Transboundary Water Assessment Programme (TWAP)

Methodology for the Assessment of Transboundary Lake Basins

25 March 2011
TWAP Lake Basin Group

Summary for Decision Makers

Overview

Lakes are important. Lakes contain 90 per cent of the liquid freshwater on the earth's surface and almost all of the inland saline water. They are invaluable for the range of provisioning, regulating, cultural and supporting ecosystem services that they provide.

Lakes must be managed at the basin level. However, as lentic systems that collect and store water from their surroundings, they are often under stress from human activities within their basins and beyond.

Lakes have a unique set of characteristics. Specific characteristics of lakes requiring consideration for both assessment and management purposes are their integrating nature, long water-retention time and complex dynamics. All three characteristics add an additional dimension of difficulty to achieving assessment prioritization objectives.

Integrated Lake Basin Management (ILBM) is essential. Lake basin management is difficult. Recent years have seen the rise of the Integrated Lake Basin Management (ILBM) paradigm as a keystone approach for local, national and even international efforts. The ILBM approach is rooted in six pillars of governance: institutions, policy, participation, technology, information, and finance.

GEF has an important role. Transboundary lake basins have an extra layer of difficulty which can be ameliorated by international interventions such as those by the Global Environment Facility (GEF). One such intervention is the GEF's Transboundary Waters Assessment Programme (TWAP). This report presents the output of the Lake Basin Working Group of the TWAP. It describes a methodology for assessing high-risk transboundary lake basins that might best benefit from GEF support. It also considers the possibility of developing regional ILBM platforms for TWAP and non-TWAP lake basins.

Key Aspects of this Report

What is a transboundary lake basin? We define a transboundary lake basin as one that spans more than one country. This is a necessary update of the previously held view of international lakes as ones that have their water surface intersected by an international border.

How many are there? This new definition makes an inventory much more difficult to develop because high-resolution basin delineations are generally not available. Currently, it is not known how many transboundary lake basins there are. The inventory of transboundary lake basins will be a key contribution of the TWAP Full-Sized Project (FSP). However, for this phase we have identified 12 847 transboundary lake basins in Africa alone.

Indicators are based on the ILBM framework. This methodology proposes a suite of indicators based on the well-tested ILBM framework. The indicators are: (1) easy to understand, (2) meaningful and relevant for identifying high-risk lake basins, (3) available at the global scale, and (4) contributed to and accepted by stakeholders. A full list can be found in Part III.

Need for an iterative approach. The sheer number of transboundary lake basins as well as the desire to populate all indicators for all basins requires that the TWAP FSP for lake basins takes an iterative approach. We propose four distinct levels for assessment:

> **Level 1.1**. Identify the transboundary lake basins and compile the basin indicators (over ~10 000 basins)
> **Level 1.2**. Compile more detailed indicators and refine the basin delineations for a reduced set of lake basins (output of Level 1 decisions, approximately 500~1 000 basins)
> **Level 1.3**. Compile most detailed indicators and auxiliary information through a stakeholder-driven questionnaire and meeting process (approximately 50~100 basins).
> **Level 2**. Validate and compare the lake basin methodology with others in 4~5 well-documented water systems that include major rivers, aquifers and large marine ecosystems.

Systems are linked. The TWAP project has five working groups: rivers, lakes, groundwater, large marine ecosystems (LMEs), and open ocean. Each waterbody type is linked to the others through the hydrological cycle;

however, the links between some types are stronger than between others. For lakes, the key link is with rivers; links with groundwater and LMEs may be important in some cases. The challenge for each working group, and TWAP as a whole, is to ensure that these links are properly addressed. The Level 2 analysis will ensure this is formally included.

General Introduction

The International Lake Environment Committee (ILEC) Foundation was contracted by the United Nations Environment Programme (UNEP, the Implementing Agency (IA) for the Global Environment Facility-International Waters (GEF-IW) focal area), to execute a medium-sized project to develop the lakes and reservoirs (hereinafter collectively referred to as 'lakes') component of the Transboundary Waters Assessment Programme (TWAP).

This report presents a draft methodology for the assessment of transboundary lake basins and forms the basis for a follow up full-sized project. Lakes, along with rivers, groundwater, large marine ecosystems, and open ocean make up the five TWAP waterbody types. While links to other waterbody types is a recurring theme in this report and in TWAP itself, we look explicitly at lakes here, and more correctly, at lakes and their drainage basins.

This report is divided into six sections:

1. **Conceptual Framework**. Here, we present the concept of Integrated Lake Basin Management (ILBM) which forms the core of this assessment methodology. We also discuss the proposed steps to be taken during the follow-up Full-Sized Project (FSP).
2. **Inventory of Lake Basins**. We discuss the techniques that will be used to systematically identify and delineate the transboundary lake basins of the world. This has never been done at the global scale because of the large number of very small (but important) lake basins. We use Africa to illustrate the technique.
3. **Indicators**. This section represents the core of the assessment methodology. It identifies three sets of appropriate indicators, and shows how each set (Level 1.1, Level 1.2, and Level 1.3) can be evaluated through an iterative approach to assist the GEF and stakeholders in achieving the goal of ranking high-risk transboundary lake basins. To the extent available, data on in-lake conditions will complement the analysis through the three levels of assessment. An important 'beyond-the-indicators' approach is the use of questionnaires and stakeholder meetings in Level 1.3 to arrive at the final assessment. Indicators will be validated in Level 2.
4. **Links with other systems**. In this chapter, we show how the lakes component of TWAP fits well with the rivers component. The link with groundwater and large marine ecosystems is more dependent on the specific case. The link with open ocean is more of comparable lessons for 'lentic' (still or slow-moving) waters than direct connections.
5. **Data and Information Management**. Large amounts of data will be collected and much new and novel information will be generated. The resulting 'knowledge base' will be of great importance for many, not just the GEF. Here, we discuss the techniques for making this information available to a wider audience.
6. **Towards Implementation of the Transboundary Lake Basin Assessment**. In this chapter, we present ideas on how the FSP stage of TWAP can be carried out with respect to lake basins.

