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Towards Sustainable Groundwater Management of Transboundary Aquifers in the Lower Mekong Region

A. Das Gupta
Water Engineering and Management, School of Engineering and Technology
Asian Institute of Technology
Pathum Thani, 12120, Thailand
adasgupta.05@gmail.com

S. Shrestha
Water Engineering and Management, School of Engineering and Technology
Asian Institute of Technology
Pathum Thani, 12120, Thailand

TPL. Nguyen
Department of Development and Sustainability, School of Environment, Resources and Development
Asian Institute of Technology
Pathum Thani, 12120, Thailand

S. KC
Water Engineering and Management, School of Engineering and Technology
Asian Institute of Technology
Pathum Thani, 12120 Thailand

ABSTRACT
The management of a transboundary aquifer shared by two or more countries is quite complex and is a challenging task. A pragmatic action plan to develop and implement sustainable groundwater development and management of a transboundary aquifer system is proposed. An Institutional system in the form of a Coordinating Council or a Multi-Country Consultative Body at the Government Level is recommended for the management of TBA. Adequate knowledge and in-house capacity with the know-how and expertise is imperative at different administrative levels to address development and management issues.

Keywords—Transboundary aquifers; Sustainable groundwater management; Framework-action plan

INTRODUCTION

In the Lower Mekong Region (LMR), groundwater from underlying transboundary aquifers (TBAs) is increasingly being used to supplement the shortage of surface water in areas where surface water is the predominant source of water supply, to meet the demand for water in areas where surface water is not easily accessible as well as to meet the demand during the dry season when a shortage of surface water availability is imminent. Groundwater also plays an important role in supporting natural river water flows and relevant ecosystems. Following the mission of the Mekong River Commission (MRC), the transboundary cooperation in surface water management in the region has progressed quite satisfactorily in recent years; however, there is no common approach or even modest recognition and cooperation for groundwater resources.

Sustainable development and management of TBAs require a rational approach in analysing and assessing groundwater from multi-disciplinary and multi-dimensional viewpoints in an interdisciplinary and integrated way. It should include scientific and hydro-geological understanding, understanding of socio-economics, institutional constraints, the frameworks of international law (if any), and needs to address wide-ranging environmental issues. These transboundary groundwater resources underlying the riparian countries merit closer attention with regards to their current use, which may not be intensive all over the region, but increasing demands on these resources will result in their intensive use in the near future. It is therefore imperative that a collaborative initiative by the Member Countries (MCs) of the LMR is undertaken to gather information about the status of TBAs, their use and the future perspectives of development for the benefit of communities in riparian countries.

This paper deals with an overview of a pragmatic action plan to develop and implement sustainable groundwater development and management of a TBA system. Goals of sustainable groundwater development and management along with measurable objectives to achieve the goals, are discussed. The comprehensive plan goes through a set of processes, conducted in coordination by the MCs working together sharing the TBAs, to come up with the operational guidelines in terms of water withdrawal on a long-term basis to maintain sustainable development of TBAs. An elaboration of implementation phases and scope of work of the pragmatic action plan is provided. Adequate institutional capacity is needed to execute all functions for implementing the sustainable development plan through long-term evaluation and monitoring of the state of the groundwater system. An Institutional system for the management of TBA in the form of a Coordinating Council or a Multi-Country Consultative Body at the Government Level is recommended. Finally, the in-house capacity requirement at different administrative levels is highlighted to provide the know-how and expertise to address development and management issues.

1 TBAs IN LOWER MEKONG BASIN (LMB)

As per the global inventory of TBAs by IGRAC and UNESCO-IHP (1), four TBAs are identified in LMB. These are Cambodia-Mekong River Delta Aquifer (AS89), Khorat Plateau Aquifer (AS90), Lower Mekong River 2 Aquifer (AS91) and Lower Mekong River 1 Aquifer (AS118), listed in Table 1. The first three are considered as the major aquifer systems with area coverage ranging from 100,000 to 200,000 km^2 shared by two or three countries in the basin.

