PAER POLICY GUIDE

Sustainable and Resilient Tonle Sap Lake:

A Progressive Scenario for Policy Action

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Key messages

- There is a need for a broader and holistic effort to address a host of environmental issues and challenges faced by the Tonle Sap Lake (TSL).
- In order to realize a sustainable and resilient TSL and its basin, this policy guide suggests three resilience enhancement measures: i) Ecohydrological resilience enhancement measures, ii) Land-use management and pollution control measures, and iii) Livelihood resilience enhancement measures; and an integrated response mechanism (IRM) consisting of five responses.
- Resilience enhancement measures are aimed at addressing both macro and micro level issues and challenges in a holistic manner.
- Integrated response mechanism, which is inspired by integrated lake basin management (ILBM) concept, facilitates implementation of resilient enhancement measures effectively.
- Platform for Aquatic Environmental Research (PAER), which is the main outcome of the SATREPS project, is positioned as a research platform for connecting and facilitating the policy-science-community/society interaction required to implement the resilience enhancement measures and establishment of adaptive lake governance over time.

Section 1: Introduction

Tonle Sap Lake, the largest freshwater lake in Southeast Asia, is a unique natural wetland system in its ecological and cultural significance. The lake ecosystem is inextricably linked to the cultural identity, livelihoods, and overall socio-economic development of Cambodia. The hydrologic cycle of the TSL is largely determined by the flow regime of the Mekong River and the lake's tributaries during the monsoon season, which creates the flood pulse. The flood pulse regulates the system dynamics (e.g., seasonal variability of the lake's depth, volume and surface area; sediments and nutrients loads; and phytoplankton and fish production as well as the structure and distribution of flooded vascular plants) that are critical for sustaining the integrity of the lake ecosystem and its biodiversity, including migratory fish species. As a result, the lake and its floodplains shelter a host of biotic communities such as bacteria, phytoplankton, mollusca and arthropods, fish, reptiles, birds, mammals, as well as aquatic and flooded vascular plants (Campbell et al. 2006, Pool et al. 2017, Uk et al. 2018, Halls and Hortle 2021; Yoshimura et al., 2022). Rich biodiversity and myriads of ecosystem services provided by the TSL ecosystem are of extreme significance for the wellbeing of dependent livelihoods, in particular, the subsistence fishers and farmers (van Zalinge et al. 2000, Evans et al. 2004, MRC 2010, Shivakoti and Bao 2019).

The sustainability of the TSL ecosystem is closely linked with the sustainable development of Cambodia as well as the broader Mekong River Basin (MRB). Although largely undeveloped prior to 1990, the MRB region has been undergoing a rapid dam construction period, with seven dams under construction on the mainstream in China, and 133 proposed for the Lower Mekong River and tributaries (Kondolf et al. 2014). The number of commissioned hydropower stations between 2000 and 2010 increased by 183%, and the total water-holding capacity has increased four-fold in comparison to that of the 1990s, and the situation has even worsened after 2010 (Lin and Qi 2017). Given the vulnerability of TSL to the environmental changes that occur both in the lake's own catchment and the MRB, sustainable management of the TSL's water environment is challenging. The lake's sheer size, heterogeneity, interactions, and dependencies across multiple dimensions of environment and socio-economy give rise to numerous complexities for its conservation and management. The lake's environment has been facing a host of human-induced stressors and external threats such as climate change impacts, land-use and land cover (LULC) changes in its catchment area (e.g., agricultural land expansion and deforestation), development interventions in the upstream of the MRB (e.g., hydropower dam construction), disturbances in the hydrological cycle, pollution of waterways from the disposal of waste and wastewater and agrochemical runoff, uncoordinated and unsustainable fishing practices, loss of habitats (e.g., loss of flooded forests), and plastic pollution (Kondolf et al. 2014, Lin and Qi 2017, Uk et al. 2018, Shivakoti and Bao 2019, Finnegan and Gouramanis 2021, Haberstroh et al., 2021, Yoshimura et al., 2022). An estimated 221,700 tons of plastic entered Tonle Sap Basin between 2000 and 2020 (Finnegan and Gouramanis 2021). Micro and macro plastic pollution from the major city, such as Phnom Penh, and along the MRB are becoming serious concern and risk to TSL ecosystem and dependent livelihoods (Haberstroh et al., 2021). Preventing environmental degradation around the lake is a major concern for the livelihoods, economy and long-term sustainability of the lake ecosystem and biodiversity. Addressing these challenges while improving the state of the lake environment requires multidimensional and longitudinal planning by considering people and economy, biodiversity and ecosystem, as well as external threats such as climate change.

The first policy report entitled "Environmental Changes in Tonle Sap Lake and its Floodplain: Status and Policy Recommendations" under the SATREPS project (*Establishment of Environmental Conservation Platform of Tonle Sap Lake*) recommended a set of policy actions emphasizing the sustained and improved local community livelihoods and fostering better communication channels for policy-science-community interface (Shivakoti and Bao 2019). The report underscored the need to apply integrated tools, such as Water Environment Analytical Tool (WEAT), as a basis for decision support to address and mitigate an array of environmental problems (e.g., sediment and nutrient dynamics, eutrophication and cyanobacteria bloom, pollution, contamination of heavy metals, pesticides, harmful microbes, emerging pollutants, and ecological and hydrological issues) and anticipated long-term changes. Further, the report suggested that it is essential to address various environmental issues in a coordinated manner following the principles of Integrated Lake Basin Management (ILBM) but particularly guided by TSL's unique characteristics and changing realities, needs and priorities. The TSL's ILBM framework should be pragmatic and grounded to reality so that it serves as a basis for future policy formulation and actions.

After the release of the first policy report, the SATREPS project has launched the "Platform for Aquatic Ecosystem Research (PAER)" (PAER 2021), released WEAT and its guidelines, as well as produced numerous scientific publications including a comprehensive technical book (*Water and Life in Tonle Sap Lake*) (Yoshimura, Khanal, and Sovannara 2022). PAER, which is the main outcome of the project, will continue to serve as a hub for connecting a wide spectrum of individuals and relevant institutions regarding research, capacity building, environmental information, technical support and management on the TSL water environment. PEAR is well positioned to complement the priority missions of Tonle Sap Authority Strategic Plan 2021-2025 (TSA 2020) which is in line with the missions of Cambodia Climate Change

Strategic Plan 2014-2023 (RGC, 2013). PEAR will consolidate all of the major findings, tools, database, network and momentum created by the SATREPS project and make it readily available to support important policy decision processes for the conservation and sustainable management of TSL and its basins. PAER could serve as a strategic platform for public-science-policy interaction and facilitation to address environmental issues occurring within the TSL ecosystem. In this context, it is highly relevant to explore relevant policy actions that could be prioritized and implemented for the sustainable management of the TSL by capitalizing on the resources available through PAER as well as those built capacities by the SATREPS project.