Overall, our approach is likely to differ from that of the other four TWAP working groups for three main reasons. First, we do not have a pre-determined census of target water bodies. This necessitates extra GIS-based work and leads us to propose a three-part, iterative approach for assessment and ranking. Second, because of this, we are not able to actually carry out the census in the MSP. We apply the techniques and demonstrate their validity for Africa (with over 12 000 identified transboundary lake basins) but the global-level work will have to be done at the beginning of the FSP. Third, we rely heavily on an accepted methodology, ILBM, which serves as the link at all stages to bind the different sections of the assessment together. ILBM is broad and ranges from highly technical issues like basin delineation all the way to community-based institutions for the management of fisheries resources. It is a globally-accepted approach and is the main product of a recently completed GEF-MSP called Towards a Lake Basin Management Initiative upon which TWAP will build.

Part I. Conceptual Framework

Objective

The objective of this 'Methodology for the Assessment of Transboundary Lake Basins' is to provide the GEF with a stakeholder-validated methodology for setting science-based priorities for financial resource allocation.

Specific objectives of this report include to:

1. Identify and demonstrate techniques for delineating the transboundary lake basins,
2. Develop a set of indicators relevant to lake basins,
3. Collect and produce information to populate those indicators,
4. Create an evaluation framework to identify high-risk transboundary lake basins.

In addition to being useful to the GEF, it is expected that national governments will be able to make use of the results when establishing national programmatic priorities. Furthermore, local basin-level stakeholders are also expected to benefit from the catalytic value provided by this stakeholder-based analysis.

Scope

The scope is global with a focus on GEF-eligible countries. All transboundary lake basins with at least one GEF-eligible country in the basin are included in the first round of analysis.

A transboundary lake basin is defined here as a drainage basin that consists of more than one country and contains a lake. Of the millions of lakes in the world, less than a few hundred have their water surface intersected by an international border. However, many are located in basins that have either their upstream area and/or the downstream area intersected by a border. Therefore, these lakes can cause and/or receive transboundary impacts and are relevant to this analysis.

The scale is very high resolution with a focus on all transboundary lake basins containing lakes greater than roughly 1 km^2 in area. This ensures that high-risk and important yet relatively small lake basins are included in the analysis.

Finally, although this TWAP working group is focused on lake basins, the integrated nature of water resources necessitates that we also include discussion on rivers and groundwater, and to a lesser extent, large marine ecosystems.

Framework

The Integrated Lake Basin Management (ILBM) concept has evolved from the findings of lake basin management experiences of different continents, detailed in the report 'Managing Lakes and Basins for Sustainable Use' (http://www.ilec.or.jp/eg/pubs/ILBM/ILBM_Report_E_07oct02.pdf), produced as an output of the GEF-financed and the World Bank-executed project, implemented during 2003-2005 by the ILEC. It is a conceptual framework for assisting lake basin managers and stakeholders to achieve sustainable management of lakes and their basins. It takes into account the biophysical features and managerial requirements of lake basin systems, which are associated with the lentic water properties of lakes as well as the inherent dynamics between humans and nature in the process of development, use and conservation of lake and basin resources. In addition to considering the biophysical features associated with lentic water systems, this management framework promotes continuous improvement of lake basin governance by integrating six elements essential for effective lake basin management: institutions, policies, participation, technology, information and finance. Being a hybrid bottom-up, top-down approach to lake basin management, development of an ILBM platform has drawn global interest in countries and regions facing serious lake basin management challenges.

The underlying key conceptual bases for ILBM are:

- **Basin Approach** (discussed extensively in Part II)
- Set of **Characteristics of Lakes** (discussed below)
- Focus on **Ecosystem Services** (discussed below)
- Focus on **Governance Challenges** (discussed below)

Characteristics of Lakes

A lake is a reflection of its watershed. All human activities and many natural processes influence the mobilization and delivery of contaminants to waterbodies, some directly through runoff from the land surface entering a lake or reservoir, and some indirectly as contaminants pass through intermediary waterbodies (frequently streams and rivers) prior to their entry into a lake or reservoir. In turn, lakes that have outflows can influence conditions in the downstream area, serving as a water storage that may contribute to river flows during droughts or dry periods and serving as an accreting buffer to protect downstream communities from contaminants entering the hydrological system upstream of the lake. At times, lakes and reservoirs can modify the contaminant loads of inflowing rivers to such a degree that the water leaving the waterbody has a significantly enhanced scouring capacity—this is especially true in the case of reservoirs.

In the broadest sense, lakes, wetlands and reservoirs can be considered 'standing water' systems, termed 'lentic'. Flowing waters (rivers) are known as 'lotic' systems. In general, because lakes usually have both inflowing and outflowing rivers, a lake basin can be characterized as a complex combination of lentic and lotic waters, with this distinction between the two being of great importance for lake management. In fact, the occurrence and management of lake problems is influenced by three key characteristics of lentic water systems—their ***integrating nature***, ***long water retention time*** and ***complex response dynamics.*** As can be seen from the descriptions of these characteristics given below, these key characteristics are important considerations in the links between lakes and other water media.