TABLE 1 TBAs in Lower Mekong Basin (LMB) [derived from Table 1, (2)]

Code	Aquifer Name	Countries Sharing	Area (km^2)	Major Aquifer Formation
AS89	Cambodia-Mekong River Delta Aquifer	Cambodia, Vietnam	204,077	Sediment – sand, gravel, silt
AS90	Khorat Plateau Aquifer	Lao PDR, Thailand	108,529	Sedimentary rock – sandstone/siltstone
AS91	Lower Mekong River 2 Aquifer	Lao PDR, Thailand, Vietnam	122,216	Sedimentary rock – sandstone/siltstone
AS118	Lower Mekong River 1 Aquifer	Lao PDR, Myanmar, Thailand	36,769	Sedimentary rock - limestone

A number of recently published articles and reports dealt with the overview of TBAs in the Mekong River Basin on the regional scale and highlighted the need for comprehensive assessment and collaborative efforts in the development of this resource [(3), (4), (2)]. The upper part of the Mekong River Basin in China is characterised by the fissured rocks or karst aquifer, whereas the delta region (Mekong Delta) is extensively covered by unconsolidated alluvial sediments, extending from the coast to the northwest in Cambodia, including the Tonle Sap Lake. In the delta region, the thickness of the alluvial sediment is large, and these units are characterised as the primary aquifer. Along the central part of the basin, consolidated rock units (basalt, limestone, fissured sandstone, etc.) serve as localised aquifers with high potential groundwater yield. In the lower basin of Mekong, groundwater provides water for approximately 60 million people. Frequent water shortage problems are normally managed by increasing the supply from groundwater, particularly in the dry season.

2 SUSTAINABLE GROUNDWATER DEVELOPMENT AND MANAGEMENT (SGWDM)

Traditionally, 'Safe Yield' concept, as used in the operation of the surface water reservoir system, has been applied for groundwater resources and is defined as the amount of water that can be withdrawn from a groundwater basin annually on a long-term basis without producing any undesirable result (5). A common misperception has been that the development of a groundwater system is 'safe' if the average annual rate of groundwater withdrawal does not exceed the average annual rate of natural recharge. The concept of 'sustainable development', which emerged in the early 1980s, centred on the idea of limiting resource use to levels that could be sustained over the long term. The concept of sustainability in relation to groundwater resources is closely aligned with safe yield, but defined in a broad context as the development and use of groundwater resources in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences (6). Sustainability of groundwater development is a function of the type of aquifer system, the climate, the recharge rate, and the type and scale of groundwater development.

Sustainable groundwater development is defined here as a groundwater pumping regime (spatial and temporal variations) determined for a specific physical system from the dynamic balance of inflow, outflow and change in storage using specified withdrawal rates, well-field locations, drawdown limits and a defined planning horizon. The withdrawal rate patterns that meet the constraint on drawdown and/or any other environmental concerns (like minimum outflow, limit on quality deterioration, land subsidence, seawater intrusion) will indicate the level of sustainable groundwater development. The analysis has to be based on proper identification and estimation of the following four elements of the groundwater system, including their states and inter-relationship: (1) *Available Groundwater Resource,* (2) *Groundwater Development and Use,* (3) *Groundwater Dependent Ecosystems, and* (4) *Governance and Management.* The first three elements are interrelated, giving the state and response of the physical system; however, the operational guidelines and regulations can only be implemented when there is adequate governance and management system in practice.

For a transboundary aquifer system, the development of sustainable groundwater use and management plan is much more crucial as the resource is shared by two or more countries having a unique mandate in resource use and management in their respective country's perspective. However, the principles and concepts applied for the national aquifer system are also applicable for a transboundary aquifer and they need to be adopted in practice in an amicable manner, ensuring equitable sharing of the resource among the countries. The ultimate goal would be to achieve a sustainable level of development of transboundary aquifer resources within an agreed period of time of operation. Groundwater development and use in the Lower Mekong Basin has been mostly unregulated. Water levels have been continually declining, particularly in the delta areas associated with water quality problems and seawater intrusion in the coastal areas. It has been reported in the published literature [e.g. (4), (2)] that the national stakeholders, including regional organisations, scientists, intergovernmental agencies and local communities, have recognised the significance of transboundary aquifer resources and their efforts are expected to institutionalise necessary management plan.

