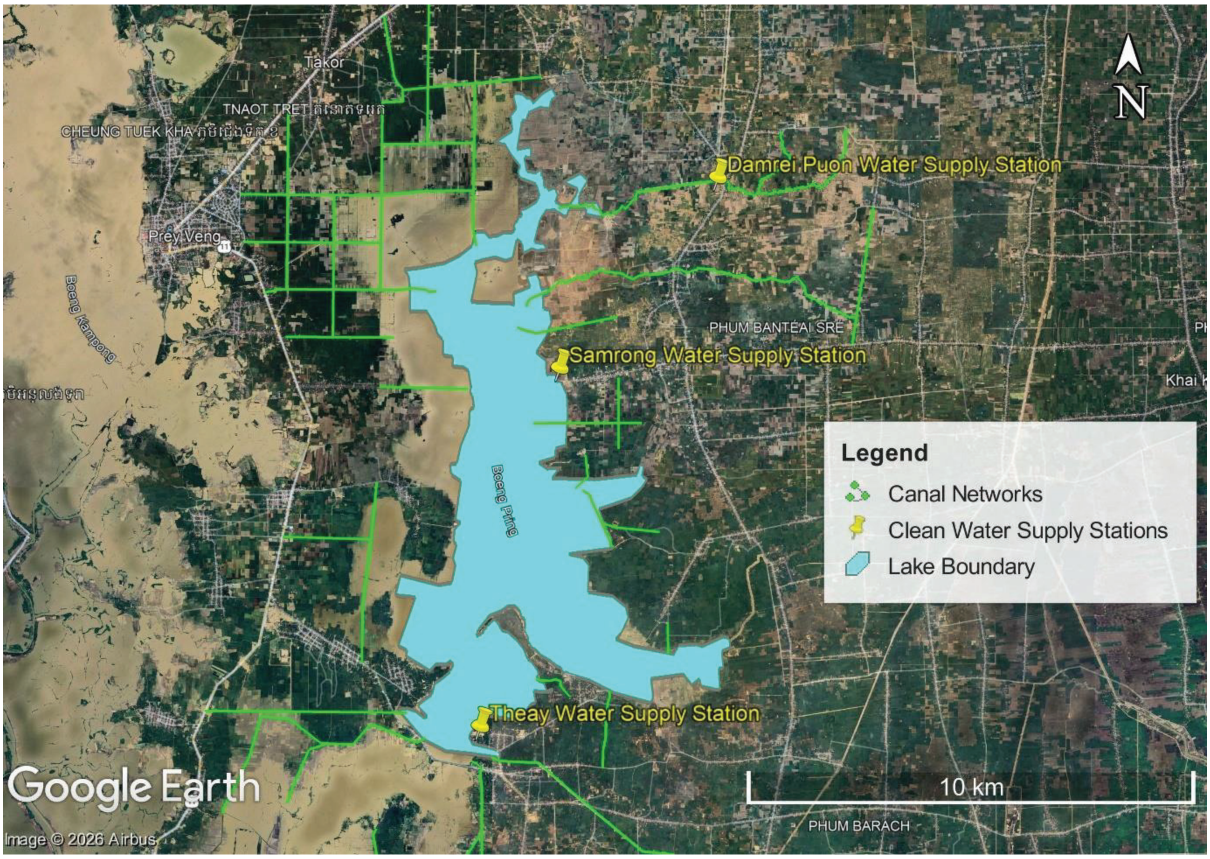
Source: Authors

5.2. Domestic consumption

Beyond agricultural demand, BSL is a vital source of domestic water supply. Currently, three clean water supply stations are located around the lake and are operated by two PWOs: Theay to the south, Samrong to the east, and Damrei Puon to the northeast (Figure 11). These facilities withdraw water directly from the lake surface and indirectly through groundwater wells, reflecting the high hydrological connectivity between the lake and the surrounding aquifer, to supply domestic users in the region.

As detailed in Table 5, the domestic clean water supply system around BSL represents a tiered expansion of regional infrastructure, with the earliest operational station established at Theay in 2020, followed by Samraong in 2021 and Damrei Puon in 2024. Although the total service area covers approximately 21,066 households, only 4,029 households (about 19 percent) are currently connected, indicating that the system remains in an early to intermediate stage of coverage expansion. Among the three facilities, Theay is the largest service provider, supplying water to 2,640 households, which exceeds the combined connections of the other two stations.

Figure 11: Locations of clean water supply stations extracting water directly and indirectly (via a drilled well) from the lake



Source: Google Earth, satellite imagery, accessed 7 July 2026.