Integrating nature. Lakes receive pollutant inputs from diverse sources in various forms from their drainage basins and beyond. The inputs to a lake can be in the form of atmospheric precipitation; flows from rivers and other inflowing channels; heat- and wind-induced energies that cause waves; thermal energies that affect mixing properties; and land-based and airborne pollutants and contaminants, nutrients, and organic substances, both living and non-living. The integrating nature refers to the mixing of these inputs within a lake so that both resources and problems are disseminated throughout the volume of a lake.

- ***The management implications*** of the integrating nature of a lake mean that many lake resources, as well as lake problems, are shared throughout the lake. As a result, it is not sensible to subject different parts of a lake to different management regimes. This is particularly relevant to transboundary lake basins. A related consequence of the integrating nature is that it is difficult to exclude users from accessing a lake's resources. These properties require lakes and their basins to be subjected to adaptive management, utilizing wide-ranging policy instruments.

Long retention time. The water residence time of a lake gives an indication of the average time water spends in the lake. Large lakes with long retention times (tens to hundreds of years) are able to absorb large inputs of floodwaters, pollutants and heat without exhibiting immediate changes. Large or small, lakes with long water retention time also allow for suspended materials to settle to the bottom, thus acting as efficient sinks for many materials. Further, the long-term stability of older lakes has allowed complex, often unique ecosystems to evolve.

- ***The management implications*** of long retention times relate to the fact that problems can build up and become noticed slowly, and take equally long to be managed, so institutions involved in lake basin management need to be prepared to engage in sustained actions, with long-term funding commitments. The implications of the long-term vulnerability of lake ecosystems necessitate management with a precautionary approach.

Complex response dynamics. Unlike rivers, lakes do not always respond to changes in a linear fashion. For example, many lakes will have a non-linear response (hysteresis) to increases in nutrient concentration. The consequence is that a lake's degradation in response to developing pressure, such as increased nutrient concentrations, may not be apparent until the nutrient concentration is high, and the lake abruptly switches its trophic (nutrient) status. The management problem for a decision maker is that the lake, once a change has occurred, cannot simply be restored to its former state simply by reducing nutrient inputs.

- ***The management implications*** of complex response dynamics, particularly in relation to long water retention times, imply that the problems need to be anticipated as far in advance as possible through monitoring, development of indicators and analytical studies, while carrying out scientific exploration to unravel the complex processes and their implications. Scientific studies may also help develop novel solutions to these problems.

Ecosystem Services

All the people on our planet depend on the bountiful services of nature for their existence, well-being and economic livelihoods. These so-called 'ecosystem services' are defined in the 2005 UN Millennium Ecosystem Assessment as 'benefits people derive from ecosystems'. In attempting to meet our increasing demands for food, freshwater, fibre, energy and other ecosystem benefits, however, we are dramatically impacting the sustainability of our planet's ecosystems. Although these changes have enhanced the lives and well-being of large portions of our global population, they have come at the expense of negative impacts on nature's ability to continue to deliver key ecosystem services (clean water and air; protection from floods, disease, etc.). Further, these impacts disproportionally affect the poor, particularly those directly dependent upon ecosystems, including lakes, for their livelihoods.

Lakes, whether natural or constructed, are important components of continental ecosystems (supporting fish and aquatic life, providing habitat for wildlife, acting as buffers for floods or reservoirs during period of drought, and providing water for all living organisms) and essential mechanisms supporting human economic activities (including providing drinking and industrial water supply, irrigation water, fish, and hydropower; supporting recreation, transportation, and aesthetic uses; and having cultural and religious significance). Such ecosystem services can be grouped into four broad categories: ***provisioning services***, such as the production of food and water; ***regulating services***, such as controlling climate and disease vectors; ***cultural services***, such as spiritual and recreational benefits; and, ***supporting services***, such as nutrient cycling, soil production, and crop pollination.

In this chapter, the role of lakes and reservoirs in satisfying current and future human demands for the ***provisioning services*** provided by aquatic ecosystems is considered. Attention is given primarily to ***regulating services*** of the environment as a basis for ensuring the continuity of the ***provisioning and cultural services***. In addition, by focusing on the ***regulating services***, and satisfying the management needs associated with such services, it is proposed that the integrity of the ecosystem ***supporting services*** can be maintained. In this, the central role of lakes and reservoirs is highlighted.

The four major classes of ecosystem services have been identified. In providing access to these services, lakes and reservoirs are fundamental to human existence and economies.

Focus on Governance Challenges

ILBM is founded on lake basin governance, which, in turn, relates to the human uses of the waterbodies within the context of their basins. Lake governance, in turn, can be viewed as the structure that supports sustainable utilization of freshwater resources. The experiences obtained from the LBMI (Lake Basin Management Initiative)-GEF Project indicate that good lake basin management requires: (1) institutions to manage the resources of the lake and its basin for the benefit of all lake basin users; (2) policies to govern people's use of lake resources and human impacts on lakes; (3) involvement of key stakeholders in lake basin management; (4) technological possibilities (with limitations) that exist in almost all cases; (5) information, both of a traditional and scientific nature; (6) sustainable financing to support all the above activities. These constitute the essential components of basin governance for which ILBM can provide the overall application framework (see figure 1).