2.1 SGWDM: principles and concepts

The concept of groundwater sustainability should encompass five interrelated goals: three that involve primarily the physical sciences and engineering domain, and two that are mainly socio-economic in nature. These goals are stated as follows (7):

- ***Protection of groundwater supplies from depletion***: where sustainability requires that withdrawals be maintained indefinitely without creating significant long-term declines in regional water levels.
- ***Protection of groundwater quality from contamination***: where sustainability requires that groundwater quality is not compromised by significant degradation of its chemical or biological character.
- ***Protection of ecosystem viability***: where sustainability requires that withdrawals do not significantly impinge on the contribution of groundwater to surface water supply and the support of ecosystem.
- ***Achievement of economic and social well-being***: where sustainability requires that allocation of groundwater maximises its' potential contribution to the social well-being (interpreted to reflect both economic and non-economic values).

- ***Application of good governance***: where sustainability requires that decisions as to groundwater use are made transparently through informed public participation and with the full account of the ecosystem needs, intergenerational equity, and the precautionary principle.

In practice, attaining groundwater sustainability is difficult due to the long timescales of groundwater processes and impacts and depends on how we use, manage, and value groundwater. At a global scale, mean residence times of groundwater are much longer than the residence times of other parts of the hydrologic cycle. For individual aquifers, mean residence times of groundwater cover a wide spectrum from <10 years to >1,000,000 years (8). However, groundwater policy horizons, typically 5 to 20 years, are often inconsistent with natural groundwater time scales, and this inconsistency creates hindrance for long-term groundwater sustainability. Impacts of aquifer depletion and groundwater contamination are often only observed after long periods of time. Likewise, renewal of a depleted aquifer and remediation of contaminated groundwater may demand measures over several generations. Three practical approaches for groundwater sustainability are advocated (9): setting long-term sustainability goals, back-casting, and management that is integrated, adaptive, inclusive, and local. It was suggested setting groundwater sustainability goals for aquifers on a multigenerational time horizon (50 to 100 years) while acknowledging longer-term impacts. Alternatively, mean residence times are a useful indicator of planning horizons because the mean residence time of an aquifer, defined as the average time for groundwater to flow from recharge to discharge areas, is an approximation of the aquifer renewal time. For groundwater systems with short mean residence time, the mean residence time can be used directly or as starting point for discussion of the planning horizon. For groundwater systems with long mean residence time, cyclic planning with adaptive management should be used to achieve the long-term sustainability goals.

Specific measurable objectives are required to avoid a series of “undesirable results”, like the negative impacts caused by continual lowering of groundwater levels, water quality degradation and land subsidence. Measurable objectives are essential as it is impossible to achieve sustainability without defining what it means and how it will be measured. The purpose of a measurable objective is to be a guide to achieving management goals; therefore, monitoring the status of a measurable objective so that it can be directly related to triggers and thresholds is important. Monitoring is the cornerstone of adaptive management. The importance of monitoring, and of learning from information collected, is what fundamentally differentiates adaptive management from trial and error. In order to guide the development process without having any undesirable consequence of the groundwater pumping, countries sharing the resources of TBAs need to define some “measurable objectives” to achieve “the sustainability goal for the basin”.

2.2 SGWDM: how to implement in practice?

The riparian countries sharing the transboundary aquifer system need to agree on “measurable objectives” to avoid “undesirable results” and to achieve “sustainability goals for the basin”. This is to be accomplished through a collaborative process of investigation, analysis and arriving at a consensus through dialogue by the professionals and designated representatives of riparian countries.

First, an understanding of the present level of groundwater utilisation of TBAs and its associated impact on the state of groundwater in terms of groundwater level change and groundwater quality is needed, whereby ‘defining clear baseline’. In case if the groundwater level has been declining on long-term basis, then the ‘allowable groundwater overdraft’ over the planning horizon can be taken as the measurable objective. This target depends on many factors ranging from hydrologic and hydraulic conditions of the aquifer system to allowable pumping lifts used for water withdrawal and the pumping cost. The riparian countries need to agree on this and the ‘quantitative threshold’ is set in terms of maximum allowable groundwater level drop; as well as they need to indicate ‘protective triggers’ for the management authorities to take necessary steps in order to contain measurable objective within a quantitative threshold. On the other hand, if groundwater quality is an issue, then the permissible level of water quality content would be set as a measurable objective, and the ‘quantitative threshold’ would be maximum permissible values for specific water quality parameters.