When normalised by household demand, clear differences in water use intensity emerge across stations and seasons. Dry-season consumption is consistently higher than wet-season demand, reflecting increased reliance on piped supply during periods of reduced alternative water availability. The highest dry-season intensity is observed at Theay (473 L/HH/day), followed by Samraong (292 L/HH/day) and Damrei Puon (110 L/HH/day). Seasonal variation is also evident at Samraong and Theay, where wet-season demand decreases to 216 L/HH/day and 284 L/HH/day, respectively, indicating partial substitution by alternative water sources during the rainy season.

Overall, these patterns indicate strong spatial and seasonal heterogeneity in domestic water demand across the BSL service network. The pronounced dry-season increase in abstraction coincides with periods of minimum lake storage, highlighting the importance of maintaining sufficient dry-season reserves to sustain domestic supply while supporting the ecological function of the lake’s nine deep-pool refugia.

Table 5: Clean water supply stations and their water extraction information

No.	Station	Source of Water	Year of Operation	Connected HHs (HHs)	HHs in Service Area (HHs)	Wet Season Withdrawal		Dry Season Withdrawal	
						(m^3/ month)	L/HH/ day	(m^3/ month)	L/HH/ day
1	Damrei Puon	Groundwater	2024	557	5,416	-	-	1,837	110
2	Samrong	Lake water & groundwater	2021	832	5,800	5,400	216	7,290	292
3	Theay	Lake water & groundwater	2020	2,640	9,850	22,500	284	37,500	473
Total				**4,029**	**21,066**	-	-	**46,627**	**-**

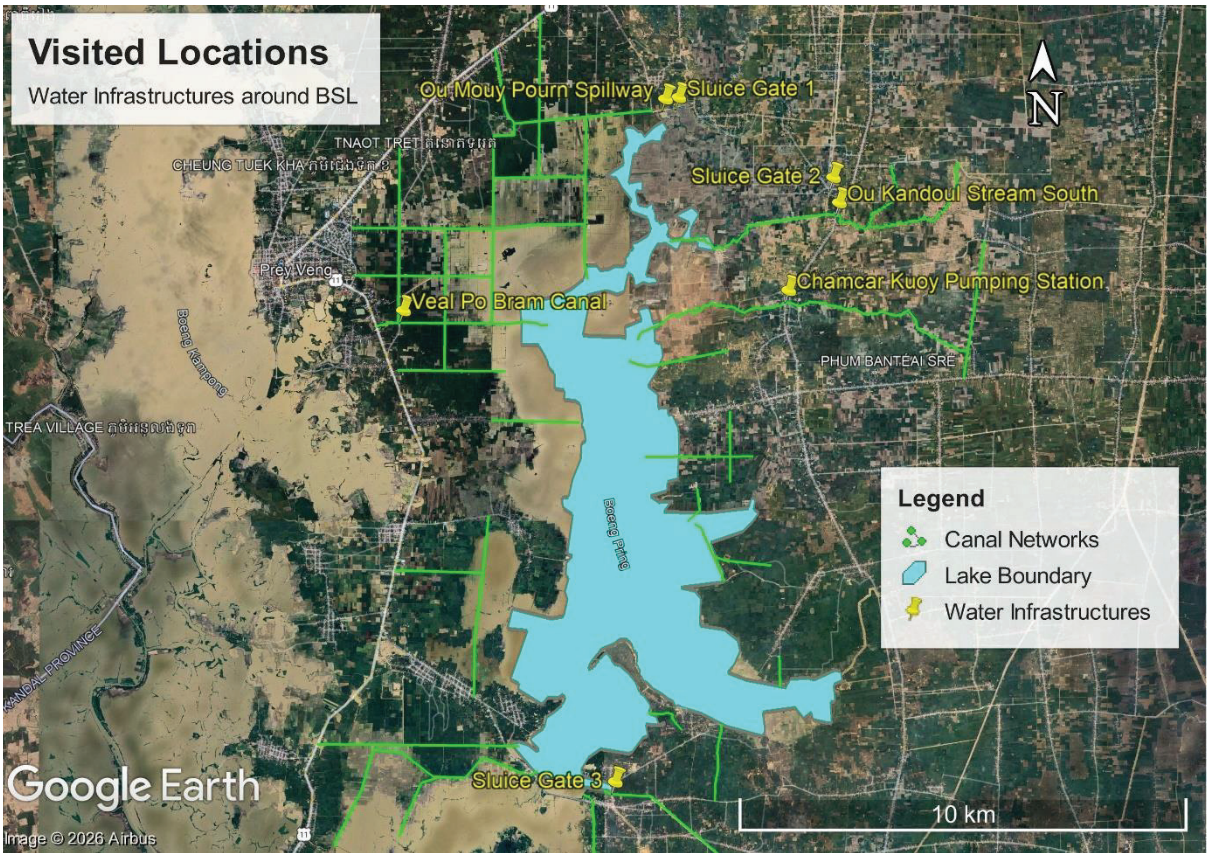
Note: The information provided in the table above was obtained from the PWOs' owner and representative during the interview on 16 December 2025.