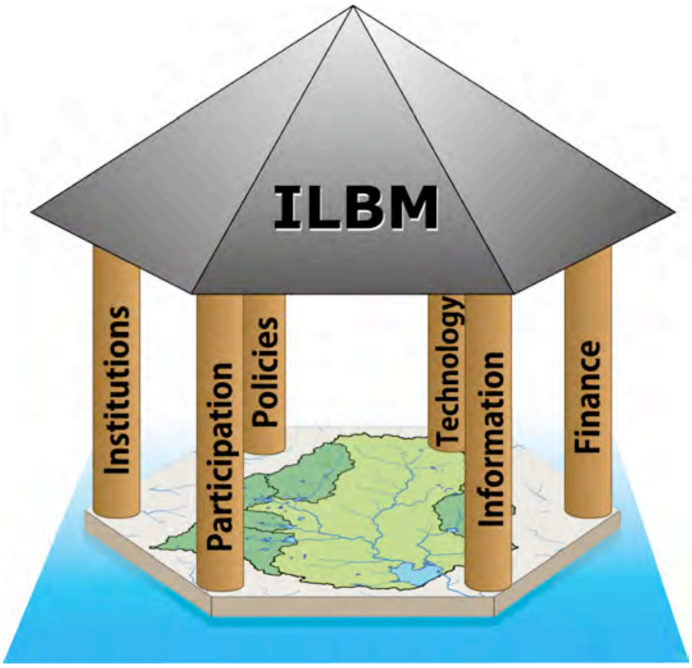

Figure 1. The ILBM Framework.

Iterative Approach

Problems with inventory. One of the challenges facing the working group on transboundary lake basins was that there is currently no complete list of the world's transboundary lake basins. This is mainly because the size of lake basins ranges from very large (already identified and well-known, like Lake Chad) to very small. If we were to look only at lakes whose surfaces are intersected by international borders, the problem of an inventory would be much simpler (using the Digital Chart of the World borders and the Global Lake and Wetland Database, it is 107 lakes). The ILBM approach, however, requires that we focus on drainage basins and this makes the inventory process much more time-consuming but much more relevant.

Problems with indicators. An additional complication that arises from the greatly varying sizes of transboundary lake basins is that the indicators used must be fine enough to capture meaningful basin-level issues for even the smallest basins. Given the extent and size heterogeneity of lake basins, coming up with a very detailed set of indicators at the beginning of an analysis is impossible.

Need for iterative approach. For these two reasons, we have propose an iterative approach in which both the lake basin delineation and the indicators are refined in stages. At each stage, the number of lake basins decreases and the detail of basin delineation and indicators increases. For reasons made clearer in Parts II and III below, we argue for a three-stage process: Level 1.1, Level 1.2 and Level 1.3. The table below provides a description of the activities we foresee at each level, including detailed steps.

Some key points are:

- There will be iterative rounds through which we gradually refine the basin delineation and develop more detailed indicators. The first round will use indicators for which we already have globally available data for all lake basins. The second and further rounds will gradually become more detailed and refined (using results from modelling work, making use of datasets that are not available for all lake basins, answers to questionnaires, discussions at regional meetings, etc.)
- GEF makes judgments along the way. It is necessary to work iteratively with the GEF to ensure the GEF goals are being met (which countries are eligible, what cut-off size of lake/lake basin is desirable, which special issues (high-altitude lakes) should receive attention, etc.)
- Information is owned. The stakeholders at the final round of lake basins will be involved in data collection and discussion. This is necessary to get 'groundtruthing' (confirming on location) of our results, to add local insight that is not possible without local stakeholders (questionnaire - part of Level 1.3), and to add legitimacy and ownership to the process which will be catalytic in starting future GEF-funded projects (and benefits will accrue even for lake basins that will not receive funding).
- The indicators at all levels (presented in Part III below) are based on the ILBM framework and are grouped into ILBM themes.

Proposed Levels and Steps in MSP/FSP

Level	Steps		MSP		FSP	
1.1	a	Identify the transboundary lake basins	Yes	Demonstrate method for Africa	Yes	Do for whole world
	b	Compile and demonstrate basic indicators	Yes	Demonstrate method for Africa	Yes	Do for whole world
	c	GEF reduces list of lake basins			Yes	Work with GEF and partners to remove sets of lake basins from the complete list (ineligible countries, lakes over a certain size, etc.)
1.2	a	Compile more detailed indicators, refine basin delineation			Yes	More detailed indicators are possible because geographic extent is smaller
	b	GEF reduces list of lake basins			Yes	Work with GEF and partners to selectively remove sets of lake basins from the modified list
1.3	a	Compile most detailed basin and in-lake indicators, refine basin delineation			Yes	A much smaller set of target lake basins allows very detailed study (TDA-like, questionnaire-based, stakeholder-owned process)
	b	Output delivery			Yes	Output delivered to GEF, including matrix of indicators/results as well as geo-referenced maps and various other GIS-based outputs.
2	a	Validate and compare methodologies with a set of well-documented systems			Yes	This Level 2 is the key step where links between waterbody types are explored (see end of Part IV for proposed cases).

Vulnerability

Lakes, as standing (lentic) bodies of water, are highly valuable but also highly vulnerable to human activities at four main scales: in-lake (such as overfishing), littoral zone (such as destruction of shoreline wetlands), basin level (such as sediment input from deforested areas) and regional/global (such as mercury deposition from fossil fuel combustion far away).

The LBMI project looked at these vulnerabilities for 28 lake basins (many of them transboundary and the focus of GEF-funded projects). The table below shows the extent to which these four scales present challenges. Upward arrows represent improving conditions, downward arrows represent deteriorating and sideways arrows unchanged conditions. A major conclusion from the LBMI project is that most of the arrows are pointing downward and most are at the littoral and basin level.