With an understanding of the hydro-geological system of TBAs and proper characterisation of the aquifer system, in the second step, the dynamic behaviour of the aquifer system is simulated when subjected to different scenarios of water withdrawal pattern in order to identify the window of pumping patterns in future over the years that will meet the requirement of measurable objectives over the planning horizon. This is interpreted as back-casting procedure to determine the simulated feasible pumping patterns in future that will meet the requirement of maintaining the aquifer response within the set threshold values. The actual pumping in future can then be regulated following a pattern within the window of back-casting options. Proper guidelines are then provided for the respective country's groundwater agency to understand what is required to achieve sustainability and what would be the guiding pattern of water withdrawal in future. As well, regular measurement and monitoring, and evaluation are to be carried out to ensure that the defined, measurable objective is within the threshold value, otherwise adjustment to management option (e.g. in terms of withdrawal pattern) is to be applied as part of adaptive management.

3 PRAGMATIC ACTION PLAN NEEDED FOR SGWDM

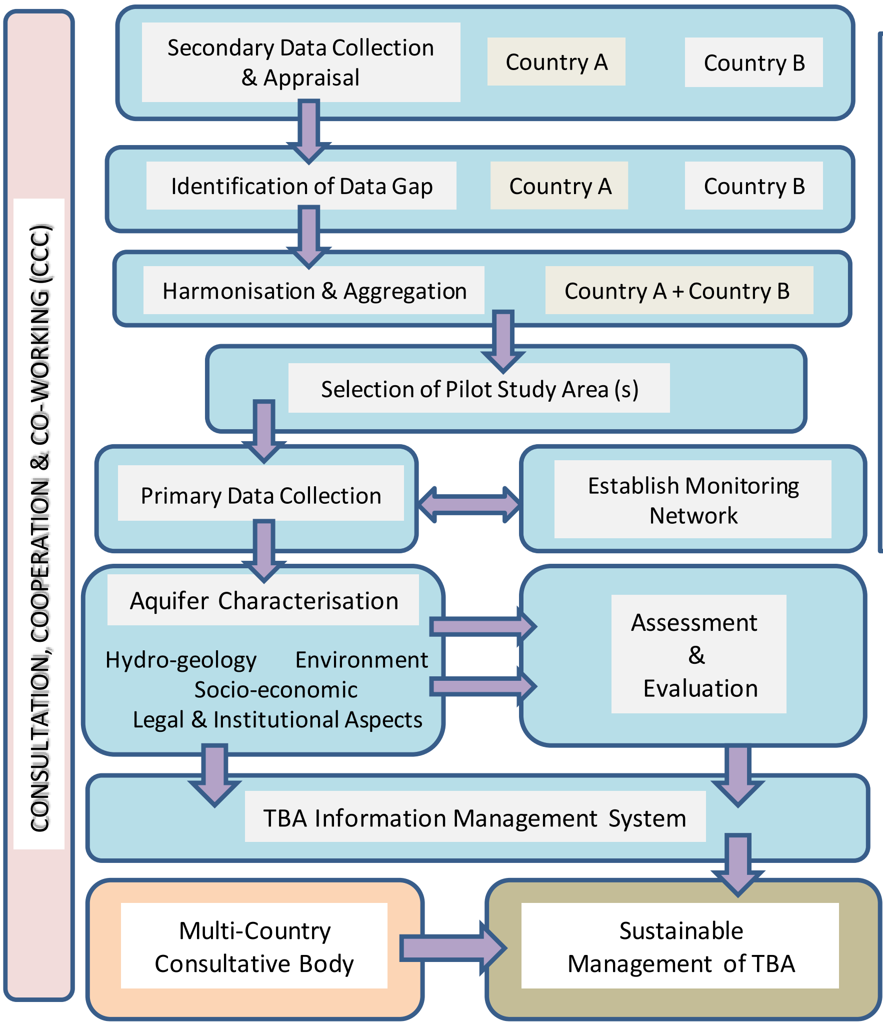
The mission of MRC is to promote and coordinate the sustainable management of water resources for the countries' mutual benefit. Although MRC includes groundwater in its mandate, the activities so far have mainly focused on surface water or integrated water resource management (IWRM) and bilateral agreements only exist under the IWRM framework. Activities focusing on shared groundwater resources management have not been adequately implemented. Management of the resources in transboundary aquifers broadly follow the same principles as those for any national aquifer resource, driven by the national priorities. However, for a shared resource, the national priorities may have to be adjusted to ensure equitable distribution. Different interests in utilising groundwater resources between countries have also restricted to undertake any initiative to utilise the resources on shared basis. Furthermore, data and information derived for hydro-geological conditions in respective countries may not be compatible to carry out a shared assessment of transboundary aquifer resources. Some form of international/regional initiative is therefore needed for the assessment of TBAs based on a sound scientific foundation.