This policy guide builds on the knowledge base, network and processes, major findings, and outcomes, in particular PAER, of the SATREPS project. It aims to guide the policy actions to realize the broader goal of sustainable and resilient Tonle Sap Lake and its basins. The policy guide synthesizes the key identified issues as well as recommendations received during the project implementation to suggest a comprehensive policy action to co-achieve the environmental and sustainable development challenges including but not limited to implications for sustainable development goals (SDGs), the Paris Agreement on Climate Change, Post-2020 Global Biodiversity Framework, the Sendai Framework on Disaster Risk Reduction (DRR) and the relevant lessons from dealing with COVID-19 crisis and other emerging issues. It is expected that the policy and decision-makers will find this guide useful to strategically plan and execute measures to safeguard the lake's environment in a sustainable and resilient manner.

The target audience of this policy guide include key government agencies in Cambodia, development partners and institutions working towards the conservation and sustainable management of the TSL ecosystem as well as international communities engaged in improving the lake environment.

Objectives:

The objective of this policy guide is to present a progressive scenario for achieving sustainable and resilient Tonle Sap Lake and its basins by introducing priority resilience enhancement measures and an integrated response mechanism.

The paper consists of five sections including this introduction (**Section 1**) and conclusion and recommendations (**Section 5**) sections as shown in **Figure 1**.

Section 1: Introduction	
Section 2: Scenario of sustainable and resilient Tonle Sap Lake and its basins	Vision Desirable outcomes Indicators
Section 3: Resilience enhancement measures	Ecohydrological resilience enhancement measures Land-use management and pollution control measures Livelihood resilience enhancement measures
Section 4: Integrated response mechanism	Policy and institutional response Monitoring and assessment response Scientific research and knowledge response Social interaction and participatory response International collaborative response
Section 5: Conclusion and recommendations	

Figure 1: Structure of this policy guide

Section 2 introduces an image of a future scenario of sustainable and resilient TSL that will not only retain the richness of the unique ecosystem but also be productive to support socio-economic needs and resilient to future challenges, in particular, climate change impacts.

Section 3 introduces key resilience enhancement measures that are critically important for realizing the goal or vision of sustainable and resilient TSL. It highlights three mutually reinforcing measures to be implemented in a coordinated manner.

Section 4 introduces an integrated response mechanism to implement identified resilience enhancement measures. It consists of five responses.

Section 2: Scenario of sustainable and resilient Tonle Sap Lake (TSL) and its basins

The scenario of “sustainable and resilient TSL and its basin” aims to ensure the continuity of the unique lake ecosystems and its services for the betterment of the local people and communities directly dependent upon the lake’s resources and services (**Figure 2**). It is a progressive outlook of the TSL against the environmental problems and challenges arising from the changes observed in and around the lake and its basin. Here ‘sustainability’ reflects the aspiration to maintain and improve a healthy lake environment in which functions and services offered by the lake ecosystem are guaranteed for the benefit of current and future generations. Meanwhile, ‘resilience’ stresses on the capacity of the whole ecosystem and dependent livelihoods to withstand, bounce back, and if necessary, transform from the disturbances in future, primarily, due to climate change impacts. The outlook back-casts a narrative for feasible policy measures that could be designed and implemented to address the immediate as well as long term social, economic and environmental issues in a sustainable manner.

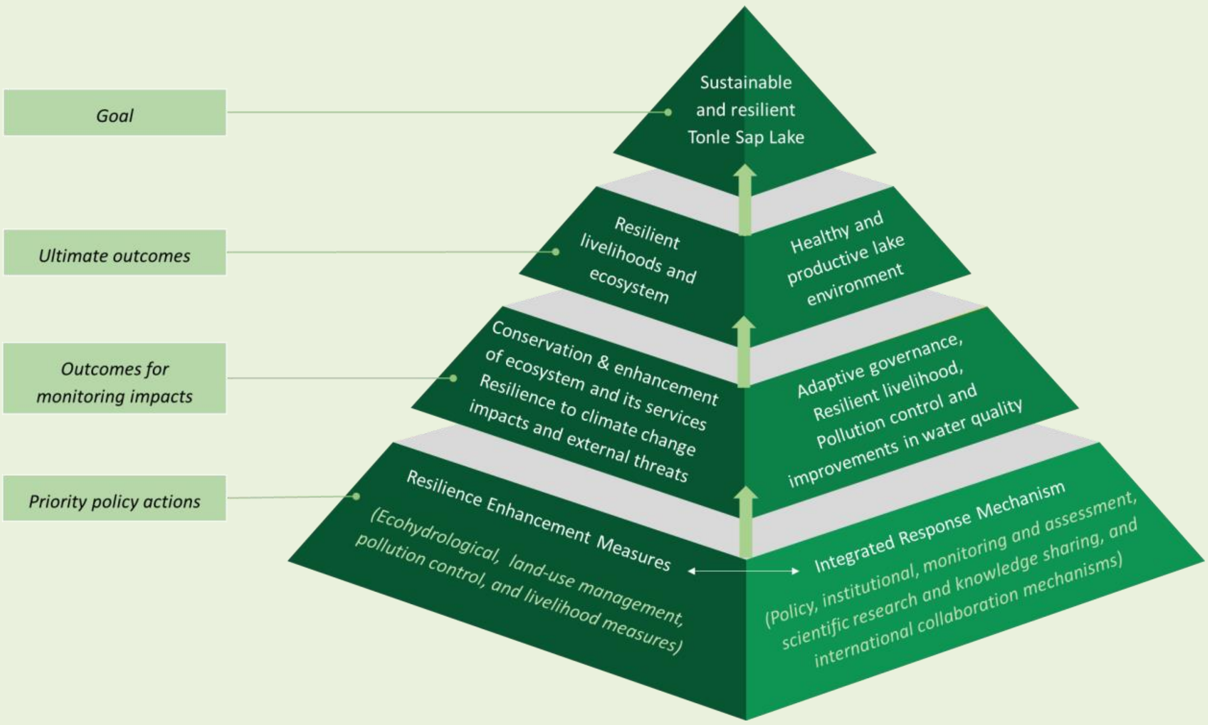

Figure 2: Conceptual diagram connecting priority policy actions with the vision of sustainable and resilient Tonle Sap Lake

The scenario anticipates that the impacts of climate changes on the TSL ecosystem are minimized through the application of one or more resilience enhancement measures in an adaptive manner and backed by an integrated response mechanism. Along the path, sustainability of the TSL is maintained, when necessary, by transforming into a safer socio-ecological system. Appropriate land-use management and pollution control measures are put in place to minimize the risks to people's health and prevent ecosystem degradation. Similarly, the resilience of the ecosystem, people and dependent livelihoods is enhanced so that they could adapt to the disturbances. Further, an integrated response mechanism supports the implementation of priority actions to address the challenges in an adaptive and integrated manner. Realization of the goal under this scenario anticipates five desirable outcomes, which could be evaluated by monitoring the associated indicators as shown in **Table 1**.