The main vulnerabilities identified were:

- In-lake
    - Unsustainable fishing practices
    - Biological invasions by non-native faunal species
    - Salinity changes

- Biological invasions by non-native floral species
- Nutrients from fish cages

• Littoral
- Shoreline effluent discharges
- Shoreline industrial discharges
- Shoreline water extraction
- Loss of wetlands

• Basin origin
- Excess sediment inputs
- Non-point source nutrients
- Agro-chemicals
- Water abstraction
- Changes in run-off
- Effluent and stormwater
- Industrial pollution

• Regional/Global
- Atmospheric nutrients
- Atmospheric industrial contaminants
- Climate change

Table 1. Summary of Problems facing the 28 LBMI lake basins.

	In-lake					Littoral				Basin origin							Regional/ Global		
Lake Basin	Unsustainable fishing practices	Introduced faunal species	Salinity changes	Weed infestations	Nutrients from fish cages	Shoreline effluent discharges	Shoreline industrial discharges	Shoreline water extraction	Loss of wetlands	Excess sediment inputs	Non-point source nutrients	Agro-chemicals	Water abstraction	Changes in run-off	Effluent and stormwater	Industrial pollution	Atmospheric nutrients	Atmospheric industrial contaminants	Climate change
Aral Sea			→						→				→						
Baikal						↓	→			↓								→	
Baringo	→									↓			↓	↓					↓
Bhoj Wetland				→		→	↓			→	→	→			→				
Biwa									↓		→	→	↑[2]		↑				↓
Chad									↓	↓			↓						↓
Champlain						↑					↑				↑			→	
Chilika Lagoon			↑	↑						↓	↓	↓	↓		↓				
Cocibolca/Nicaragua						↓				↓		↓			↓				
Constance		↓				↓			→		→	→			→				
Dianchi					↑	→	→		↓	↓[3]	↓[3]	↓[3]	↓		↓			→	
Great Lakes (N. American)		↓				↑	↑				↓	↓			↑	→		→	
Issyk-Kul		→								↓	↓	↓				↓[4]			↓
Kariba Reservoir					↓	→					↓								↓
Laguna de Bay	→	↓	→	→	↓	→	→			↓	↓				↓	→			
Malawi/Nyasa	↓[5]			↓						↓	↓	↓		↓	↓		↓		↓
Naivasha	↑	→		↑		↓		→	→	↓							↓		
Nakuru										→	→		↓	↓	↓				
Ohrid	→	↓				→	↓		↓	↓	↓	↓			↓				
Peipsi/Chudskoe	↓			→		→					→[6]				↓	→[6]			
Sevan	↓	↓				↓			↓	↓			↓						
Tanganyika	↓[5]					↓	↓			↓					↓				↓
Titicaca		↓				→	↓			↓					↓	↓			
Toba	↓	↓		↓	↓	→			↓	→	→	↓	↓	→	↓		↓		
Tonle Sap	↓	↓								↑[7]					↓				
Tucurui Reservoir				→						→									
Victoria	→	↓[8]		↑		↓	↓		↓	↓	↓				↓	↓[4]	↓		
Xingkai/Khanka	↓					→	→		↓	↓		↓			↓	↓[9]			
Total Occurrences	12	11	3	9	4	18	10	1	11	21	16	12	9	4	19	7	4	4	7

Legend	A ↓ symbol means that the problem is not improving significantly; a → symbol means that it has improved somewhat; and a ↑ symbol means that there has been significant improvement.
1	The lake briefs are not exhaustive in their description of problems; a blank cell in the table does not mean that the lake does not experience the problem. In many lake briefs, there is only limited information on the extent of improvement of a problem; the direction of change shown in the table is based on this information.
2	Most water abstraction for Kyoto/Osaka/Kobe is downstream of Lake Biwa.
3	Despite considerable investment, nutrient and chemical concentrations in Lake Dianchi have yet to show improvements. There is some evidence that COD is improving.
4	Mining in the basin is the source of toxic chemicals reaching the lake.
5	Includes loss of fish biodiversity through overharvesting for aquarium trade.
6	Improvements in the nutrient and pollutant status of the lake are the result of a decline in use of nutrients in agriculture and industrial production following the collapse of the Soviet Union rather than from a deliberate policy intervention.
7	There is a large amount of sediment deposited around Tonle Sap each year, but this is regarded as an essential service rather than as a problem.
8	Introduced species, particularly Nile perch and Nile tilapia, have contributed to the loss of many native species as well as providing a valuable source of income for the regional community. Here they have been assessed for their effect on the lake's biodiversity.
9	High copper (Cu) concentrations are recorded in Lake Xingkai/Khanka, but the origins are unknown.

Contribution to existing global assessments

Other related global assessments that are either ongoing or concluded include:

- UNESCO-based, UN-wide World Water Action Programme (WWAP)
- GEF-funded Global International Waters Assessment (GIWA)
- GEF-funded Lake Basin Management Initiative (LBMI)

However, this is the first global assessment that comprehensively targets transboundary lake basins down to the square kilometre level. This allows the capture of often-overlooked smaller yet highly important water bodies and in that sense represents a significant and new contribution to the above assessments.

Part II. Inventory and Characterization of Transboundary Lake Basins

Assessment units/boundaries (identifying transboundary lake basins)

Unlike continental-scale aquifers or river basins, there is no inventory or list of transboundary lake basins. The global extent of lakes, combined with their typically small size, has discouraged a comprehensive delineation of their basins. However, by making use of various high-resolution, geo-referenced datasets, we can now identify the location of the world's transboundary lake basins to high accuracy. Given the high resource demands (particularly within GIS), we have limited the analysis to Africa for this MSP; however, the process described below is fully applicable to all regions of the world.

Overall, once we know where lakes, drainage basins, and international borders are, it is a straightforward process in a GIS to find the transboundary lake basins.

Where are the lakes?