The transboundary groundwater resources underlying the Lower Mekong Region merit closer attention with regards to their current use, which may not be intensive, but increasing demands on these resources will result in their intensive use in the near future. It is therefore imperative that the MRC takes initiative to institutionalise a collaborative initiative among the sharing countries to gather information about the status of TBAs, their use and the future perspectives of development for the benefit of communities in riparian countries. A pragmatic action plan is required to guide the process, starting with data collection, data harmonisation and aggregation, all through the analysis and evaluation leading to sustainable management of transboundary aquifer. An overview of the action plan with specific elements is provided in Fig. 1. This action plan is recommended considering the long-term need for a system to be in place to address the sustainable use of groundwater of TBAs. It comprises of the following steps: (1) Secondary Data Collection and Appraisal, (2) Identification of Data Gap, (3) Harmonisation and Aggregation, (4) Selection of Pilot Study Area(s) in TBA, (5) Establishment of Monitoring Network, (6) Aquifer Characterisation, (7) Assessment and Evaluation, (8) TBA Information Management System, and (9) Multi-Country Consultative Body.

3.1 Implementation stages and scope of work

The implementation of activities with the goal of attaining SGWDM can be phased in three stages. Stage I is on secondary data collection, documentation and preliminary assessment, Stage II is on detailed analysis and development, and Stage III is on implementation, operation, management and monitoring. The scope of work of each stage requires discussion and agreement among the water users and stakeholders of riparian countries sharing the groundwater resources. The suggested scope of work under each stage is as follows:

Stage I: Preliminary Assessment - The major scope of work planned during Stage I deals with collection of secondary data available on hydro-meteorology, geology, hydro-geology, groundwater use, socio-economic aspect and institutional system; their preliminary analysis and evaluation to develop an understanding of the state of the groundwater system of TBAs in the respective sharing country. Also, identification of pilot study area (s) through discussion and deliberation of sharing countries for detailed data collection and analysis would be an important outcome of this stage.



Harmonisation implies that the same standard (like the level of detail, the period of time and frequency of measurement, units, etc.) is agreed upon by MCs and used in observation and compilation of data for the entire TBA system; while, **Aggregation** is the process of assembling all data and information from MCs in the same form for the TBA shared by countries to produce different mapping output in unified manner.

Fig. 1. Elements of Action Plan to achieve long-term objective of sustainable management of TBA: hypothesised 1 TBA shared by two countries (Country A & Country B)

Stage II: Detailed Analysis and Development - Once the pilot study area (s) have been identified, the main scope of this stage is to conduct a more detailed evaluation following a multidisciplinary approach. The hydro-geological analysis that is needed for the management of transboundary aquifers should run in parallel with and close relationship to the socio-economic, legal, and institutional analyses. Unless these components of the activities (indicated under Aquifer Characterisation in Fig. 1) are closely linked, the interrelationships may not be fully established and the final outcome may be weak. Following this**,** Assessment and Evaluation are done with the objective to understand the current state and future use of groundwater resources, to identify any environmental issues to be addressed in the development process, and to provide a sustainable development plan. One of the objectives of this stage of development is to evaluate the extent to which interregional harmonisation is needed in areas of data collection, data compilation, data analysis, and information dissemination and reporting. Stage II does not seek to change national approaches, rather to seek synergies and equivalences.
Stage III: Implementation, Operation, Management, and Monitoring - The sequence of activities in Stage III should be considered in the longer term. There are many reasons for this; mainly, that seeking finances and stakeholder support is generally a process that must not be hurried. Apart from this, a fundamental reason for this stage to extend to the long term is that aquifers respond more slowly than

surface water systems. Consequently, the management and monitoring of transboundary aquifers are closely linked and have to be viewed from that perspective.