Source: Authors

5.3. Water infrastructures

Figure 12 presents a geo-referenced satellite image of the BSL area, highlighting the locations of key water infrastructure sites visited during the field survey conducted on 30 September 2025. These physical structures—comprising canals, sluice gates, spillways, pumping stations, and natural streams—play a critical role in regulating water inflow to and outflow from BSL, as well as in distributing water for irrigation across surrounding agricultural lands.

Figure 12: The major visited locations of water infrastructures around BSL



Source: Google Earth, satellite imagery, accessed 7 July 2026.

Field observations revealed that the majority of these infrastructures are interconnected components of the Boeng Sneh irrigation and drainage system, directly influencing the lake's hydrological balance and water availability for both agricultural and domestic use. The system supports the operation of FWUCs and Community Fisheries (CFis), underscoring the tight linkage between engineered and natural water pathways in maintaining local livelihoods and ecosystem functions.

Table 6 provides a summary of the eight major sites visited, detailing their functions, structural characteristics, and approximate geographic coordinates. These include major inflow and outflow control points such as the Ou Mouy Pourn Spillway, Sluice Gates 1–3, and the Chamcar Kuoy Pumping Station, which collectively manage water exchange between BSL, the Mekong River, and adjacent agricultural areas. The field assessment found that while most structures remain operational, several require maintenance and improved monitoring to ensure equitable and sustainable water distribution, particularly during the dry season when extraction pressure intensifies.

Table 6: Summary of visited locations of water infrastructures around BSL

No.	Name*	Type of Structure	Description*	Latitude	Longitude
1	Veal Po Bram Canal	Irrigation canal	Canal is withdrawing irrigation water from the lake.	11°28'17.48"N	105°21'8.66"E
2	Ou Mouy Pourn Spillway	Spillway	Structure allowing excess water to overflow into the lake.	11°31'2.41"N	105°24'12.67"E
3	Sluice Gate 1	Intake gate	Gate regulating inflow from upstream into the lake.	11°31'3.47"N	105°24'22.56"E
4	Sluice Gate 2	Intake gate	Gate controlling inflow from Boeng Krapik, hydraulically connected to the Mekong River.	11°30'5.10"N	105°26'17.34"E
5	Ou Kandoul Stream South	Natural stream	Natural inflow channel contributing to the lake's replenishment.	11°29'46.67"N	105°26'21.67"E
6	Chamcar Kuoy Pumping Station	Pumping station	Facility pumping water for irrigation; constructed in 2018 under the Climate-Resilient Rice Commercialisation Sector Development Program.	11°28'42.74"N	105°25'43.94"E
7	Sluice Gate 3	Intake gate	Gate regulating inflow from Boeng Krapik, connected to the Mekong River.	11°22'47.03"N	105°23'35.30"E

* Names and descriptions are not official and are based on information provided by DTWG representatives during the field visit. Source: Authors

5.4. Local perspectives on water management

Primary data from FGDs and KIIs involving FWUC leaders, CFi members, and local producers indicate that traditional, customary water management frameworks are currently under acute strain. While longstanding communal committees once successfully allocated flows based on local rules, participants observed that the rapid intensification of agriculture—specifically the expansion of triple-cropping—has outpaced informal institutional controls. Stakeholders noted that community-operated sluices and the lake's nine deep-pool sanctuaries (listed in Table 4) are increasingly over-exploited due to increased pumping and the expansion of cultivated areas.

Stakeholder recollections of progressively worsening dry-season shortages—particularly observations that canals frequently run dry by late April or May, forcing some fields to remain unwatered—closely align with the volumetric drawdown trends illustrated in Figure 7. While participants recalled historically more resilient dry-season storage levels, the 2023–2024 records indicate that storage declined to critical minima of approximately 5–15 million m^3, significantly breaching the 27 million m^3 operational storage threshold. Participants also reported increasingly erratic rainfall patterns and unreliable canal inflows, reinforcing evidence of heightened climate variability and hydrological uncertainty.

