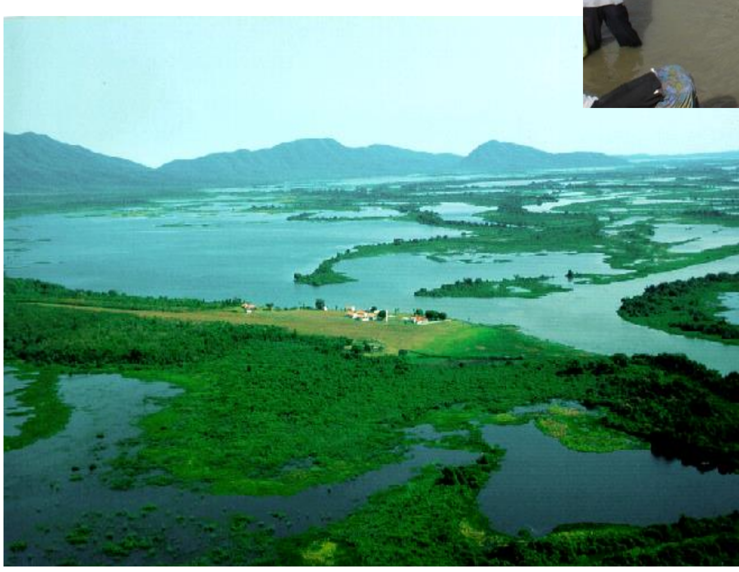
TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME (TWAP)

Lake and Reservoir Basins Component

International Lake Environment Committee Foundation
Kusatsu, Japan



EXECUTIVE SUMMARY

Water is an essential requirement for all life, and the most important global integrator connecting aquatic and terrestrial ecosystems and the atmosphere in a continuing cycle of use and replenishment. Humans use freshwater systems to address the widest range of human health and socioeconomic development needs. Lakes and reservoirs are especially important in this context, numbering in the millions and existing on every continent (the term 'lakes' refers to both natural and artificial lakes [reservoirs]). The total number of lakes on our planet collectively covers a land area equivalent to half the land area of the contiguous United States, with more than 90 per cent of all the liquid freshwater on the land surface being located in lakes, reservoirs, wetlands and other lentic (pooled) water systems.

Lakes possess unique characteristics that make it difficult to accurately assess their environmental status at any given time, including long water-residence times, an integrating nature that ensures everything comes together in a lake, and non-linear responses to stresses that make their behavior unpredictable and uncontrollable. Accordingly, lakes typically exhibit a 'lag' phenomenon characterized by slow, incremental non-linear responses to environmental stresses that can mask degradation until it has become a serious lake-wide problem, as well as positive signs of remedial measures, making it difficult to accurately determine the status of a lake at any given time.

The methodology for the TWAP Lakes Component included reducing an initial list of more than 1 600 transboundary lakes to 156 transboundary lakes, using GIS-based spatial analysis of global-scale databases, with an additional 50 lakes in developed countries being added for comparison purposes. The list of 206 TWAP transboundary lakes comprised 30 lakes in the South America and Caribbean region, 34 in Africa, 70 in the European region, 52 in the Asia region, and 20 in North America. However, since the majority of these transboundary lake basins were not provided with precise geographic dimensions, it was necessary to undertake the GIS-based spatial analyses with digital elevation model (DEM) calculations to delineate the lake basin areal extent, and their relationship withconnecting river systems.

Another methodological challenge was very scarce uniform data on the in-lake conditions, preventing their direct comparisons. Accordingly, it was decided to use information and data on their basin characteristics that could be translated to ranking scores defining the relative threats facing the transboundary lakes. The basin-scale data from a previous global study conducted by Vörösmarty *et al.* (2010), comprising 23 basin-scale drivers grouped under the thematic areas of catchment disturbance, pollution, water resource development, and biotic factors, was adapted for this purpose. A limitation of using basin characteristics, rather than in-lake conditions, to determine relative threats is that a lake calculated as being threatened may not presently being seriously degraded (although its basin characteristics suggest it may become threatened over the longer term).

A Scenario Analysis Program was then used to determine the relative lake threat ranks on the basis of the computed scores derived from the 23 drivers adjusted for specific basin characteristics. Because of insufficient data to compare all 206 transboundary lakes, the study list was reduced to a final total of 53 transboundary lakes presumed to merit the most attention, including 23 African, 8 Asian, 9 European, 6 South American, and 7 North American lakes.

Based on this approach, the initial transboundary lake rankings were expressed in terms of Incident Human Water Security (HWS) and Biodiversity (BD) threats. The top dozen transboundary lakes exhibiting the highest Incident HWS threats included five European, four Asian, two North American and one African lake. The top dozen lakes exhibiting the highest Incident BD threats included five European, four North American, and three Asian lakes. Contrary to expectations, the African lakes as a group generally ranked in the bottom half of the 53 transboundary study lakes.

The Incident threats, however, do not tell the whole story. Firstly, the transboundary lake threat ranks can be markedly different even for the same set of lakes if interpreted on the basis of other defining criteria. The threat ranks can be affected by the weights assigned to the ranking factors, for example, and the specific criteria or preconditions used to interpret the rankings. One major factor was the ability of the basin countries to undertake technological investments to reduce identified water threats (water supply stabilization, improved water services, etc.). An Adjusted Human Water Security (Adj-HWS) threat criterion was developed to account for this possibility. In contrast to their high incident HWS threat ranks, the more economically-developed countries (e.g., Europe; USA) exhibited lower Adj-HWS threats (Table 4.3). Countries less able to make such investments, mainly developing countries, exhibited higher relative Adj-HWS threats, highlighting a greater need for catalytic funding for management interventions than those with lower Adj-HWS scores. The relative threats to many African transboundary lakes, for example, increased substantially on the basis of the Adj-HWS threat, while those of European and North American countries decreased under this same criterion, with 11 of the 13 highest ranked transboundary lakes being located in Africa. The Adj-HWS threat ranks of the Asian lakes also generally increased, although not by the same magnitude as for the African lakes.

Secondly, factors other than economic characteristics can readily affect meaningful interpretation of the calculated transboundary lake ranks. Examples include lake or basin size, basin population number or density, specific water uses or important ecosystem services, cultural significance, etc. Non-transboundary lakes and extra-boundary factors can also be important internal drivers influencing the lake threat ranks. Many lakes are located along migratory bird flyways, for example, with thousands congregating in them during their annual migrations. Non-transboundary lakes, therefore, can assume transboundary significance during certain times of the year. Climate change considerations can also influence lake dynamics and fisheries.

Therefore, to obtain more accurate insights for this purpose, Expert Group Meetings were conducted in Brazil, Ghana, India, Italy, Kenya, Malaysia, Mexico, Turkey and the Philippines to obtain valuable on-the-ground information and data for this purpose. Region-specific questionnaires were also developed to obtain information about how lake basin stresses affected its ecosystem services and lake basin stakeholder uses of these ecosystem services. Further, a literature-based knowledge system, LAKES-III *("Learning Acceleration and Knowledge Enhancement System"*) was developed to substantiate conclusions regarding the status, potential and priority for addressing the transboundary lake threats. These various data and information sources, used in conjunction with the Scenario Analysis Program, demonstrated the calculated lake threat ranks can be misleading unless the most important factor(s) for the user of the rankings was also considered in interpreting the ranking results.

Thirdly, In order to provide appropriate context for interpreting the transboundary lake ranking results, a parametric sensitivity analysis was used to assign differing relative weights in the Adj-HWS and BD threat calculations. The Human Development Index (HDI) was also included in the analyses. Based on this sensitivity analysis, the African transboundary lakes as a group continued to exhibit the greatest threats, comprising 20 of the top 24 most threatened lakes. The remaining four lakes comprised three South American and one Asian lake. The ranking was not the same obtained using the Adj-HWS, BD or HDI data individually, however, with the more developed countries exhibiting the lowest threats.

Further, the transboundary lake rankings were also used to identify those lakes most likely to benefit from GEF-catalysed management interventions. Some management interventions, for example, should consider addressing multiple lake needs (e.g., Lakes Albert and Edward, Chilwa and Chiuta, and Cohoha, Ihema and Rweru/Moero in Africa). Other transboundary lakes require evaluation of their scientific and/or political situation prior to considering management interventions (e.g., Asian Lake Danbandikhan; South American Salto Grande). Others require consideration of the larger river basins in which they were located (e.g. Cahora Bassa in the African Zambezi River basin), while a large number merited review of their current GEF status. The range of the ranks obtained for the transboundary lakes again highlighted the need to determine the appropriate context for interpreting the threat ranks, and the difficulty in obtaining an unequivocal definition of the current threat status of a given transboundary lake.

A noteworthy lack of mention of lakes and other lentic water systems in international agreements supports the need to streamline these important water bodies into global water discussions, both to better protect and conserve the large quantities of their readily-available freshwater, and to address the sustainability of the range of ecosystem goods and services they provide.

As a concluding observation, Integrated Water Resources Management (IWRM) has become widely used to facilitate policy reforms regarding water resources, particularly in developing countries. However, 'operationalization' of IWRM principles has been difficult for lakes, the latter typically requiring longer-term incremental and gradual basin governance improvements for sustainable resource use and conservation. Thus, an integrated approach, Integrated Lake Basin Management (ILBM), was developed to address this deficiency, focusing on the sustainable management of lakes and other lentic water systems through gradual, continuous and holistic improvement of basin governance. Complementing the IWRM approach, the conceptual ILBM framework represents a virtual stage for collective stakeholder actions to improve lake basin governance to facilitate sustainable ecosystem services. ILBM also can enhance the utility of

TDA/SAP-developed activities for managing relevant national water issues falling outside the purview of GEF-supported interventions.

Several summary conclusions merit reiteration:

- Considering the Incident HWS and BD threats alone, many European and North American transboundary lakes rank as being most threatened. Considering the ability of countries to undertake necessary investments to address water problems, however, resulted in developing country transboundary lakes collectively exhibiting the greatest threats, particularly African lakes, and some Asian and South American lakes;
- The lake threat ranks change significantly when different ranking criteria or preconditions are given differing importance in the analyses. An accurate, meaningful risk assessment must consider a range of interacting scientific, socioeconomic and governance issues, whose relationships can be very subtle and incremental in impact. Selecting the appropriate context for interpreting the relative lake threats remains the task of the user of the ranking results;
- The scarcity of uniform lake data on a global scale compels the international water community to undertake knowledge base development focusing on lakes and other lentic water systems, including their upstream and downstream linkages. Our increasing knowledge of the role of lakes in influencing such global-scale issues as climate change impacts and fisheries vulnerability also merits greater discussion in the international water arena;
- The assessment process encompassed within the Scenario Analysis Program developed for the Lakes Component of TWAP, facilitating meaningful interpretation of the assessment results, is also a significant contribution to the transboundary lakes assessment;
- Future transboundary water assessments will be more useful and realistic if the hydrologic and jurisdictional links between transboundary water systems, and their defining characteristics, are considered together. Thus, future transboundary assessment working groups should include representatives from each transboundary water media working collectively;
- Although the activities associated with future transboundary assessments can be incorporated within future programmes of UN and other international agencies to some degree, a core requirement for undertaking future assessments will be the availability of sufficient, sustainable financial resources and institutional support.

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TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME (TWAP):
Lake and Reservoir Basins Component

1. INTRODUCTION

1-1. Programme Goals and Objectives

The health and socioeconomic development of the global population, and the sustainability of both terrestrial and aquatic ecosystems, are both dependent fundamentally on the water resources of the world. The freshwater resources existing in the form of lakes, rivers and groundwater aquifers are especially important in this regard. Containing more than 90 per cent of the liquid freshwater on the surface of our planet, lakes in particular support the widest range of human water uses. Further, although many lakes lie within individual countries, many also are transboundary in nature, crossing one or more national boundaries, or shared by one or more countries. They can also form a complete or partial border between countries. Accordingly, they can be degraded by a wide range of human activities in their drainage basins and, in some cases, even from sources outside their basins.

The Transboundary Waters Assessment Programme (TWAP) was funded by the Global Environment Facility (GEF) and implemented by the United Nations Environment Programme (UNEP). The overall goals were to provide an indicator-based assessment of the state of, and threats to, the transboundary water resources of the world. This includes providing an overview of their current status, identifying and ranking the transboundary water systems at most risk from human activities, and providing a database that can be used to facilitate the most effective allocation of the limited funds of the GEF International Waters portfolio. In doing so, the TWAP results will assist the GEF, as well as other water stakeholders interested in or affected by the status of transboundary lakes, whether natural or artificial (reservoirs) in meeting human water needs while also sustaining the life-supporting ecosystems goods and services provided by them. It is hoped the results obtained from this initial global-scale transboundary waters assessment will provide an impetus for similar periodic assessments in future years as a means of monitoring the changing status of lakes and other freshwater systems, as well as providing guidance on how efficiently they are being managed and used.

UNEP is conducting the project with the assistance of five separate transboundary waters working groups: lakes/reservoirs, rivers, groundwater aquifers, large marine ecosystems and the open oceans (Figure 1.1). Each working group is comprised of individuals and various supporting organizations, focusing on their specific water systems.

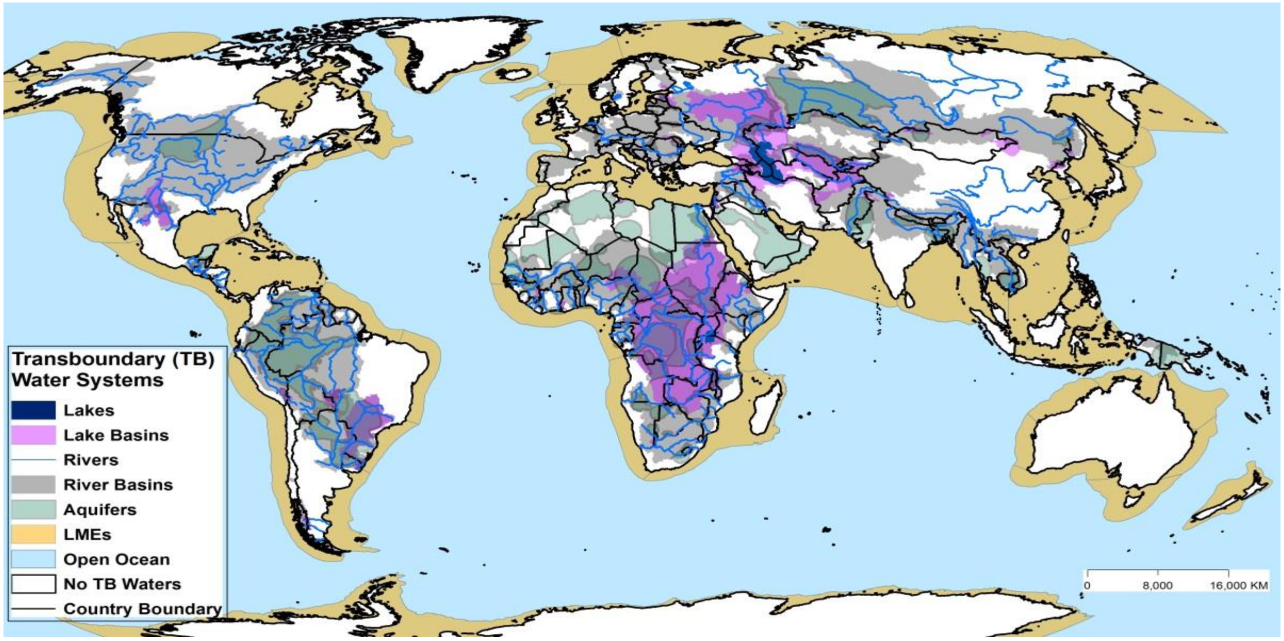


Figure 1.1 Transboundary Water Systems Comprising Transboundary Waters Assessment Programme (TWAP)

1-2. TWAP Lakes and Reservoirs Component

The portion of the TWAP dealing with lakes and reservoirs is being conducted by the International Lake Environment Committee (ILEC), headquartered in Kusatsu, Japan. In contrast to organizations collaborating with the other TWAP working groups, ILEC is not part of the UN System. Located on the shoreline of Lake Biwa, an ancient lake in Japan, ILEC focuses on promoting rational management of lakes and their catchment areas, consistent with the underlying policy of sustainable development. ILEC conducts its activities in collaboration with its multinational advisory Scientific Committee, and in cooperation with counterparts from the scientific, governmental, academic and private sectors involved in the conservation of lakes and other lentic water systems. This includes: (1) collecting and disseminating information and data on environmental aspects of lakes; (2) promoting technical and management training and workshops on the lake environment; and (3) collaborating with governmental agencies, research institutes and NGOs throughout the world, particularly in developing countries, on environmentally-sound lake management directed to the sustainable use of life-supporting lake ecosystem goods and services.

1-3. Basic Structure of TWAP Transboundary Lakes Report

This report follows a general sequence of data identification and acquisition, development and application of methodology, and presentation and discussion of results. The first chapter describes the overall function of lakes in the global hydrologic cycle, including their unique features that make their accurate and meaningful assessment a challenging task. It also compares the characteristics of the standing or pooled water systems and flowing water systems, and the assessment and management implications of their links.

The GIS-based spatial analysis needed to locate and delineate the TWAP transboundary lakes and their drainage basins is described in the methodology chapter. Also highlighted is that the lack of a uniform, global-scale lake-focused database did not permit the threats to the transboundary lakes to be based on comparison of their in-lake conditions. Rather, the threats to the lakes were based on assessing the stresses to them from their drainage basins, with due recognition of the limitation of this approach. The subsequent development of a spreadsheet-based Scenario Analysis Program for assessing the relative stresses and resulting threats to the transboundary lakes is described in the methodology chapter. It allows users to specify various contexts or preconditions (lake or basin size, basin population, socioeconomic criteria, etc.) for interpreting the lake threat ranking results. Ancillary data sources also are discussed, including input received from regional Expert Group meetings and region-specific Questionnaires.

The transboundary lake assessment results from the Scenario Analysis Program are discussed on the basis of a range of filtering criteria, including consideration of non-transboundary and extra-boundary factors, illustrating the context they denote can produce markedly different interpretations of the threat ranks in many cases. A parametric sensitivity analysis also is presented, allowing the interpretation of the transboundary lake ranks within the context of alternative criteria weights. The results also are discussed in the context of providing guidance to the GEF regarding the possibilities for funding potential transboundary lake management interventions.

In addition to discussing the lessons learned in this assessment, the utility of ILEC's Integrated Lake Basin Management (ILBM) Platform process, and its extension as Integrated Lentic Lotic Basin Management (ILLBM), as an assessment tool is discussed, including its utilization within the context of the GEF Transboundary Diagnostic Analysis (TDA) and Strategic Action Program (SAP) framework. Observations for facilitating future transboundary lake assessments also are provided.

In considering the results of the transboundary lakes assessment, the term 'lakes' refers to both natural lakes and artificial lakes (reservoirs) throughout this report. Where the distinctions between these two types of lakes are relevant for the purposes of the TWAP goals, they are pointed out in the discussions.

2. FUNCTION OF LAKES IN THE HYDROLOGIC CYCLE

2-1. Lentic and Lotic Water Systems

As observed by Wetzel (1975) in the last century, the quantity of freshwater on our planet is very small, compared to that contained in the oceans. The former waterbodies have more rapid renewal times as a result, with both assessment and management implications. Defined in limnological terms, rivers, streams and brooks are lotic (flowing) water systems comprising the primary surface freshwater transporting systems in a drainage basin. In contrast, lakes and wetlands are lentic waters systems that collect and pool water from upstream lotic systems and, in most cases, discharge water into downstream water systems. There is an enormous number of lakes, one estimate being that our planet contains more than 300 million lakes with surface areas of 0.1 hectare or more, comprising approximately 90 per cent of the total number of lakes. Of this total, 27 million lakes have surface areas of one hectare or more, and 17 lakes larger than 10 000 km^2 in area, collectively covering about one million km^2. The total number of lakes on our planet collectively cover approximately 4.2 million km^2 of land area, equivalent to about half the land area of the contiguous United States (Downing *et al.* 2006). Overall, it is estimated that more than 90 per cent of all the liquid freshwater on the surface of our planet is located in lakes, wetlands and other lentic water systems. On a global scale, surface liquid freshwater is concentrated in the basins of several large, deep natural lakes, including Lake Baikal, Lake Tanganyika, the Laurentian Great Lakes, and the Caspian Sea, most being transboundary. The Laurentian Great Lakes and Lake Baikal, for example, collectively contain nearly 40 per cent of the liquid freshwater on the surface of our planet. Further, noting that lakes are typically located within basins that occupy larger land surface areas, surface freshwater basins can be viewed as comprising a collection of nested lotic and lentic water systems (Figure 2.1).

Artificial lakes (reservoirs) also have prominence in the hydrologic cycle. Humans have added about half-a-million reservoirs with surface areas of at least one hectare. This includes 24 reservoirs with surface areas exceeding 1 000 km^2 and three reservoirs exceeding 10 000 km^2. The total number of these reservoirs collectively covers nearly 259 000 km^2 of surface area. Although humans have constructed various types of reservoirs for water supply and food production for thousands of years, the largest increase in reservoir water storage has occurred since the 1950s, with a ten-fold increase in the water volume previously compounded in these constructed lakes (Downing *et al*, 2006). These latter water bodies were constructed mainly to address the variable nature of the timing and volume of precipitation falling on the land surface which results in an uneven distribution of runoff waters on our planet. As water storage systems, reservoirs serve the dual function of ensuring continuing water supplies during periods of water scarcity, and providing a means of controlling excessive water volumes during flood periods,

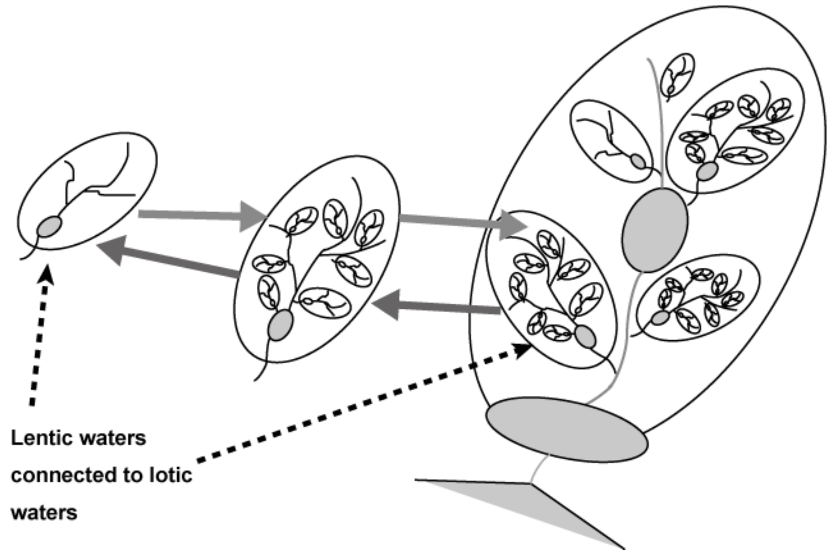


Figure 2.1 Schematic of Linked Lentic and Lotic Water Systems in Lake Drainage Basin
(modified from Nakamura and Rast, 2014)

thereby allowing their more controlled downstream release. In spite of various negative impacts attributable to their fragmentation of river systems and alteration of aquatic habitats, reservoirs are usually very important water systems in the regions in which they are constructed (WCD, 2000). To this end, the water volume in reservoirs has increased an estimated twelve times since 1945, including an approximately 40-fold increase in South America, and a hundred-fold increase in Africa and Asia. Further, some have suggested that the risks and uncertainties associated with the impacts of global climate change on the hydrologic cycle dictate the inevitable construction of additional reservoirs in the future as a necessary response measure.

2-2. Unique Features of Lakes as Lentic Water Systems

In a physical sense, natural lakes are formed in basins or depressions in the land surface that become inundated with water over time. The depressions are typically the result of a range of geological-scale events (tectonics, glaciers, volcanoes), discussion of which is beyond the scope of this report. Because the velocity of upstream waters flowing into lakes typically decreases as they enter a lake, much of the organic and inorganic material carried in it tends to sink to the bottom (Loucks and Van Beek, 2005). Thus, lakes are destined to become filled with sediments and other materials from their basins over time, whether geological or generational in scale, depending on their size and volume, and the activities occurring within their drainage basins.

There are several distinguishing characteristics of lakes and their basins that fundamentally influence their accurate assessment, and which must be considered to develop effective management programmes. As discussed below, these include their integrating nature, long water retention times, and complex response dynamics.

Integrating Nature

Typically being located at the hub of their drainage basins, lakes represent the flow-regime integrators within river-lake basin complexes. They receive inflowing water (and the materials contained in the water) from upstream rivers and tributaries draining into them. Thus, regardless of the upstream sources of these materials, they all come together in a lake. This integrating effect essentially transcends the entire lake and its riparian land interfaces, making lake issues mostly inseparable. Lake resources and their associated problems, therefore, form a complex web of cause-effect relationships that propagate throughout a lake. Thus, except possibly for embayments with narrow mouths to the main body of a lake, it is not possible to assess only part of a lake, or to make accurate conclusions about the status of the entire lake based on considering only part of it. The same is true for implementing management or restoration programmes. Because in-lake issues are largely inseparable, a broad range of management programmes and policies may be necessary to address, for example, the often large number of pollutant sources introducing contaminants to a lake from its surrounding basin, being particularly challenging when the sources are located in multiple jurisdictions, or are transboundary. This is an important consideration for the Global Environment Facility, since an ultimate goal of developing a Transboundary Diagnostic Study (TDA) and Strategic Action Programme (SAP) is to facilitate better understanding and more effective management of transboundary waters systems and the range of the life-supporting ecosystem goods and services they provide.

Long Water Retention Time

The water retention (renewal) time refers to the average time water spends in a lake. Large lakes obviously contain large volumes of water, thereby having longer water retention times. This gives them a 'buffer capacity' that allows them to assimilate large inputs of water and associated pollutants and sediments without immediately exhibiting visible signs of degradation. Thus, lakes constitute a 'sink' for such inputs, thereby being a reflection of the cumulative impacts of human activities generating such materials in their drainage basins. As a defining lake characteristic, this buffering capacity represents a double-edged sword. On the one hand, it means lake problems can build up slowly as pollutant inputs, for example, accumulate in lake bottom sediments, or are otherwise neutralized over time. This buffering capacity results in changes often occurring in small, often invisible, increments, thereby masking negative degradation problems until they have become serious problems throughout a lake. In contrast, this same buffering capacity can mask the positive effects of remedial programmes to restore a degraded lake for a considerable period of time after their implementation. This 'lag' phenomenon is an important consideration in lake assessment, since it can result in erroneous conclusions about the status of a lake, as well as the effectiveness of remedial programmes implemented to address lake problems.

Complex Response Dynamics

Another distinguishing feature of lakes is that they do not necessarily respond to pollution or other environmental disturbances in a linear manner, mainly because their large impounded water volumes can buffer lake responses to external perturbations. Accordingly, the physical, chemical and biological reactions occurring in lakes are intertwined in complex ways, making it difficult to assess or control their responses to such disturbances. This 'hysteresis' property represents a non-linear lake response, for example, to increasing pollutant inputs, mainly because 'everything affects everything else' in the lake. Because of essentially irreversible changes in the ecological components of a lake ecosystem, consistent with hysteresis effects, it is also often not possible for a seriously polluted lake to return to its original unpolluted state. An example is the non-linear response of a lake to increasing nutrient inputs (Figure 2.2), which would not necessarily translate into nuisance-level phytoplankton populations (algal blooms) until a fundamental shift in its trophic status occurs. Thus, a lake ecosystem represents a 'mixing' pot for materials from its surrounding basin, with its resultant behaviour often unpredictable and uncontrollable. As illustrated in Figure 2.2, this hysteresis property makes it very difficult to make an accurate assessment of the status of a given lake because of uncertainty in accurately determining the position of a lake within the hysteresis cycle. Thus, scientific studies are often required to facilitate better understanding of the underlying processes and their assessment and management implications.

In identifying these defining features of lentic water systems, it is reiterated that lakes, both natural and artificial, are used for a wider range of life-supporting ecosystem goods and services than other types of freshwater systems. Accordingly, they also are typically more subject to water-use conflicts than other freshwater systems, another important consideration in their assessment and management goals. In fact, maintaining the status of a lake also can be a function of downstream water needs, an example being the management goals of Lake Biwa being a function of the downstream water needs of Osaka, Japan (Nakamura and Rast, 2014). Accordingly, institutions with mandates that include lake basin management must be prepared to engage in sustainable remedial programmes, with long-term funding commitments, in order to accurately assess and effectively address lake degradation issues.