Currently, the best-quality, highest-resolution, global-scale dataset for waterbodies is the SRTM Waterbody Dataset (SWBD) produced by NASA as a product of the Shuttle Radar Topography Mission (SRTM) in February 2000. The data has a resolution of 1 arc second (~30m) and has been groundtruthed with Landsat imagery. Lakes with width > 183m and length > 600m (approximately > 0.1 km^2 in area), rivers wider than 90m, and all coastlines are delineated.

The dataset is available for free download from NASA and USGS in 1x1 degree tiles. We have compiled the tiles for the entire world (12 229 tiles), merged them, and corrected some topological errors and stored this new, single file in a geo-database. (There is a need to dissolve all the features where the tiles join; however this is a time-consuming step and we have completed the work only for Africa for the MSP.)

Within Africa, there are 17 177 individual lakes in the SWBD (minimum lake area approximately > 0.1 km^2). See figure 2.

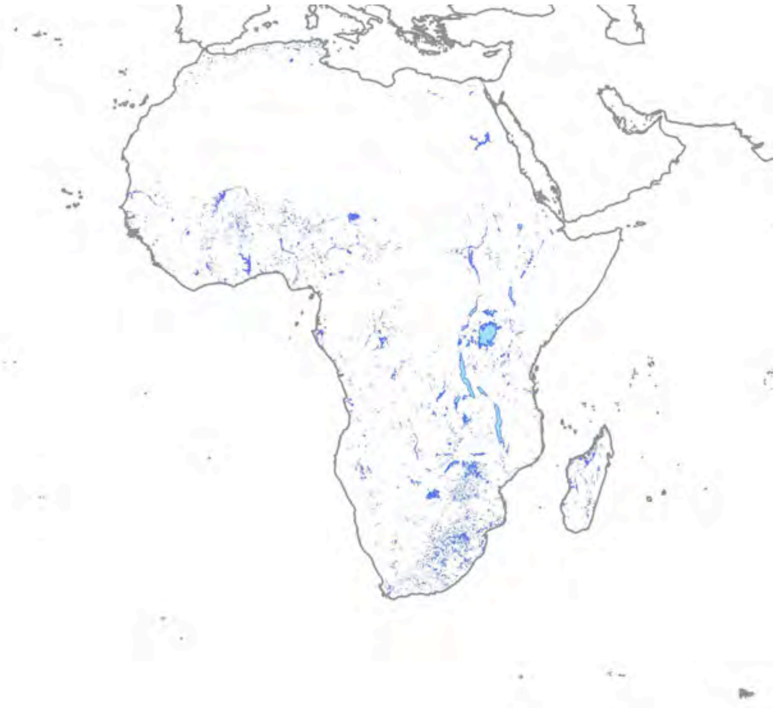

Figure 2. African lakes in the SWBD.

Names of lakes are available through the National Geospatial Intelligence Agency's (NGA) GEOnet Names Server (http://earth-info.nga.mil/gns/html/).

Where are the lake basins?

Typically, for individual and specific lake basin mapping, we use the SRTM digital elevation data (DEM) provided by NASA. The data is available in various resolutions, the highest being 3 arc seconds (~90 m). In GIS, we take the elevation data and perform a series of steps to determine the direction that water would flow. Once the 'flow direction raster' has been created, it is a straightforward task to determine what land drains where. We can specify a given lake as the 'pour point' and within GIS we can determine the land that would drain into it.

The raw SRTM data requires a significant amount of pre-processing as well as editing to compensate for inherent limitations of the SRTM sensor. During the MSP, it was impossible to carry out that level of work for all the lake basins in the world. Therefore, we have used a lower-resolution dataset called Hydrosheds (from USGS) which, although not as detailed or correct as our normal method, provides us with a acceptable method for determining drainage basins. Hydrosheds also provides pre-delineated river basins at various resolutions, the highest being 15 arc seconds (~450 m). We make use of this 'shapefile' as well as their 15 arc second flow direction data.

Hydrosheds provides polygons for 169 012 drainage basins in Africa (see figure 3). The Hydroshed definition of a drainage basin is one that either drains to the ocean (exorheic) or terminates at a low point on land (endorheic). The vast majority of these are very small, dry endorheic basins in between sand dunes in the Sahara. The Hydroshed drainage basins are not necessarily lake drainage basins, and in some cases, they do not even contain rivers (for hyper-arid regions).

Figure 3. Drainage basins in Africa according to Hydrosheds.

Where are the borders?

For international (and subnational) boundaries, we use the Global Administrative Areas Dataset (GADM) which is also available for free download. For Africa, we have the following:

Figure 4. International borders in Africa according to GADM.

Analysis

With the above data, we can now determine the location and extent of international lake basins in Africa. This involves the following steps:

1. **Selecting the drainage basins that are intersected by international borders**. The result is 583 basins. However, the majority of these do not contain lakes.
2. **Determining which of these international drainage basins contain lakes**. We take the result from step 1 and select only the drainage basins that contain at least one of the SWBD lakes. There are 114 that meet this criterion. See figure 5 below.
3. **Counting the number of lakes**. Within these 114 international basins, there are 12 847 lakes. That means that 74.8 per cent of the lakes in Africa lie in an international basin. Of these 12 847 lakes, only 70 lakes are actually intersected by an international border.
4. **Delineating each lake's immediate drainage basin**. Polygons for each lake basin do not exist: they are nested in the larger river basins provided in Hydrosheds. However, using Hydrosheds' 15 arc second flow direction raster data, along with the SWBD polygons, we can delineate these.

Figure 5. International Basins in Africa that contain lakes.