To mitigate the risk of total crop failure, farmers have adopted adaptive strategies, including transitioning to drought-tolerant rice varieties or short-cycle crops during the late dry season. Qualitative accounts describe a forced trade-off in which farmers postpone planting or leave fields fallow in exceptionally dry years, balancing the potential for high yields against the risk of debt-inducing losses. Despite these individual adaptations, village chiefs and DTWG members emphasised that systemic management remains constrained by significant monitoring gaps. There is a consistent and urgent demand from local stakeholders for the establishment of regular water-level records and improved meteorological monitoring to generate a transparent, shared database. Participants directly linked the availability of reliable hydrological information to improved planning, more equitable allocation quotas, and the effective resolution of intensifying tensions between irrigation demands and fisheries conservation.

6. Enhancement of management and monitoring

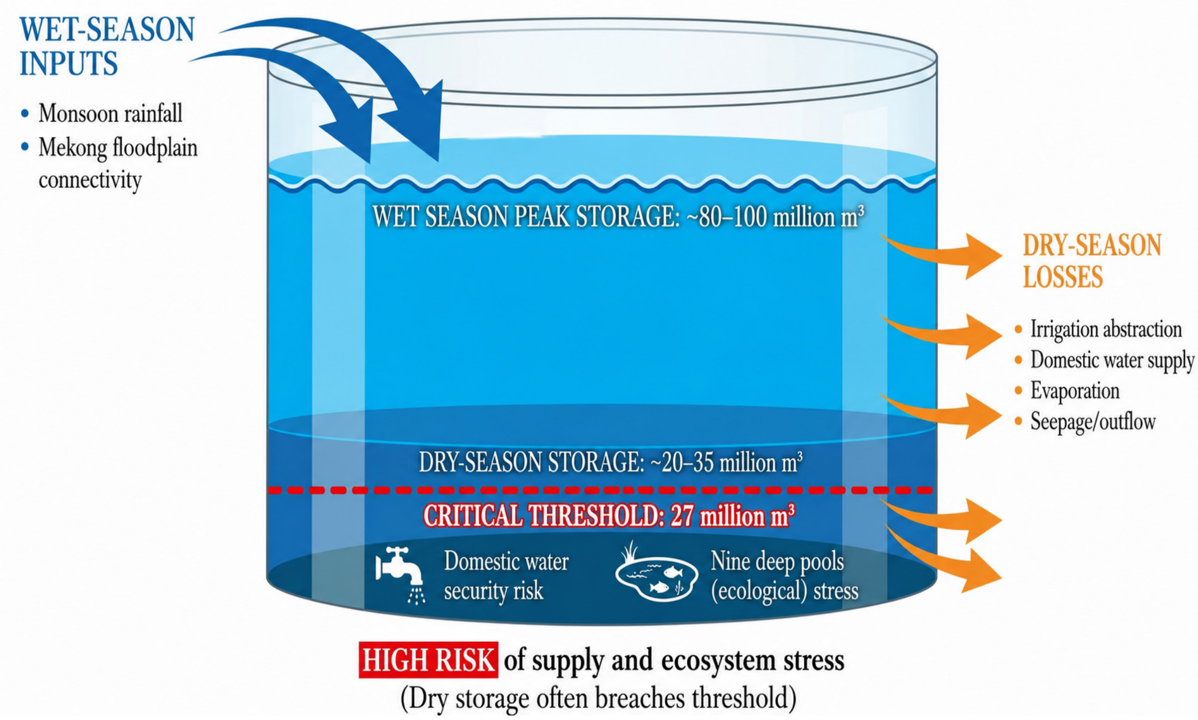
6.1. Lake water balance (conceptual)

To strengthen the IWRM of BSL, it is essential to establish a robust understanding of the system's hydrological balance. Figure 13 presents a conceptual diagram of the lake's water balance, illustrating the primary inflows and outflows that govern seasonal storage and resource availability. The system is characterised by substantial wet season inputs, particularly monsoonal rainfall and strong hydraulic connectivity with the Mekong floodplain, which together drive peak wet season storage to between 80 and 100 million m^3. This seasonal abundance is critical for regional flood regulation and the replenishment of the lake's ecological infrastructure.

However, the system faces substantial dry-season losses that trigger a rapid drawdown. These losses comprise four primary components: intensive irrigation abstraction, domestic water supply extraction, high rates of evaporation during the dry months, and natural seepage or outflow. In typical years, the dry-season storage stabilises between 20 and 35 million m^3; however, as shown in the conceptual model, this storage often breaches the operational storage threshold of 27 million m^3.