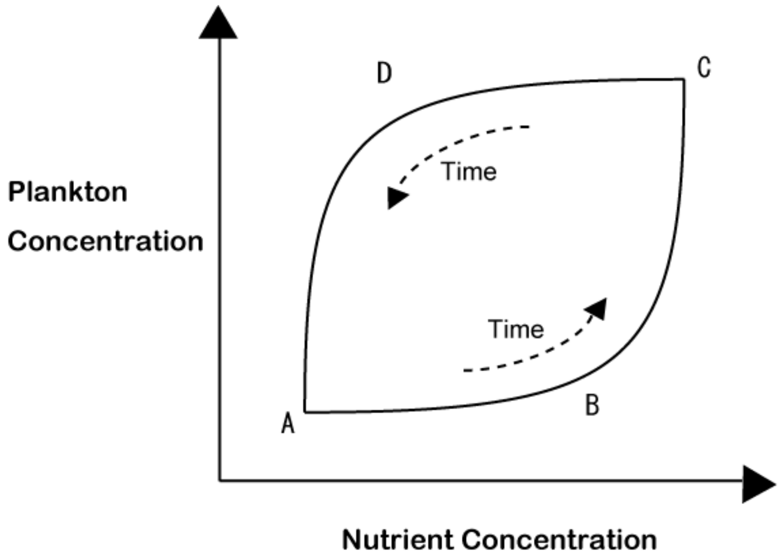


Figure 2.2 Buffering Capacity of Lakes to Increasing Nutrient Inputs, Illustrating Non-linear (Hysteresis) Responses to Degradation and Remediation.

3. ASSESSMENT METHODOLOGY

3-1. Overall Assessment Framework

3-1-1. Assumptions and Improvisations to Address Assessment Limitations and Uncertainties

It is extremely challenging to pursue a global-scale assessment of threats facing transboundary lake basins for the purpose of prioritizing potential management interventions at the international level. This is because of factors such as the transboundary lake basins differing widely in their locations and associated environmental conditions, varying lake volume and basin surface areas, complex riparian situations, and other characteristics influencing such assessments.

The availability of data and information for assessment purposes also depends on a number of factors. The data are generally highly skewed, in that some lake basins have extensive coverage and study, while others have received little or no attention to date. Further, those with extensive coverage may also have already been regarded, for one reason or another, as meriting priority attention. Thus, basing this assessment solely on whatever data and information are currently available or accessible would probably not lead to a fair and unequivocal comparison and assessment of transboundary lake priority considerations.

Thus, as discussed throughout the remaining parts of this chapter and in the Discussion chapter, a range of assumptions and improvisations were introduced to address such limitations and uncertainties. These were introduced in preparing the data for use in the computational analyses, and making comparative assessments of the computational lake basin threat results.

To deal with these challenges, an assessment framework was developed, consisting of sequential steps for data preparation and refinement, scenario development and assessment, as well as a parametric sensitivity analysis and interpretation.

3-1-2. Sequential Steps in Assessment of Lake Basin Threat Prioritization Scenarios

The overall transboundary lake Assessment Framework may be regarded as consisting of three broad categories of steps: (1) Data Preparation and Refinement; (2) Scenario Development and Assessment; and (3) Parametric Sensitivity Analysis and Interpretation.

(1) Data Preparation and Refinement Step – This includes Identification of Transboundary Lakes, described in Section 3.2, and Delineation of Transboundary Lake Drainage Basins, described in Section 3.3;
(2) Scenario Development and Assessment Step – This includes Lake Threat Assessment Methodology, described in Section 3.4;
(3) Parametric Sensitivity Analysis and Interpretation Step – This will be discussed broadly in the Results chapter, and more specifically under Threatened Africa, Asia and South American

Transboundary Lakes from Perspective of Potential Management Interventions, described in Section 4.4.

These three steps also are closely related to the overall methodological flow of the transboundary lakes analysis, involving an interactive and iterative process, as shown in Figure 3-1. The logic flow consists of the three main categories of activities: Preparation of Basic Data, Indicators, and Analytical Tools; Threats Assessment translating to Assessment of Alternative Scenarios; and Parametric Prioritization Analysis translating to Assessment of Rankings and Sensitivities. The three steps discussed in Sections 3-2 through 3-9, and the three categories of activities in Figure 3.1 are closely, but complexly, intertwined. This methodological flow is discussed further in the Technical Appendices.

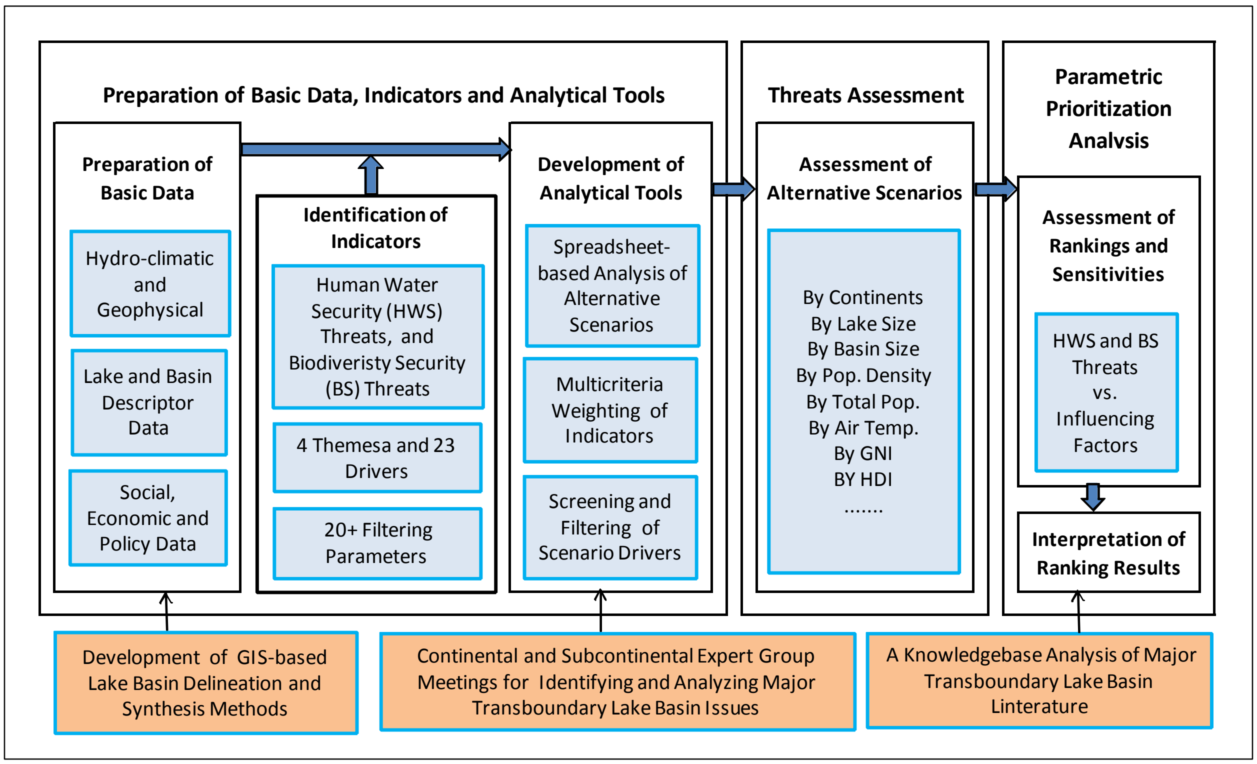


Figure 3.1 Methodological Flow for Assessment of Alternative Lake Prioritization Scenarios.

3-2. Identification of Transboundary Lakes

An initial major constraint encountered in the transboundary lakes assessment was the absence of uniform lake data on a global scale. The subsequent difficulties encountered in the TWAP transboundary lakes analyses attributable to this data situation cannot be overemphasized. The scientific literature contains many limnology-based studies dealing with lakes in general. In fact, the initial list of lakes identified for this component of the TWAP effort totalled more than 600 000 lakes, although with no focus on transboundary lakes. This initial list was subsequently reduced to approximately 1 600, on the basis of national boundaries. Even with this reduced number of transboundary lakes, however, the availability of information, data and on-the-ground lake knowledge still varied considerably in both quantity and quality. Some lakes had previously been studied and regularly monitored. Most, however, had little or no previous studies or measurements, many being located in relatively remote locations with sparsely-populated basins. Accordingly, a subsequently analysis utilizing fine resolution techniques with global information system (GIS) was used to identify and separate transboundary lakes from the larger body of lakes. This approach included the use of Google Earth and related spatial analyses, facilitating confirmation of lake locations and surface areas, including compilation of a polygon-based data base. Nevertheless, there were a few transboundary lakes which could not be explicitly identified.

This initial GIS-based spatial analysis was also used to identify very small transboundary lakes, and other lakes previously identified in the literature as being transboundary. Subsequent visual inspection of the latter, however, indicated some lakes originally identified as transboundary were actually not transboundary, therefore being removed from the TWAP lakes list. Transboundary lakes located in countries not eligible for GEF funding also were deleted from the list.

The number of transboundary lakes in GEF-eligible countries was reduced to a final list of 156. For comparison purposes, an additional group of prominent transboundary lakes located in developed countries also were included in this list. This analysis resulted in a total of 206 transboundary lakes and reservoirs in the TWAP effort (see Figures 3.2– 3.7), including 30 lakes in the South American region, 34 in Africa, 70 in the European region, 52 in the Asia region, and 20 in North America. As noted in Figure 3.7, a substantial number of the transboundary lakes in the European region were small border lakes between Scandinavian countries and/or the Russian Federation. A list of the transboundary lakes in the TWAP effort is provided in the Technical Appendices.

The quantity of data, and the level of associated knowledge regarding the transboundary lakes varied considerably. Although some had relatively comprehensive data sets, others were studied solely from the perspective of scientific exploration, with little attention given to the management implications of the study results. Indeed, the lakes with the most available data tended to be those previously exhibiting water quantity, quality and/or biodiversity problems that made them the subject of previous studies. Fewer than a dozen transboundary lakes, however, were the subject of previous GEF studies. The overall reality was that the large majority of the transboundary lakes in the TWAP study have received little attention with regard to their assessment or managerial challenges on the basis of systematic, long-term scientific studies.

Figure 3.2 Transboundary Lakes in South America and Caribbean Region

As previously noted, this lack of uniform lake data necessitated use of GIS-based spatial analyses of global-scale databases. The major sources for this component of the lakes analysis included: NASA/USGS Shuttle Radar Topography Mission (SRTM) digital topographic data and resulting SRTM Water Body Data (SWBD); WWF Global Lakes and Wetlands Data Base (GLWD); and USGS HydroSHED (Hydrological data and maps, based on Shuttle Elevation Derivatives at multiple Scales). Further information on these data sources is provided in the Technical Appendices***.***

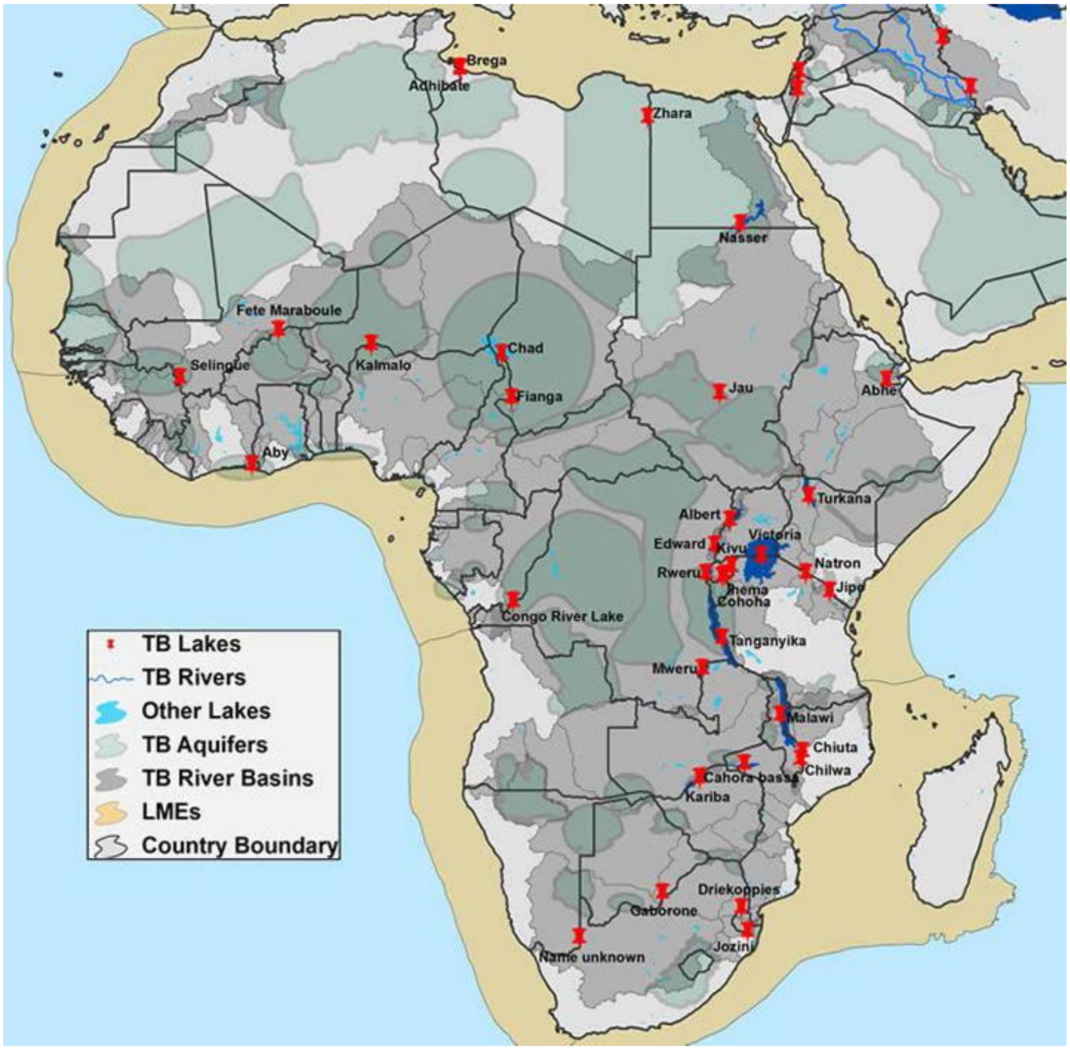


Figure 3.3 Transboundary Lakes in Africa and West Asia region

3-3. Delineation of Transboundary Lake Drainage Basins

In identifying the TWAP study transboundary lakes, it was noted that the large majority also lacked reliable data on the boundaries and areal extent of their drainage basins. As noted in a following section, this is an important factor since the lake threat rankings were ultimately based on the stresses to the lakes emanating from their drainage basins. This data deficiency was particularly evident for lake basins located in remote areas or with sparse basin populations, necessitating more detailed GIS-based spatial analyses of other global-scale data bases. Accordingly, the GIS-derived lake area polygons were used in combination with a GIS-based digital elevation model to determine the areal extent of the transboundary lake drainage basins. The resulting basins are shown in Figure 3.8. The main data sources for this component of the analyses were the same as those used to identify the transboundary lakes, used in combination with several digital elevation models (GDEM and GMTED10). Other ancillary data sources and topographic information were used where feasible to augment the results of the above-noted analyses. There were a small number of transboundary lakes, however, whose basins could not be explicitly identified, mainly located in arid regions exhibiting flat terrains. Further details on the drainage basin delineation procedure are provided in the Technical Appendices***.***

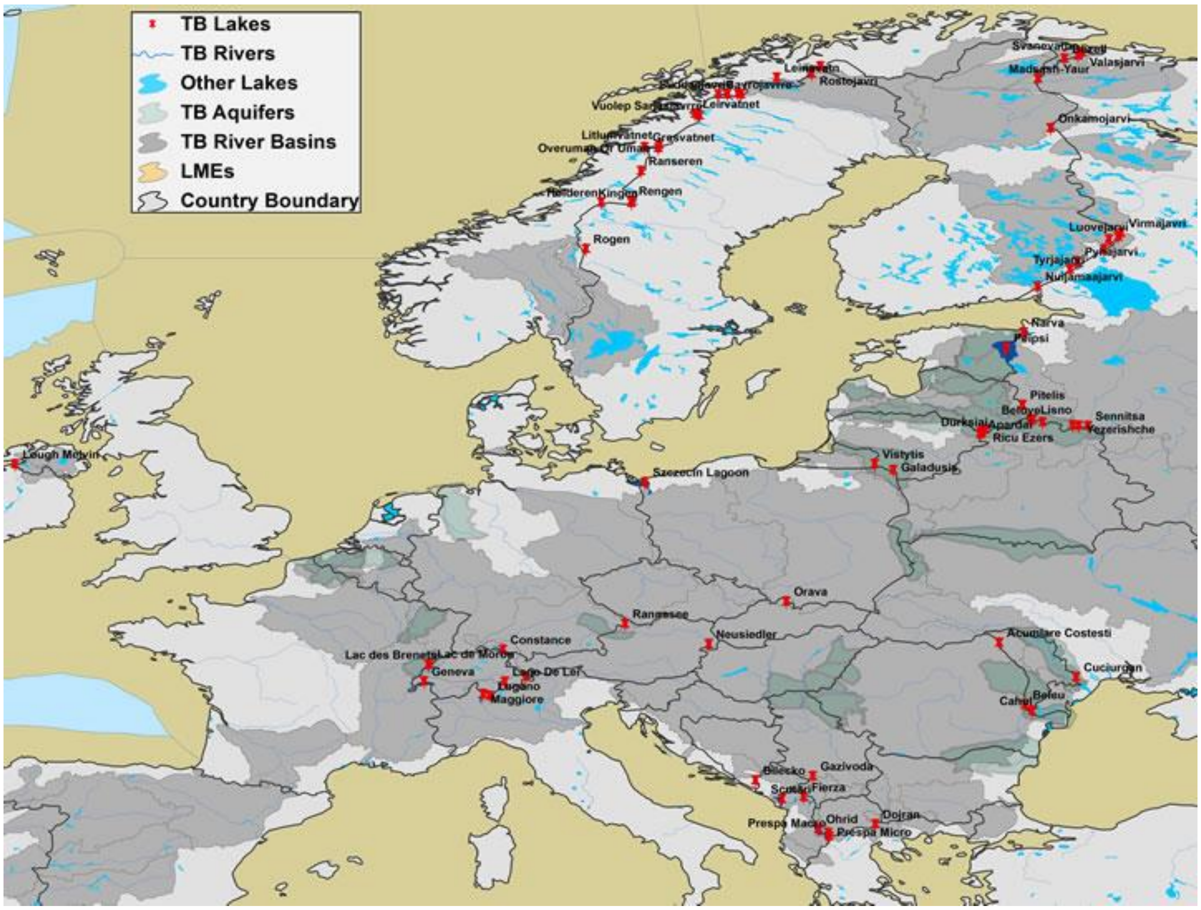


Figure 3.4 Transboundary Lakes in European Region

3-4. Lake Threat Assessment Methodology

As previously noted, lack of a uniform global-scale lake data base was a major problem in assessing the current status of the majority of the transboundary lakes and their relative risks. It also did not allow accurate or meaningful comparisons between them. The situation was not as problematic for lakes previously studied because of earlier national or international concerns (e.g., Lake Victoria, Aral Sea, Caspian Sea, Lake Titicaca). Even these lakes, however, lacked consistent time-series data for directly evaluating and comparing in-lake conditions and trends. Thus, it was not possible to assess the status of the TWAP transboundary lakes on the basis of their in-lake conditions. Rather, as discussed in the next section, the relative risks to the lakes were evaluated on the basis of the nature and magnitude of the stresses impacting them from their surrounding drainage basins, and the possible impacts on the sustainability of the ecosystem goods and services they provide to basin stakeholders. This approach, necessitated because of the lack of uniform global-scale in-lake data, and the limited resources available for the lakes component of the TWAP study, differed fundamentally from those of the other TWAP water components.

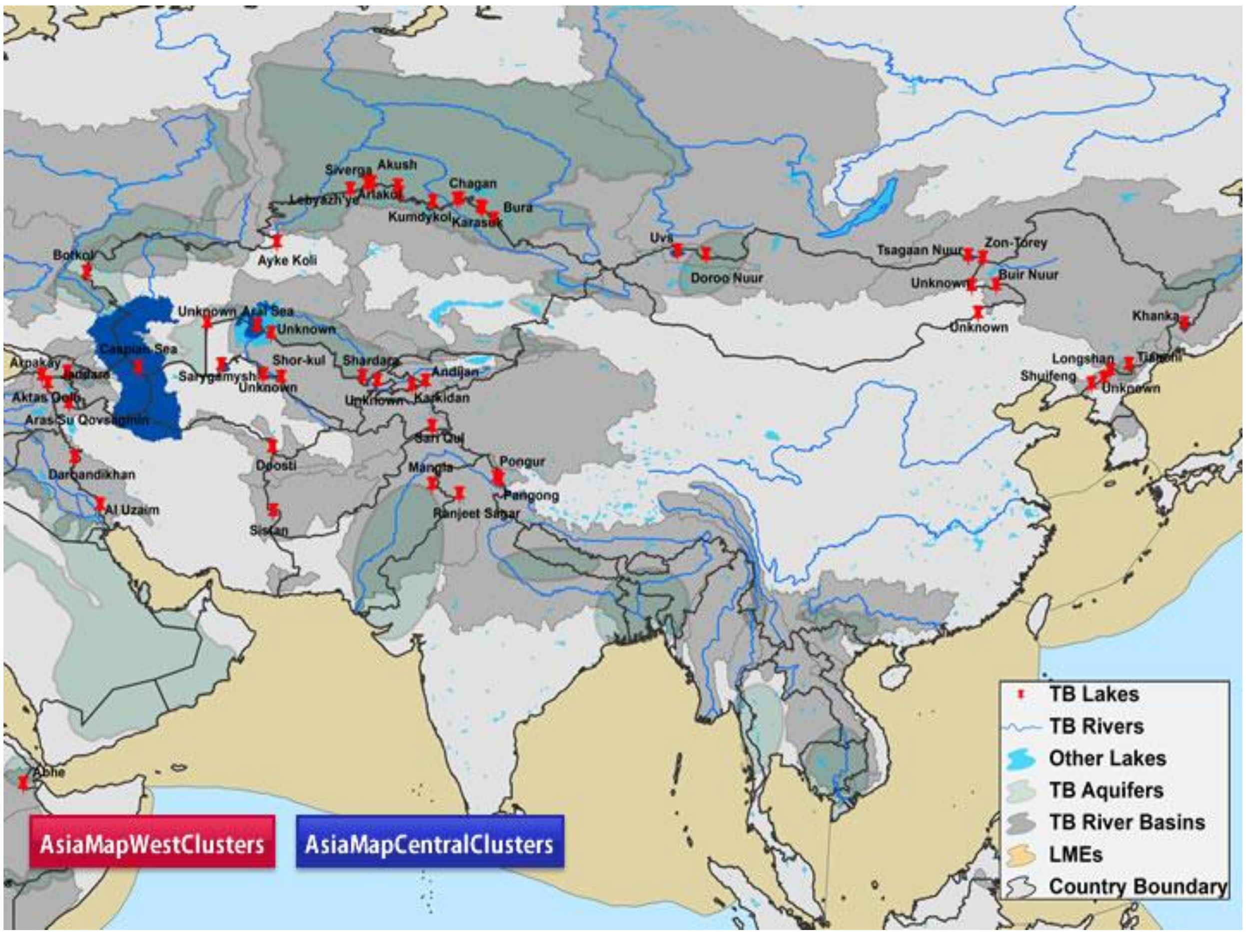


Figure 3.5 Transboundary Lakes in Asia Region

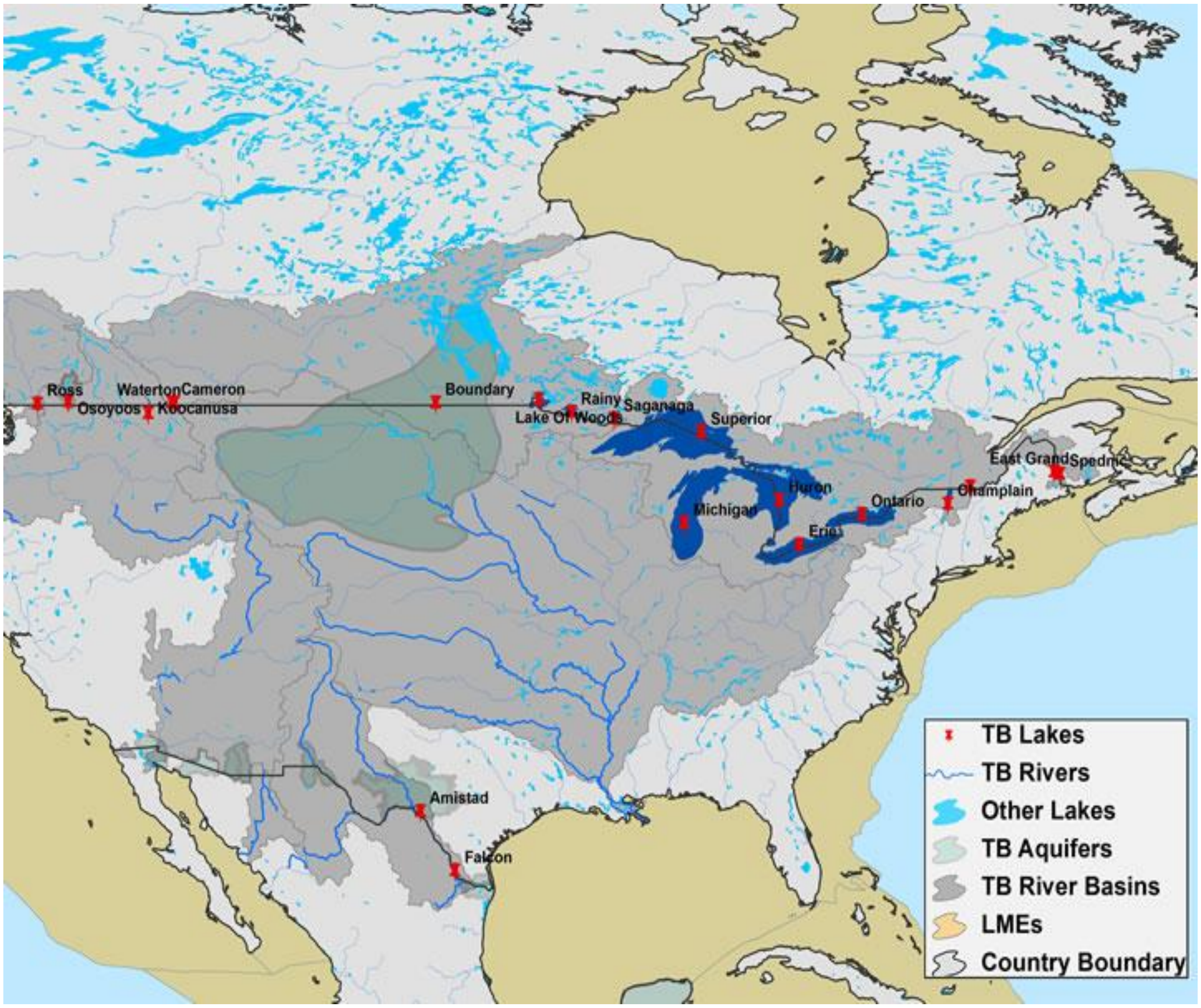


FIgure 3.6 Transboundary Lakes in North America Region

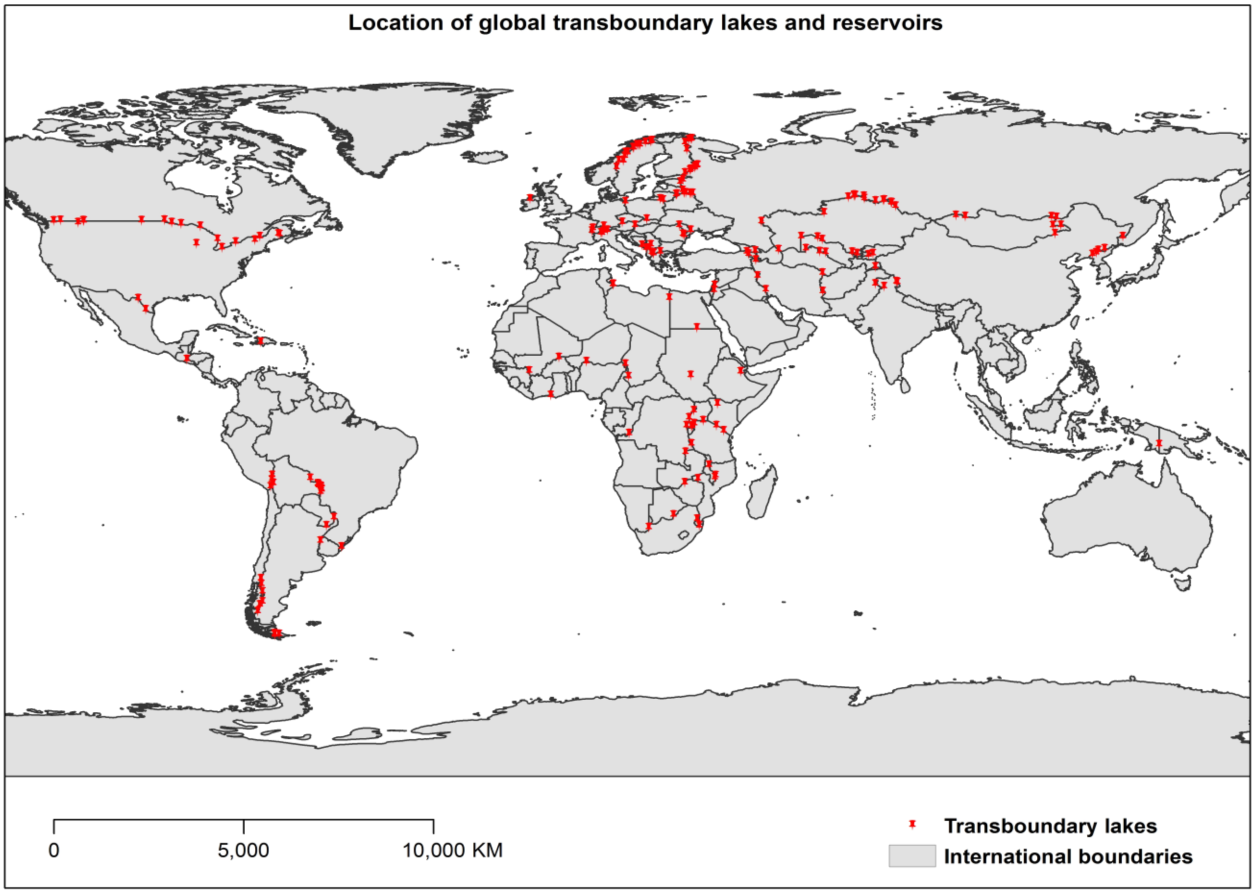


Figure 3.7. Global Distribution of Transboundary Lakes and Reservoirs in TWAP Study

3-5. Lake Basin Database

The approach for assessing the relative threats to the transboundary lake basins was adapted from the global-scale database derived by Vörösmarty *et al.* (2010). It focused on calculating the incident Human Water Security (HWS) and Biodiversity (BD) threats to the lakes on the basis of the characteristics of their surrounding basins. It also used the Adjusted Human Water Security (Adj-HWS) in the assessment, which incorporated the ability of basin countries, particularly the developed countries, to undertake investments in water infrastructure to address their transboundary water problems. A spatial framework was then used to quantify multiple basin-scale stressors, including their cumulative impacts on the downstream transboundary lakes contained within them. Among the conclusions reported by Vörösmarty *et al.* (2010) in their study was that nearly 80 per cent of the global population was exposed to significant water security threats, while habitats associated with 65 per cent of continental water discharges were moderately or highly threatened.