Because this 4-step procedure is computationally intensive, we have only done the Nile River basin and its associated lake basins as a demonstration for the MSP.

- To limit the analysis, we look only at the lakes greater than 1 km^2 in area. There are 359 of these in the Nile Basin.
- Figure 6 below shows each lake and its drainage basin. Note that in the downstream area there are several blank zones within the Nile Basin that are actually small endorheic drainages.
- There are various techniques available for aggregating these individual basins into broader basins. For example, in the figure, all the lakes upstream of Lake Victoria have their upstream basins delineated. If we wish to know only Lake Victoria's basin, then we can aggregate all the upstream polygons.

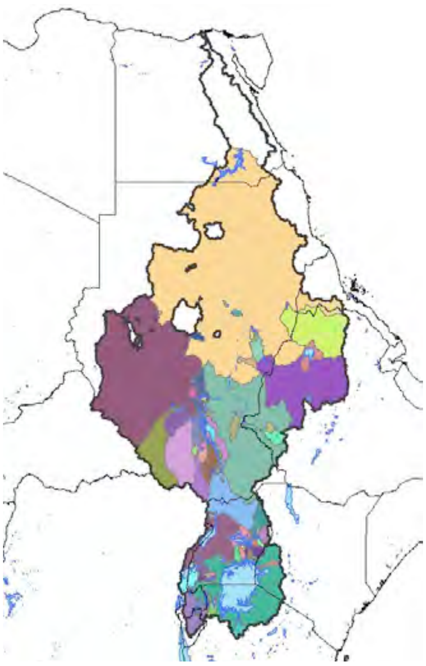

Figure 6. Individual Lake Basins within the Nile River Basin.

Notes

Overall, the technique described here will work for all areas except Antarctica and those above 60°N latitude. However, other datasets exist that can be used in conjunction with SRTM to provide complete global coverage.

For the first stages of identifying lake basins and their indicators, this Hydrosheds-based approach provides a good compromise between processing time and quality. However, for the final lake basin maps (and associated outputs), it will be necessary to use the raw SRTM (3 arc second data) and groundtruth all the information. We will also make use of remotely sensed images such as Landsat (as well as the questionnaires and stakeholder meetings) to ensure the accuracy of the mapping.

Inventory of agencies, programmes, datasets and sources

While large transboundary lake basins have attracted the attention of various global agencies, resulting in a number of programmes, the majority of the transboundary lake basins have not been studied because of their relatively small size. Therefore, for the majority of our target lake basins, there are no readily-available, centralized data sources. We therefore employed datasets and sources created for non-lake basin-related reasons to obtain information. The indicator tables in Part III discuss the sources we plan to use.

For Level 1.3, we will rely heavily on the results of questionnaires sent to teams of stakeholders belonging to each Level 1.3 lake basin (an overview of the draft questionnaire can be found at http://www.ilec.or.jp/eg/pubs/ILBM/Guidelines_for_Lake_Brief_Preparation.pdf). We will also convene workshops and other meetings to further elucidate the results of the questionnaires.

Identification of major stakeholders and partners

As noted above, the major globally-available data sources have already been identified and are discussed in Part III. The identification of major stakeholders and partners at the individual basin level will rely on the extensive global network of the International Lake Environmental Committee (ILEC) with contributions from GEF and other agencies, where possible. Logistically, the identification of stakeholders and partners depends on which lake basins are chosen at the end of the Level 1.2 analysis.

Priority issues, emerging issues and hot spots

Naturally, a full accounting of priority issues, emerging issues and hot spots can only be made after the results of the analysis are available; however, we can make some preliminary observations based on the LBMI work as well as recent ILEC activities.

Priority issues

Experience from GEF and other projects demonstrates that most of the problems facing lakes originate in their drainage basins (see Table 1). Without dismissing the importance of stresses in the lake itself, or regional/global stresses, it is clear that basin-level interventions should have top priority for the sustainable management of lakes. Basin-level stresses can occur very close to the waterbody along the lakeshore through destruction of wetlands, human encroachment and a wide range of other pressures. They can occur in the middle reaches of the basin though irrigated agriculture and the application of nutrients and fertilizers to crops. But perhaps most challenging are those that occur in the upper reaches of the watershed such as deforestation that can change hydrological regimes. This last class of problems is often ‘out of sight, out of mind’ given the long distance from the lakes, yet it is crucial to include in any lake basin management efforts.

A related priority is to get the lake management-related institutions to coordinate their efforts at the basin level. While establishment of a lake basin authority is not always necessary, it is crucial that all the actors with control over the various stress-causing activities are coordinated (at the least) or integrated (at the best) in their programmes. This is much easier said than done but there is a growing body of examples from around the world of how this can be achieved.

Emerging Issues

One of the most pertinent emerging issues is global climate change. It is becoming clear that changes in temperature and precipitation patterns will have major effects on the productivity and health of aquatic ecosystems. Furthermore, the stability of high-elevation lakes such as those in the Andes or Himalayas is threatened by climate change. The regulatory effect of these lakes on downstream water supplies is significant, and the potential for glacial outbursts poses a impending danger to downstream communities.

Another emerging issue is related to the projected increase in water use by agriculture over the coming decades. As human populations continue to grow and place an increasing demand on natural resources, more land will need to be converted into agricultural land. This will also include conversion of wetlands, use of water from lake basins for irrigation, and a decrease in water available to maintain healthy aquatic ecosystems. Furthermore, increased agricultural activities are expected to result in more pollution caused by nutrient and pesticide runoff. One of the great challenges of the future will be to find solutions for increased food production that do not compromise the ecosystem services provided by lakes.