When volumes fall below this critical threshold, the system enters a high-risk state for both domestic water supply and ecosystem stability. Crossing this limit exposes connected households to acute water security risks and imposes severe ecological stress on the nine deep pools. As storage declines further—reaching extreme minima of 5–15 million m^3 in recent years—these refugia lose their capacity to maintain the dissolved oxygen levels and thermal stability required for brood-fish survival. Consequently, a clear understanding of the lake's water balance forms the foundation of a trigger-based allocation framework designed to regulate extraction rates and prevent the system from entering this critical danger zone.

Figure 13: Conceptual diagram of lake water balance



Source: Authors

6.2. Decision support (GEE tool)

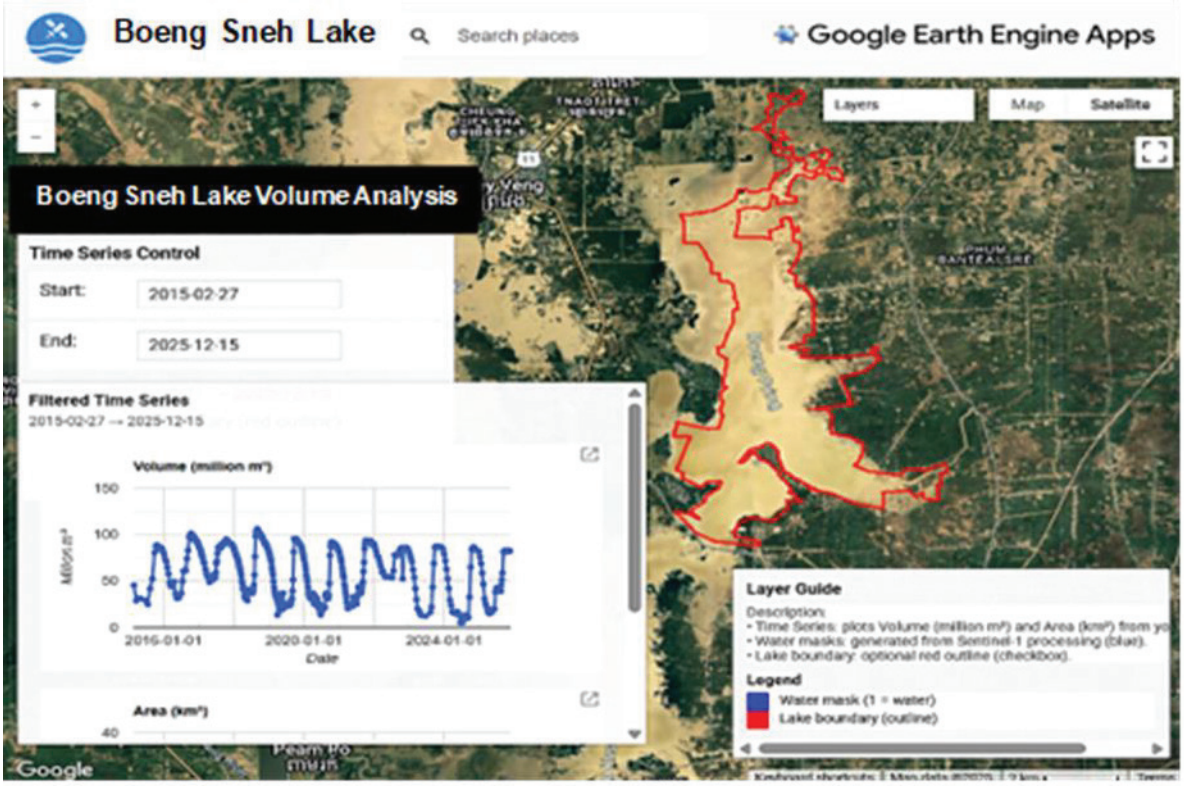
To address the "critical lack of evidence-based hydrological insights" identified by stakeholders, a near real-time monitoring system has been developed using a GEE Web App (accessible at https://ee-avinthageo.projects.earthengine.app/view/volume-analysis). This tool operationalises the hydrological data collected for the past ten years from 2015 to 2025 into an active decision support platform (Figure 14):

- **Integrated data engine:** The app integrates the DEM derived from 121 lake-depth measurements with multi-temporal satellite imagery. By applying the non-linear "Water Elevation vs. Area/Volume" relationship (Figure 6b), the app automatically calculates the current lake area and storage volume based on the most recent satellite-detected lake water level with a frequency of 10–14 days.