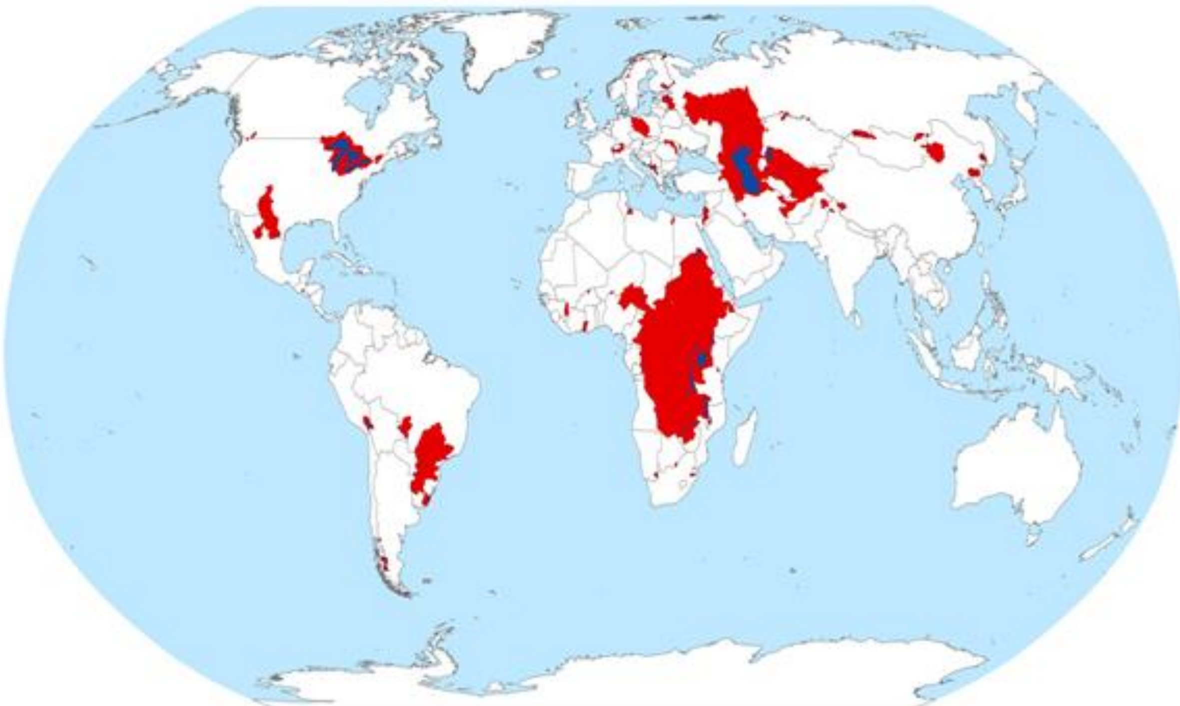


Figure 3.8 Global Distribution of Transboundary Lake and Reservoir Basins (Illustrating Contiguous Linkages of Adjacent Transboundary Basins, Particularly in Africa and Asia)

In conducting the transboundary lake analyses, it was noted that a river basin undergoing degradation does not automatically mean a lake within the basin, and receiving inputs from it, is being degraded in a similar manner, either temporally or spatially. This conclusion is based on the hysteresis effect that characterizes lakes and other lentic water systems. Rather, identifying a degraded river basin, or one undergoing degradation, suggests that a lake located within it may become degraded if the degrading activities in the basin continue unabated. It obviously would have been preferable to calculate the relative threats to the transboundary lakes on the basis of their in-lake conditions. As noted above, however, the data availability for this approach would produce such a skewed picture that developing an unbiased assessment involving all TWAP lakes would be quite challenging, and likely lead to erroneous conclusions. The imbalance of data associated with previously-studied lake basins, compared with those receiving little or no previous studies or measurements, can cause serious biases in the TWAP lake prioritization assessment. The GIS data developed for the river threats overview by Vörösmarty *et al.* (2010), therefore, was suitably modified for use in the lakes assessment. The river basin data generally cover the whole global geography, and are uniformly fitted to the delineated basins of the identified transboundary lakes. This refitted GIS data was used for the initial threat approximation and for shortlisting the candidate transboundary lake basins for subsequent analyses. Various additional data and information were obtained from other global databases and scientific literature.

Vörösmarty *et al.* (2010) used 23 drivers, grouped under four major thematic areas, to assess the incident Human Water Security (HWS) and Biodiversity (BD) threats, as follows:

Theme I – Catchment Disturbance
Drivers:

- Cropland – fraction of land area devoted to growing crops;
- Impervious surface – fraction of impervious surface area;
- Livestock density – domesticated animal distribution;
- Wetland disconnectivity – proportion of wetlands occupied by cropland or urban areas.

Theme II – Pollution
Drivers:

- Soil salinization – electrical conductivity based on derived soil properties;
- Nitrogen loading – anthropogenic nitrogen loads to rivers and their catchments;
- Phosphorus – anthropogenic phosphorus loads to rivers and their catchments;
- Mercury deposition – anthropogenic mercury deposition for 2000;
- Pesticide loading – country-level pesticide application to croplands;
- Sediment loading – projected annual water erosion rates;
- Organic loading – labile organic carbon loading from sewage;
- Potential acidification – combined acidifying potential from SO_x and NO_x deposition;
- Thermal alteration – thermal impacts attributable to thermoelectric power and manufacturing water uses.

Theme III – Water Resource Development
Drivers:

- Dam density – density and distribution of very large, large and medium-size dams;
- River fragmentation – fragmentation of naturally continuous river networks;
- Consumptive water loss – water use for agricultural, industry and other consumptive purposes;
- Human water stress – ratio of discharge to local human population;
- Agricultural water stress – ratio of discharge to cropland area;
- Flow disruption – estimated magnitude of flow distortion based on water residence time in large reservoirs.

Theme IV – Biotic Factors
Drivers:

- Non-native fishes (per cent) – percentage of non-native (exotic) fish species in each river basin;
- Non-native fishes (number) – absolute number of non-native fish species in each river basin;

- Fishing pressure – spatial distribution of fishing pressure;
- Aquaculture pressure – spatial distribution of aquaculture pressure.

These drivers were selected on the basis of the availability of existing global-scale data, or an ability to generate the data from existing data sets. Relative weights for the drivers were developed, based on the collective opinions of independent experts with a wide range of disciplinary expertise, including the lake scientists and managers participating at ILEC's 15th World Lake Conference in 2014 Based on the Parametric Sensitivity Analysis discussed in the Results chapter, it was subsequently determined the driver weights derived from the World Lake Conference were not significantly different from those of the Vörösmarty *et al.* study Nevertheless, derivation of such weighting factors must always be derived on the basis of the best-available lake basin data.

Thirteen of the drivers were routed, meaning their values in a given grid reflect the cumulative impacts of upstream conditions, while nine drivers are non-routed, with their impacts independent of their location in the drainage basin. All data sets were converted to a 30' latitude-longitude grid (0.5^{o}) for subsequent analyses. A more detailed description of the calculation of these drivers and their relative weights and significance is available online (www.nature.com/nature) as an accompanying document. The calculated incident HWS and BD threats to river basins on a global scale that were utilized in the lakes assessment are illustrated in Figure 3.9.

3-6. Lake Basin Scenario Analysis Program

The next major task was to develop a methodology to integrate and analyse these data for the purpose of ranking the transboundary lake threats. This was accomplished with the development of a scenario analysis 'engine' for the lakes assessment.   This is a spreadsheet-based, interactive Scenario Analysis Program that allows its users to select the lake(s) to be analysed, the drivers to be considered for the analyses, the appropriate weights for the drivers, and a range of 'filters' or screening criteria designed to provide realistic contexts for interpreting the threat ranking results. The calculated threat ranks were expressed in terms of Incident and Adjusted Human Water Security (HWS) and Incident Biodiversity (BD) scores. In fact, the development of the Scenario Analysis Program for determining the relative transboundary lake threat rankings is considered to be as important as the actual ranking results themselves. It provides a means to select the transboundary lakes of concern, to decide which drivers to consider and which weights to assign to them, and to select which criteria could provide the most appropriate context for interpreting the ranking results. A screen-shot image of the interactive elements of the Scenario Analysis Program is provided in Figure 3.10.

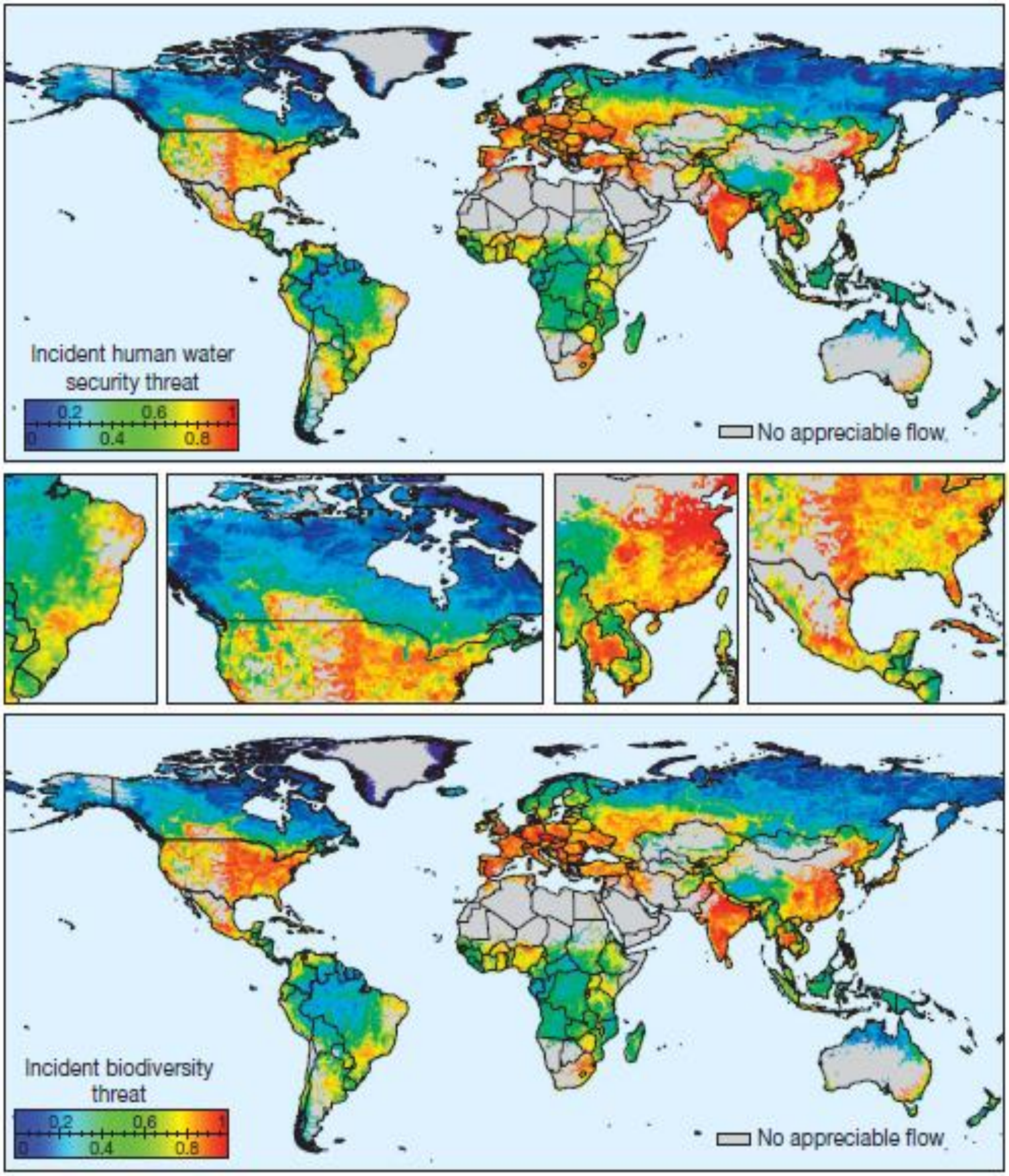


Figure 3.9 Global Overview of Incident Human Water Security (HWS) and Biodiversity (BD) Threats (Vörösmarty *et al.* 2010)

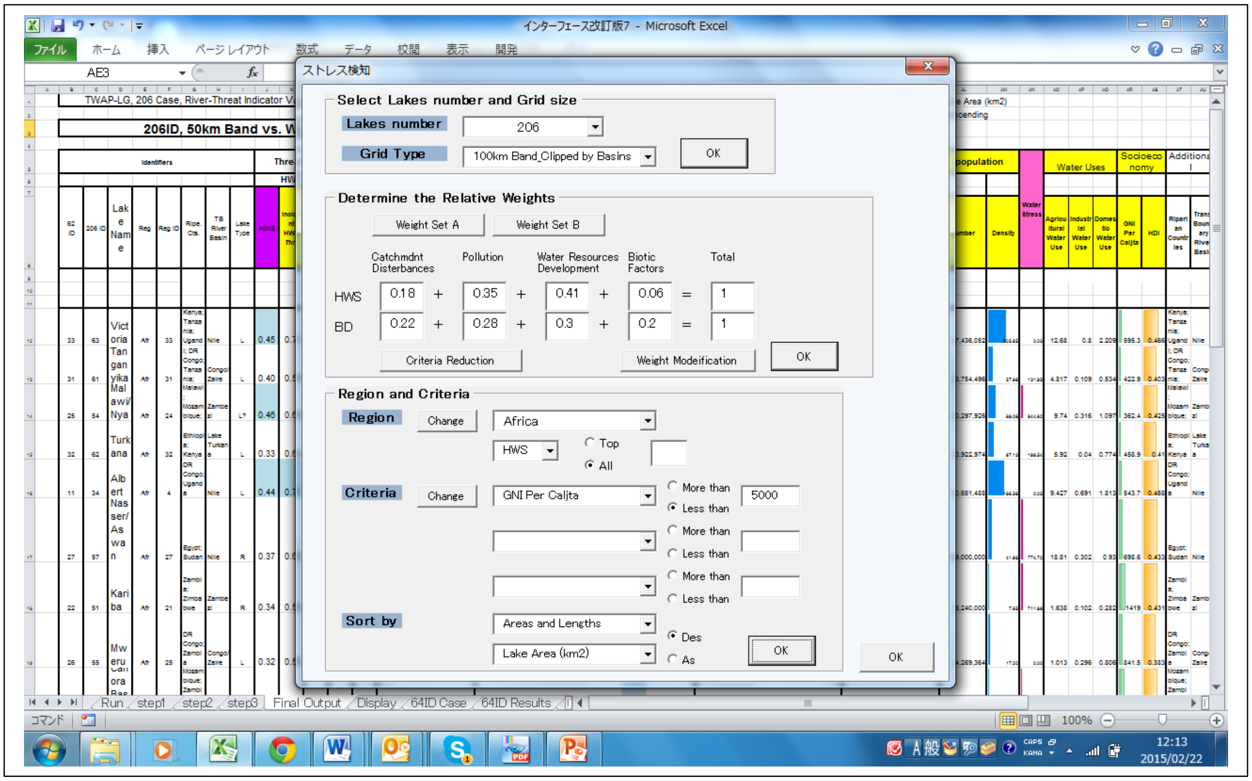


Figure 3.10 Screen-shot Image of Spreadsheet-based, Interactive Scenario Analysis Program

The magnitude of the HWS and BD threats to a lake (or any water body in a drainage basin) will also be influenced by multiple factors such as the existing or anticipated water uses; the drainage basin stakeholder perceptions regarding the identified problems; and the possibilities for addressing them. To this end, the Scenario Analysis Program allows the user to consider a range of assessment criteria for a given lake, including factors such as lake basin location and area, basin population and density, water stresses and uses, basin land uses, socioeconomic characteristics, and average temperature and precipitation patterns, all of which provide optional contexts for interpreting the assessment results.

The Scenarios Analysis Program also provided a means to delineate the areal extent of the drivers within the transboundary lake basins, noting that some were routed, while others were not. The closer the location of the stresses to a lake (expressed by the lake basin drivers), the greater the magnitude of the HW and BD threats were likely to be. Based on an initial sensitivity analysis, it was determined that an areal band of 100 km^2 around the lakes themselves, appropriately clipped for the river basin in which the lakes were located, was a realistic upper boundary of the basin area considered in the lakes analyses. Increasing the areal extent of the lake basin bands did not produce results markedly different from those obtained with the 100 km^2 bands.

Several other relevant factors also were considered within the Scenario Analysis Program. There are many small transboundary lakes, for example, in the Scandinavian–Russia border region and Central Asia (see Figure 3.7). Further, a number of transboundary lakes were located in remote regions with few basin inhabitants, an example being the Patagonia region of South America. Accordingly, the transboundary lake analyses focused on lakes with areas of at least 50 km^2. Further, the mean air temperature was an important factor when considering the high-altitude transboundary mountain lakes in the Himalayan, Andes and Alps mountains. These lakes are also of interest from a 'cluster lake' perspective, since they exhibit many similar characteristics, generally being subjected to the same types of stresses. At the same time, they are frozen for considerable portions of the year, thereby unusable from a human perspective. Their relatively remote locations also minimize major human influences in their basins. Thus, the transboundary lakes analyses focused on the lakes in areas with a mean air temperature of at least 5^oC, ensuring that only lakes that did not freeze were included in the assessment. Finally, a population density of at least 5 persons/km^2 was chosen as the lower boundary in evaluating the relative transboundary lake basin threats.

3-7. Expert Group Meetings

The Lakes Working Group conducted a series of Expert Group Meetings for obtaining 'on-the-ground' information and data on the TWAP transboundary lakes, and for discussing the initial results obtained for various regions. These meetings were held in Guadalajara, Mexico (Central America), Rio de Janeiro, Brazil (South America), Perugia, Italy (Europe/Mediterranean region), Accra, Ghana (West Africa), Nairobi, Kenya (East Africa), Istanbul, Turkey (Eastern Europe/West Asia), Kuala Lumpur, Malaysia (East/Southeast Asia), Delhi, India (South Asia), and Manila, Philippines (South/Southeast Asia). They provided useful additional insights for the TWAP lake analyses. The many lake experts participating in the ILEC 15th World Lake Conference also provided valuable data and insights into the nature and magnitude of the stresses facing the transboundary lakes, the impacts of these stresses, and the degree to which the ecosystem goods and services were degraded because of them. They also collectively provided information regarding appropriate weights for the various basin-derived drivers provided by Vörösmarty *et al.* (2010) that were adapted for the transboundary lakes analyses.

3-8. Lake Basin Questionnaire

The Lakes Working Group developed a region-specific lake Questionnaire that was distributed at Expert Group meetings in Guadalajara, Mexico (Central America), Rio de Janeiro, Brazil (South America), Perugia, Italy (Europe/Mediterranean region), Accra, Ghana (West Africa), Nairobi, Kenya (East Africa), Istanbul, Turkey (Eastern Europe/West Asia), Kuala Lumpur, Malaysia (East/Southeast Asia), Delhi, India (South Asia), and Manila, Philippines (South/Southeast Asia), and at ILEC's 15th World Lake Conference. The Questionnaire was designed to be as simple as possible in order to obtain more specific information regarding the TWAP transboundary lakes, including their in-lake conditions, the extent the stresses on the lakes affected their ecosystem goods and services, the impacts of the stresses on the lakes, and the extent to which the impacts affected the use of the lake resources by lake basin stakeholders. The acquired data were both quantitative and qualitative in nature, being useful for assessing threats where the assessment results were confusing or different from known conditions. An example of the Questionnaire for East Africa is provided in the Technical Appendices.

3-9. Lakes Knowledge System (LAKES-III)

The Learning Acceleration and Knowledge Enhancement System (LAKES-III) is a knowledge-based system previously developed and refined at Shiga University (Japan), and has been used for ILEC lake projects in many countries over the past decade. It currently contains a database of approximately 1 700 documents and reports from public-domain literature and other relevant information sources. LAKES-III identifies those documents containing desired keywords down to the page, paragraph and sentence level, thereby providing context for interpreting the information. It was used to obtain additional information and data for deriving more accurate conclusions regarding the status, potential and priority for addressing the threats to the transboundary study lakes. Screen-shot images of the interactive access page and the interactive data sources page of LAKES-III are in Figures 3.11 and 3.12.

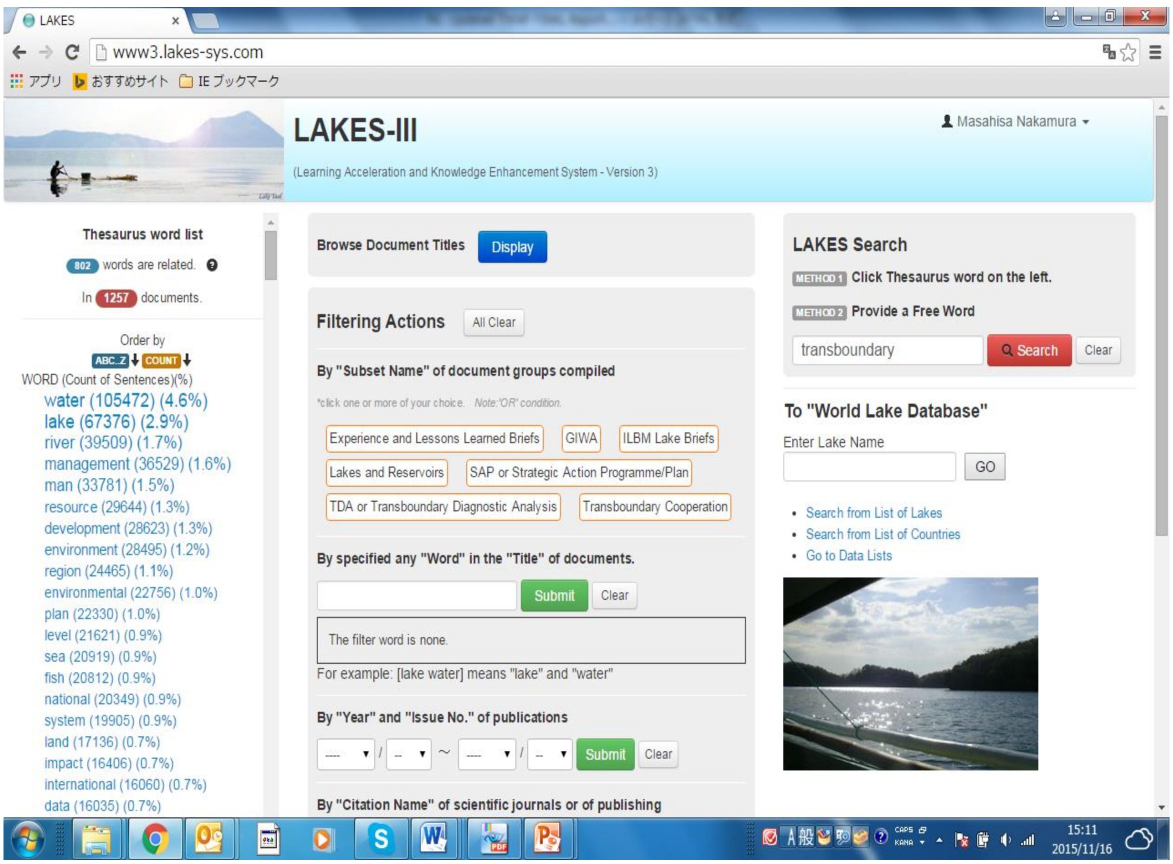


Figure 3.11 Screen-shot Image of LAKES-III Interactive Access Page

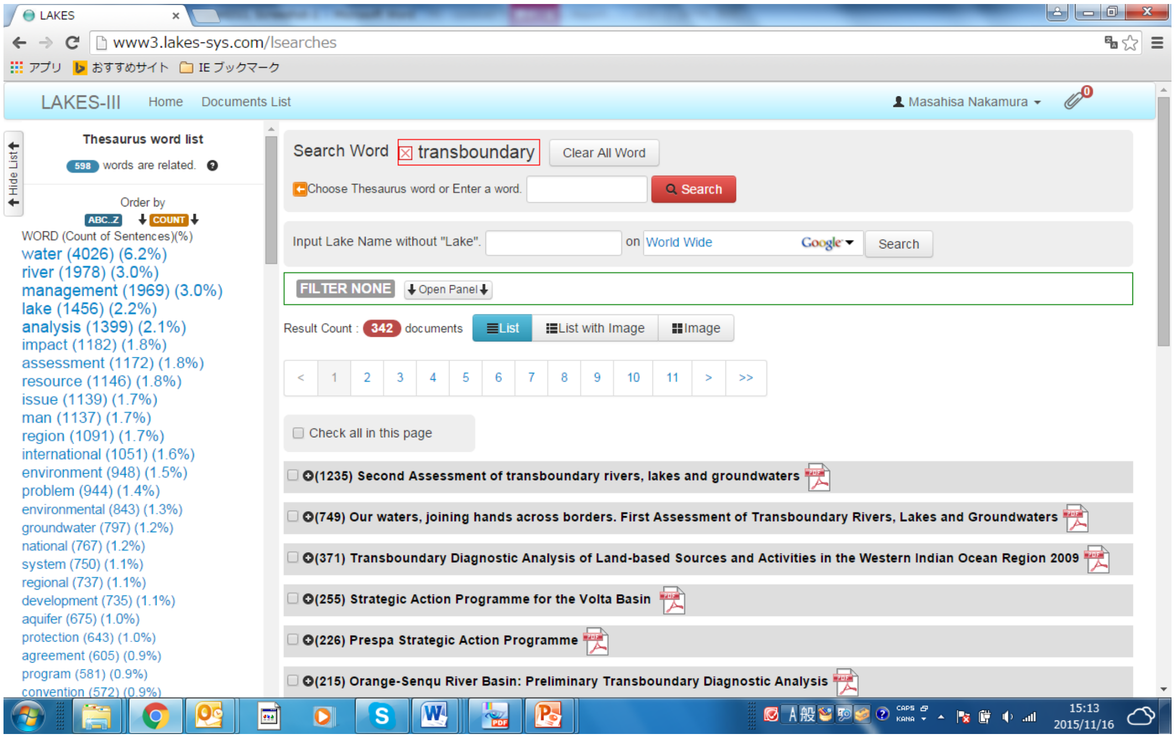


Figure 3.12 Screen-shot Image of LAKES-III Interactive Data Sources Page

A schematic of the Scenario Analysis Program User Interface that illustrates its analyses and links with these various information sources is shown in Figure 3.13.