Table 1: Desirable outcomes and indicators for evaluating progress towards sustainable and resilient Tonle Sap Lake

Desirable outcomes	**Indicators**
Conservation and enhancement of ecosystem and its services	● State of hydrodynamics ● Temperature regulation ● Storm and flood regulation ● Habitat including of flooded forests, shrubs, and grasslands ● Primary production ● Trophic interaction ● Carbon fixation ● Species diversity (species richness) ● Invasive species control ● Phytoplankton status ● Annual fishery production ● Status of flood-plans, flooded rice fields and their productivity ● Eco-tourism
Resilience to climate change impacts and external threats	● Adaptation measures against fluctuating water levels in the lakes and floodplains targeting fishery, farming, public health and ecosystem ● Seasonal water level (timing, depth, extent, duration, and regularity of flood pulse) ● Lake's water temperature ● Seasonal total suspended solids/nutrients/Chlorophyll a
Adaptive governance	● Monitoring, evaluation, education, and research ● Science-based policy formulation and decision making ● Level of multi-stakeholder participation, including local communities, NGOs, Non-Profit Organizations ● Level of coordination and collaboration in Cambodia ● Level of coordination and collaboration across the MRB

Resilient livelihood	● Income level of people directly dependent on the lake ecosystem such as floating villagers, fisherman ● Farm productivity in the floodplains ● Access to safe drinking water and sanitation ● Health condition of the local people
Pollution control and improvements in water quality	● Water quality monitoring and assessment ● Nutrient/agrochemical loads from agriculture ● Pollutant/nutrient loads from houses, industries ● Pollutant/nutrients loads from the Mekong River Basin ● Macro- and micro-plastic pollution ● Water quality profile (e.g., microbial, nutrients, and toxic materials) in tributaries, Tonle Sap River, and TSL, including areas around floating villages

- <u>Conservation and enhancement of ecosystem and its services</u>: It reflects the overall improvement of the lake's environmental condition. Indicators inform the decision-makers or stakeholders whether the sustainability of the lake environment is the positive direction or not. Similarly, the state of indicators helps to examine the overall speed and effectiveness of the environmental conservation measures taken so far.
- <u>Resilience to climate change impacts and external threats</u>: The TSL's hydrology and ecosystem are highly vulnerable to climate change impacts as well as development interventions in the whole MRB region such as the cascade of dams constructed and those planned in the upstream. To address and adapt to these external threats it is essential to identify and implement appropriate resilience enhancement measures to minimize the overall impacts on the lake's hydrodynamics and ecosystem. The indicators, therefore, help to improve our understanding of not only the overall impacts of the external threats to the lake environment but also the effectiveness of the resilience enhancement measures to normalize the impacts.
- <u>Adaptive governance:</u> It anticipates a robust response mechanism in which institutions, policies, laws and regulations can adapt and perform effectively under dynamic and uncertain conditions. Here, adaptive governance seeks to create an enabling environment that promotes multi-level coordination, multi-stakeholder participation across the science-policy-society interface, international collaboration, and continuous learning.
- <u>Resilient livelihood</u>: This outcome relates to the overall capacity of the local people and their livelihoods to face and adapt to the challenges caused by environmental degradation and external threats. It also reflects the societal capacity to adjust, bounce back and if necessary transform their livelihood decisions and strategies in response to changing situations in and around the lake. The scenario anticipates improvement in the condition of indicators related to resilient livelihood in its human, social, physical, natural, and economic dimensions.
- <u>Pollution control and improvements in water quality</u>: It is the immediate priority outcome for ensuring the sustainable management of the lake. The indicators are directly related to the current environmental status of the lake and therefore determine the level of environmental pressures on the lake from natural as well as human actions. Tools and

solutions to control pollution from point and nonpoint sources are already available, the only requirement is their effective implementation.

Section 3: Resilience enhancement measures

Resilience enhancement measures are the priority policy responses geared towards co-achieving the key outcomes outlined in Section 2. It is essential that the resilience enhancement measures are designed by considering the seasonal hydro-dynamics of the lake which experience lower water levels during the dry season and flooded situations during the wet season. For instance, the wet season is critical for breeding and nurturing aquatic species while in the dry season the lake and associated rivers provide refuge to several aquatic species. These considerations are critical when developing the resilience enhancement measures. Although sustainable management of TSL requires a host of measures, this policy guide suggests three mutually reinforcing measures each to be applied at a particular spatial level (**Figure 3**). Under each measure, more than one intervention could be considered.

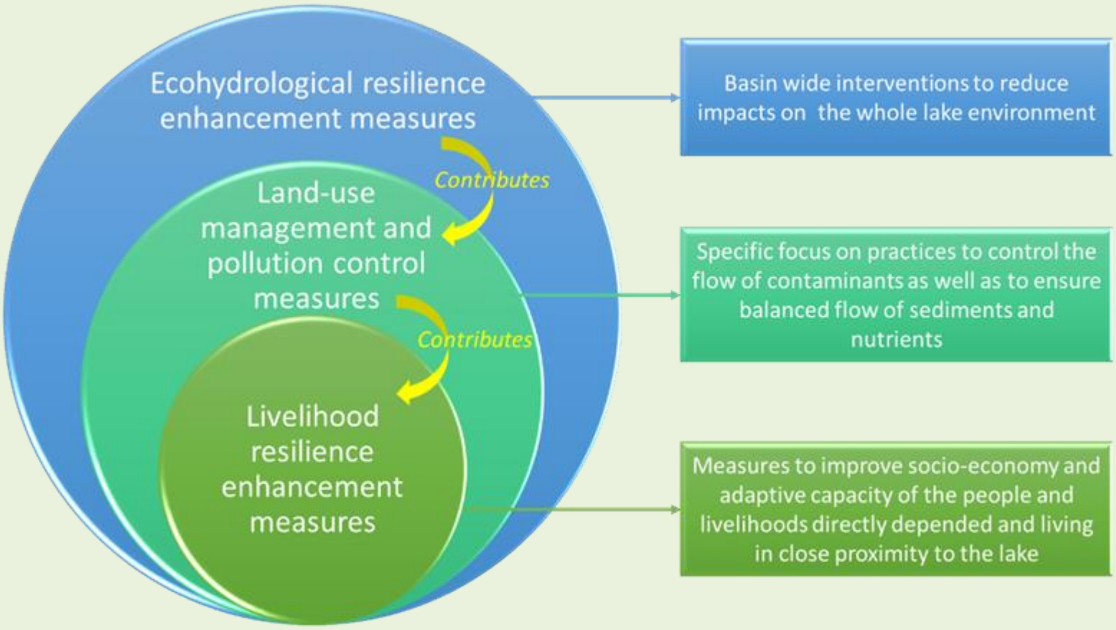

Figure 3: Three mutually resilience enhancement measures for realizing sustainable and resilient Tonle Sap Lake