- **Operational utility:** This development allows the DTWG to overcome the current absence of physical water-level gauges. The app provides instantaneous updates on storage trends, specifically monitoring the "seasonal drawdown". It alerts users when the lake volume approaches the operational storage threshold of 27 million m^3, which is essential for preserving the deep pools (e.g., Tanhan and Kul Prumsen) as fish refugia.

- **Conflict mediation support:** By providing a transparent, publicly accessible record of water availability, the GEE app serves as a neutral evidence base for mediating conflicts between the irrigation demand and fishery needs. Stakeholders can track the "frequency and medium" of lake changes in a format suitable for digital coordination platforms (e.g., Telegram group) and local governance meetings.

Figure 14: Interface of the GEE Web App for BSL area and volume analysis



Source: Google Earth, satellite imagery, accessed 18 December 2025.

7. Options and opportunities for adaptive management

The hydrological assessment reveals that BSL is managed at the absolute limit of its physical capacity, with dry storage frequently breaching critical thresholds. To address these challenges, a structured decision support framework has been developed to map management options to specific volumetric triggers.

While the proposed framework emphasises adaptive operational management through improved monitoring and trigger-based decision making, it may also be complemented by structural interventions, including conventional engineering infrastructure, green-grey infrastructure, and nature-based solutions where technically, environmentally, and economically appropriate. The feasibility and effectiveness of such interventions should be evaluated through dedicated engineering and environmental studies.

7.1. Timing and trigger-based allocation

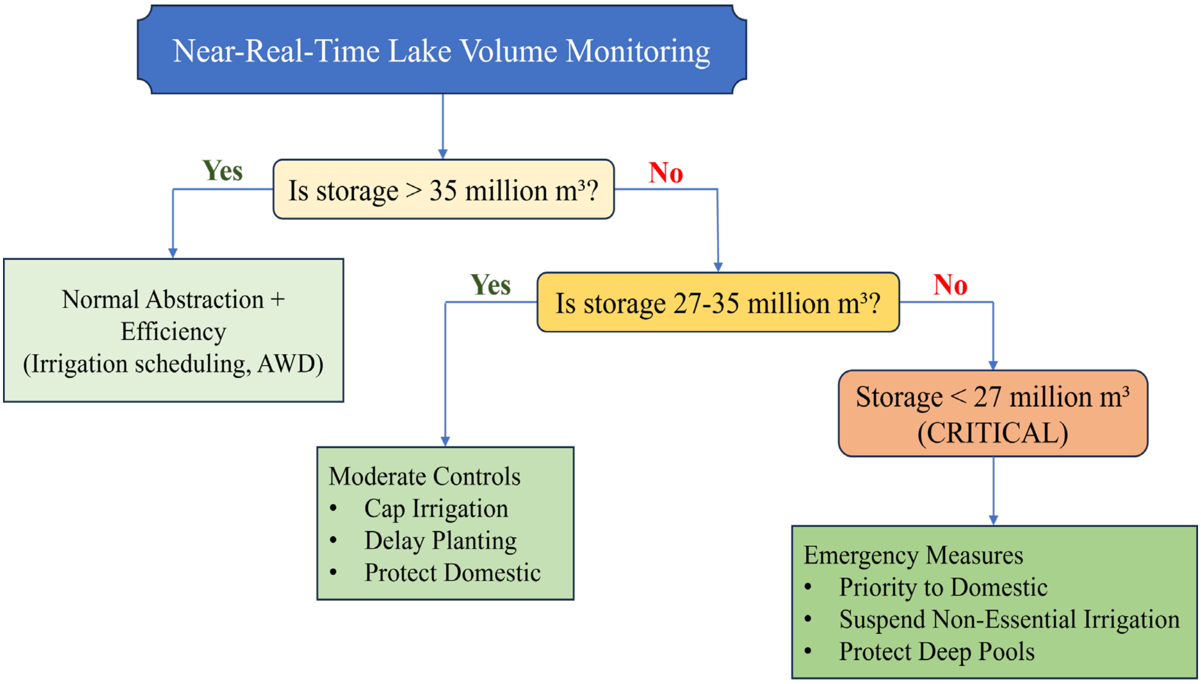
Effective water allocation must pivot from fixed calendars to dynamic, evidence-based rules. Figure 15 presents the operational logic for the DTWG, utilising near real-time monitoring of lake volume to activate specific management phases.