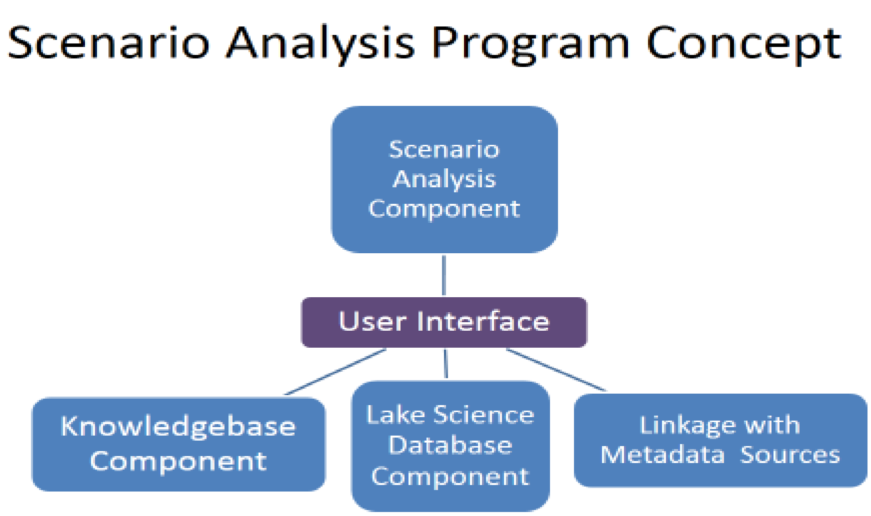


Figure 3.13 Schematic of Scenario Analysis Program Structure and Links

4. TRANSBOUNDARY LAKES THREAT RANKING RESULTS

4-1. Interpreting Threats to Transboundary Lakes

Several important caveats must be mentioned before presenting the results of the transboundary lakes analyses. As highlighted in Chapter 2, one caveat is that the characteristics of lakes (and other lentic water systems), particularly their non-linear responses to environmental stresses (see Figure 2.2), can easily skew the accuracy and meaning of the threat rankings. This hysteresis characteristic, for instance, can mask the actual status of a given lake since it is difficult to determine *a priori* the position of a lake on the hysteresis curve for many lake stresses. Further, it is difficult to demonstrate unequivocally on the basis of computational analyses alone that a transboundary lake ranked ‘1’ in regard to its threats is significantly different from a lake ranked ‘2’ or even from ’12’ or ’23.’ The significance of the threats facing a small lake in a small, sparsely-populated basin also can be very different from those facing a large lake in a large basin containing a large population.

As previously noted, the transboundary lake threat rankings are not based on assessment of their in-lake characteristics because of inadequate uniform in-lake data on a global scale for the majority of the TWAP study lakes. Instead, the characteristics of the transboundary lake basins, expressed in terms of the 23 drivers, was used to calculate the relative Human Water Security (HWS) and Biodiversity (BD) threats to the lakes. This approach does not mean a lake exhibiting a low threat rank on the basis of its basin characteristics is not currently threatened or, alternatively, that a lake with a high threat rank based on the same characteristics is currently being degraded. Rather, it means transboundary lakes exhibiting high threat ranks likely merit primary consideration for management interventions because their drainage basins exhibit properties that can degrade waterbodies contained within them. This is particularly the case for lakes and other lentic water systems. Although there are a number of institutions with data and information relevant to other transboundary water systems, including the Transboundary Freshwater Spatial Database (Oregon State University) for transboundary rivers, Internationally Shared Aquifer Resources Management Initiative (UNESCO) for transboundary aquifers, and Large Marine Ecosystem Concept (NOAA) for large marine ecosystems, there is no similar institutional-based support for transboundary lakes. Indeed, one of the important conclusions arising from the transboundary lakes analysis was the urgent need for the international community to engage in knowledge base development focusing on lakes, reservoirs and other lentic water systems.

There also were several difficulties in using the river basin-scale driver data derived by Vörösmarty *et al.* (2010) in the transboundary lake analyses, as follows:

- Data grid size – The grids for the 23 river basin-scale drivers (30’ grid [0.5^{o}]) were often larger than those of some transboundary lake basins. Thus, it was necessary to downscale the grid values into 100 m resolution pixels for subsequent analyses;

- Missing data for some grids –There were no driver data for some grids for about 10 per cent of the transboundary lakes. These grids were excluded from subsequent calculations of the HWS and BD threats, increasing the uncertainties regarding the threats for these particular lakes.

The transboundary lake threats were determined by superimposing the transboundary lake basins over the river basin grids denoting the 23 drivers identified by Vörösmarty *et al.* (2010). The HW and BD threat ranks were then calculated using the Scenario Analysis Program. All 206 transboundary lakes were initially analysed on the basis of these factors. Specific filtering criteria were then selected to define the most appropriate or useful context for interpreting the assessment results, being important for determining their relative significance. The Scenario Analyses Program was developed specifically to compute the transboundary lake threat rankings on the basis of criteria other than their Incident HWS and BD scores. The filtering criteria allowed the assessment results to be interpreted within the context of such factors as basin area, continental location of the transboundary lake, basin population number and density, per capita Gross National Income (GNI), and Human Development Index (HDI), thereby providing a more realistic context for identifying the transboundary lakes with the highest HWS and BD threats.

Based on these concerns, reliable data for this approach were available only for 53 of the 206 transboundary lakes. Because this smaller group is more likely to exhibit the highest threat priority from the perspective of GEF goals, the subsequent assessment focused on these selected lakes. This focus does not mean other transboundary lakes are not experiencing various threats, but rather that sufficient data were only available for these 53 lakes (23 African, 8 Asian, 9 European, 6 South American, and 7 North American lakes) to conduct a defensible assessment of their relative threat ranks (Table 4.1).

The following sections highlight the Incident Human Security Water (HWS) and Biodiversity (BD) threats on a global and continental scale, derived with the Scenario Analysis Program. This initial assessment used the basin-scale drivers and relative weights developed by Vörösmarty *et al.* (2010), refined with input from lake experts at the 15th World Lake Conference, the transboundary lake expert group meetings, and region-specific questionnaires. Other analyses results are discussed from the perspective of factors thought important for their users, such as whether those using the ranking results were interested more in the most threatened lakes with the largest basins or surface areas, the largest population, the greatest population density, relative economic capacity, or some other issue. In providing a mechanism for calculating the transboundary lake rankings within the context of such filtering criteria, the Scenario Analysis Program was a major contribution to the TWAP effort. However, providing the appropriate context and preconditions for interpreting the ranking results is not within the scope of the transboundary lake analyses, but rather is the responsibility of those using the results, including decision makers.

Table 4.1 Regional Distribution of 53 Priority Transboundary Study Lakes

Waterbody Name	TWAP-based Regional Designation	Lake (L) or Reservoir (R)	River Basin
AFRICA REGION			
Abbe/Abhe	Eastern & Southern Africa	L	Awash
Aby	Western & Middle Africa	L	Bia+Tano
Albert	Eastern & Southern Africa; Western & Middle Africa	L	Nile
Cahora Bassa	Eastern & Southern Africa	R	Zambezi
Chad	Western & Middle Africa	L	Chad (endorheic)
Chilwa	Eastern & Southern Africa	L	Chilwa (endorheic)
Chiuta	Eastern & Southern Africa	L	Chiuta (endorheic)
Cohoha	Eastern & Southern Africa	L	Nile
Edward	Eastern & Southern Africa	L	Nile
Ihema	Eastern & Southern Africa	L	Nile
Josini/Pongolapoort Dam	Eastern & Southern Africa	R	Maputo
Kariba	Eastern & Southern Africa	R	Zambezi
Kivu	Eastern & Southern Africa; Western & Middle Africa	R	Ruizizi
Lake Congo River	Western & Middle Africa	L	Congo
Malawi/Nyasa	Eastern & Southern Africa	L	Zambezi
Mweru	Eastern & Southern Africa; Western & Middle Africa	L	Congo
Nasser/Aswan	Northern Africa & Western Asia	R	Nile
Natron/Magadi	Eastern & Southern Africa	L	Southern Ewaso Ng'iro
Rweru/Moero	Eastern & Southern Africa	L	Nile
Selingue	Western & Middle Africa	R	Nile
Tanganyika	Eastern & Southern Africa; Western & Middle Africa	L	Congo
Turkana	Eastern & Southern Africa	L	Turkana (endorheic)

Victoria	Eastern & Southern Africa	L	Nile
ASIA REGION			
Aral Sea	Eastern & Central Asia	L	Aral (endorheic)
Aras Su Qovsaginin Su Anbari	Southern Asia; Northern Africa & Western Asia	R	Kura-Arkas
Caspian Sea	Northern Africa & Western Asia; Eastern & Central Asia; Southern Asia; Eastern Europe	L	Caspian (endorheic)
Darbandikhan	Northern Africa & Western Asia; Southern Asia	R	Tigris-Euphrates
Mangla	Southern Asia	R	Indus
Sarygamysh	Eastern & Central Asia	L	Amu Darya
Shardara/Kara-Kul	Eastern & Central Asia	R	Syr Darya
Sistan	Southern Asia	L	Helmand
Europe Region			
Cahul	Eastern Europe	L	Danube
Dead Sea	Northern Africa & Western Asia; Southern Asia	L	Jordan
Galilee	Northern Africa & Western Asia	L	Jordan
Macro Prespa (Large Prespa)	Northern, Western & Southern Europe	L	Macro Prespa (endorheic)
Lake Maggiore	Northern, Western & Southern Europe	L	Po
Neusiedler/Ferto	Eastern Europe; Northern, Western & Southern Europe	L	Danube
Ohrid	Northern, Western & Southern Europe	L	Black Drin
Scutari/Skadar	Northern, Western & Southern Europe	L	Drin
Szczecin Lagoon	Eastern Europe; Northern, Western & Southern Europe	L	Oder
North America Region			
Amistad	Northern, Western & Southern America	R	Rio Grande
Champlain	Northern, Western & Southern America	L	St. Lawrence
Erie	Northern, Western & Southern America	L	St. Lawrence
Falcon	Northern, Western & Southern America	R	Rio Grande
Huron	Northern, Western & Southern America	L	St. Lawrence
Michigan	Northern, Western & Southern America	L	St. Lawrence

Ontario	Northern, Western & Southern America	L	St. Lawrence
South America & Caribbean Region			
Azuei	Central American & Caribbean	L	Azuei (endorheic)
Chungarkkota	Southern America	L	Titicaca-Poopo System
Itaipu	Southern America	R	La Plata
Lago de Yacyreta	Southern America	R	La Plata
Salto Grande	Southern America	R	La Plata
Titicaca	Southern America	L	Titicaca-Poopo System

4-2. Overview of Transboundary Lake Ranks Based on Human Water Security and Biodiversity Threats

4-2-1. Incident Human Water Security (HWS) and Biodiversity (BD) Threats on Global Scale

Based strictly on computational results (i.e., not considering specific filtering criteria), the top five lakes exhibiting the highest incident HWS and BD threats (Table 4.2) are two European lakes (Cahul on the Moldova/Ukraine border; Neuseidler/Ferto on the Hungary/Austria border), two North American lakes (Michigan on the USA/Canada border; Amistad on USA/Mexico border) and one Western Asia lake (Darbandikhan – Iraq/Iran). The socioeconomic differences between these lakes is evident, with the per-capita GNI lowest for the smallest lakes. The other parameters in the table (lake area, population number and density, per capita Gross National Income (GNI), Human Development Index (HDI), mean annual air temperature) are provided mainly for information, and included in the discussions where appropriate.

Based on this computational approach, most African transboundary lakes appear in the bottom half of the 53 transboundary lakes. The per capita GNI of many of the top dozen highest-ranked HWS-threatened lakes is among the highest in the group of 53 transboundary lakes. But a high per-capita GNI value does not necessarily mean a lake is not under threat. Rather, it means the countries sharing the lake have sufficient financial and human resources to attempt to address the problem(s). As discussed below, the Adjusted Human Water Security (Adj-HWS) threat reflects the degree to which investments in infrastructure can ameliorate the situation, and significantly change the lake threat ranks. The Incident BD threats generally follow the same trend as the Incident HWS threats (Table 4.2), although the relative ranks of the Dead Sea and Sea of Galilee increase.

Table 4.2 Incident Human Water Security (HWS) and Biodiversity (BD) Threats on Global Scale (Eur, Europe; N Am, North America; Afr, Africa; S Am, South America)

	Record1										
No.	206/100km_A//All/HWS/All/None/	Conti.	Lake Area(km^2)	Adjust. HWS	HWS	BD	Population Number	Population Density	GNI	HDI	Temp
1	Cahul	Eur	89.0121073	0.82	0.608	0.614	44,155	24.17	2655.70	0.69	10.50
2	Falcon	N.Am	120.56	0.5	0.61	0.62	6,364,997	14.02	28059.79	0.85	15.50
3	Mangla	Asia	85.40	0.87	0.59	0.62	9,832,974	210.23	1438.94	0.54	9.75
4	Galilee	Eur	161.99	0.87	0.59	0.55	545,267	169.92	25387.39	0.88	17.61
5	Aras Su Qovsaginin Su Anbari	Asia	52.10	0.89	0.57	0.53	3,924,400	52.34	5704.32	0.73	6.36
6	Dead Sea	Eur	642.65	0.9	0.57	0.49	9,454,130	160.95	7347.42	0.72	18.44
7	Darbandikhan	Asia	114.34	0.87	0.56	0.54	1,822,575	76.62	6617.20	0.68	12.76
8	Neusiedler/Ferto	Eur	141.91	0.58	0.54	0.61	115,345	69.57	38400.34	0.88	9.69
9	Szczecin Lagoon	Eur	822.41	0.53	0.54	0.51	16,862,454	67.09	15730.24	0.83	8.14
10	Josini/Pongolapoort Dam	Afr	128.62	0.85	0.52	0.48	334,110	32.40	6558.27	0.61	18.25
11	Shardara/Kara-Kul	Asia	746.12	0.86	0.52	0.46	20,281,740	66.55	1714.53	0.65	6.52
12	Erie	N.Am	26560.77	0.51	0.51	0.57	13,804,450	113.73	50260.55	0.93	8.78
13	Macro Prespa (Large Prespa)	Eur	262.97	0.51	0.50	0.49	34,938	20.36	5682.50	0.75	8.61
14	Azuei	SAm	117.280578	0.96	0.499	0.432	205,664	183.96	878.95	0.46	23.70
15	Ohrid	Eur	354.29	0.47	0.49	0.49	165,335	45.76	4732.08	0.74	8.97
16	Michigan	N.Am	58535.50	0.44	0.48	0.56	8,365,188	48.67	50120.00	0.94	7.01
17	Ontario	N.Am	19062.23	0.48	0.46	0.53	10,394,370	102.35	50702.85	0.92	7.10
18	Caspian Sea	Asia	377543.2	0.73	0.451	0.396	105,000,000	20.12	10566.91	0.77	6.30
19	Amistad	N.Am	131.29	0.49	0.421	0.392	4,724,154	13.84	31659.06	0.86	14.27
20	Victoria	Afr	66841.53	0.91	0.42	0.44	47,436,052	205.95	595.33	0.47	20.76
21	Ihema	Afr	93.15	0.97	0.41	0.44	11,415	46.40	561.80	0.44	20.91
22	Sistan	Asia	488.19	0.98	0.41	0.38	908,224	8.60	2131.60	0.46	14.76
23	Scutari/Skadar	Eur	381.50	0.62	0.40	0.45	381,012	48.57	6309.59	0.78	10.64
24	Lake Maggiore	Eur	211.427972	0.33	0.398	0.505	894,071	80.52	51840.66	0.89	5.81
25	Huron	N.Am	60565.22	0.42	0.40	0.47	3,321,799	15.60	50507.04	0.93	5.41
26	Rweru/Moero	Afr	125.53	0.96	0.40	0.42	359,565	284.92	254.41	0.36	20.21
27	Champlain	N.Am	1098.90	0.29	0.39	0.49	661,788	19.86	50164.61	0.94	5.74
28	Cohoha	Afr	64.80	0.96	0.39	0.41	188,059	322.02	327.36	0.38	20.54
29	Chad	Afr	1294.61	0.84	0.38	0.36	43,764,044	38.24	1211.49	0.43	26.48
30	Itaipu	SAm	1154.07	0.75	0.36	0.42	57,040,744	56.51	11612.65	0.73	21.62
31	Chungarkkota	SAm	52.57	0.82	0.36	0.31	2,218,424	36.01	4297.65	0.71	6.13
32	Natron/Magad	Afr	560.42	0.93	0.36	0.33	393,719	20.67	798.33	0.51	19.13
33	Albert	Afr	5502.31	0.91	0.35	0.37	70,651,488	186.58	543.72	0.46	21.32
34	Aby	Afr	438.78	0.83	0.35	0.35	2,587,139	80.27	1463.16	0.52	26.23
35	Edward	Afr	2231.99	0.94	0.34	0.35	5,134,252	196.77	398.16	0.43	20.41
36	Kariba	Afr	5258.61	0.75	0.33	0.34	6,240,000	7.65	1419.06	0.43	21.06
37	Turkana	Afr	7439.18	0.9	0.33	0.30	10,922,974	67.13	458.94	0.41	23.47
38	Titicaca	SAm	7479.94	0.82	0.33	0.29	2,169,134	36.91	4283.89	0.71	6.08
39	Kivu	Afr	2375.12	0.91	0.31	0.33	2,203,403	345.20	427.70	0.38	17.80
40	Lago de Yacyreta	SAm	1109.41	0.75	0.31	0.34	64,421,204	54.99	11493.15	0.73	21.24
41	Abbe/Abhe	Afr	310.63	0.93	0.31	0.29	12,254,142	105.28	409.78	0.40	23.29
42	Selingue	Afr	334.40	0.87	0.30	0.32	729,567	19.33	566.61	0.36	25.75
43	Aral	Asia	23919.28	0.84	0.295	0.276	48,540,276	30.53	1791.35	0.60	9.19
44	Salto Grande	SAm	532.94	0.67	0.29	0.30	5,001,392	15.64	12343.38	0.74	18.74
45	Nasser/Aswan	Afr	5362.72	0.86	0.29	0.32	149,000,000	41.98	698.63	0.43	25.46
46	Malawi/Nyasa	Afr	29429.15	0.91	0.29	0.32	10,297,926	88.06	362.41	0.42	21.43
47	Cahora Bassa	Afr	4347.37	0.78	0.29	0.31	17,478,704	13.73	1254.49	0.43	21.14
48	Chilwa	Afr	1084.20	0.86	0.28	0.30	1,459,490	150.34	332.03	0.41	22.31
49	Sarygamysh	Asia	3777.69	0.82	0.26	0.25	2,119,732	14.40	3442.87	0.67	13.95
50	Chiuta	Afr	143.34	0.85	0.25	0.26	229,629	70.70	346.92	0.41	23.34
51	Tanganyika	Afr	32685.45	0.84	0.25	0.29	13,754,496	57.66	422.89	0.40	22.40
52	Mweru	Afr	5021.54	0.81	0.24	0.28	4,269,364	17.20	841.54	0.38	20.86
53	Lake Congo River	Afr	306.00	0.75	0.20	0.22	76,295,784	18.18	495.39	0.34	23.67

4-2-2. Adjusted Human Water Security (Adj-HWS) and Incident Biodiversity (BD) Threats on Global Scale

As previously noted, the computed Incident HWS and BD threats do not necessarily provide an accurate picture of the relative transboundary lake risks. Rather, technological investments can significantly improve human water security and reduce the relative lake threats. To this end, Vörösmarty *et al.* (2010) calculated an 'investment benefits factor,' which was used to derive an Adjusted Human Water Security (Adj-HWS) threat. This revised threat category reflects the ability of lake basin countries to undertake the needed investments for goals such as water supply stabilization, improved water services, and access to waterways. Thus, even if experiencing serious lake problems that result in high calculated Incident HWS threats, developed countries (such as USA, Western Europe, and Japan) will nevertheless exhibit lower Adj-HWS threats because of their ability to significantly invest in water infrastructure. This means the higher Adj-HWS threat scores identify countries with less capacity to address transboundary lakes problems. These typically comprise developing countries, presumably in greater need of catalytic funding for management interventions than those with lower Adj-HWS scores. The relative threat to transboundary lakes in many African countries, for example, increases substantially on the basis of the Adj-HWS threat (Table 4.3), while the threats to those in the economically-wealthier European and North American countries decrease. Based on this consideration, 11 of the 13 highest ranked transboundary lakes on the basis of the Adj-HWS threat are in Africa.

The computed Adj-HWS threat ranks of the Asian lakes also generally increase, although not to the same extent as the African lakes. An inland endorheic Asian lake (Sistan), whose basin includes large parts of southwestern Afghanistan and southeastern Iran, has the highest Adj-HWS threat. It is in an extremely dry region of Asia, subject to prolonged droughts. In contrast, the Adj-HWS ranks of the Dead Sea and Sea of Galilee decrease, relative to their Incident HWS status. It was not possible to calculate an equivalent Adjusted Biodiversity (Adj-BD) threat in the same manner as the Adj-HWS threat because there is no unequivocal means of determining the positive impacts of investments in biodiversity in the same manner. Nevertheless, a modified BD threat metric was developed as a surrogate for this parameter, as discussed in a following section.

Table 4.3 Adjusted Human Water Security (Adj-HWS) and Biodiversity (BD) Threats on Global Scale (Eur, Europe; N Am, North America; Afr, Africa; S Am, South America)

No.	Record1 206/100km_A//All/HWS/All/None/	Conti.	Lake Area(km^2)	Adjust. HWS	HWS	BD	Population Number	Population Density	GNI	HDI	Temp
1	Sistan	Asia	488.19	0.98	0.41	0.38	908,224	8.60	2131.60	0.46	14.76
2	Ihema	Afr	93.15	0.97	0.41	0.44	11,415	46.40	561.80	0.44	20.91
3	Azuei	SAm	117.280578	0.96	0.499	0.432	205,664	183.96	878.95	0.46	23.70
4	Rweru/Moero	Afr	125.53	0.96	0.40	0.42	359,565	284.92	254.41	0.36	20.21
5	Cohoha	Afr	64.80	0.96	0.39	0.41	188,059	322.02	327.36	0.38	20.54
6	Edward	Afr	2231.99	0.94	0.34	0.35	5,134,252	196.77	398.16	0.43	20.41
7	Natron/Magad	Afr	560.42	0.93	0.36	0.33	393,719	20.67	798.33	0.51	19.13
8	Abbe/Abhe	Afr	310.63	0.93	0.31	0.29	12,254,142	105.28	409.78	0.40	23.29
9	Victoria	Afr	66841.53	0.91	0.42	0.44	47,436,052	205.95	595.33	0.47	20.76
10	Albert	Afr	5502.31	0.91	0.35	0.37	70,651,488	186.58	543.72	0.46	21.32
11	Kivu	Afr	2375.12	0.91	0.31	0.33	2,203,403	345.20	427.70	0.38	17.80
12	Malawi/Nyasa	Afr	29429.15	0.91	0.29	0.32	10,297,926	88.06	362.41	0.42	21.43
13	Dead Sea	Eur	642.65	0.9	0.57	0.49	9,454,130	160.95	7347.42	0.72	18.44
14	Turkana	Afr	7439.18	0.9	0.33	0.30	10,922,974	67.13	458.94	0.41	23.47
15	Aras Su Qovsaginin Su Anbari	Asia	52.10	0.89	0.57	0.53	3,924,400	52.34	5704.32	0.73	6.36
16	Mangla	Asia	85.40	0.87	0.59	0.62	9,832,974	210.23	1438.94	0.54	9.75
17	Galilee	Eur	161.99	0.87	0.59	0.55	545,267	169.92	25387.39	0.88	17.61
18	Darbandikhan	Asia	114.34	0.87	0.56	0.54	1,822,575	76.62	6617.20	0.68	12.76
19	Selingue	Afr	334.40	0.87	0.30	0.32	729,567	19.33	566.61	0.36	25.75
20	Shardara/Kara-Kul	Asia	746.12	0.86	0.52	0.46	20,281,740	66.55	1714.53	0.65	6.52
21	Nasser/Aswan	Afr	5362.72	0.86	0.29	0.32	149,000,000	41.98	698.63	0.43	25.46
22	Chilwa	Afr	1084.20	0.86	0.28	0.30	1,459,490	150.34	332.03	0.41	22.31
23	Josini/Pongolapoort Dam	Afr	128.62	0.85	0.52	0.48	334,110	32.40	6558.27	0.61	18.25
24	Chiuta	Afr	143.34	0.85	0.25	0.26	229,629	70.70	346.92	0.41	23.34
25	Chad	Afr	1294.61	0.84	0.38	0.36	43,764,044	38.24	1211.49	0.43	26.48
26	Aral	Asia	23919.28	0.84	0.295	0.276	48,540,276	30.53	1791.35	0.60	9.19
27	Tanganyika	Afr	32685.45	0.84	0.25	0.29	13,754,496	57.66	422.89	0.40	22.40
28	Aby	Afr	438.78	0.83	0.35	0.35	2,587,139	80.27	1463.16	0.52	26.23
29	Cahul	Eur	89.0121073	0.82	0.608	0.614	44,155	24.17	2655.70	0.69	10.50
30	Chungarkkota	SAm	52.57	0.82	0.36	0.31	2,218,424	36.01	4297.65	0.71	6.13
31	Titicaca	SAm	7479.94	0.82	0.33	0.29	2,169,134	36.91	4283.89	0.71	6.08
32	Sarygamysh	Asia	3777.69	0.82	0.26	0.25	2,119,732	14.40	3442.87	0.67	13.95
33	Mweru	Afr	5021.54	0.81	0.24	0.28	4,269,364	17.20	841.54	0.38	20.86
34	Cahora Bassa	Afr	4347.37	0.78	0.29	0.31	17,478,704	13.73	1254.49	0.43	21.14
35	Itaipu	SAm	1154.07	0.75	0.36	0.42	57,040,744	56.51	11612.65	0.73	21.62
36	Kariba	Afr	5258.61	0.75	0.33	0.34	6,240,000	7.65	1419.06	0.43	21.06
37	Lago de Yacyreta	SAm	1109.41	0.75	0.31	0.34	64,421,204	54.99	11493.15	0.73	21.24
38	Lake Congo River	Afr	306.00	0.75	0.20	0.22	76,295,784	18.18	495.39	0.34	23.67
39	Caspian Sea	Asia	377543.2	0.73	0.451	0.396	105,000,000	20.12	10566.91	0.77	6.30
40	Salto Grande	SAm	532.94	0.67	0.29	0.30	5,001,392	15.64	12343.38	0.74	18.74
41	Scutari/Skadar	Eur	381.50	0.62	0.40	0.45	381,012	48.57	6309.59	0.78	10.64
42	Neusiedler/Ferto	Eur	141.91	0.58	0.54	0.61	115,345	69.57	38400.34	0.88	9.69
43	Szczecin Lagoon	Eur	822.41	0.53	0.54	0.51	16,862,454	67.09	15730.24	0.83	8.14
44	Erie	N.Am	26560.77	0.51	0.51	0.57	13,804,450	113.73	50260.55	0.93	8.78
45	Macro Prespa (Large Prespa)	Eur	262.97	0.51	0.50	0.49	34,938	20.36	5682.50	0.75	8.61
46	Falcon	N.Am	120.56	0.5	0.61	0.62	6,364,997	14.02	28059.79	0.85	15.50
47	Amistad	N.Am	131.29	0.49	0.421	0.392	4,724,154	13.84	31659.06	0.86	14.27
48	Ontario	N.Am	19062.23	0.48	0.46	0.53	10,394,370	102.35	50702.85	0.92	7.10
49	Ohrid	Eur	354.29	0.47	0.49	0.49	165,335	45.76	4732.08	0.74	8.97
50	Michigan	N.Am	58535.50	0.44	0.48	0.56	8,365,188	48.67	50120.00	0.94	7.01
51	Huron	N.Am	60565.22	0.42	0.40	0.47	3,321,799	15.60	50507.04	0.93	5.41
52	Lake Maggiore	Eur	211.427972	0.33	0.398	0.505	894,071	80.52	51840.66	0.89	5.81
53	Champlain	N.Am	1098.90	0.29	0.39	0.49	661,788	19.86	50164.61	0.94	5.74

4-2-3. Adjusted Human Water Security (Adj-HWS) and Biodiversity (BD) Threats by Continent

The transboundary lake Adj-HWS and BD threats were also considered on the basis of their continental distribution, providing a locational focus. Although there is no corresponding 'adjusted' metric for the BD ranks, these are also included in the tabular results for information and comparison.