3.1. Ecohydrological resilience enhancement measures: The measures will consider various interventions at the basin level to address water environment issues and challenges in tributaries and the lake such as environmental flows and water depth, dynamics of annual ‘flood pulse’ and dry season flows, fish migration and breeding, deforestation and forest degradation, intended and unintended forest fire, and land-use and land-cover (LULC) changes in the seasonally inundated areas and floodplains. The design of ecosystem conservation measures should be prioritized, when feasible, by using nature-based solutions (NbS), and backed by robust scientific assessments of the impacts. The basin-wide interventions are expected to normalize the future impacts (such as on flooded forests and farmlands, fish migration and spawning, sediments and nutrient flow, fish refuge during the dry season, water transport, tourism, fishing, etc.) caused by deforestation and forest degradation, LULC changes, and seasonal alteration of hydrology (maximum and minimum water level, timing, duration, regularity of flooding, and seasonal decrease/increase in water levels) by climate change and intervention in the upper MRB. **Table 2** summarizes the potential ecohydrological measures for implementation.

Table 2: Ecohydrological resilience enhancement measures

Problems and issues to be addressed	● Fluctuation in seasonal water level regimes ● Reducing environmental flow in the river ● Alternation of hydrological process and groundwater table ● Deforestation and land cover change from watershed ● Riverbank and soil erosion from the basins ● Habitat and biodiversity losses, and invasion of alien species ● Lowering base flow and the problem of drying out of some tributaries during the dry season
Measures to be implemented	● Coordinate to regulate the downstream flow from the dams to minimize environmental impacts based on scientific facts, including, through careful water infrastructure planning and development, environmentally sensitive and coordinated dam operational rules for releasing water, and decommissioning of high impacts dams ● Define and protect buffer zone along the tributaries of the TSL, protected flooded forests, and conservation zones inside the lake ● Adaptive management of environmental flows and water depth in rivers/tributaries and lakes including enhanced monitoring and assessment with public participation. The adoption of environmental flow and water depth in the lake will enable assessment of the impacts upon aquatic ecosystems of hydrological changes resulting from resource development. In turn, it will enable ecohydrological based mitigation efforts with benefits for those communities who rely on ecosystem services with potentially large socio-economic implications. ● Establish a long-term monitoring of surface and groundwater flow patterns along with resultant ecological and societal responses for the development of effective improved water management strategies and regulations, including for surface water and groundwater diversions ● Develop and implement the best management practices (BMPs) scenario for land-use management and soil erosion control in the whole basin ● Assess the lake's basin carrying capacity, which refers to the sustainable supportive capacity of available water resources in terms of quantity and quality to meet socio-economic needs while considering the ecosystem's requirements.
Required conditions for implementation	● Governments at all levels should develop and practice a clear legal, policy and organizational basis for regulating water use and allocation in every watershed across the whole basin. ● Develop best agricultural and land-use management practices and operational guidelines for soil erosion control in the whole basin and

	engage stakeholders, especially farmers, to implement the guidelines effectively. ● Relevant stakeholders should recognize the protected buffer zone, maintain forest cover, and ensure environmental flows as a core component of water resource planning and essential priority for the protection of ecosystem services and achievement of ecological objectives. ● For each watershed, improve knowledge on trade-off between water use economic and environmental flow requirements for effective decision support. For this, technical government agencies could enhance cooperation with stakeholders, especially, research and academic institutions and transboundary institutions. ● Requires enhanced cooperation with the Mekong River Commission (MRC) and relevant upstream countries to set a limit of minimum water flow on monthly basis in the downstream and accordingly regulate operation of the dams. Establish a mutually agreeable mechanism to assess and determine optimum flow requirements for each month in the Mekong River mainstream to support the lake's natural hydrodynamics. ● Tonle Sap Authority (TSA) and Ministry of Water Resources and Meteorology (MoWRAM) need to consider assessing environmental flows for all tributaries to determine the requirements for different competing needs (such as nature, energy, food and water supply) to inform multi-stakeholder dialogues, environmental policies, objectives and strategies and to enable the monitoring of interventions. ● Climate change modeling and scenario analysis should provide projections for future allocation objectives and policies based on robust trade-off analysis (that also includes ecological, social, cultural and economic parameters). ● Create a strong and fully supported scientific team comprising of different scientific disciplines, including from the government, to conduct basin wide carrying capacity assessment and to develop the decision support system for TSL basin. Access water resources (quantity, quality, environmental flows) to sustain the ecosystem's normal functions as well as current and future demands for socio-economic development scenarios.
Outcomes	● Conservation and enhancement of ecosystem functions and services ● Resilience to climate change impacts and external threats ● Adaptive governance

Relevant analysis conducted under the SATREPS project	● Chapter 9: Groundwater and surface water interaction in Tonle Sap catchment. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 16: Hydrodynamic Property Characterized by Two-Dimensional Hydraulic Simulation. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 44: Projection of Land Use and Land Cover in the Lake Basin. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 48: Management of flooded forests and fish resources. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Assessment of Groundwater and Surface Water Exchange Under Climate Change Scenario in the Tonle Sap Basin ● The Assessment of Environmental Flow Under Climate Change: The Case Study of Stung Sen Catchment ● Land Use Change Scenarios for Hydrological Impact Assessment in a Tropical River of Tonle Sap Basin ● Seasonal comparison of groundwater level and quality in the catchment of the Tonle Sap Lake, Cambodia ● Analysis of Climate Change Impacts on Hydrology in a Sub-catchment of the Tonle Sap Great Lake