- **Normal phase (> 35 million m^3):** When storage remains above 35 million m^3, normal abstraction is permitted alongside proactive efficiency measures such as improved irrigation scheduling and the promotion of Alternate Wetting and Drying (AWD).
- **Moderate phase (27–35 million m^3):** As storage declines into this range, the DTWG must initiate moderate controls. Actions include capping irrigation withdrawal for lower-

priority schemes, advising farmers to delay planting of subsequent crops, and prioritising the protection of domestic clean water station intakes.

- **Critical phase (< 27 million m³):** Breaching the 27 million m³ operational storage threshold triggers emergency measures. Management must strictly prioritise domestic supply, suspend non-essential irrigation (e.g., commercial water convolvulus pumping), and protect the deep pools to prevent the collapse of fish sanctuaries.

Figure 15: Options mapped to decision points



Source: Authors

7.2. Agricultural demand reduction

To mitigate the risk of reaching critical storage levels, agriculture—the dominant water user—must transition toward an efficiency-first management model.

- **Irrigation efficiency:** Promoting AWD can reduce total water requirements without compromising yield. However, its wider adoption in Cambodia remains constrained by technical and institutional challenges, including uneven land levelling, poor water control, unclear irrigation scheduling, and limited collective water management capacity among farmers and FWUCs. Farmers also often perceive continuous flooding as a safer strategy against crop failure and lack sufficient incentives to shift practices (Vernet et al. 2025). These constraints highlight the need for field-level efficiency gains to be supported by improvements in conveyance infrastructure, including canal lining and routine maintenance to reduce seepage losses within the secondary network. Strengthening coordinated field-level scheduling through FWUCs is also essential to optimise water distribution and minimise unnecessary withdrawals.

- **Groundwater regulation:** Given the high hydrological connectivity between BSL and the local aquifer, dry-season groundwater pumping effectively acts as a secondary draw on the lake's storage. The DTWG should establish a governance mechanism to monitor and regulate agricultural wells, preventing illegal or unregulated pumping from undermining shared surface water conservation.
- **Crop choice and intensity:** In the driest years, the DTWG should consider limiting the third short-duration rice crop and instead prioritise less water-intensive crops or high-value vegetables that can be sustained with lower volumetric inputs. Such adjustments would help align agricultural demand with seasonal water availability while maintaining farmer incomes.
- **Planting schedule adjustment:** Adjusting planting schedules—particularly by shifting or shortening late dry-season rice to avoid the peak drawdown period (March–May)—can further reduce pressure on lake storage. This strategic shift ensures that the most water-sensitive crop growth stages do not coincide with periods of maximum thermal stress and minimum water availability.

7.3. Domestic supply safeguards

Domestic water security constitutes a primary objective of the multiple-use area co-management plan. Safeguarding a reliable supply for connected households must therefore remain a central pillar of dry-season allocation decisions.

- **Priority allocation:** Legally formalising domestic abstraction as a non-negotiable priority during critical low-storage periods is essential to prevent disruptions to clean water supply and to uphold public health safeguards.
- **Infrastructure integrity:** Strengthening leakage control measures, implementing accurate volumetric metering for PWOs, and promoting water conservation measures to encourage efficient domestic water use will help ensure that dry-season withdrawals are minimised, monitored, and used efficiently.

7.4. Governance and coordination

The effectiveness of these technical measures ultimately depends on the strength and coherence of supporting institutional structures.

- **DTWG protocols:** The DTWG should use the findings and recommendations of this study to formalise dry-season abstraction quotas by irrigation scheme and communicate these targets transparently through established digital platforms, such as Telegram, to ensure clarity and compliance.
- **Public transparency:** Regularly disseminating lake storage status—derived from the GEE monitoring tool—is essential for fostering accountability, strengthening compliance, and facilitating conflict resolution between FWUCs, CFis, and other stakeholders.

8. Conclusion and recommendations

BSL's hydrology is fundamentally shaped by its seasonal integration within the Mekong floodplain and increasingly by intensified human utilisation. Our analysis confirms that the lake possesses a substantial wet-season peak storage of 80–100 million m^3, supported by nine deep pool refugia—such as the Tanhan (5.95 m) and Kul Prumsen (5.90 m) deep pools—that function as vital dry-season sanctuaries for aquatic biodiversity. However, climate variability and upstream regulation are systematically reducing this supply, while local demand continues to escalate. Remote sensing reveals a progressive year-on-year contraction of the lake area from the mid-dry-season onward, with 2024 recording the lowest surface area on record. These quantitative findings directly match community reports of severe late-season shortages, confirming that the lake's critical role in supporting 53 species of large waterbirds and regional capture fisheries is jeopardised by the pursuit of yield-oriented agricultural targets.