The 23 African transboundary lakes (Table 4.4) include some very large lakes (Tanganyika, Malawi/Nyasa, Victoria). Not unexpectedly, the African transboundary lakes collectively have the highest Adj-HWS threats, as well as the highest population densities and lowest per-capita GNI scores. These findings exemplify the typically poorer economic conditions that can preclude major investments to address the identified threats. Two of the top five ranked lakes are relatively small lakes located on the Rwanda/Burundi border (Rweru/Moero, Cohoha) in Central Africa, and one on the Rwanda/Tanzania border (Ihema). The fifth-ranked lake (Abbe) is a salt lake on the Ethiopia/Djibouti border. Interestingly, Lake Chad, currently undergoing a significant reduction in volume and surface size, is among the bottom third of the 23 ranked African transboundary lakes.

The eight transboundary lakes in the Asia region include the largest freshwater lake in the world (Caspian Sea) and the Aral Sea. The latter is well known because of its severe degradation resulting from the nearly complete diversion of its major influent streams (Syr Darya and Amu Darya) for irrigation purposes. Its resulting water quality, quantity and ecosystem degradation dramatically define the serious deterioration of this transboundary lake, once the sixth largest lake in the world. Its demise is even more significant when it is considered that its degradation occurred essentially within a generation. The Asian lake Adj-HWS threat ranks exhibit a smaller range than those of the African lakes, with their per capita GNI being generally higher than for the African lakes.

The nine European region transboundary lakes exhibit a wide range of Adj-HWS scores, with the Dead Sea and Sea of Galilee having the highest threats. The remaining lakes in this group include the largest lake in the Balkan Peninsula (Skadar), the largest endorheic and shallow lake in central Europe (Neuseidler/Ferto), and a long-time important fishing habitat (Sczcecin Lagoon). Except for North America, these lakes are characterized by the highest per-capita GNIs, indicating a relatively high economic status of their basin countries.

Table 4.4 Adjusted Human Water Security (Adj-HWS) and Biodiversity (BD) Threats by Continent (Eur, Europe; N Am, North America; Afr, Africa; S Am, South America)

	Record1										
No.	206/100km_A//All/HWS/All/None/	Conti.	Lake Area(km^2)	Adjust. HWS	HWS	BD	Population Number	Population Density	GNI	HDI	Temp
1	Ihema	Afr	93.15	0.97	0.41	0.44	11,415	46.40	561.80	0.44	20.91
2	Rweru/Moero	Afr	125.53	0.96	0.40	0.42	359,565	284.92	254.41	0.36	20.21
3	Cohoha	Afr	64.80	0.96	0.39	0.41	188,059	322.02	327.36	0.38	20.54
4	Edward	Afr	2231.99	0.94	0.34	0.35	5,134,252	196.77	398.16	0.43	20.41
5	Abbe/Abhe	Afr	310.63	0.93	0.31	0.29	12,254,142	105.28	409.78	0.40	23.29
6	Natron/Magad	Afr	560.42	0.93	0.36	0.33	393,719	20.67	798.33	0.51	19.13
7	Albert	Afr	5502.31	0.91	0.35	0.37	70,651,488	186.58	543.72	0.46	21.32
8	Victoria	Afr	66841.53	0.91	0.42	0.44	47,436,052	205.95	595.33	0.47	20.76
9	Malawi/Nyasa	Afr	29429.15	0.91	0.29	0.32	10,297,926	88.06	362.41	0.42	21.43
10	Kivu	Afr	2375.12	0.91	0.31	0.33	2,203,403	345.20	427.70	0.38	17.80
11	Turkana	Afr	7439.18	0.9	0.33	0.30	10,922,974	67.13	458.94	0.41	23.47
12	Selingue	Afr	334.40	0.87	0.30	0.32	729,567	19.33	566.61	0.36	25.75
13	Nasser/Aswan	Afr	5362.72	0.86	0.29	0.32	149,000,000	41.98	698.63	0.43	25.46
14	Chilwa	Afr	1084.20	0.86	0.28	0.30	1,459,490	150.34	332.03	0.41	22.31
15	Josini/Pongolapoort Dam	Afr	128.62	0.85	0.52	0.48	334,110	32.40	6558.27	0.61	18.25
16	Chiuta	Afr	143.34	0.85	0.25	0.26	229,629	70.70	346.92	0.41	23.34
17	Chad	Afr	1294.61	0.84	0.38	0.36	43,764,044	38.24	1211.49	0.43	26.48
18	Tanganyika	Afr	32685.45	0.84	0.25	0.29	13,754,496	57.66	422.89	0.40	22.40
19	Aby	Afr	438.78	0.83	0.35	0.35	2,587,139	80.27	1463.16	0.52	26.23
20	Mweru	Afr	5021.54	0.81	0.24	0.28	4,269,364	17.20	841.54	0.38	20.86
21	Cahora Bassa	Afr	4347.37	0.78	0.29	0.31	17,478,704	13.73	1254.49	0.43	21.14
22	Lake Congo River	Afr	306.00	0.75	0.20	0.22	76,295,784	18.18	495.39	0.34	23.67
23	Kariba	Afr	5258.61	0.75	0.33	0.34	6,240,000	7.65	1419.06	0.43	21.06
24	Sistan	Asia	488.19	0.98	0.41	0.38	908,224	8.60	2131.60	0.46	14.76
25	Aras Su Qovsaginin Su Anbari	Asia	52.10	0.89	0.57	0.53	3,924,400	52.34	5704.32	0.73	6.36
26	Mangla	Asia	85.40	0.87	0.59	0.62	9,832,974	210.23	1438.94	0.54	9.75
27	Darbandikhan	Asia	114.34	0.87	0.56	0.54	1,822,575	76.62	6617.20	0.68	12.76
28	Shardara/Kara-Kul	Asia	746.12	0.86	0.52	0.46	20,281,740	66.55	1714.53	0.65	6.52
29	Aral	Asia	23919.28	0.84	0.295	0.276	48,540,276	30.53	1791.35	0.60	9.19
30	Sarygamysh	Asia	3777.69	0.82	0.26	0.25	2,119,732	14.40	3442.87	0.67	13.95
31	Caspian Sea	Asia	377543.2	0.73	0.451	0.396	105,000,000	20.12	10566.91	0.77	6.30
32	Dead Sea	Eur	642.65	0.9	0.57	0.49	9,454,130	160.95	7347.42	0.72	18.44
33	Galilee	Eur	161.99	0.87	0.59	0.55	545,267	169.92	25387.39	0.88	17.61
34	Cahul	Eur	89.0121073	0.82	0.608	0.614	44,155	24.17	2655.70	0.69	10.50
35	Scutari/Skadar	Eur	381.50	0.62	0.40	0.45	381,012	48.57	6309.59	0.78	10.64
36	Neusiedler/Ferto	Eur	141.91	0.58	0.54	0.61	115,345	69.57	38400.34	0.88	9.69
37	Szczecin Lagoon	Eur	822.41	0.53	0.54	0.51	16,862,454	67.09	15730.24	0.83	8.14
38	Macro Prespa (Large Prespa)	Eur	262.97	0.51	0.50	0.49	34,938	20.36	5682.50	0.75	8.61
39	Ohrid	Eur	354.29	0.47	0.49	0.49	165,335	45.76	4732.08	0.74	8.97
40	Lake Maggiore	Eur	211.427972	0.33	0.398	0.505	894,071	80.52	51840.66	0.89	5.81
41	Erie	N.Am	26560.77	0.51	0.51	0.57	13,804,450	113.73	50260.55	0.93	8.78
42	Falcon	N.Am	120.56	0.5	0.61	0.62	6,364,997	14.02	28059.79	0.85	15.50
43	Amistad	N.Am	131.29	0.49	0.421	0.392	4,724,154	13.84	31659.06	0.86	14.27
44	Ontario	N.Am	19062.23	0.48	0.46	0.53	10,394,370	102.35	50702.85	0.92	7.10
45	Michigan	N.Am	58535.50	0.44	0.48	0.56	8,365,188	48.67	50120.00	0.94	7.01
46	Huron	N.Am	60565.22	0.42	0.40	0.47	3,321,799	15.60	50507.04	0.93	5.41
47	Champlain	N.Am	1098.90	0.29	0.39	0.49	661,788	19.86	50164.61	0.94	5.74
48	Azuei	SAm	117.280578	0.96	0.499	0.432	205,664	183.96	878.95	0.46	23.70
49	Chungarkkota	SAm	52.57	0.82	0.36	0.31	2,218,424	36.01	4297.65	0.71	6.13
50	Titicaca	SAm	7479.94	0.82	0.33	0.29	2,169,134	36.91	4283.89	0.71	6.08
51	Lago de Yacyreta	SAm	1109.41	0.75	0.31	0.34	64,421,204	54.99	11493.15	0.73	21.24
52	Itaipu	SAm	1154.07	0.75	0.36	0.42	57,040,744	56.51	11612.65	0.73	21.62
53	Salto Grande	SAm	532.94	0.67	0.29	0.30	5,001,392	15.64	12343.38	0.74	18.74

The seven North American transboundary lakes include four of the five Laurentian Great Lakes (Michigan, Huron, Erie, Ontario). The Laurentian Great Lakes collectively contain the largest volume of liquid freshwater on the surface of our planet, and also have large surface areas. Two reservoirs on the USA-Mexico border (Amistad, Falcon) and a large lake (Champlain) on the USA-Canada border comprise the remaining North American transboundary lakes. They collectively exhibit the lowest Adj-HWS threats, consistent with their high per capita GNI values.

South America contains a number of large reservoirs, as well as high-altitude Andean lakes and remote Patagonian lakes. This region contains the highest navigable lake in the world (Titicaca), and several large reservoirs constructed mainly for hydropower production (Itaipu and Lago Yacyreta on the Paraná River; Salto Grande on the Uruguay River). However, the lake exhibiting the highest Adj-HWS threat in the Latin American region is Azuei, a small lake on the Haiti-Dominican Republic border on the island of Hispaniola in the Caribbean. Interestingly, this brackish lake supports more than 100 species of waterfowl and American crocodiles, while its riparian countries exhibit the lowest per capita GNI among the Latin American countries bordering transboundary lakes.

Although the data are not shown here, ranking the transboundary lakes on the basis of their Adj-HWS scores, as expressed from the perspective of other filtering criteria was also undertaken. These included lake area, basin population number and density, per-capita Gross National Income (GNI) and Human Development Index (HDI), the results being presented in the Technical Appendices. It remains the responsibility of the user of the ranking results to determine the most appropriate context for interpreting the results.

4-3. Reordering of Lake Ranks Based on Alternative Ranking Criteria

The relative threat ranks of the transboundary lakes also can differ on the basis of the criteria or 'lens' used to interpret the ranks. Accordingly, this section discusses the ranking order from the perspective of alternate ranking criteria. The first section focuses on comparison of the threat ranks derived from the Adj-HWS scores, compared to those considered from the perspective of several filtering criteria such as lake area, basin population and GNI. The second section provides the transboundary lake threat ranks on the basis of the sum of their relative ranks derived from their Adj-HWS, RvBD and HDI scores. The RvBD ('Reverse BD') metric was calculated by subtracting the incident BD score from 1.0, with the lowest RvBD score indicating the greatest biodiversity threat. The third section discusses the rankings based on a parametric analysis that considers changing the weights of the Adj-HWS and BD scores, as well as inclusion of the HDI scores.

4-3-1. Reordering of Adjusted Human Water Security (Adj-HWS) Threat Ranks with Differing Filtering Criteria

This section identifies the five highest-ranked lakes on the basis of their Adj-HWS threats, compared to several filtering criteria characterizing their basins, including lake area, basin population and density, and GNI (Table 4.5). In the case of Africa, lakes Rweru/Moero, Cohoha and Victoria are among the top five most threatened African lakes under most of the ranking criteria, including their Adj-HWS threats. They exhibit a range in sizes, with Rweru/Moero being the second largest lake in the Congo River basin and exhibiting the second-highest Adj-HWS threat. In contrast, Cohoha, a small lake on the Burundi-Rwanda border, also exhibits a high Adj-HWS threat. Lakes Albert and Edward also are identified several times under the four filtering criteria.

Many of the Asia region transboundary study lakes exhibit high ranks for all the filtering criteria. Shardara/Kara-kul, a reservoir on the Kazakhstan- Uzbekistan border, is ranked among the top five most threatened lakes regarding the Adj-HWS and all filtering criteria. The well-known case of the Aral Sea appears among the top five most threatened lakes for all the filtering criteria, although not among the five highest ranked Adj-HWS threatened lakes. Mangla, a multi-purpose reservoir on the Pakistan-India border, also ranks among the top five most-threatened lakes under three of the filtering criteria. Interestingly, the Caspian Sea is not as prominent when considered from the perspective of most of the filtering criteria.

The Dead Sea exhibits the highest Adj-HWS threats of the Europe region transboundary lakes, as well as being among the top five lakes for all filtering criteria, exhibiting the highest threat for three of them. Scutari/Skadar on the Albania-Montenegro border, the largest lake in the Balkan Peninsula, is ranked in the top five lakes for three filtering criteria, although its Adj-HWS threat is substantially lower than for the Dead Sea. Galilee, with the second highest Adj-HWS threat rank, also is ranked among two of the filtering criteria.

The North American transboundary lakes include all the Laurentian Great Lakes, except Superior. Lake Erie, the next-to-last downstream lake in the Great Lakes chain, exhibits the highest Adj-HWS threat, also being among the top five lakes for all filtering criteria. Overall, the North American transboundary lake Adj-HWS scores are considerably lower than those observed for other continents. Lakes Michigan and Ontario in the Laurentian Great Lakes appear among the top five ranked lakes under three filtering criteria. Amistad, a USA-Mexico border reservoir used to allocate the international waters of the Rio Grande between the two countries, is ranked among the top five lakes under three filtering criteria.

Table 4.5 Lakes Exhibiting Highest Adj-HWS Threat Scores for Different Filtering Criteria

Adjusted HWS (Adj-HWS)		Lake area (km^2)	Population number	Population density (persons km^{-2})	Per-capita Gross National Income (GNI)
AFRICA REGION					
Ihema		Victoria	Nasser/Aswan	Kivu	Rweru/Moero
Rweru/Moero		Tanganyika	Lake Congo River	Cohoha	Cohoha
Cohoha		Malawi/Nyasa	Albert	Rweru/Moero	Chilwa
Edward		Turkana	Victoria	Victoria	Chiuta
Abbe/Abhe		Albert	Chad	Edward	Malawi/Nyasa
ASIA REGION					
Sistan		Caspian Sea	Caspian Sea	Mangla	Mangla
Aras Su Qovsaginin Su Anbari		Aral Sea	Aral Sea	Darbandikhan	Shandara/Kara-kul
Mangla		Sarygamysh	Shandara/Kara-kul	Shandara/Kara-kul	Aral Sea
Darbandikhan		Shandara/Kara-kul	Mangla	Aras Su Qovsaginin Su Anbari	Sistan
Shardara/Kara-kul		Sistan	Aras Su Qovsaginin Su Anbari	Aral Sea	Sarygamysh
EUROPE REGION					
Dead Sea		Szczecin Lagoon	Szczecin Lagoon	Galilee	Cahul
Galilee		Dead Sea	Dead Sea	Dead Sea	Ohrid
Cahul		Scutari/Skadar	Lago Maggiore	Lago Maggiore	Macro Prespa
Scutari/Skadar		Ohrid	Galilee	Neuseidler/Ferto	Scutari/Skadar
Neuseidler/Ferto		Macro Prespa	Scutari/Skadar	Szczecin Lagoon	Dead Sea
NORTH AMERICA REGION					
Erie		Huron	Erie	Erie	Falcon
Falcon		Michigan	Ontario	Ontario	Amistad
Amistad		Erie	Michigan	Michigan	Michigan
Ontario		Ontario	Falcon	Champlain	Champlain
Michigan		Champlain	Amistad	Huron	Erie
SOUTH AMERICA AND CARIBBEAN REGION					

Azuei		Titicaca	Lago de Yacyreta	Azuei	Azuei
Titicaca		Itaipu	Itaipu	Itaipu	Titicaca
Chungarkkota		Lago de Yacyreta	Salto Grande	Lago de Yacyreta	Chungarkkota
Lago de Yacyreta		Salto Grande	Chungarkkota	Titicaca	Lago de Yacyreta
Itaipu		Azuei	Titicaca	Chungarkkota	Itaipu

The South America transboundary lakes comprise the smallest group in this study. They include the highest navigable lake in the world (Titicaca) and several large reservoirs (Itaipu, Lago de Yacyreta). Lake Titicaca and Lago de Yacyreta, exhibiting the second and fourth highest rank, respectively, regarding the Adj-HWS threat are both ranked among the top five lakes under all filtering criteria. Lake Azuei, with the highest Adj-HWS threat rank, also is the highest ranked lake for two of the three filtering criteria under which it appears.

4-3-2. Lake Ranking Order Structure Affected by the Choice of Threat Indicators

In addition to the differing perspectives for interpreting the transboundary lake Adj-HWS and Incident BD threat ranks noted above, this section provides additional context by ranking the threats on the basis of several other criteria, including the initial 23 basin drivers and associated driver weights, the socioeconomic factors encompassed within the HDI, and a modified version of the Incident BD threats. An overall threat rank was then derived by summing the computed ranks from these various parameters. It is reiterated that it remains the responsibility of the user of the ranking results to identify the most appropriate context for interpreting them, particularly in regard to developing management interventions.

Based on these latter criteria, the relative threat ranks of the TWAP transboundary study lakes are summarized in Table 4.6, which presents the Incident HWS and BD scores, as well as the Adj-HWS scores and the Human Development Index (HDI) scores, for each transboundary lake. Also provided is a new metric representing a surrogate for an ‘adjusted BD’ score, similar in intent to the Adj-HWS score. This metric was developed because the information and data needed to develop a realistic overview of anticipated BD improvements from investments in biodiversity do not exist. This RvBD assessment parameter (‘Reverse BD’) was calculated by subtracting the incident BD score from 1.0. The lowest rank score indicates the greatest biodiversity threat. This approach is consistent for all the ranking parameters, with the lowest rank scores indicating the greatest threats (i.e., a lake ranked ‘1’ is more threatened than a lake ranked ‘10’).

Table 4.6 summarizes the overall ranks of the TWAP transboundary study lakes, calculated as the sum of the ranks based on the lake Adj-HWS, RvBD, and HDI scores. Not unexpectedly, the large majority of the most threatened transboundary lakes are in Africa. This includes the 13 most threatened lakes based on these ranking parameters, and 21 of the 25 top ranked lakes. There is no consistent observed pattern for these lakes regarding their basin areas, lake sizes, or population density, although several top-ranked lakes exhibit high basin populations. The non-

African exceptions to the 25 top ranked lakes include Lakes Sistan and Sarygamysh, and the Aral Sea in Asia, and Lake Azuei, the latter a transboundary lake located between Haiti and the Dominican Republic in the South America region. The African transboundary lakes are in areas with high annual mean air temperatures, indicating a relatively warm climatic setting.

The majority of the remaining most-threatened transboundary lakes are in Asia and South America, with an interspersed pattern in their overall rankings. Consistent with earlier observations that developed nations have a greater capacity to make needed investments in water infrastructure to address water problems, the transboundary lakes in Europe and North America comprise the less-threatened group of transboundary lakes on the basis of their Adj-HWS scores. Interestingly, the Incident BD scores for Asia and South America are generally lower than those for the developed countries, supporting the assertion that developed countries have already negatively impacted their biodiversity during the course of their economic development process. In contrast, the developing countries generally exhibit lower BD threats (i.e., better biodiversity status) than the developed countries because they often lack the necessary resources for extensive economic development. The most-threatened transboundary lake in the European region is the Dead Sea, ranking 14th on the basis of its absolute Adj-HWS score, but exhibiting less threatened conditions on the basis of its HDI and RvBD scores. The lakes exhibiting the least threat on the basis of their cumulative rank scores include four of the five Laurentian Great Lakes and two transboundary reservoirs on the international section of the Rio Grande between Texas and Mexico. As a group, the South American transboundary lakes are somewhat more threatened than the European and North American lakes.

Table 4.6 Transboundary Lake Threat Ranks by Multiple Filtering Criteria

Continent	Lake Name	Adj-HWS	HWS	BD	HDI	Adj-HWS Rank	HDI Rank	RvBD Rank	Sum Adj HWS + RvBD	Overall Rank	Sum Adj-HWS + HDI	Overall Rank	Sum Adj-HWS + RvBD + HDI	Overall Rank
Africa	Abbe/Abhe	0.93	0.31	0.29	0.40	7	7	7	14	1	14	3	21	1
Africa	Turkana	0.9	0.33	0.30	0.41	13	10	9	22	2	23	10	32	2
Africa	Selingue	0.87	0.30	0.32	0.36	16	2	15	31	11	18	5	33	3
Africa	Malawi/Nyasa	0.91	0.29	0.32	0.42	9	12	14	23	3	21	9	35	4
Africa	Chiuta	0.85	0.25	0.26	0.41	23	9	3	26	5	32	15	35	5
Africa	Cohoha	0.96	0.39	0.41	0.38	3	4	28	31	12	7	1	35	6
Africa	Kivu	0.91	0.31	0.33	0.38	12	6	18	30	8	18	4	36	7
Africa	Rweru/Moero	0.96	0.40	0.42	0.36	4	3	30	34	16	7	2	37	8
Africa	Lake Congo River	0.75	0.20	0.22	0.34	35	1	1	36	18	36	19	37	9
Africa	Tanganyika	0.84	0.25	0.29	0.40	26	8	6	32	14	34	17	40	10
Africa	Edward	0.94	0.34	0.35	0.43	6	13	22	28	7	19	6	41	11
Africa	Chilwa	0.86	0.28	0.30	0.41	21	11	10	31	10	32	14	42	12
Africa	Mweru	0.81	0.24	0.28	0.38	33	5	4	37	21	38	20	42	13
Asia	Sistan	0.98	0.41	0.38	0.46	1	20	25	26	6	21	8	46	14
Africa	Natron/Magad	0.93	0.36	0.33	0.51	8	23	17	25	4	31	13	48	15
Africa	Nasser/Aswan	0.86	0.29	0.32	0.43	20	16	16	36	19	36	18	52	16
Africa	Albert	0.91	0.35	0.37	0.46	10	19	24	34	15	29	12	53	17
Africa	Ihema	0.97	0.41	0.44	0.44	2	18	33	35	17	20	7	53	18
S.Amer	Azuei	0.96	0.50	0.43	0.46	5	21	31	36	20	26	11	57	19
Asia	Aral	0.84	0.29	0.28	0.60	27	26	5	32	13	53	31	58	20
Asia	Sarygamysh	0.82	0.26	0.25	0.67	29	29	2	31	9	58	32	60	21
Africa	Cahora Bassa	0.78	0.29	0.31	0.43	34	15	13	47	25	49	25	62	22
Africa	Victoria	0.91	0.42	0.44	0.47	11	22	32	43	24	33	16	65	23
Africa	Chad	0.84	0.38	0.36	0.43	25	17	23	48	26	42	21	65	24
Africa	Kariba	0.75	0.33	0.34	0.43	36	14	19	55	30	50	28	69	25
S.Amer	Titicaca	0.82	0.33	0.29	0.71	32	32	8	40	22	64	35	72	26
Africa	Aby	0.83	0.35	0.35	0.52	28	24	21	49	27	52	30	73	27
S.Amer	Chungarkkota	0.82	0.36	0.31	0.71	31	33	12	43	23	64	34	76	28
Asia	Shardara/Kara-Kul	0.86	0.52	0.46	0.65	22	28	35	57	31	50	27	85	29
Europe	Dead Sea	0.9	0.57	0.49	0.72	14	34	38	52	29	48	24	86	30
Africa	Josini/Pongolapoort Dam	0.85	0.52	0.48	0.61	24	27	37	61	34	51	29	88	31
S.Amer	Salto Grande	0.67	0.29	0.30	0.74	40	38	11	51	28	78	39	89	32
Asia	Darbandikhan	0.87	0.56	0.54	0.68	17	30	46	63	35	47	23	93	33
S.Amer	Lago de Yacyreta	0.75	0.31	0.34	0.73	38	36	20	58	32	74	38	94	34
Asia	Aras Su Qovsaginin Su Anbari	0.89	0.57	0.53	0.73	15	35	44	59	33	50	26	94	35
Asia	Mangla	0.87	0.59	0.62	0.54	18	25	53	71	39	43	22	96	36
S.Amer	Itaipu	0.75	0.36	0.42	0.73	37	37	29	66	37	74	37	103	37
Asia	Caspian Sea	0.73	0.45	0.40	0.77	39	41	27	66	36	80	40	107	38
Europe	Galilee	0.87	0.59	0.55	0.88	19	46	47	66	38	65	36	112	39
Europe	Cahul	0.82	0.61	0.61	0.69	30	31	51	81	42	61	33	112	40
Europe	Scutari/Skadar	0.62	0.40	0.45	0.78	41	42	34	75	41	83	41	117	41
N.Amer	Amistad	0.49	0.42	0.39	0.86	47	45	26	73	40	92	47	118	42
Europe	Macro Prespa (Large Prespa)	0.51	0.50	0.49	0.75	44	40	40	84	43	84	42	124	43
Europe	Ohrid	0.47	0.49	0.49	0.74	49	39	39	88	46	88	44	127	44
Europe	Szczecin Lagoon	0.53	0.54	0.51	0.83	43	43	43	86	44	86	43	129	45
N.Amer	Huron	0.42	0.40	0.47	0.93	51	50	36	87	45	101	51	137	46
Europe	Neusiedler/Ferto	0.58	0.54	0.61	0.88	42	47	50	92	47	89	45	139	47
N.Amer	Ontario	0.48	0.46	0.53	0.92	48	49	45	93	48	97	49	142	48
Europe	Lake Maggiore	0.33	0.40	0.50	0.89	52	48	42	94	50	100	50	142	49
N.Amer	Falcon	0.5	0.61	0.62	0.85	46	44	52	98	53	90	46	142	50
N.Amer	Erie	0.51	0.51	0.57	0.93	45	51	49	94	51	96	48	145	51
N.Amer	Champlain	0.29	0.39	0.49	0.94	53	52	41	94	49	105	53	146	52
N.Amer	Michigan	0.44	0.48	0.56	0.94	50	53	48	98	52	103	52	151	53

It also is possible to examine the transboundary lake threats on the basis of their Adj-HWS and RvBD scores alone, or their Adj-HWS and HDI scores alone. Although the data are not presented here, several examples highlight the fact that consideration of different combinations of ranking criteria can significantly change the relative rankings. As an example, based on (i) the sum of the Adj-HWS + RvBD + HDI scores, (ii) the Adj-HWS + RvBD scores, and (iii) the Adj-HWS + HDI scores, Lake Selingue in Africa ranks 3, 11 and 5, respectively. Lake Rweru/Moero ranks 8, 16 and 2, respectively, under the same conditions. Even more illustrative is Lake Sarygamysh in Asia, which ranks 21 on the basis of all the ranking criteria, compared with 9 on the basis of the Adj-HWS and RvBD scores, and 32 on the basis of the Adj-HWS and HDI scores.