Finally, the overall aim of the action plan is to assess the current state of the resource, to identify current and potential transboundary issues and explore possibilities for common groundwater management. The outcomes of the assessment need to be easily understood and used by decision makers and even by the general public. For this, some effort needs to be put into producing an "Assessment Report" containing a clear and non-technical message, using thematic maps, tables and other graphical features accompanied with short explanations. An updating of this reporting would be a regular outcome of the joint management operation of TBA sharing countries. By considering the long-term perspective of resource use, assessment and evaluation, "TBA Information Management System (TBA-IMS)" is set up where all the compiled data, interpreted maps and results are stored. TBA-IMS is used during the recurring assessment and evaluation as development progresses. For proper functioning of the whole process a "Multi-Country Consultative Body" is formed to oversee the operation and management of TBAs.

3.2 Institutional system and capacity requirement

Each TBA has a unique feature from hydro-geological perspectives and the utilisation of its resource in respective sharing countries would be varying depending on the extent of its use in various development activities. Sharing countries have their institutional system for governance and management of groundwater that may not be compatible with each other. The overall scope of work to prepare the plan for sustainable groundwater use from transboundary aquifers requires discussion and agreed upon by the countries sharing the groundwater system. In order to facilitate this, a "Coordinating Council at the Government Level" is to be established to institutionalise a thorough consultation process and to take necessary actions for strengthening the collaborative process. This Coordinating Council is basically a "Multi-Country Consultative Body" as mentioned above. It is recommended that this "Coordinating Council" or "Multi-Country Consultative Body" consists of (1) A chair with strong leadership and communication skills, and (2) Three to Four independent members from sharing countries. These independent members should have collective expertise that would enable them to resolve all the legal, financial, hydrological, hydro-geological, environmental, groundwater management, and communication issues likely to come before them.

A proper organisational and institutional set-up with in-house capabilities has to be formed through joint effort and collaboration of countries sharing the groundwater basin. Expertise from outside and support of aid organisations will certainly assist in addressing key issues at the local and regional level; however, the long-term sustainable groundwater management will inevitably depend on the in-country professionals to provide the know-how and expertise. Sustainable use and management of groundwater resources require not only the technical and scientific skills in geology, hydro-geology but also the capability in socio-economics and the whole scope of water security to address issues of climate change. Groundwater is most effectively managed at the local and regional levels. Better authorities and tools at the local level are needed to support effective management. Capacity development needs are, therefore, to be assessed at different administrative levels in order to have well trained human resources and adequate financial resources at all levels to address groundwater resource development and management issues. All the stakeholders involved in groundwater development and use, and groundwater management need to have a basic knowledge and understanding of groundwater and the environment. Professionals with special expertise in different disciplines related to groundwater are to be in the institutional system all the way to the lowest possible level as measures are to be adopted at the local level to address development and management issues. Target group-oriented training programs are therefore required for in-house capacity development. The most important target groups are: Water Authorities; Water and Wastewater Associations; Engineers, Geologists and Hydro-geologists; and Community and Groundwater Users.

4 CONCLUDING REMARKS

Unlike all other water bodies, aquifers are located in the subsurface and visible only through the eyes of science – hydrogeology. As a consequence, aquifer boundaries are often very poorly known and many aquifers remain unknown or only partly recognised as separate, often unconnected, entities. This is particularly true for transboundary aquifers, which are often not recognised by countries as shared resources. This lack of recognition increases their vulnerability to anthropogenic pressures. Therefore, there is a need for a systematic effort to identify and delineate aquifers that are transboundary (Inventory) and to provide a standardised description of their main characteristics in terms of hydro-geology, environmental role and implications, socio-economic value and governance structure (Characterisation).

The management of a TBA shared by two or more countries is quite complex and is a challenging task as countries may have different forms of institutional and governance systems for management purpose. Adequate knowledge and understanding of the physical behaviour and functioning of the aquifer system, its state and extent of usage and their future trend are needed to plan for sustainable use and management of the resource. Implementation phases and scope of work of a pragmatic action plan are elaborated. It goes through a set of processes, conducted in coordination by the MCs working together sharing the TBAs, to come up with the operational guidelines of groundwater development on a long-term basis to maintain sustainable development of the TBA system. An Institutional system in the form of a Coordinating Council or a Multi-Country Consultative Body is recommended for the management of TBA. The in-house capacity and resources at different administrative levels to provide the know-how and expertise should be adequate to address development and management issues.

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