At the socio-institutional level, the assessment highlights intensifying tensions between the agricultural and fisheries sectors. The demarcated irrigation command area—extending up to 13 km south of the lake and several kilometres in other directions from the lake boundary—demonstrates the substantial extraction pressure imposed on BSL by triple-cropping rice systems and year-round vegetable cultivation. This demand is further compounded by the expansion of domestic water infrastructure, with stations such as Theay recording a 66.7 percent increase in monthly withdrawals during periods of greatest hydrological vulnerability. Although fragmented governance across multiple ministries continues to constrain coordinated management, the pilot DTWG represents a promising institutional innovation for improving cross-sectoral water allocation and conflict resolution.

Reliable data and participatory planning emerge as cross-cutting priorities for the region's future. We identified critical data gaps—including the absence of continuous water-level records and incomplete irrigation scheme boundaries—that currently impede evidence-based water budgeting. Respondents highlighted that uncertainty in hydrological information undermines trust between user groups, a gap that the GEE monitoring tool seeks to bridge by providing high-frequency updates every 10–14 days. In conclusion, the BSL assessment demonstrates that balancing ecosystem integrity and rural livelihoods requires the rigorous application of sound hydrological science alongside inclusive stakeholder input. Enhancing the DTWG's data capabilities is the non-negotiable next step to ensuring that lake storage does not fall below the 27 million m^3 operational storage threshold required to sustain both ecological and socio-economic values under increasing climatic stress.

To build on these findings, the following next steps are recommended:

- **Data collection and validation:** Address critical data gaps through systematic collection and verification of hydrological and land-use information. Continuous and regular monitoring of lake water levels should be established, irrigation networks and scheme boundaries formally documented, and cropping calendars validated. This will require collaboration with PDWRAM to install and maintain physical water-level gauges and consolidate meteorological observations, alongside consultations with local authorities to update crop maps. Remote sensing outputs—such as lake surface area and actual evapotranspiration (ETa)—should be ground-truthed against field measurements to improve the accuracy of water balance estimates.

- **Development of lake storage-level relationships:** Undertake targeted field surveys to refine key hydrological parameters, including a comprehensive bathymetric survey of BSL during the next monsoon peak. A higher-resolution bathymetric survey is recommended for future work (e.g., ~200 m systematic grid combined with targeted high-density sampling of the nine deep pools and steep shoreline transition zones) to further improve representation of fine-scale bathymetric variability. This will enable the construction of precise lake storage–level curves, allowing DTWG and PDWRAM to estimate available storage volume directly from observed water levels. Such curves would provide a practical, low-technology complement to the GEE monitoring platform and enhance operational decision-making during critical periods.

- **Institutional capacity building:** Strengthen local water management institutions to effectively utilise and interpret generated data. Training sessions should be organised for DTWG members, PDWRAM officials, and FWUC representatives on hydrological data management, interpretation, and application to seasonal allocation planning. Workshops should emphasise translating technical lake data into operational decisions. Concurrently, FWUCs should be supported in documenting water use and participating in the maintenance of shared infrastructure, thereby embedding technical evidence into routine district processes.

- **Policy engagement and institutional alignment:** Integrate the assessment's insights into broader governance and planning frameworks. Key findings should be presented to commune councils and provincial leadership to inform revisions of the draft BSL management plan, incorporating quantified water balance scenarios and risk thresholds. Consideration should also be given to institutionalising the pilot DTWG as the District Working Group for Food Security and Nutrition (DWG-FSN) to align with national food systems governance structures and secure long-term government support. Such institutional consolidation would ensure that BSL's management advances on a foundation of robust data, cross-sectoral coordination, and sustained public investment. Future studies should also assess the monetary value of the lake's ecosystem services, including fisheries, biodiversity conservation, water supply, and flood regulation, to strengthen evidence-based investment and policy decisions under IWRM.

- **Monitoring, evaluation, and adaptive management:** Establish a structured monitoring and evaluation framework to continuously assess hydrological conditions, water abstraction patterns, and institutional performance. This system should support adaptive management by enabling periodic review and adjustment of water allocation strategies in response to changing climatic conditions, demand pressures, and ecological thresholds. Future monitoring should also consider the impacts of climate variability and land-use change on the lake's hydrology to support climate-resilient IWRM. Embedding adaptive feedback loops into the DTWG process will strengthen the responsiveness and long-term sustainability of lake management.

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