The results highlighted in Table 4.6 indicate that obtaining the most meaningful lake threat rankings requires the users of the ranking results to clearly define the factors most important for any proposed management interventions. As discussed further in the next section, defining priorities regarding relative lake threats is not simply an exercise of computing absolute lake threat scores and comparing them between lakes. Rather, a recurring conclusion of this lake assessment exercise is that identifying the factors most important to the individual or organization establishing management priorities is fundamental to understanding the broad implications of the transboundary lake threats. Additional factors that can influence management intervention goals include issues such as the sustainability of ecosystem goods and services, institutional and/or policy goals, different management options, cultural considerations, and financial sustainability.

4-3-3. Parametric Assessment of Overall Lake Rankings Relative to Ranking Combinations of Adj-HWS and BD Threats and HDI Scores

A parametric sensitivity analysis of the ranking results was performed to determine the extent that different weights assigned to the Adj-HWS and BD threats affected the relative transboundary lake rankings. It also highlights the reality that the significance of the ranking results are typically a function of multiple interrelated factors.

This analysis involved increasing or decreasing the weights applied to the Adj-HWS and BD ranks in Table 4.6 and recalculating the relative threat ranks. One parameter would assume greater importance (greater weight) and the other lesser importance along a numerical gradient. One extreme was the Adj-HWS rank assuming 100 per cent importance (i.e., rank weight of 1.0) and the BD rank having no importance (i.e., rank weight of 0.0) in recalculating the relative lake ranks. The relative weights were changed in 0.2 increments and the summary rankings calculated. Changing the increments and recalculating the results continued until the other extreme was reached (i.e., BD rank assumed 100 per cent importance and Adj-HWS rank having no importance). A mid-point weight (i.e., Adj-HWS and BD ranks given equal consideration) was also used in the recalculations. This latter consideration is referred to as Case A in the following discussions.

In considering management intervention possibilities, another informative perspective is to consider the ability of the countries involved to undertake the investments needed to address the identified HWS and BD threats. This approach uses a surrogate indicator of the socioeconomic characteristics of the transboundary lake basin countries to help identify the lakes most in need of catalytic funding for implementing management interventions compared with those for which management interventions might produce the greatest return for catalytic funding. To this end, this latter analysis incorporates a surrogate socioeconomic indicator in the form of the Human Development Index (HDI) scores, considered together with the Adj-HWS and BD threat scores. For this analysis, the Adj-HWS and BD threat ranks were given equal consideration in the calculations (i.e., a 'midpoint' weight of 0.5 for both criteria). Although the sum of the ranks varied slightly in some cases from that based on the midpoint value, the latter was used throughout the calculations for consistency.

The subsequent recalculated ranks are displayed in two ranking orders. The first displays the rankings with the HDI score going from lowest to highest value, thereby giving greater priority to countries with lower investment possibilities, and presumably most in need of catalytic funding (identified as Case C in subsequent discussions). The second displays the ranking results with the HDI scores going from highest to lowest values, indicating a better potential for the involved countries to undertake management interventions on their own (referred to as Case E in subsequent discussions). As noted above, the midpoint Adj-HWS and BD weights of the Case A situation were used for both HDI scenario analyses. Although not shown in this report, scenario cases B, D and F more explicitly considered the BD threats

The results for the **African** transboundary lake scenarios are presented in Tables 4.7-4.9. The recalculated ranking scores vary with the individual Adj-HWS and BD increment combinations (Case A in Table 4.7). However, the overall rank based on the sum of the individual ranks identify Ihema, Cohoha, Rweru/Moero, Edward, Victoria and Albert as the most threatened lakes. This ranking is almost identical to those obtained with the Adj-HWS and BD threats assuming equal importance (i.e. the 50-50 increment). The results are presented graphically, indicating Ihema, Cohoha, Rweru/Moero and Edward are generally insensitive to the changing increments under a decreasing Adj-HWS and increasing BD weigh scenario until the BD threat assumes greater importance. Some ranks do change considerably, however, when different increments are considered. Lake Victoria, for example, is ranked ninth on the basis of its Adj-HWS threat alone, but becomes the third most threatened African transboundary lake when its BD alone is considered. The situation is even more dramatic for Josini/Pongolapoort, ranked 16th when its Adj-HWS was considered, but exhibiting the highest threat when its BD was considered. The reverse situation is noted for other lakes. Lakes Natron/Magadi and Malawi/Nyasa, for example, are approximately in the middle of the ranks when their Adj-HWS threat alone is considered, but exhibited a less threatened rank when their BD threat alone was considered.

Table 4.7 African Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights

Case A: **Adj-HWS Threat (H-L) Rank vs. BD Threat (H-L) Rank**

Threat Rank Weight									
Adj-HWS Threat	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
BD Threat	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
Threat Ranks									
Lake Name	Adj-HWS Threat			Mid-point			BD Threat	Sum of Ranks	Over-all Rank
Ihema	1	1	1	1	1	1	2	8	1
Cohoha	2	2	2	2	3	5	5	21	3
Rweru/Moero	3	3	3	3	2	2	4	20	2
Edward	4	4	4	4	5	7	8	36	4
Victoria	9	7	5	5	4	4	3	37	5
Albert	8	6	6	6	6	6	6	44	6
Josini/Pongolapoort	16	13	8	7	7	3	1	55	8
Natron/Magad	6	5	7	8	8	9	12	55	7
Kivu	10	10	10	9	9	10	11	69	9
Malawi/Nyasa	7	9	9	10	11	14	15	75	10
Abbe/Abhe	5	8	11	11	15	16	19	85	12
Chad	17	16	14	12	10	8	7	84	11
Selingue	12	12	12	13	14	15	14	92	13
Nasser/Aswan	13	14	13	14	12	13	13	92	14
Aby	19	18	16	15	13	11	9	101	15
Turkana	11	11	15	16	16	18	18	105	16
Chilwa	14	15	17	17	18	17	17	115	17
Kariba	23	22	18	18	17	12	10	120	18
Chiuta	15	17	19	19	20	21	22	133	19
Cahora Bassa	21	20	21	20	19	19	16	136	20
Tanganyika	18	19	20	21	21	20	20	139	21
Mweru	20	21	22	22	22	22	21	150	22
Lake Congo River	22	23	23	23	23	23	23	160	23

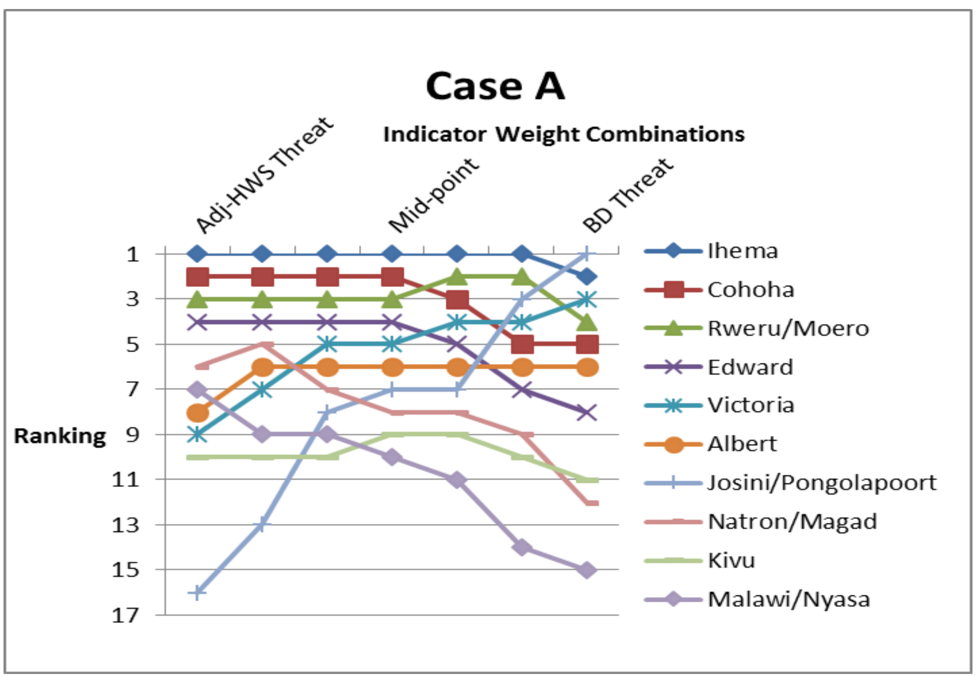
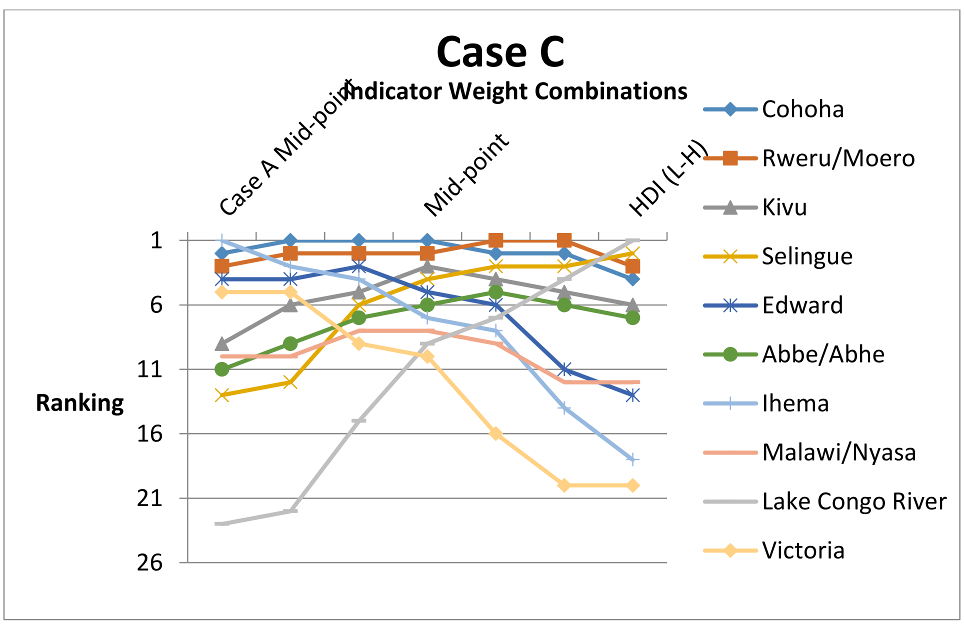


Table 4.8. African Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights and Increasing HDI Scores

Case C: Midpoint of Case-A Rank vs. HDI (L-H) Rank

	Threat Rank Weight								
Case A Midpoint	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
HDI (L-H)	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
	Threat Ranks								
Lake Name	Case A Mid-point			Mid-point			HDI (L-H)	Sum of Ranks	Over-all Rank
Cohoha	2	1	1	1	2	2	4	13	1
Rweru/Moero	3	2	2	2	1	1	3	14	2
Kivu	9	6	5	3	4	5	6	38	3
Selingue	13	12	6	4	3	3	2	43	4
Edward	4	4	3	5	6	11	13	46	5
Abbe/Abhe	11	9	7	6	5	6	7	51	6
Ihema	1	3	4	7	8	14	18	55	7
Malawi/Nyasa	10	10	8	8	9	12	12	69	8
Lake Congo River	23	22	15	9	7	4	1	81	9
Victoria	5	5	9	10	16	20	20	85	10
Albert	6	7	10	11	15	19	19	87	11
Turkana	16	15	13	12	11	10	10	87	12
Mweru	22	21	19	13	10	7	5	97	13
Chilwa	17	16	16	14	14	13	11	101	15
Chiuta	19	18	18	15	12	9	9	100	14
Natron/Magad	8	11	11	16	20	21	21	108	17
Chad	12	13	14	17	17	17	17	107	16
Tanganyika	21	20	20	18	13	8	8	108	18
Josini/Pongolapoort	7	8	12	19	21	22	23	112	19
Nasser/Aswan	14	14	17	20	18	16	16	115	20
Kariba	18	19	21	21	19	15	14	127	21
Cahora Bassa	20	23	23	22	22	18	15	143	22
Aby	15	17	22	23	23	23	22	145	23



When the African lakes are considered in the lower to higher HDI scenario (Case C in Table 4.8, indicating a progressively increasing HDI), the most threatened African transboundary lakes include Cohoha, Rweru/Moero and Kivu, all bordering Rwanda, Burundi and/or Democratic Republic of Congo. The threat to Kivu increases notably from its rank in Table 4.7. New lakes also appear in the most threatened group in this new scenario, including Abbe/Abhe on the Ethiopia/ Djibouti border, and Lake Selingue on the Guinea/Mali border, neither being identified among the top ten most threatened lakes when the Adj-HWS and BD threats alone were considered (Table 4.7). The threat to Lake Congo River and Selingue increase significantly when the HDI is considered in the lower to higher order. In contrast, the threat to Lakes Ihema and Victoria decreases markedly under the same conditions.

A different ranking is observed with the HDI considered in a decreasing order (Case C in Table 4.9). This scenario assumes that the transboundary lakes in countries with higher HDI scores are more capable of undertaking the investments needed to address their identified lake problems, in contrast to the previous assumption that the countries with lakes having lower HDI scores would have more difficulty in providing the funds needed to undertake management interventions. There are familiar names among the ten most threatened lakes identified in Tables 4.8 and 4.9 (Ihema, Victoria, Edward, Cocoha and Malawi), although generally in reversed order. New lakes also emerge in this new scenario, including Albert (Uganda/Democratic Republic of Congo), Natron (Kenya/Tanzania), Aby (Cote d'Ivoire/Ghana) and Chad (Cameroon/Chad). The relative threat rank of Cohoha decreases significantly as the BD threat increases, while Aby exhibits the least threatened condition when the Adj-HWS alone is considered, but changes to a significantly more threatened rank as the BD becomes more important.

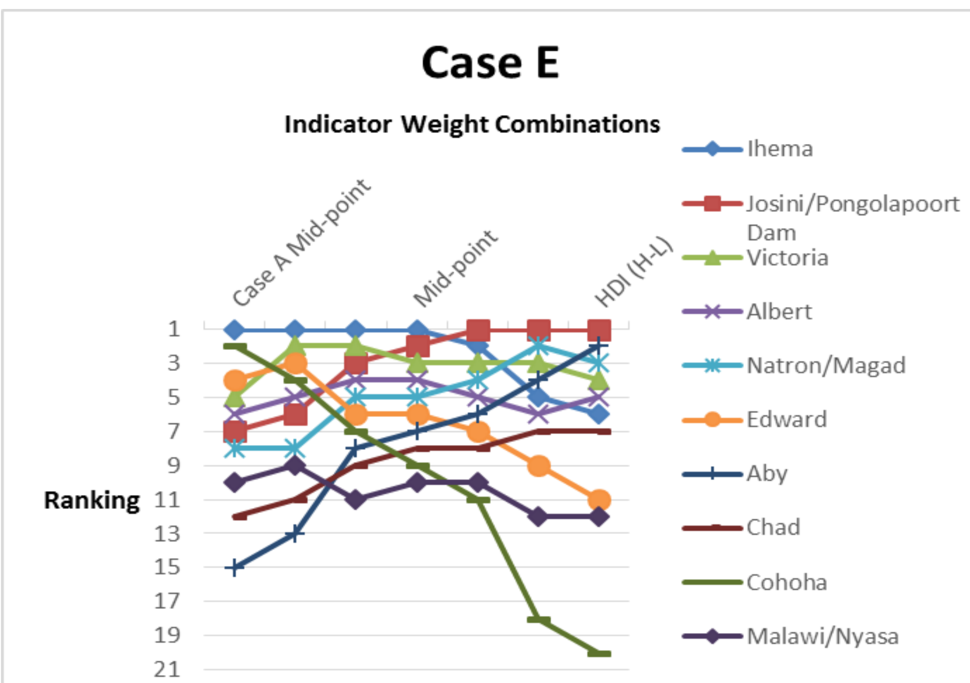
The **Asian** transboundary lake scenario results are presented only in tabular form in Tables 4.10-4.12. As a smaller group, the Asian transboundary lakes obviously exhibit fewer ranks than the African lakes. Although the relative ranks change for these lakes under the changing Adj-HWS and BD increments (Case A in Table 4.10), they are not as dramatic as for the African lakes (reading from left to right for these and the remaining tables in this section). Aras Su Qovsaginin Su Anbari (Iran/Azerbaijan), Darbandikhan (Iraq/Iran) and Mangla (India/Pakistan) are the most threatened lakes when the Adj-HWS and BD threats are considered equally important in the calculations (the 'midpoint' value). Sistan (Iran/Afghanistan) is the most threatened when the Adj-HWS is given priority, but becomes markedly less threatened when its BD increases in importance. The reverse is seen for Mangla, which becomes more threatened when its BD is the primary concern.

When the HDI in decreasing order is added to the scenario (Case C in Table 4.11), Mangla, Darbandikhan and Aras Su Qovsaginin Su Anbari remain the most threatened lakes, along with Sistan. However, the relative rank of Aras Su Qovsaginin Su Anbari and Darbandikhan decrease markedly. The opposite is observed for the Aral Sea and Sistan when the decreasing HDI scenario is considered.

Table 4.9. African Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights and Decreasing HDI Scores

Case E: **Midpoint of Case-A Rank vs. HDI (H-L) Rank**

	Threat Rank Weight								
Midpoint Case A	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
HDI (H-L)	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
Threat Ranks									
Lake Name	Case A Mid-point			Mid-point			HDI (H-L)	Sum of Ranks	Over-all Rank
Ihema	1	1	1	1	2	5	6	17	1
Josini/Pongolapoort	7	6	3	2	1	1	1	21	2
Victoria	5	2	2	3	3	3	4	22	3
Albert	6	5	4	4	5	6	5	35	5
Natron/Magad	8	8	5	5	4	2	3	35	4
Edward	4	3	6	6	7	9	11	46	6
Aby	15	13	8	7	6	4	2	55	7
Chad	12	11	9	8	8	7	7	62	8
Cohoha	2	4	7	9	11	18	20	71	9
Malawi/Nyasa	10	9	11	10	10	12	12	74	10
Nasser/Aswan	14	14	12	11	9	8	8	76	11
Rweru/Moero	3	7	10	12	14	20	21	87	12
Kivu	9	10	13	13	15	17	18	95	13
Abbe/Abhe	11	12	14	14	16	15	17	99	14
Kariba	18	18	15	15	12	11	10	99	15
Cahora Bassa	20	19	18	16	13	10	9	105	16
Turkana	16	16	16	17	18	14	14	111	17
Chilwa	17	17	17	18	17	13	13	112	18
Chiuta	19	20	20	19	19	16	15	128	19
Selingue	13	15	19	20	21	22	22	132	20
Tanganyika	21	21	21	21	20	19	16	139	21
Mweru	22	22	22	22	22	21	19	150	22
Lake Congo River	23	23	23	23	23	23	23	161	23



Case A: Adj-HWS Threat (H-L) Rank vs. BD Threat (H-L) Rank

Threat Rank Weights									
Adj-HWS Threat	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
BD Threat	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
Threat Ranks									
Lake Name	Adj-HWS Threat			Mid-point			BD Threat	Sum of Ranks	Over-all Rank
Aras Su Qovsaginin Su Anbari	2	2	1	1	3	3	3	15	1
Darbandikhan	3	3	2	2	2	2	2	16	2
Mangla	4	4	3	3	1	1	1	17	3
Sistan	1	1	4	4	4	5	6	25	4
Shardara/Kara-Kul	5	5	5	5	5	4	4	33	5
Aral	6	6	6	6	7	7	7	45	6
Caspian Sea	8	8	7	7	6	6	5	47	7
Sarygamysh	7	7	8	8	8	8	8	54	8

Table 4.10 Asian Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights

Case C: Midpoint of Case-A Rank vs. HDI (L-H) Rank

Threat Rank Weights									
Midpoint Case A	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
HDI (L-H)	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
Threat Ranks									
Lake Name	Case A Mid-point			Mid-point			HDI (L-H)	Sum of Ranks	Over-all Rank
Mangla	3	3	1	1	2	2	2	14	
Sistan	4	4	2	2	1	1	1	15	2
Aras Su Qovsaginin Su	1	1	3	3	6	7	7	28	4
Darbandikhan	2	2	4	4	4	5	6	27	3
Shardara/Kara-Kul	5	5	5	5	5	4	4	33	5
Aral	6	6	6	6	3	3	3	33	6
Sarygamysh	8	8	7	7	7	6	5	48	7
Caspian Sea	7	7	8	8	8	8	8	54	8

Table 4.11 Asian Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights and Increasing HDI Scores

Case E: Midpoint of Case-A Rank vs. HDI (H-L) Rank

Threat Rank Weights									
Midpoint Case A	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
HDI (H-L)	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
Threat Ranks									
Lake Name	Case A Mid-point			Mid-point			HDI (H-L)	Sum of Ranks	Over-all Rank
Aras Su Qovsaginin Su	1	1	1	1	1	1	2	8	1
Darbandikhan	2	2	2	2	2	3	3	16	2
Caspian Sea	7	6	4	3	3	2	1	26	3
Mangla	3	3	3	4	5	7	7	32	4
Shardara/Kara-Kul	5	5	5	5	4	5	5	34	5
Sistan	4	4	6	6	8	8	8	44	6
Aral	6	7	7	7	7	6	6	46	8
Sarygamysh	8	8	8	8	6	4	4	46	7

Table 4.12 Asian Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights and Decreasing HDI Scores

When the HDI is considered in increasing order (Case E in Table 4.12), several changes are noted. The relative ranks of Mangla and Sistan decrease markedly. In contrast, the ranks of Aras Su Qovsaginin Su Anbari, Darbandikhan, and the Caspian Sea increase markedly, suggesting a better potential for undertaking the management interventions needed to address identified transboundary lake problems. The increased rank of the Caspian Sea in Tables 4.11 and 4.12 is especially dramatic.

The results for the **South American** transboundary lakes are presented in Tables 4.13-4.15. When the Adj-HWS and BD threats are given equal weight in the calculations (Case A in Table 4.13), Azuei (Haiti/Dominican Republic), Chungarkkota (Bolivia/Peru) and Itaipu (Brazil/Paraguay) are the most threatened transboundary lakes. With a decreasing weight given to the Adj-HWS and an increasing BD weight, the ranks of Titicaca (Peru/Bolivia) and Chungarkkota decrease markedly. In contrast, the ranks of Itaipu and Lago de Yacycreta (Argentina, Paraguay), both reservoirs on the Paraná River system, increase substantially.

When the decreasing HDI scenario is considered (Case C in Table 4.14), the rank of Itaipu decreases significantly, while that of Titicaca becomes almost the most threatened south American transboundary lake. Azuei, a transboundary lake located on the border of one of the poorest countries in the Latin American/Caribbean region continues to exhibits the highest threat under both scenario cases.

Case A: Adj-HWS Threat (H-L) Rank vs. BD Threat (H-L) Rank

Threat Rank Weights									
Adj-HWS Threat	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
BD Threat	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
Threat Ranks									
Lake Name	Adj-HWS			Mid-point			BD Threat	Sum of Ranks	Over-all Rank
Azuei	1	1	1	1	1	1	1	7	1
Chungarkkota	2	2	2	2	3	4	4	19	3
Itaipu	4	3	3	3	2	2	2	19	2
Lago de Yacyreta	5	5	5	4	4	3	3	29	4
Titicaca	3	4	4	5	5	6	6	33	5
Salto Grande	6	6	6	6	6	5	5	40	6

Table 4.13 South American Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights

Case C: Midpoint of Case-A Rank vs. HDI (L-H) Rank

Threat Rank Weights									
Midpoint Case A	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
HDI (L-H)	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
Threat Ranks									
Lake Name	Case A Mid-point			Mid-point			HDI (L-H)	Sum of Ranks	Over-all Rank
Azuei	1	1	1	1	1	1	1	7	1
Chungarkkota	2	2	2	2	2	3	3	16	2
Titicaca	5	5	4	3	3	2	2	24	3
Itaipu	3	3	3	4	5	5	5	28	4
Lago de Yacyreta	4	4	5	5	4	4	4	30	5
Salto Grande	6	6	6	6	6	6	6	42	6

Table 4.14 South American Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights and Increasing HDI Scores

Case E: Midpoint of Case-A Rank vs. HDI (H-L) Rank

Threat Rank Weights									
Midpoint Case A	1.0	0.8	0.6	0.5	0.4	0.2	0.0		
HDI (H-L)	0.0	0.2	0.4	0.5	0.6	0.8	1.0		
Threat Ranks									
Lake Name	Case A Mid-point			Mid-point			HDI (H-L)	Sum of Ranks	Over-all Rank
Itaipu	3	3	1	1	1	2	2	13	4
Chungarkkota	2	2	2	2	3	4	4	19	2
Azuei	1	1	3	3	5	6	6	25	1
Lago de Yacyreta	4	4	4	4	4	3	3	26	5
Salto Grande	6	6	5	5	2	1	1	26	6
Titicaca	5	5	6	6	6	5	5	38	3

Table 4.15 South American Transboundary Lake Threats Based on Altered Adj-HWS and BD Rank Weights and Decreasing HDI Scores

In regard to the increasing HDI scenario (Case E in Table 4.15), Azuei and Titicaca exhibit the major changes. In contrast, Lake Itaipu assumes the top rank when the HDI is considered. The ranks of the remaining South American transboundary lakes remain relatively the same.

With regard to the European region lakes (see Technical Appendix 6), the HDI assumes less importance in regard to the relative threat ranks, since the European countries typically exhibit higher HDI scores and economic characteristics permitting considerable investment possibilities to address transboundary lake issues. Although the data are not presented here, Cahul (Ukraine/Moldova), Sea of Galilee (Israel/Syria), and Neuseidler/Ferto (Austria/Hungary) assume the top ranks in the Case A scenario (equal Adj-HWS and BD threat weights). The relative threats to the Dead Sea (Israel/Jordan/Palestine) and Scutari/Skadar (Albania/Montenegro) decrease, however, as the importance of the Adj-HWS threats decrease and the BD threats increase, while the threat to Lake Maggiore (Italy/Switzerland) increases in the same scenario.

In the increasing HDI scenario (Case C), Cahul and Galilee remain in the top three most threatened lakes, with Cahul being the most threatened lake in both the Case A and C scenarios. Neuseidler/Ferto remains among the top three threatened lakes under both the Case C and E scenarios. The ranks of Galilee and Neuseidler/Ferto display markedly decreasing ranks with increasing HDI scores, while Ohrid and Macro Prespa assumes a higher rank with a decreasing HDI score. The increasing HDI scenario (Case E) indicates that the relative rank of Cahul decreases significantly with decreasing HDI, while that of Maggiore increases with an increasing HDI.

The HDI is also of less concern regarding the North American transboundary lakes (see Technical Appendix 6), since they include only four of the Laurentian Great Lakes, Lake Champlain, and two

USA/Mexico border reservoirs. Falcon (USA/Mexico) and the two most downstream Laurentian Great Lakes exhibit the highest threat ranks under the Case A scenario (i.e., Adj-HWS and BD threats assume equal importance). Changing Adj-HWS and BD weights do not produce differing results as dramatic as those of some other transboundary lake groups. The exception is Amistad (USA/Mexico), whose threat rank decreases markedly as the Adj-HWS threat decreases and the BD threat increases.

In the Case C scenario (decreasing HDI scores), Lakes Michigan and Erie assume lower ranks with increasing HDI scores. This is in contrast to Amistad, whose rank increases with decreasing HDI scores. When the lakes are ranked on the order of increasing HDI scores, the rank of Falcon decreases markedly, while that of Lakes Michigan and Champlain increase.

To conclude this section, it is clear that the criteria used to calculate the relative lake threat rankings, as well as the context under which they are considered by the user, can significantly influence the interpretation of the calculated ranks of the transboundary lakes. The rankings presented in Table 4.2, for example, are based on calculations involving the Incident Human Water Security (HWS) and Biodiversity (BD) threats, while those in Table 4.3 are based on the Adjusted Human Water Security (Adj-HWS), with some major differences observed between the two tables. Further, Table 4.6 uses a range of relevant ranking criteria, again illustrating different calculated threat ranks. This section also provides threat rankings based on assigning differing weights to the previously-calculated Adj-HWS and BD ranks, and including the Human Development Index (HDI) as an assessment criterion. There are some significant differences arising from this latter approach, again highlighting that the user of the ranking results must determine the context under which they are to be interpreted and used for both scientific and management purposes. The Scenario Analysis Program developed during the course of the transboundary lakes analysis (see Section 3.6) provides a useful analysis tool to use in considering the ranking results in a realistic and meaningful manner, particularly for decision-makers.