3.2. Land-use management and pollution control measures: While ecohydrological measures focus on basin-wide processes, dedicated attention is necessary to control the deteriorating water environment of the lake and its tributaries mainly from land-use practices and disposal of waste and wastewater. Spatial and seasonal considerations are necessary for controlling pollution from point and nonpoint sources. For instance, impacts of nutrient loads, such as eutrophication, are found generally higher during the dry season when the water level in rivers/tributaries and the lake is at its minimum. Meanwhile, pesticides and heavy metals are mostly detected during the rainy season when the chances of runoff of these contaminants are higher (Yoshimura et al., 2022). There are increasing concerns that unregulated uses of pesticides, such as dieldrin and heptachlor, are detected in surface water above the standard limits of drinking water. Banned pesticides such as endrin and DDT were also found in water samples taken from tributaries and the lake. Heavy metals, such as lead, are also detected in some parts of the lake. Appropriate land-use management is essential for controlling runoff of nutrients and harmful agrochemicals, especially, from the farmlands in the basin. Similarly, more efforts are required to control pollutant loads from point sources such as waste (in particular, the plastic wastes) and wastewater disposal into the waterways or directly into the lake from houses, industries and tourism activities. Spatiotemporal studies utilizing integrated modeling approaches can help policy makers to understand the impacts of different land-use, waste and wastewater management practices in a comprehensive manner. Based on the integrated modeling analysis, various land-use management interventions could be employed such as good agricultural practices, efficient application of fertilizers, better nutrient management, adoption of aquaculture in ponds or rice fields to store, recycle and prevent excess nutrient runoffs. Similarly, effective waste management measures can help prevent uncontrolled disposals of solid wastes, such as plastics, into the waterways, tributaries and near the lake. Similarly, a combination of different decentralized wastewater management solutions, including, nature-based solutions are required in areas contributing to higher pollution loads or near certain sections of the lake where human activities are mostly concentrated. **Table 3** summarizes the potential land-use management and pollution control measures for implementation.

Table 3: Land-use management and pollution control measures

Problems/Issues to be addressed	● Inappropriate land uses, agricultural runoff ● Untreated wastewater discharges and waste disposal ● Macro- and micro-plastic pollution ● Unregulated use of pesticides and agrochemicals ● Improper handling and disposal of used pesticides containers
Measures to be implemented	● Mapping, detection, and predicting land-use changes and development of future land-use scenarios and impacts ● Assess the impacts of land-use practices on the surface water (lake, river, streams, ponds) and groundwater quality ● Monitor and assess the fate of heavy metals, herbicides, and pesticides ● Aquaculture in ponds and rice fields for nutrient recycling, excess nutrient storage, and control of nutrient runoff. Assess the effectiveness of aquaculture to control nutrient runoff. ● Efficient nutrient management (optimize fertilizer application rate and timing) and good agricultural practices (especially limiting the use of pesticides and agrochemicals) ● Source control of pesticide imports through formal and informal/illegal channels ● Training and dialogues with farmers on health risks of pesticide misuses, safe handling of pesticides, and introduction of safer alternatives such as integrated pest management (IPM) ● Regulate the disposal of solid wastes and plastic wastes into waterways and the lake ● Education and awareness to reduce waste generation (especially plastics) and stop inappropriate disposal of wastes into the water environment ● Monitor, assess, and regulate wastewater disposal from houses, industries, and tourism businesses. Further adopt decentralized and low-cost nature-based wastewater treatment and reuse options
Required conditions for implementation	● Implement relevant national land-use, waste management, and pollution control policies, laws and strategies (e.g., Law on Water Resources Management, Sub-Decree on Water Quality) and take necessary steps to fulfill policy, legal and institutional gaps to address land-use and pollution control measures ● Coordinate and collaborate among the agencies (e.g., the Ministry of Land Management, Urban Planning and Construction (MLMUPC), MoWRAM, Ministry of Environment (MOE), Ministry of Agriculture, Forestry and Fisheries (MAFF), TSA) and their sub-

	national institutions on land-use, agriculture, waste and wastewater management ●Improve technical capacity for monitoring and assessment of land-use practices and their environmental impacts, wastes, nutrients and pollutants ●Research and development on land-use management, waste management, wastewater management, and pollution control ●Establish a guidance on land-use management for TSL and its basins
Outcomes	●Conservation and enhancement of ecosystem functions and services ●Pollution control and improvements in water quality ●Resilient and improved livelihood
Relevant analysis conducted under the SATREPS project	●Chapter 22: Basin-wide distribution of water quality. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ●Chapter 23: Basic physicochemical water quality—spatiotemporal distribution. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ●Chapter 24: Nutrient Availability and Phosphorus Dynamics. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ●Chapter 25: Phosphorus Dynamics—Modeling and Simulation. In In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ●Chapter 26: Phosphorus Dynamics Based on Model Analysis. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ●Chapter 36: Heavy Metals. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ●Chapter 37: Residual Pesticides. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ●Chapter 45: Permissible Phosphorus Load. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ●Chapter 46: Effect of Environmental Factors on Eutrophication. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022)

3.3 Livelihood resilience enhancement measures: Implementation of the preceding measures helps create a favorable environmental condition of the lake ecosystem and its surrounding areas in terms of direct health benefits, higher agricultural productivity, and better ecosystem services including fish catches. Additional measures are needed to further safeguard livelihoods from health risks and improve socio-economic conditions of, especially, the poor and most vulnerable people living in the close proximity to the lake such as floating villages (FV) and seasonally flooded villages or land-water based villages (WLV). Livelihood resilience enhancement measures are important not only for building a better socio-economic condition but also for reducing the burden on the lake resources. Better livelihood options help to reduce the dependency of the people on lake resources such as fishing which is the primary profession of the majority of local communities in TSL and accounts for over 90% of the income for many of them. Unsustainable fishing practices, the fluctuating extent of seasonally flooded areas, and deforestation and degradation of flooded forests are responsible for decreased fish catch and increasing vulnerability of these fishing communities (Ngor et al., 2018, Ly et al. 2021, Halls & Hortle, 2021). Another important requirement for enhancing livelihood resilience is by provisioning safe water, sanitation, and hygiene (WASH) such as introducing on-site water purification, on-site decentralized wastewater management, and hygiene. Safer WASH is critical for minimizing health risks, improving living conditions, and long-term resilience-building as the lake water is still widely used for drinking by people in FV (52.9%) and WLV (49.2%) with or without any treatments. This fact, together with the low availability of toilets (58.2% and 28.8% in FV and WLV, respectively), eutrophication and bloom of potentially harmful toxin-producing cyanobacteria algae increase the considerable risk of waterborne infectious diseases, which are quite common in FV and WLV. Compared to on-site water purification, on-site wastewater management is not so easy in floating villages with limitations of places for storage and treatment and of access to each household. Relocation of the floating villagers to the upland, which is currently promoted by the Cambodian government, should be considered in the cost-effective sense.