4-4. Integrative Assessment of Transboundary Lake Ranking Orders with Possible GEF-catalysed Management Interventions

In assessing the relative threats to the 53 TWAP transboundary study lakes, due attention should be given to additional considerations regarding priorities for GEF-facilitated funding of potential management interventions. These considerations are extracted from the information and data in ILEC's knowledge base system, "*Learning Acceleration and Knowledge Enhancement System"*. Originally developed and refined at Shiga University (Japan), ILEC has used this system over the past decade to support comprehensive lake basin management efforts in various countries around the world. The third version of this system (LAKES-III) contains a database of approximately 1 700 documents available from public-domain literature and other sources, as well as manuscripts published from all past issues (1988-2015) of ILEC's journal, "*Lakes and Reservoirs: Research and Management*."

Based on the lessons learned from the TWAP transboundary lakes analyses, complemented by insights from LAKES-III, it was possible to develop some observations regarding potential funding priorities for GEF-catalysed management interventions for the African, Asian, and South American transboundary study lakes listed in Table 4.6. These observations also integrate the lake ranking results derived from Sections 4-3-1, 4-3-2 and 4-3-3 with the insights regarding management intervention possibilities gained from LAKES-III. The lakes are discussed below by continent in alphabetical order.

4-4-1. African Transboundary Lakes

Observations regarding the African transboundary study lakes include:

- Abbe/Abhe is a saline lake in the Ethiopia and Djibouti Rift Valley highland lake basin complex. This region has three major rivers (Awash, Meki-Katar, Dijo) draining to Lakes Abhe, Ziway and Shala, respectively. Terminal lakes Abiyata and Shala exhibit high alkalinities. There are currently no comprehensive management plans for these lakes. Any GEF intervention should probably consider not only Abbe/Abhe, but also the whole highland lake region, as well as the national regional development programmes of Ethiopia and Djibouti.
- Aby is reported to be exhibiting a gradually deteriorating lake environment, and would probably benefit greatly from a GEF-facilitated management intervention. Such project possibilities, however, would ideally be linked with those in Lake Volta and the Volta River basin.
- Cahora Bassa is a major hydropower dam in the Zambezi River system. Available information suggests that it does not exhibit the same resource development and conservation issues related to the lake environment, compared to Lake Kariba, another upstream reservoir constructed in the same river basin.
- Chad is a lake that has already received GEF funding.
- Cohoha could be a subject for GEF funding considerations, together with Rweru/Moero and Ihema, all three lakes located in the same general vicinity in the upper catchment wetland region of Rwanda and Burundi. They share similar economic (fishery management) and environmental (progressing eutrophication) challenges. To effectively consider these lakes for GEF funding, a new strategic approach may be needed to deal with them as a lake cluster containing both transboundary and national (non-transboundary) lake basins. The cluster lake concept applied to African Rift Valley lakes and West African coastal lakes is illustrated in Figure 4.1.
- Edward and Albert are located among the East African Great Lakes. Compared to some other lakes in the region (e.g., Malawi/Nyasa, Tanganyika, Victoria), however, they have not received as much attention, and information on their scientific and management challenges is rather sparse. At the same time, the riparian population is facing rapidly-deteriorating

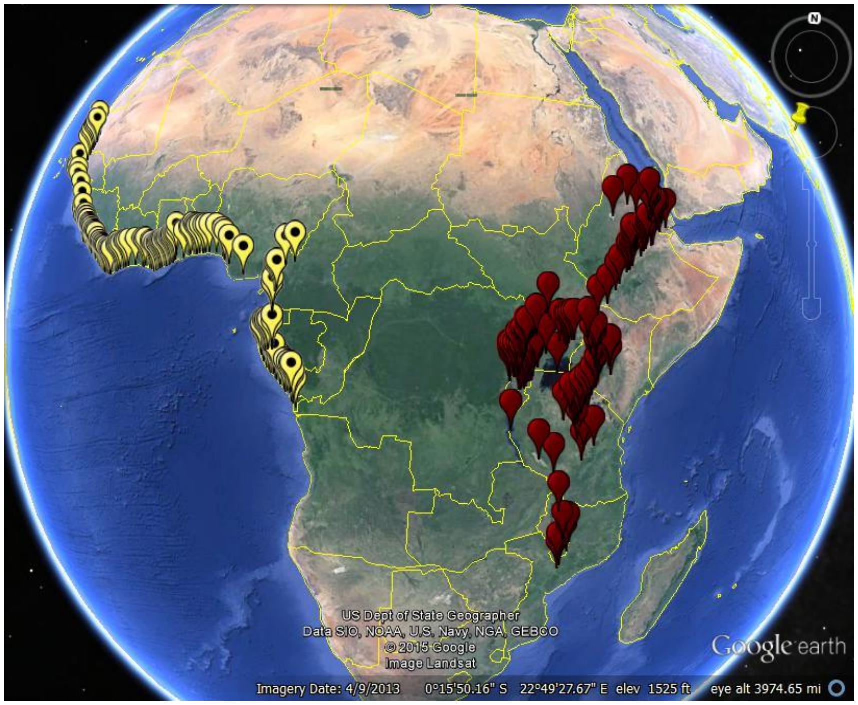


Figure 4.1 African Rift Valley and Western African Coastal Lake Clusters

environmental challenges, an example being newly-emerging oil exploration projects posing some politically-volatile challenges for Lake Albert.

- Josini/Pongolapoort Dam has little available information regarding its environmentally-related management challenges, although some concerns exist regarding minimum environmental flow requirements in its river system. Nevertheless, it may not exhibit serious transboundary issues requiring possible GEF project interventions.
- Kariba is facing gradual deterioration of its water quality and its riparian ecosystems, potentially affecting its fishery and tourism industries.
- Kivu, one of the African Great Lakes lying along the Rwanda-Democratic Republic of Congo border, is facing degrading ecological functions and deteriorating social welfare in its riparian countries. It is reported to have underwater methane gas reserves attracting commercial exploration interests. The northern Kivu region, however, has experienced ethnic conflicts, which may pose difficulties in the pursuit of substantial international cooperation.
- Lake Congo River is a major reservoir on the Congo River. There is very little information regarding environmental or other important transboundary issues for the lake, although the entire Congo River System may be of interest for support through the GEF.
- Malawi/Nyasa could be a subject for potential GEF funding consideration, along with Chiuta and Chilwa, all of which are in relatively close proximity to each other. They share common needs regarding issues such as improving fishery practices and overcoming public health hazards, including recently-experienced cholera epidemics.

- Mweru supports fisheries, mining, and tourism industries, although the magnitude of their environmental implications is not clear.
- Nasser/Aswan may need GEF funding considerations within the context of the Nile Basin Initiative, in view of the overall political concerns of the Nile River riparian countries.
- Natron/Magadi would benefit considerably if the two riparian countries (Kenya and Tanzania) included this lake within the context of their national strategic plan for collective integrated management of the region's Rift Valley lakes. This approach would also have synergistic effects in terms of both the GEF transboundary approach and national strategic plan development and implementation.
- Selingue is a multipurpose reservoir in West Africa facing environmental challenges related mainly to climate-driven causes. It is not clear how a GEF-funded management intervention could be usefully developed for this lake.
- Turkana is considered to be a seriously-challenged lake in regard to its environmental condition and managerial challenges. Possible GEF funding considerations would depend on the politically-contended situation in the riparian countries.
- Victoria is a lake that has already received GEF funding.

4-4-2. Asian Transboundary Lakes

Observations regarding the Asian transboundary study lakes include:

- Aral Sea is a lake that has already received GEF funding. However, it is again becoming a subject for possible GEF-facilitated management interventions, which would require due elaboration within an appropriately-established international consultative process.
- Aras Su Qovsaginin Su Anbari has a long history of bilateral discussions between Iran and Azerbaijan regarding its operation and management. There is little information, however, regarding the need for GEF interventions for any transboundary environmental issues.
- Caspian Sea is a lake that has already received GEF funding.
- Darbandikhanis reported to be facing water quality degradation causing occasional fish kills. It is not clear, however, whether or not the riparian countries (Iraq, Iran) have any direct interest in addressing the issue through an international intervention facilitated by the GEF.
- Mangla has a long history of bilateral discussions between Pakistan and India on its operation and management. There is little information, however, regarding the need for GEF interventions for any transboundary environmental issues.
- Sarygamysh is closely related to the Aral Sea in regard to transboundary water management efforts in this part of the Central Asia. Assessment of GEF funding possibilities, therefore, will also relate to outcomes of ongoing international discussions on the Aral Sea.
- Shardara/Kara-Kul is also closely related to the Aral Sea in regard to transboundary water management efforts in this part of Central Asia. Thus, assessment of GEF funding possibilities also will relate to outcomes of ongoing international discussions on the Aral Sea.
- Sistan is a lake that has already received GEF funding.

4-4-3. South American Transboundary Lakes

Observations regarding the South American transboundary study lakes include:

- Azuei is a highly-degraded transboundary lake between Haiti and the Dominican Republic. This area is reported to be experiencing highly-depressed economic conditions. The viability of possible GEF funding depends on many factors, including the potential economic and social development gains in this region from such interventions.
- Chungarkkota is an intermittent satellite lake attached to the Lake Titicaca complex. The viability of considering this lake for GEF funding, therefore, is related to the same consideration as Titicaca.
- Itaipu has previously experienced environmental issues. It is not clear from the available information, however, that such issues would be better addressed through GEF intervention.
- Lago de Yacyreta has long faced some serious environmental challenges. It is again becoming a subject for potential GEF consideration that would require elaboration of an appropriately-established international consultative process.
- Salto Grande is facing a wide range of environmental problems, including eutrophication and trace organic chemical contamination. The suitability of this lake for GEF funding depends on many factors, including the potential economic and social development gains to be realized for this region.
- Titicaca is a lake that has already received GEF funding. However, the lake is again becoming a possible subject for GEF funding, although this would require due elaboration of an appropriately-established international consultative process.

4-4-4. Overview of GEF Intervention Possibilities

A summary of key GEF prioritization issues for the African, Asian and South American transboundary lakes, augmented by information contained in LAKES-III, is presented in Table 4.16. The lakes are identified alphabetically by continent. The table includes the lake summary threat ranks in Table 4.6, as well as those derived from the mid-point ranks identified in Cases A, C and E of the Parametric Sensitivity Analyses (Tables 4.7-4.15). The different threat ranks derived from these sources are striking in some cases, again highlighting that identifying the appropriate context is fundamental to obtaining a meaningful understanding and appreciation of the lake threat ranks, particularly in regard to potential management interventions.

Table 4.16 provides observations regarding the potential for undertaking management interventions for individual transboundary lakes, based on their ranking order and available literature concerning their current status. The existing information suggests that management interventions could be considered in some cases in the context of addressing multiple lake needs, as noted with African Lakes Albert and Edward, Chilwa and Chiuta, and Cohoha, Ihema and Rweru/Moero. Many lakes require further consideration of their scientific and/or political situation prior to considering any management interventions, Asian Lake Danbandikhan and South American Salto Grande being examples. Others require consideration of their situation within the context of the larger river basins in which they are located, such as Cahora Bassa in the Zambezi River basin. A large number merit review of their current GEF status. The effects of changing the ranking criteria also are illustrated with the range of lake ranks highlighted in the table.

The individual comments regarding this literature-based assessment summary are defined as:

- Explore: Explore the feasibility of interventions with the help of local experts. The available information on the prevailing biophysical and limnological state of the lake environment warrants the use of external interventions. However, the political climate, government readiness, and governance constraints are not clear. Thus, a combined assessment would be possible only with direct involvement of local experts;
- Survey: Some scientific and managerial data and information are available, but are not sufficient to undertake comprehensive, conclusive assessments. A reconnaissance survey conducted with the help of local experts may lead to necessary conclusions on the desirability and feasibility of external interventions;
- Improve: The quantity of information on the scientific and managerial challenges is not sufficient to reach any meaningful conclusions. A concerted effort is required to improve the lake knowledge base;
- Defer: It is premature to make a positive assessment for external interventions;
- Review: Review the current GEF status;
- Recommendable: Consider GEF intervention.

Table 4.16 Summary of Ranking Order Related to GEF Intervention Possibilities

Lake	Range of Lake Ranks				Literature Assessment	Key Observations for GEF Prioritization Considerations
	Sum of Threat Ranks	Case A	Case C	Case E		
AFRICA						
Abbe/Abhe	1	11	6	14	Explore, Improve	Joint implementation with other Ethiopian and Djiboujtian highland lakes may be usefully explored.
Aby	27	15	23	7	Explore, Improve	Possibly consider together with Volta River and Lake Volta
Albert	17	6	11	4	Explore, Survey	Joint implementation with Edward could be an option.
Cahora Bassa	22	2	1	9	Review, Defer	Need to confirm how lake is assessed within Zambezi River transboundary system.
Chad	24	12	17	8	Defer	Review current GEF status.
Chilwa	12	17	14	18	Explore, Improve	Joint implementation with Chiuta may be usefully explored. Examine viability of relating with Malawi/Nyasa follow-up.
Chiuta	5	19	15	19	Explore, Improve	Joint implementation with Chilwa may be usefully explored. Examine viability of relating with Malawi/Nyasa follow-up.

Cohoha	6	2	1	9	Explore, Improve	Consideration may be given to possible joint implementation with Ihema and Rweru/Moero as an option.
Edward	11	4	5	6	Explore, Survey	Joint implementation with Albert could be an option.
Ihema	18	1	7	1	Explore, Improve	Possibly consider together with Rweru/ Moero and Cohoha.
Josini/Pongola poort Dam	31	7	19	2	Defer	Current status of bilateral position is not clear.
Kariba	25	18	21	15	Explore, Improve	Need to confirm how lake is assessed within Zambezi River transboundary system.
Kivu	7	9	3	13	Defer	Political and social instability will have to be overcome before consideration.
Lake Congo River	9	23	9	23	Defer	Need to confirm how lake is assessed within Congo River transboundary system.
Malawi/Nyasa	4	10	8	10	Review	Review current GEF status, and relationship with Chiuta and Chilwa.
Mweru	13	22	13	22	Explore, Improve	Possibly consider together with Rweru/ Moero and Cohoha.
Nasser/Aswan	16	14	20	11	Review, Defer	Need to confirm how lake is assessed in Nile River transboundary system.
Natron/Magadi	15	8	16	5	Explore, Survey	Explore transboundary/non-transboundary framework.
Rweru/Moero	8	3	2	12	Explore, Improve	Consideration may be given to possible joint implementation with Ihema and Cohoha as an option.
Selingue	3	13	4	20	Defer	Need to undertake more preliminary scientific situation assessment.
Tanganyika	10	21	18	21	Review	Review current GEF status.
Victoria	23	5	10	3	Review	Review current GEF status.
ASIA						
Aral Sea	20	6	6	7	Review	Review current GEF status.
Aras Su Qovsaginin Su Anbari	35	1	3	1	Defer	Need assessment of current scientific and political situation.
Caspian Sea	38	7	8	3	Review	Review current GEF status.
Darbandikhan	33	2	4	2	Defer	Need assessment of current scientific and political situation.
Mangla	36	3	1	4	Defer	Current status of bilateral position is not clear.
Sarygamysh	21	8	7	8	Explore	Possibly consider together with Aral Sea follow-up, if that is realized.
Shardara/Kara-kul	29	5	5	5	Explore	Possibly consider together with Aral Sea follow-up, if that is realized.
Sistan	14	4	2	6	Review	Review current GEF status.
SOUTH AMERICA						

Azuei	19	1	1	3	Recommend-able	Explore possibility and viability.
Titicaca	26	5	3	6	Review	Review current GEF status.
Chungarkkota	28	2	2	2	Defer	Review current status in relation to Titicaca.
Itaipu	32	3	4	1	Defer	Need assessment of current scientific situation.
Lago de Yacyreta	34	4	5	4	Defer	Need assessment of current scientific situation.
Salto Grande	37	6	6	5	Defer	Need assessment of current scientific situation.

5. DISCUSSION

5.1 Major TWAP Transboundary Lake Observations

5.1.1 Transboundary Lake Assessment and Management Linkages

Although it is obvious that lakes and other lentic water systems contain large volumes of freshwater, it is less obvious that they typically do not respond rapidly to environmental stresses or to remedial actions, that they have long 'memories' of such stresses, and that their ultimate responses to stresses are often unpredictable and uncontrollable (e.g., see Figure 2.2). Equally important is that the lake rankings are less meaningful if the factor(s) considered most important from the perspective of the user of the rankings are not also identified. To this end, much explanation regarding the transboundary lakes rankings, and the factors affecting these rankings, was presented in the preceding Results chapter, with both scientific and management implications. With a few exceptions, lakes unfortunately remain a relatively neglected element in international water arena discussions.

Although previously discussed in the Results chapter, several important conclusions merit reiteration:

- Based on the computed Incident HWS and BD threats (see Table 4.2), many European and North American lakes rank as being most threatened;
- Using the Adj-HWS threat in the analyses, however, which considers the ability of countries to undertake the investments necessary to address identified water problems, produces markedly different ranking results, with developing country lakes collectively exhibiting the greatest threats, particularly in Africa, as well as some in Asia and South America (see Table 4.3);
- The lake threat ranks change significantly when different ranking criteria are given greater or lesser importance or weight in the analyses. Cuciurgan Reservoir and Lake Rotunda in Europe, for example, exhibit the top two ranks on the basis of their Incident HWS threats, while Lake Sistan in Asia and Lake Ihema in Africa exhibit the top ranks when their Adj-HWS is considered. If basin population is an important factor, Lake Nasser in Africa (which includes the upstream Lake Victoria, Edward and Albert basins) and the Caspian Sea exhibit the highest threats. The regional lake questionnaire also identified local perceptions of transboundary lake problems as important ranking criteria. Thus, the user of the ranking results must determine the most appropriate context in order to gain the most meaningful interpretation of the relative lake threats (see Tables 4.6-4.16);
- The responses of transboundary river basins to environmental stresses will typically be slower, and often less pronounced, with an increasing number of lakes and other lentic waterbodies in their basins;
- The scarcity of uniform lake data on a global scale was a major challenge in the lakes ranking exercise. The international water community must undertake knowledge base development

focusing on lakes and other lentic water systems, including their links with upstream and downstream water bodies (see Figure 2.1);

- The assessment process encompassed within the Scenario Analysis Program, which allows user selection of specific ranking parameters and development of appropriate context for using the results, is an important tool derived for the TWAP lakes effort that is as significant as the ranking results themselves;
- Non-transboundary lakes and extra-boundary factors can be very important internal drivers exerting major influences on transboundary lake and/or river basin threat rankings. Thousands of migratory birds, for example, typically congregate in transboundary and non-transboundary lakes during their annual migrations (Ramsar Convention Secretariat, 2011), meaning that non-transboundary lakes can assume transboundary significance during certain times of the year;
- To be most realistic and useful, future transboundary assessments of this type must better consider the hydrologic and jurisdictional links between transboundary water systems, suggesting that future transboundary working groups collectively should include representatives and inputs from each water system involved.

Although beyond the scope of this assessment, the magnitude of the anticipated improvement in a degraded transboundary lake also merits attention in management interventions. In other words, how can one decide that a given management intervention would produce the greatest benefit(s) for the greatest number of people? One could treat the threatened lakes in a serial fashion, going from the most 'threatened' lake first, then the next more threatened, etc. The demonstrated potential for producing differing ranking results when different contexts are considered, however, suggests that this approach would be relatively ineffective. Rather, a case-by-case assessment approach that considers the anticipated improvements for specific management interventions, as well as the water systems to which a transboundary lake is linked, are also important considerations. The upstream-downstream links between Itaipu and Lago de Yacycreta reservoirs in South America, and between Lakes Kariba and Cahora Bassa in Africa, provide useful examples. The 'cluster' links between lakes in relatively close proximity are also relevant considerations, examples being transboundary Lake Aby and non-transboundary Volta Lake in Western Africa, Lake Abbe/Abhe and other highland lakes in Ethiopia and Djibouti in East Africa, and Lakes Sarygamysh and Shadara/Kara-kul in Asia. Pernetta and Bewers (2012) reached similar conclusions, reporting that lakes located entirely within a single country can nevertheless cause transboundary problems if they lie within a transboundary basin.

5.1.2 Transboundary Lake Threats and Climate Change Implications

Anther relevant TWAP observation is that lakes are increasingly being linked to water-related uncertainties associated with projected climate change impacts, including possible modifications to the global hydrologic cycle. This issue merits consideration within the context of the TWAP goals particularly in regard to lake basin adaptation and restoration strategies. To this end, the

IPCC 5th Assessment scenario RCP8.5 (i.e., maximum temperature increase under a high emissions 'business-as-usual' scenario), a contribution to the IPCC Fifth Assessment Report, was assessed using the IPSL-CM5A-LR model for 2070 predictions. As a worst-case basis for calculating predicted changes in monthly mean air temperatures and mean annual precipitation, predictions were made for the TWAP transboundary lake basins for the period from 2010 to 2070. This analysis indicated the mean monthly air temperature for all 206 transboundary lake basins is predicted to generally increase in all five lake study regions by about 4 to 6 ^{o}C, and possibly up to 8 ^{o}C in the high latitude regions by 2070, compared to the mean conditions during 1950-2000. (Figure 5.1). The mean annual precipitation is predicted to increase for the transboundary lake basins located in Europe, Africa and North America, to remain about the same for those in Asia, and to decrease for those in South America (Figure 5.2).

Focusing on the African transboundary lake basins, however, clearly illustrates that significant differences in these parameters can be observed on a sub-continental scale. It was predicted, for example, that the transboundary lake basins located in the northern, middle and eastern African sub-regions would receive more precipitation in 2070 than in 2010. In contrast, those in western and southern Africa would receive less precipitation (Table 5.1; Figure 5.3). All the African transboundary lake basins assessed would experience a higher mean atmospheric temperatures in 2070 than in 2010, with those in the western and eastern African sub-regions experiencing notably higher mean temperatures than those in the remaining sub-regions. Such strong sub-regional tendencies make it very problematic to use combined sub-continental ranking scores to make unilateral and unequivocal comparisons regarding the prioritization of transboundary lake threats, readily leading to erroneous conclusions regarding the Adj-HWS, Incident BD and RvBD threat ranks. It was not possible to provide a similar analysis of the South American transboundary lake basins since there were no official sub-regions in any of the UN Region 1, 2 or 3 categorization systems, although it is likely the same general conclusions would be reached.

Projected climate change risks also extend to transboundary lake resources, including the vulnerability of fisheries to climate-related impacts (e.g. see Magadza, 2011). Observations regarding Africa, for example, include more frequent dry periods and declining fish yields for Lake Chilwa (Malawi/Mozambique). Fish yields in Lake Tanganyika have decreased partly because of declining wind speeds and rising water temperatures, constraining the mixing of nutrient-rich deeper waters with surface waters that support fish production. Lake Chad is experiencing continuing water-level declines, with associated decreased fish production potential. Although not without controversy, such observations suggest that potential threats associated with climate-driven uncertainties also are factors to be considered appropriately in ranking the threats to transboundary lakes.

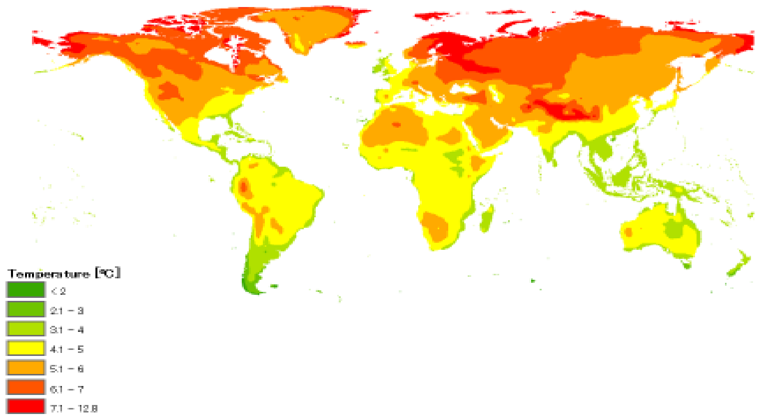


Figure 5.1 Predicted Changes in Mean Monthly Air Temperatures under IPCC scenario CP8.5 (maximum temperature increase under 'business-as-usual' scenario)

Table 5.1 Predicted Changes in Mean Monthly Air Temperature (MMAT) and Mean Annual Precipitation (MAP) for 34 African Transboundary Lake Basins, 2010 to 2070

Northern Africa (n=5)		Western Africa (n=4)		Middle Africa (n=5)		Eastern Africa (n=16)		Southern Africa (n=4)	
MMAT (ºC)	MAP (mm yr^{-1})	MMAT (ºC)	MAP (mm yr^{-1})	MMAT (ºC)	MAP (mm yr^{-1})	MMAT (ºC)	MAP (mm yr^{-1})	MMAT (ºC)	MAP (mm yr^{-1})
3.28	100.29	4.59	-34.84	2.77	174.77	4.69	495.39	3.27	-79.01

5-2. Transboundary Lakes and International Activities and Agreements

The encompassing water strategy of the Global Environment Facility (GEF) is to assist countries to develop and implement comprehensive, ecosystem-based approaches for managing international waters, with the goal of maximizing global environmental benefits for the maximum number of stakeholders (Duda, 2002). It uses a two-step process of analysis and action to achieve this goal, comprising a Transboundary Diagnostic Analysis (TDA) and Strategic Action Program (SAP). The TDA focuses on joint fact-finding activities between the cooperating countries, representing the knowledge base for a subsequently-agreed SAP to address the priority concerns and their root causes. As the collective-action phase of the effort, basin-scale activities can include policy, legal and/or institutional reforms at both the national and multi-country level. As discussed further in the next section, this transboundary lake assessment will also assist the GEF

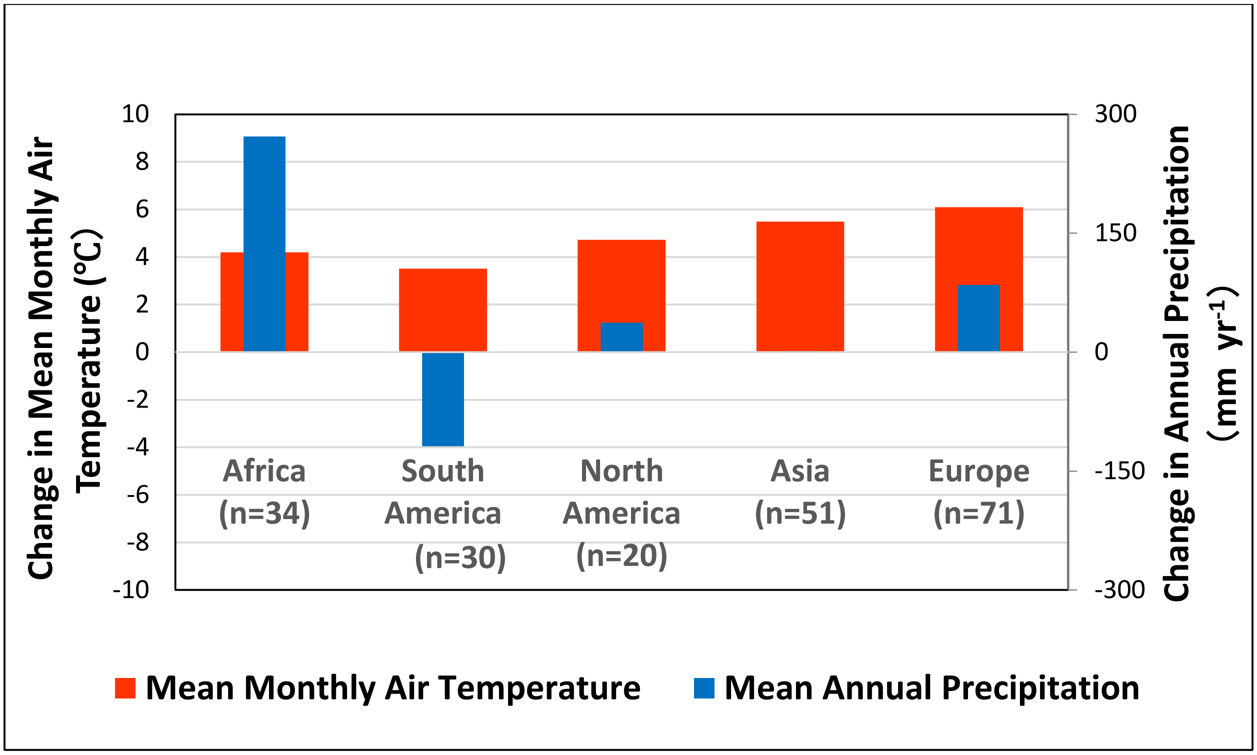


Figure 5.2 Changes in Mean Monthly Air Temperature and Mean Annual Precipitation for 206 Transboundary Lakes, 2010 to 2070

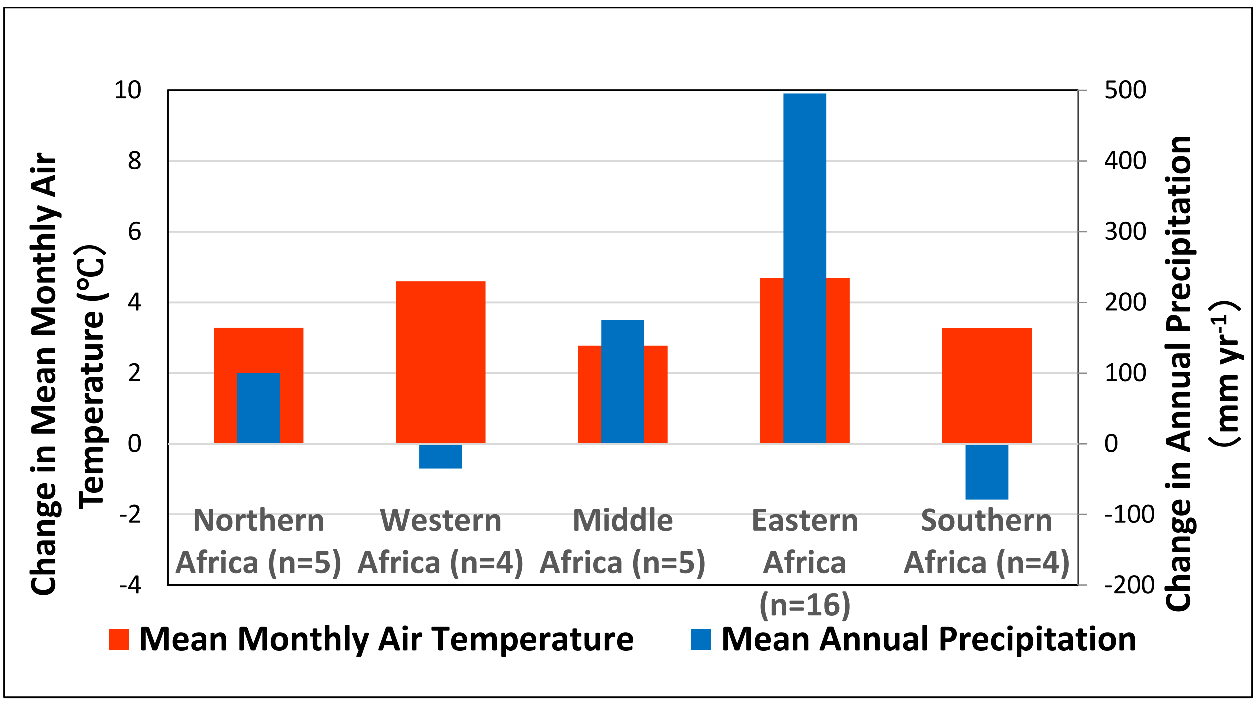


Figure 5.3 Changes in Mean Monthly Air Temperature and Mean Annual Precipitation for African Trransboundary Lakes, 2010 to 2070

in determining whether or not its catalysed lake management interventions are justifiable in terms of addressing the identified threats, and for evaluating anticipated improvements from such interventions (also see Table 4.16).