Even if some communities are relocated, farming and fishing practices should be resilient against environmental changes. Farming practices near the lake such as rice cultivation needs to adapt to both high flow and low water for an extended period of time. The Sustainable Rice Platform (SRP) launched by the United Nations Environmental Programme, German Agency for International Cooperation (GIZ), and the International Rice Research Institute in 2011 (https://www.sustainablerice.org) is a good option to reduce pollutants, increase resource efficiency, and promote sustainability both on the farm and throughout the value chain. Nature-based aquaculture or hydroponics near the lake could be promoted to reduce pressures on the lake from fishing as well as contributing to reducing the risk of income losses from insufficient fish catches. Additional income enhancement measures such as community-based eco-tourism (CBET) in floating villages, and generation of off-farm employment are equally important to diversify the economic base and reduce over-dependence on the lake resources. Provision of alternative resources or training to enhance the livelihoods of people and increase the efficiency and value of fish processing is also necessary.

Table 4: Livelihood resilience enhancement measures

Problems/Issues to be addressed	● Health risk to lake communities (water quality, bioaccumulation of harmful contaminants in fish, and human health impacts) ● Over dependence on fishing ● Unsustainable fishing practices and decreasing fish catches ● Lack of alternative income and inadequate support for CBET
Measures to be implemented	● Conduct localized water quality assessment using 3-D models for improved understanding of temporal health risk

	from microbes (e.g., E.coli) in floating villages and educate villagers about the health risks (e.g., when and where to use the lake water to minimize water-borne diseases) ● Monitor bioaccumulation of harmful heavy metals/chemicals in fish to prevent their intake through the food chain. ● Apply Sustainable Rice Platform (SRP) and nature-based aquaculture and fish refuge ponds in the TSL floodplains and their basins ● Install/construct safer toilets and nature-based decentralized wastewater treatment ● Encourage the establishment of CBET and local participation in conservation measures such as protecting and restoring fish habitats/refuges, particularly the flooded forests, shrubs, and grasslands, for their myriad of benefits and services to humans and the environment, control of invasive species, patrolling and control illegal activities ● Introduce healthy and economic stoves to replace firewood ● Communication, education, participation, and awareness (e.g., primary education) on environmental conservation, climate change impacts, and healthy lifestyle
Required conditions for implementation	● Relevant governmental agencies should cooperate and work with development/NGO partners to create a supportive platform for SRP implementation, namely from the provision of climate resilient-rice seeds, to cultivation methods, and accessible market within and beyond the national level ● Technology and finance to install water purification, safer toilets, and decentralized wastewater treatment facilities ● An environment for community participation in environmental studies and implementation of conservation measures ● Scientific information on annual fishing catch and quota and environmental conservation ● Resources (cash & kinds) and training on off-farm skills or alternative income generation and livelihoods improvements. ● Mandates, bylaws and supports (technical, financial) to establish community protected areas for the establishment of CBET inclusive of women participation
Outcomes	● Conservation and enhancement of ecosystem functions and services ● Resilience to climate change impacts and external threats ● Pollution control and improvements in water quality ● Resilient and improved livelihood
Relevant analysis conducted under the SATREPS project	● Chapter 28: Microcystin Production and Oxidative Stress. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022)

	● Chapter 31: Primary Production. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 32: Flooded Forests. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 36: Heavy Metals. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 37: Residual Pesticides. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 38: Heavy Metal Accumulation in Fish. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 39: Pesticide Residues in Vegetables from Provinces around Tonle Sap Lake. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022) ● Chapter 48: Management of Flooded Forests and Fish Resources. In Yoshimura C., Rajendra K., Sovannara U. (eds.), Water and Life in Tonle Sap Lake (2022)

Section 4: Integrated response mechanism

Coordinated implementation of the resilience enhancement measures require an integrated response mechanism (IRM) based on adaptive governance. At the conceptual level, IRM could be thought of as an integrated lake basin management (ILBM), which is an approach for achieving sustainable management of lakes and reservoirs through the gradual, continuous, and holistic improvement of the basin governance, including sustained efforts for the integration of institutional responsibilities, policy directions, stakeholder participation, scientific and traditional knowledge, technological possibilities, and funding prospects and constraints (RCSE and ILEC 2014). ILBM consists of six pillars (i.e., institutions, participation, policies, information, technology and finance). For designing IRM, customization of ILBM is necessary to match with the anticipated outlook of sustainable and resilient TSL. Here, IRM reorganizes a strong need to create a system of science-policy-community interaction for an effective and coordinated response. For that this guide proposes five specific responses which will complement the six pillars of ILBM as shown in **Figure 4**.