Some existing international water agreements could benefit from the transboundary lake knowledge gained through TWAP, although they mainly address highly-visible lakes (e.g., Lakes Chad and Victoria (Africa); Lake Constance (Europe); Lake Titicaca (South America)). Several international freshwater-based conventions also could benefit from the transboundary lakes assessment results, notably the UN Convention on the Law of the Non-navigational Uses of International Watercourses, and the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes. The UN watercourses convention is general in scope, while many UNECE provisions are detailed or prescriptive in nature. The UN watercourse convention does not explicitly recognize the unique characteristics or assessment needs of transboundary lakes or other lentic water systems. Further, although the UNECE convention notes that protecting international lakes requires enhanced cooperation, it lacks practical advice directed to assessment and management needs unique to lakes and other lentic water systems.

Another noteworthy transboundary lakes agreement is the Great Lakes Water Quality Agreement between the USA and Canada, with the stated goal *"to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes."* Initially focusing on water quality, it was subsequently amended to include the nearshore environment, aquatic invasive species, habitat degradation, and climate change threats. Although possibly the most successful example of bi-national cooperation focusing on transboundary lakes, the financial, manpower, and associated technical expertise necessary to sustain it over the long term is usually beyond the reach of many countries, particularly developing nations.

Other UN and international organizations deal with open oceans, large marine ecosystems, regional seas, and international rivers, aquifers, and wetlands. There is no corresponding international support structure directed to developing a global-scale forum for transboundary lakes, or even to undertake such global-scale lake assessments. Rather, their sustainability is usually encompassed within the context of other, often broader, policy or institutional frameworks, which typically do not adequately address, or even recognize, their unique assessment and management needs.

Another international initiative relevant to the TWAP baseline information and data analyses is the pursuit of the Sustainable Development Goals (SDGs), to be launched in 2015 when the Millennium Development Goals (MDGs) expire. The subsequently-adopted 2030 Agenda for Sustainable Development contains specific goals germane to sustainable water resources for human health and ecosystem integrity (Open Working Group, 2015). Specifically, SDG Goal 6 is to *"Ensure availability and sustainable management of water and sanitation for all."* Under this goal, Target 6.6 focuses on the need to protect and restore water-related ecosystems by 2020, including mountains, forests, wetlands, rivers, aquifers and lakes, expanding the original MDG water goal to encompass the entire global water cycle. A particular significance of this target is identification of 'lakes' as a specific component in an agreed sustainability agenda to be pursued on a global scale. SDG Goals 13 *("Take urgent action to combat climate change and its impacts"*), 14 *("Conserve and sustainably use the oceans, seas and marine resources for sustainable development"),* and 15 (*"Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss")* also are relevant to the global freshwater agenda. In fact, as noted by UN-Water (2015), water is at the core of sustainable development, with strong links to all the SDGs. Thus, achieving SDG Goal 6 would also substantially improve our ability to achieve most other 2030 Agenda targets.

5-3. TWAP and Integrated Management Approaches for Addressing Transboundary Lake Issues

Integrated Water Resources Management (IWRM) has become the *modus operandi* of the GEF, United Nations and other organizations and agencies for addressing sustainable freshwater resource issues. The Global Water Partnership (2000) defined IWRM *as "a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."* IWRM focuses on economic efficiency in water use, equity, and environmental and ecological sustainability, and many countries have subsequently used this definition as the basis for developing an integrated approach for addressing transboundary and national-level water issues (Jønch-Clausen, 2004). In addressing the global water resources crisis, IWRM has facilitated policy reforms regarding water resources, particularly in developing countries. As a complementary effort focusing on river basin degradation, the process of Integrated River Basin Management (IRBM) has also facilitated policy and programme development in river basin management.

Experience within the lake scientific and management community, however, suggests 'operationalization' of both the IWRM and IRBM principles has not been easy for addressing on-the-ground basin management challenges facing lakes and other lentic water systems. These experiences suggest that lake basin management stakeholders are typically not in a position to play an influential role regarding most IWRM integration needs. Further, many IWRM-based activities tend to rely on a top-down, project-oriented approach, due mainly to its orientation to water-infrastructure investments not amenable to addressing lentic water systems and their issues, which would require much longer-term incremental and gradual basin governance improvement for sustainable resource use and conservation. Also, it does not appear to directly address the unique characteristics of lakes, nor the importance of lentic-lotic linkages characterizing a lake and its basin.

To address this deficiency with regard to the over-exploitation, degradation and non-sustainable use of lakes, the International Lake Environment Committee (ILEC) developed an integrated approach to address governance deficiencies involving lakes, their basins and their resources. This approach, Integrated Lake Basin Management (ILBM), is defined as *"an approach for* *achieving sustainable management of lakes and reservoirs through gradual, continuous and holistic improvement of basin governance, including sustained efforts for integration of institutional responsibilities, policy directions, stakeholder participation, scientific and traditional knowledge, technical possibilities, and funding prospects and constraints"* (Nakamura and Rast, 2014). In considering lake basins as linked lentic-lotic water systems, it moves beyond expressing the physical state of freshwater in a hydrodynamic-hydrostatic context, to considering lentic-lotic waters as an expression of the ecological and anthropogenic state of freshwater, with evolutional and historic memories of human-nature interactions. Because IWRM does not fundamentally consider the global threats facing lakes and other lentic water systems, infusing it with an integrated lake management framework such as Integrated Lake Basin Management (ILBM), is needed to achieve sustainable use of their ecosystem goods and services.

To this end, ILEC has developed a conceptual framework for ILBM and associated implementation processes, in the form of ILBM 'Platforms'. These represent a virtual stage for collective stakeholder actions to improve lake basin governance. ILBM complements the existing IWRM approach, with its platform 'elements' graphically illustrated within the ILBM governance 'pagoda' concept presented in Figure 5.4. The pagoda highlights the major governance elements of concern, based on ILEC's experiences in many countries to address the sustainable use of the ecosystem goods and services provided by lakes and other lentic water systems.

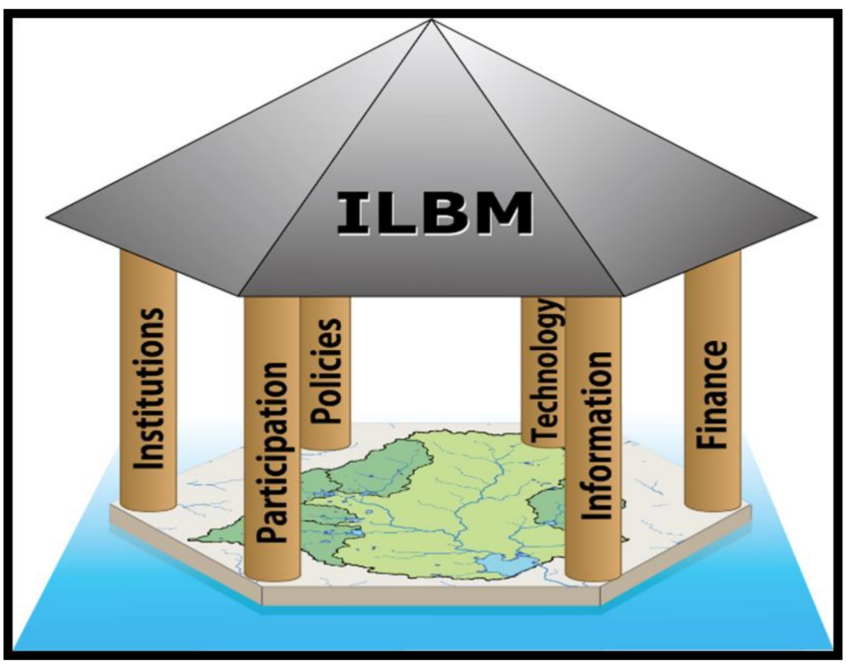


Figure 5.4 Overview of ILBM Governance Framework (Nakamura and Rast, 2014)

Although a detailed description of the ILBM Platform process is beyond the scope of this report, its primary activities, undertaken collectively in a stepwise manner by basin stakeholders (Nakamura and Rast, 2014), include:

(1) Describing the state of lake basin management;
(2) Identifying and analysing the issues, needs and challenges regarding the six governance pillars (Figure 5.4);
(3) Integrating the ways and means of meeting the governance challenges, and implementing agreed actions to address them.

The data and information gained in the TWAP assessments can be used in all these steps to provide insights into the status of a transboundary lake system, and to develop effective management interventions to address identified problems. To this end, the ILBM Platform process also demonstrates that planning and governance must be properly geared together for sustainable management of transboundary lakes (Figure 5.5).

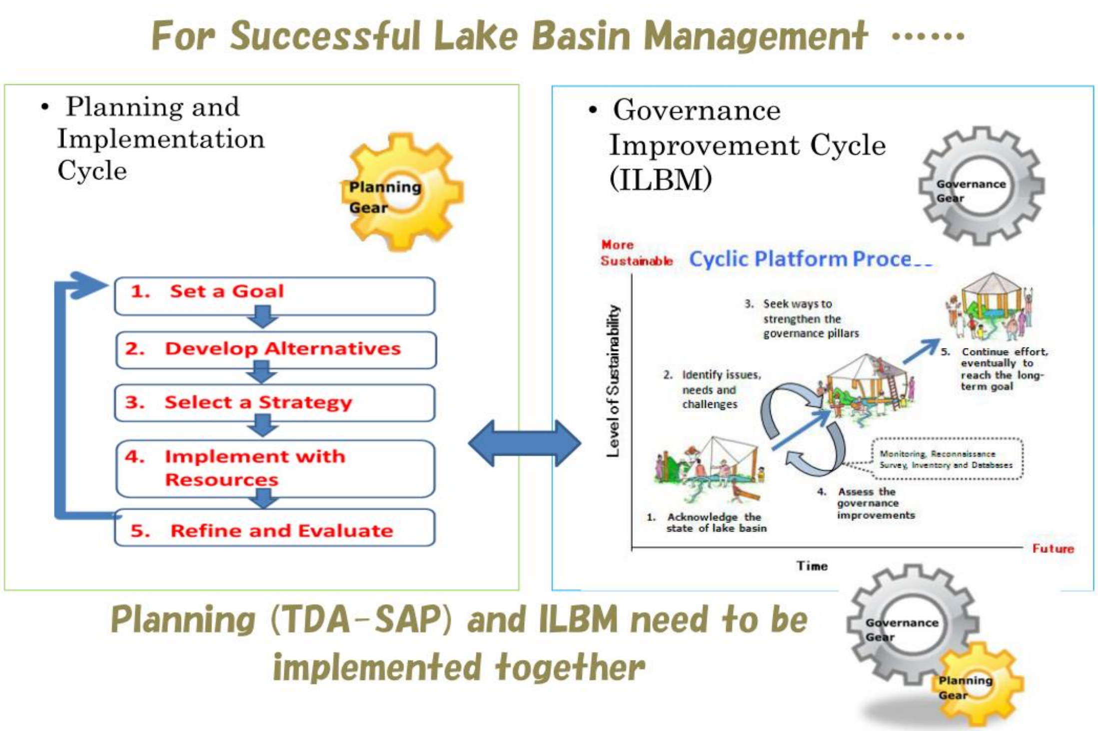


Figure 5.5 Implementing Planning and ILBM Together for Successful Transboundary Lake Basin Management (Nakamura and Rast, 2014)

An accompanying 'Lake Brief' framework was developed to provide guidance regarding the type of data and information needed to accurately characterize a lake basin and its linked water systems, and to develop management interventions and governance actions to facilitate their sustainable use (Nakamura *et al.* 2010). This framework encompasses the quantitative scientific and technical information needed to define the quality, quantity and location of water resources within a basin, as well as the qualitative socioeconomic, institutional, political, policy, stakeholder participation, and financial considerations that fundamentally define how humans use water resources. The Lake Brief framework also provides examples of the types of questions requiring resolution to effectively address lake basin assessment and governance issues. For example, there are multiple political and governance issues involving use of the resources of Lakes Abbe/Abhe, Turkana, Cohoha, Kivu and Nasser in Africa (see Table 4.6) that would benefit from addressing the governance questions outlined in the Lake Brief. The data and insights gained from the region-specific lake basin Questionnaires used in the TWAP transboundary lake analyses also can contribute to addressing lake governance issues.

For comparison purposes, previous GEF international waters projects focusing on transboundary lakes and rivers were reviewed (Table 5.2). While some water-focused stresses are attributable to larger issues such as global climate change, more immediate impacts related to chronic pollutant discharges, over-use of resources, and species modifications, are a constant refrain in virtually all TDAs. Accordingly, most lake-focused SAPs contain a similar set of remedies, focusing on governance issues, introduction and enforcement of appropriate laws and regulations, and sustained financing to support human interventions, capacity building and organizational strengthening of both governmental and non-governmental organizations.

As previously noted, Pernetta and Bewers (2012) summarized past GEF experiences in addressing marine-based international waters projects, reporting that a key need of the TDA/SAP process was flexibility to deal with constraints to addressing the root causes of marine resource degradation or over-exploitation. They also highlighted inconsistencies between TDA projects, directly attributable to inadequate guidelines for conducting TDAs, and inadequate specification of the detail needed for rectifying transboundary environmental problems. Further, they pointed out that lakes represent freshwater analogues of marine systems, thereby also being subject to water issues affecting river basins. Because non-transboundary lakes located within a single country can cause transboundary problems if located within a transboundary river basin, thereby fundamentally affecting an accurate assessment of the 'nature, impacts, causes and possible solutions' to transboundary problems, they also noted that the hydrologic links between different water systems are an important factor in developing an effective TDA/SAP. The TWAP transboundary lake analysis came to similar conclusions regarding these last two items (see Chapter 2).

Accordingly, a more standardized analysis and response process to facilitate the flexibility of the TDA/SAP process, as suggested by Pernetta and Bewers (2012), is embodied within the ILBM Platform Process, enhancing the utility of TDA/SAP-developed activities in managing national water issues of concern that may fall outside the purview of GEF-supported interventions. Some transboundary water concerns, for example, can share common causal factors with national and/or local concerns, a situation not typically directly addressed with a TDA/SAP procedure lacking a unifying approach, even if the former fundamentally contributed to transboundary problems. The philosophy of incorporating local actions to assist in addressing global concerns, including those involving transboundary and non-transboundary lakes and the other nested lentic and lotic water systems in the basin (see Figure 2.1), can be supported within the ILBM Platform process. Nakamura and Rast (2014) provide further detailed discussion of the utility, experiences and lessons-learned in applying the ILBM Platform process over the past several years to lakes in a number of countries, as does the ILEC website (www.ilec.or.jp).

Table 5.2 Previous GEF Lake and River Basin Transboundary Diagnostic Analyses (TDA) and Strategic Action Programme (SAP) Activities

Inland Lake Basin	TDA	SAP	International River Basin	TDA	SAP
Europe					
Lake Baikal	X		Danube River Basin	X	X
Lake Peipsi	X		Dnipro River Basin		X
Lake Prespa	X	X	Kura-Aras River Basin	X	
Lake Shkoder	X		Tumen River Basin		X
Caspian Sea	X	X			
Africa					
Lake Chad	X	X	Okavango River Basin	X	
Lake Tanganyika	X	X	Orange-Senqu River Basin	X	
Lake Victoria	X	X	Niger River Basin		X
			Senegal River Basin		X
			Volta River Basin	X	
South America					
			Amazon River Basin		X
			Bermejo River Basin	X	X
			Plata River Basin		X
			San Francisco River Basin		X

Thus, although many transboundary lake issues and root causes can be identified in the TDA/SAP process, the systematic approach provided by the ILBM Platform process readily facilitates development of effective strategies for managing lakes, their resources and their basins. The approach exceeds that used in many TDAs, the latter emphasizing more specific, previously-defined concerns agreed by the basin countries. The comprehensive assessment used in the ILBM Platform process provides a firm foundation for both bi- and multi-lateral actions regarding transboundary waters, and complementary national and local management measures. The

TDA/SAP process is envisioned as an ongoing process, with the TDA and SAP periodically being updated to reflect changing conditions and emerging transboundary issues. Incorporating the ILBM Platform process during such TDA/SAP update efforts would provide a better focus for a given SAP, introducing more specific management measures targeted at the key issues facing specific transboundary waterbodies. Consistent with this goal, Table 4.16 provides analytical insights into the feasibility of possible management interventions for the TWAP transboundary lakes.

The GEF has developed a three-volume manual to guide TDA/SAP exercises. An observation in the manual was that the International Lake Environment Committee (ILEC) has produced a number of substantive reports highlighting lake-based management lessons learned, including governance challenges, in a range of GEF-funded international water projects (ILEC 2005). The manual also acknowledges the reality that lake basin management requires considerably more attention, having previously been poorly studied, except for some highly-visible transboundary lakes on the global scale (Global Environment Facility 2013), another conclusion also derived from the TWAP transboundary lakes analyses.

5-4. Sustaining Future Transboundary Lake Assessments

Developing a mechanism for sustaining future transboundary water assessments was another TWAP goal, the intention being the experiences gained in this assessment would inform future such efforts. The TWAP baseline information and data are obviously useful for identifying and evaluating the environmental and socioeconomic aspects of transboundary water systems, and as a basis for evaluating their responses to management interventions.

The earlier observations regarding the need for appropriate context for considering the transboundary lake threat ranking results, for incorporating multi-dimensional transboundary aspects in evaluating lake threats, for considering lentic-lotic links between transboundary water systems, and for evaluating anticipated improvements in lake basin conditions in response to management interventions, remain germane for future lake assessments. Properly addressing transboundary lake assessment and management issues, however, requires that lakes and other lentic water systems be mainstreamed in global water discussions such as the World Water Forum and other international water conventions and agreements. The important scientific and management implications of their unique characteristics will continue to be largely ignored if not explicitly recognized in future transboundary waters assessments.

Some UN agencies have varying capacity to incorporate future transboundary assessments into their present or future work programmes. No similar situation, however, exists for addressing transboundary lakes. The International Lake Environment Committee (ILEC), for example, the lead agency for the transboundary lake assessment, is not a UN organization or a federal government agency. Although it facilitates the development of rational management approaches for lakes and their catchment basins, it does not operate within the context of a member-agreed mandate or work programme of the type exhibited by UN and other international organizations. Thus, it does not enjoy the continued financial or institutional support needed to effectively conduct future transboundary lake assessments as a core activity.

Many insights reported in this transboundary lakes assessment were gained from cooperative lake basin management programmes undertaken by ILEC in a number of developing countries over recent years. To this end, the cooperating ministries and international and academic organizations will continue to assist ILEC as feasible in future assessment activities. ILEC also engages in projects likely to produce results that can inform future assessments (e.g., water and sanitation issues in Africa; cluster lake studies in Africa and Asia). ILEC also will continue to refine and implement its ILBM Platform process in other collaborating countries around the world, providing data and information from such activities for future transboundary lake assessments. It also will continue to use the expertise and experience of its region-specific Scientific Committee members to the maximum extent in any future transboundary lake assessment and management activities.

Nevertheless, the availability of sufficient financial and institutional support will remain a core requirement for sustaining future transboundary lakes assessments. This reality is also likely to apply to the other water media groups involved in the TWAP assessment (rivers, aquifers, LMEs, open oceans). Some agencies involved in the various TWAP working groups can possibly incorporate some specific assessment activities into their future work programmes. As noted above, however, this situation is generally less tenable for transboundary lakes, since relevant assessment activities cannot rely on agency- or government-driven budgets, but are usually the product of projects directed at regional- or national-scale lake basin management activities, focusing on provision of water resources. ILEC will continue its country-based lake management activities throughout the world in cooperation with its partners and individual experts, with the results and experiences of such projects readily available to all interested parties. The expenses associated with conducting future transboundary lake assessments, however, will likely require external funding, both for ILEC and for its assessment partners and collaborators.

6. CONCLUSIONS

This transboundary lakes assessment has demonstrated that lakes and other lentic water systems exhibit unique buffer properties that complicate their accurate assessment and classification. Except for assessment of their pollution status by comparison of in-lake water quality to accepted water quality standards, there are no unequivocally-accepted boundaries between acceptable and unacceptable conditions regarding many other stressors affecting transboundary lakes. Further, even the data necessary to make accurate water quality assessments are lacking for most TWAP transboundary lakes, or are sufficiently sporadic to seriously confound any accurate conclusions about lake status. The non-linear response of lakes and other lentic systems, exemplified by the eutrophication hysteresis curve in Figure 2.2, highlights this difficulty. Thus, there is no 'one-fits-all' assessment approach for identifying the range or severity of challenges facing transboundary lakes and other lentic water systems. Thus, an accurate, meaningful risk classification requires consideration of a range of interacting scientific, socioeconomic and governance issues, the relationships between which can be very subtle, and often incremental in impact.

Regardless of the filtering or weighting criteria used in the transboundary lakes assessment, the African transboundary lakes merit the greatest attention from the perspective of relative threats, and the need for management interventions to address them. This is followed by Asia and South America. The nature and magnitude of the threats varies considerably between these lake groups, however, based on regional/sub-regional environmental and socioeconomic conditions, stakeholder perceptions, and existing monitoring data and information.

Millions of lakes and reservoirs exist on virtually every continent. Most have not been studied or sampled in a consistent manner, or else solely for the provision of water resources, a deficiency also affecting the majority of the transboundary lakes. Thus, there is an urgent need for the international water community to undertake knowledge base development focusing on transboundary lakes, and their links with other lentic and lotic water systems.

The transboundary lakes assessment has highlighted that determining the true significance or meaning of a 'threat' to a transboundary lake is not simply a matter of examining a computed threat score or rank. Rather, the lake threat rank is also a function of issues important to the user of the ranking results. Thus, maximizing the meaning of the computed threats to transboundary lakes requires the user of the ranking results to determine an appropriate context(s) for interpreting them.

The notion of 'transboundary' also can be major consideration in evaluating relative threats to transboundary lakes, noting that non-transboundary lakes within a transboundary river basin can have transboundary impacts and implications. In assessing relative threats to transboundary lakes, therefore, it is important to consider that non-transboundary lakes and other factors originating outside a transboundary drainage basin, such as being located along migratory bird flyways or the long-term effects of climate change, can be important drivers exerting major influences on a transboundary lake and/or river basin.

The data, information and insights derived from this global-scale assessment are important factors for determining the status of transboundary water systems. Nevertheless, global-scale assessments remain a major undertaking for all those involved. Other groups within the TWAP assessment have provided suggestions for facilitating this goal, with a major thrust to incorporating future assessments within the context of future programs of UN and other international agencies. However, differing mandates of many UN and other international organizations are often narrow in scope or inflexible regarding revisions to planned activities. This also was a conclusion of the 'Assessment of Assessments' undertaken in response to a 2005 UN General Assembly request focusing on the state of the marine environment (UNEP and IOC-UNESCO, 2009). Thus, another important conclusion is that the availability of sufficient and sustainable financial and institutional support and interactive collaboration will remain a core requirement for undertaking future transboundary waters assessments.

Recognizing the importance of considering the links between the lentic and lotic water systems typically comprising transboundary drainage basins, and the properties particular to each of the five water media considered within the TWAP effort, a final conclusion arising from the transboundary lakes assessment is that future assessments should include representatives of all working groups working collectively as a single unit to identify and examine the scientific and management implications of linked water systems.

In presenting these conclusions, it is reiterated the Integrated Lake Basin Management (ILBM) Platform Process developed by ILEC provides a powerful integrating framework for analysing the multitude of factors comprising the TWAP assessment process, as well as their scientific and management implications. Used in combination with the Scenario Analysis Program developed to assess the transboundary lake threat rankings, ILBM is a very useful and versatile complement to the IWRM approach currently being used in many countries to address their water resources issues (see Figures 5.1 and 5.2). A particularly attractive feature of the ILBM Platform Process is that it facilitates the ability of its users to critically evaluate the strength of the governance elements necessary to achieve sustainable use of lakes and other lentic water systems, which provide the widest range of life-supporting ecosystem goods and services to humanity. It also provides guidance regarding the governance elements requiring attention in order to achieve these goals. Further, as an extension of the ILBM framework, the process of Integrated Lentic-Lotic Basin Management (ILLBM) also provides a virtual framework for assessing and strengthening river-lake-coastal basin governance, focusing on gradual, continuous and holistic improvement of basin governance.

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8. TECHNICAL APPENDICES

Appendix 1. Characteristics of Transboundary Study Lakes
Appendix 2. MetaData Sets for Delineation of Transboundary Lake Basins
Appendix 3. GIS-based Procedure for Delineating Transboundary Lake Basins
Appendix 4. Sample Transboundary Lake Questionnaire for East Africa
Appendix 5. Transboundary Lake Ranks, Expressed as Adjusted Human Water Security (Adj-HWS) Threats on Basis of Selected Criteria
Appendix 6. Transboundary Lake Threats Based on Altered Adj-HWS, BD and HDI Rank Weights