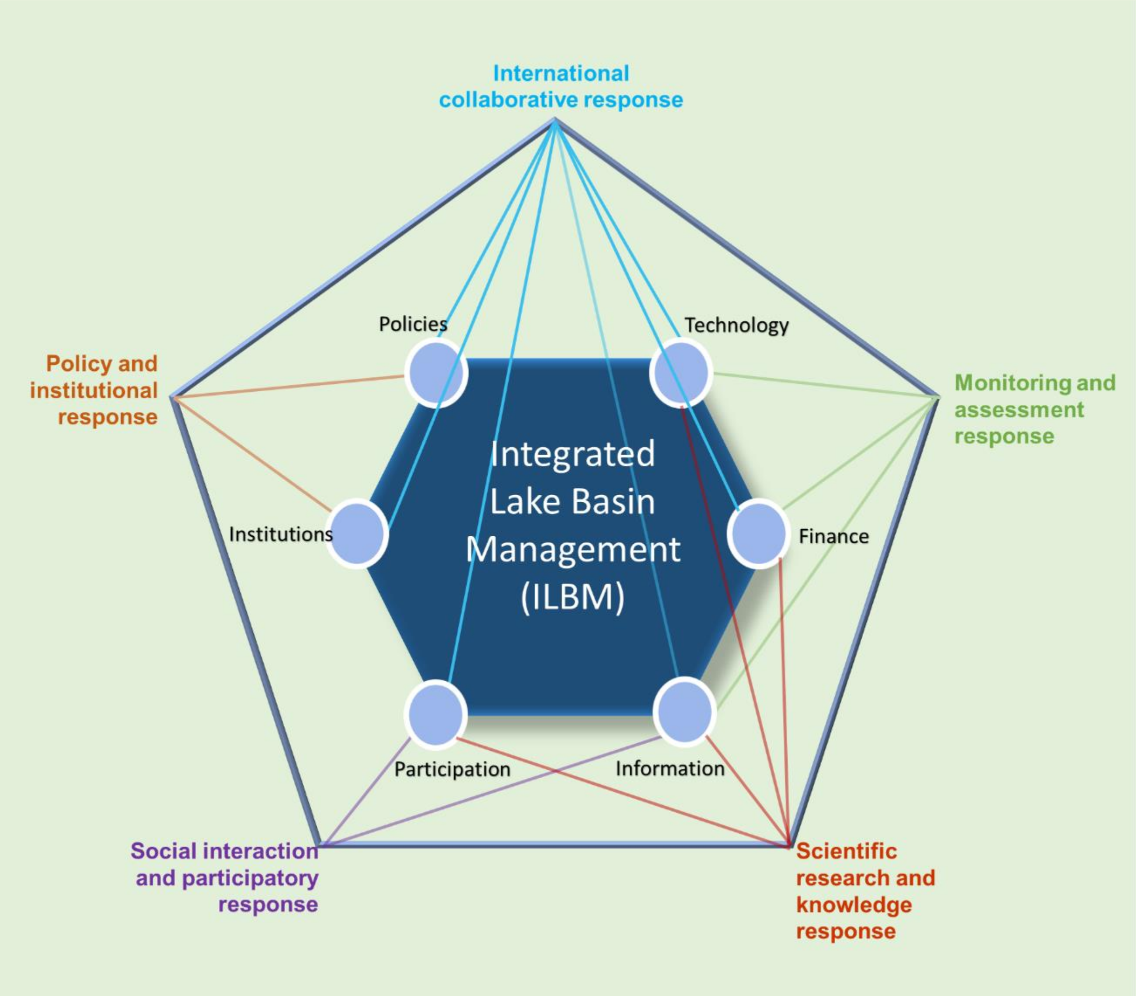

Figure 4: Five integrated response mechanisms and their interlinkage with the six pillars of integrated lake basin management (ILBM)

4.1 Policy and institutional response: This response directly complements the institutions and policies pillars of ILBM. The key objective of the policy and institutional response is to facilitate the implementation of the proposed resilience enhancements measures through necessary policies, strategies, laws, acts, guidelines and directives. The responses should build on the pre-existing arrangements by filling the necessary gaps in terms of scientific assessments, technology, finance, and human resources at relevant agencies or organizational setups. Meanwhile, the response also anticipates enhanced inter-agency collaboration (e.g., MLMUPC, MoWRAM, MOE, MAFF, TSA) at different levels and a lead role in facilitating multi-stakeholder engagements.

4.2 Monitoring and assessment response: Implementation of the resilience enhancement measures should be evidence-based (i.e., based on sound science and reliable information) given the factors such as sheer size of the lake, spatially and temporally heterogeneous processes, and complex lake ecosystem and interactions. The availability of scientific data and information at multiple scales and time periods is key for quantitative assessment of the environmental impacts on the TSL and accurate understanding of the ecosystem process (Kodikara et al. 2017, Uk et al. 2017, Siev et al. 2018, Uk et al., 2018; Ann et al. 2018, Khanal et al. 2019, Ung et al. 2019, Hoshikawa et al. 2019, Shivakoti and Bao 2019, Theng et al. 2021, Khanal et al. 2021, Uk et al. 2021; Ly et al., 2021; Yoshimura et al. 2022). Monitoring and assessment of environmental conditions are, therefore, not only of critical importance for understanding the current status of the lake ecosystem but also for formulating scientifically robust evidence and recommendations for decision making on identified resilience enhancement measures. This response complements the technology, information and finance pillars of ILBM by promoting the use of scientific tools, generating information, as well as allocating adequate resources or funds to implement essential monitoring and assessment tasks. A comprehensive and longitudinal monitoring to generate data for identified outcome indicators in **Table 1** is suggested not only to understand the changes and threats but also to monitor/measure the progress made following the implementation of resilience enhancement measures.

For the assessment, a multi-scale approach is needed to incorporate both macro and micro processes and their interactions. For that purpose, the WEAT package has been developed under the SATREPS project to assess multi-scale processes (**Figure 5**). WEAT consists of three different hydrological/hydraulic models with a spatially nested scheme covering three spatial scales: Basin Model (i.e., for the MRB), Lake Model (i.e., for the TSL Basin), and 3) the Village Model (i.e., for floating villages). WEAT structure can tackle the complex processes in the lake and the floodplains, including scenario analysis to compare specific resilience enhancement options. WEAT can consider multiple environmental and anthropogenic stress factors and management scenarios (e.g., population growth, climate change, and LULC changes). WEAT reproduces hydrological, hydraulic, and biogeochemical processes and health risks. WEAT can support decision support such as by providing a comparison of effective management options and scenarios, assisting an effective resource allocation by designing cost-effective environmental monitoring schemes, or helping reduce uncertainty, etc. The tools can be used by scientists, students or researchers as well as the end-users such as government agencies, communities, NGOs and INGOs. To be simply feasible, WEAT comes with user guides.

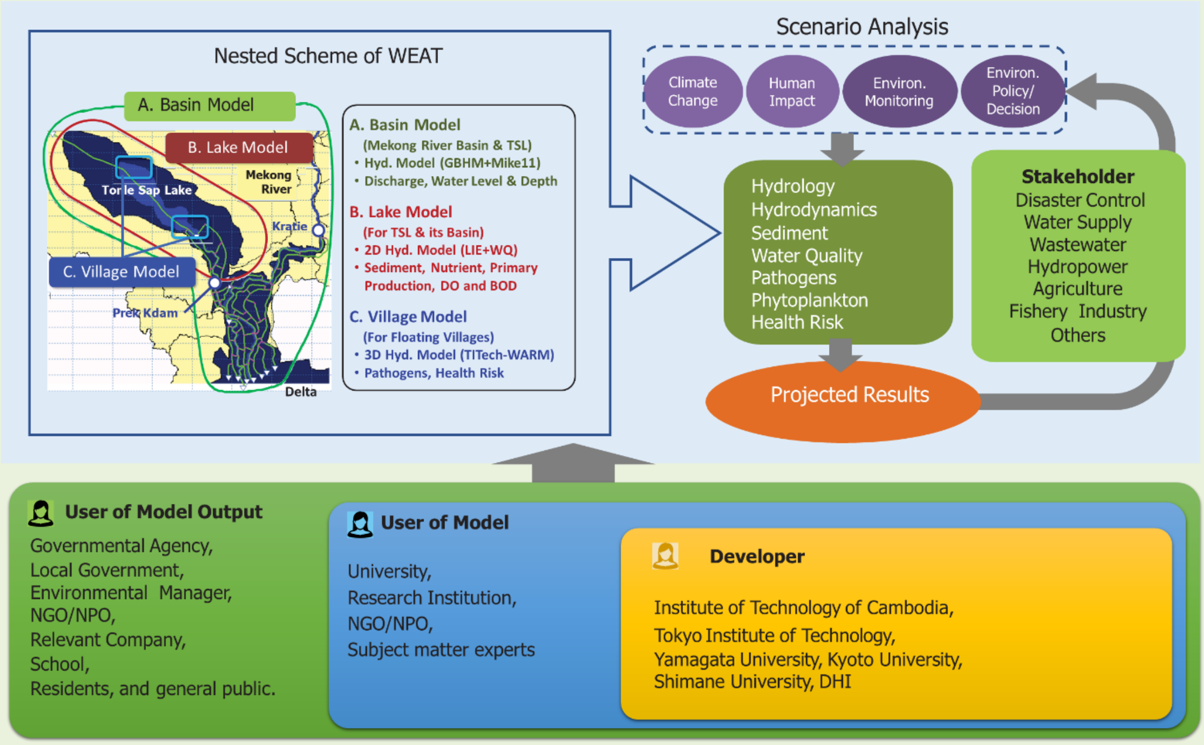

Figure 5: Overview of Water Environmental Analytical Tool (WEAT)

4.3 Scientific research and knowledge response: This response builds on monitoring and assessment response and complements information, participation, finance, and technology pillars of ILBM. Scientific research considers the arrangements to conduct solution-oriented research and gradual building of the capacity. Over the six years, the SATREPS project has successfully contributed to building the research capacity, especially, by setting up necessary laboratory facilities, developing WEAT and its user's guidelines, and human resource capacity building of both faculty and students. Continuity of a culture of scientific research to advance knowledge and understanding such as through various modes of publication and communication is quite essential. As the main outcome of the project, PAER has been established to consolidate all major achievements. PEAR is envisioned as a strategic knowledge hub to promote research, development and education about the TSL environment (**Figure 6**). It is expected to bridge the gap at the policy-science-community/society interface. For that PAER can create a conducive environment for supporting evidence-based environmental management policy to the related local government agencies such as TSA, MoWRAM, and MoE. PAER can host international experts for research collaboration and exchanges. There will be exchange programs between Cambodia and other countries for students/researchers in order to gain research experience. PAER has successfully created an enabling environment and served as an effective platform for connecting various stakeholders down to the grass-root, including policy makers such as TSA, MoE, MoWRAM, researchers in both Cambodia and other ASEAN countries, development partners, international organizations, NGOs as well as local citizens toward enhancing and supporting scientific-evidence based environmental policy making for the improvement of the TSL environment. In addition, a series of "International Symposium on Conservation and Management of Tropical Lakes" involving multi-stakeholders are held annually to promote knowledge exchange and good practices sharing on lake management between Cambodian and international researchers. Further, PAER can serve as a window to promote social interaction and participatory response such as for promoting a citizen-science approach to assess and co-develop solutions.

Figure 6: Basic functions of PAER to facilitate science-policy-community/society interface

4.4 Social interaction and participatory response: Social interaction and participatory response are vital for the coordinated response as well as for multi-stakeholder engagements for the effective implementation of resilience enhancement measures. This response is more about reaching out to relevant stakeholders, especially local communities, about key policy decisions and plans as well as the timely transfer of information on key research findings and recommended actions. At the grass-root level, innovative methods of public participation can facilitate discussion and consensus to identify a variety of complex environmental issues and challenges that only local communities living in and around the lake are usually aware of. Participation allows key stakeholders' opinions and insights to be reflected in the decisions. In doing so, it is important to make sure that vulnerable groups (e.g. women, children, ethnic minority groups etc.) are given sufficient space for meaningful participation. For effective information sharing and public communication, complex research findings should be conveyed into simple and easily understandable messages through a variety of communication methods such as mass media and social media channels (e.g. Facebook, Youtube, Tiktok, etc.), as well as published outreach materials such as policy guidebook, awareness-raising leaflets in the form of poster calendar, which can be easily distributed to the public audience and other relevant stakeholders. All of these responses directly complement the information and participation pillars of ILBM.

4.5 International collaborative response: As a part of transboundary MRB, management of TSL requires international collaboration primarily with the riparian countries and its institutional body such as MRC. Besides that, TSL is a unique wetland system and cultural heritage of international significance. Therefore, international collaboration is a must in a range of areas such as research, education, scientific and policy dialogues, and the transfer of appropriate solutions and technology directly complementing the proposed resilience enhancement measures. At the same time, TSL could be a good showcase for disseminating progress and outcomes that could directly complement the national and global efforts towards key agreements such as SDGs, Post-2020 Global Biodiversity Framework, Sendai framework on Disaster Risk Reduction, and the Paris Agreement on Climate Change. This pillar can complement all pillars of ILBM such as through fulfillment of regional and global policy targets, transfer of technologies, financial support, information exchanges (such as a part of reporting or negotiation), participation in international forums and agreements, etc.

Section 5: Conclusion and recommendations

The TSL ecosystem is facing multiple environmental challenges and threats, which are likely to be amplified further due to various anthropogenic factors such as population growth, rapid economic development and industrialization across the MRB, LULC changes, commercial fishing, tourism, and climate change, etc. Unless these challenges and threats are addressed in an integrated and scientific manner, the situation might further deteriorate in the future and turn detrimental for the sustainability and ecological integrity of the lake. Building on the experience and findings from the SATREPS project, this PAER policy guide proposes a desirable scenario for realizing sustainable and resilient TSL and its basin by addressing current and future challenges and threats in an integrated manner. For that, three resilience enhancement measures of ecohydrology, land-use management and pollution control, and livelihood are suggested backed by an integrated response mechanism to support the implementation of the measures. First, the resilience enhancement measures address a basin-wide intervention to address broader challenges such as changes in hydrological condition, climate change, and LULC changes that directly affect the lake environment and ecosystem. Second, they address the pollution control measures due to land-use practices or disposal of waste, wastewater and pollutants to the lake. The third measures directly address the socio-economic challenges faced by communities living around the lake and most vulnerable to environmental changes in the lake.

To support the coordinated implementation of the resilience enhancement measures, the integrated response mechanism focuses on five response arrangements based on the generic principles of integrated lake basin management. The integrated response framework will support the creation of a conducive setting for multi-level and multi-stakeholder collaboration and participation.

Following are the specific recommendations:

- Establish broader process adaptive governance in an integrated manner.

- Strengthen policy-science-community interaction and collaboration by utilizing knowledge, resources, and capacity generated by SATREPS. Effectively mobilize PAER that is best positioned to facilitate such interaction.

- Make effective use of resources, knowledge, and tools (such as WEAT) developed under SATREPS for assessing and designing solutions on each resilience enhancement measure. When possible, consider multi-stakeholder engagements for co-designing the solutions.

- Foster the involvement of and collaboration amongst stakeholders and institutions relevant and interested in sustainable management and resilient enhancement of the lake ecosystem.

- Enhance community participation in monitoring and assessment of the lake environment as a part of awareness building and for promoting a citizen-science approach.

- Use scientific assessment as a basis for agenda setting and discussion with riparian countries to minimize impacts on the TSL ecosystem

- Make efforts to link TSL with global frameworks and agreements such as SDGs, the Paris Agreement, Post-2020 Global Biodiversity Framework, etc.

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