In addition, recent work (e.g. on Lake Victoria by Tamatamah, Hecky and Duthie in Biogeochemistry 73: 325-344) has demonstrated the magnitude of atmospheric deposition, which can have a dominant effect on the nutrient balance of lakes.

Each of these threats will need to be taken into account when planning for the future sustainable management of the world's lakes.

Hotspots

Hotspots are likely to occur at the confluence of the many (projected) impacts discussed above. It is reasonable to assume that the lakes facing the greatest problems will be high-value lakes (such as those with outstanding biodiversity, large fish catches or significant use as a water supply) in areas with high population density, low income and subject to climate change. The Sahel, as well as parts of the East African Rift Valley, and much of South Asia stand out. Many of the large reservoirs in South America are also likely to face high pressure.

Identification of demonstration/pilot projects involving links

An example of our proposed basin delineation and inventory method is given in Part II for Africa and the Nile Basin. A demonstration of indicators in Part III is forthcoming and will use the Nile Basin as a whole and a few upstream lake basins in the Nile Basin (Tana, Roseires; Rweru, Victoria) to illustrate the details.

The questionnaire and workshop method has been extensively tested in the GEF-LBMI project as well as an on-going Japanese Ministry of Education project on global lake basin governance. Lessons from those two projects will be incorporated into the questionnaire and workshop design.

Part III. Indicators

Indicators (Proposed Indicators)

Desirable Properties of Indicators: The ILBM Approach

Prioritizing transboundary lake basins for international interventions and funding is a challenging task, especially because of the lack of a comprehensive tally of international lake basins. To help tackle this challenge, a list of environmental, geophysical, and political parameters has been put together, which can be used as indicators for the risk status of each lake.

Any set of indicators used to rank transboundary basins must meet four criteria:

1. **Easy to understand**. Although experts benefit from and are comfortable using esoteric indices in their work, the results of the TWAP project must be easily understood by a wide range of stakeholders. The essence of each indicator must be made explicit in one simple, short phrase.
2. **Meaningful and relevant**. There is no extra policy-relevant information gained from developing a large suite of indicators which rely on a small number of redundantly-used inputs. Such an approach can mask important underlying facts and trends. Therefore, to the extent possible, each indicator should tell its own story; i.e. be based on information not captured in other indicators. Furthermore, each indicator should relate directly either to either a potential action or to a description of fundamental constraints that affect actions.
3. **Available at the global scale**. Large gaps in information which are inherent in a 'wish list' set of indicators preclude comparison and assessment of transboundary lake basins. For Level 1.1, the challenge is to develop a broad set of indicators for which uniform, globally-available data exists and that can be used to compare *all* transboundary lake basins. As the list of target lake basins is reduced through Levels 1.2 and 1.3, more detailed and refined indicators can be applied.
4. **Stakeholder-driven and owned**. In many cases, important information will be available for some but not all of the target lake basins. Much of this information can only be captured through direct consultation with local stakeholders (questionnaires and workshops).

All these factors argue for an iterative, consultative approach through which the number of target basins is reduced and the indicators refined at each stage. This approach adds legitimacy, promotes catalytic buy-in, and will result in more robust conclusions. This is essentially the ILBM approach.

The concept of ILBM was a key output of the Lake Basin Management Initiative, financed by GEF, implemented by the World Bank and executed by ILEC. It has been adopted in many countries (from Japan to Nepal, Malaysia, Mexico, etc.) as the leading method used to guide changes on the ground that promote improved livelihoods in lake basins. ILBM provides an over-arching structure but should be flexible enough to adapt to specific local needs.

The main ILBM issue domains are: understanding the situation (biophysical conditions, human use); meeting the governance challenge (institutions, policy, people, technology, information, and finance); and synthesis (planning). The indicators we propose below follow this structure. Note that it is possible to relate each ILBM indicator to one of the commonly-used GEF indicators such as Process Indicators (P), Stress Reduction Indicators (SR), Environment/Water Resources Status Indicators (EWR). It is equally possible to relate them to the commonly used Driving Force - Pressure - State - Impact - Response (DPSIR) framework.

Indicators

The proposed indicators for each of the three levels are listed below. Note that as discussed in Part I, we need to refine the indicators to reflect the incremental improvements in our basin delineations and add more meaningful information as the set of lake basins is narrowed, including in-lake conditions.

All basin and in-lake indicators are refined as the basin delineation becomes refined from Level 1.1 to Level 1.2 to Level 1.3. Most indicators are also refined to reflect small changes in their definition that make them more appropriate. For example, in Level 1.1, the indicator 'Hydrological Position' uses lake area but in Level 1.2 (and onwards), it uses lake volume, which is a better measure but not possible to determine for all the lakes at Level 1.1 (but possible with the smaller set of lakes at Level 1.2). Finally, as the analysis progresses and the list of target lake basins is decreased, it becomes possible to add indicators that could not be included at Level 1.1 (or 1.2). For example, in Level 1.3, we are able to make future projections on runoff so Hydrological Position can also now be calculated as Projected Hydrological Position. Note that the 'unprojected' Hydrological Position indicator is maintained in Level 1.3. This is because it contains important information and is revised from the Level 1.2 value (because of more precise basin delineation). Although not discussed here, to the extent that they are available, indicators of in-lake conditions become more relevant as a complement to the basin-scale indicators, as the focus proceeds through the increasingly narrower and more detailed levels 1.2 and 1.3 of the assessment.

One way of keeping track of all these changes (which not are uniform across indicators except for the increasingly refined basin delineation) is to assign unique numbers to each indicator. For example, Hydrological Position evolves from 'Hydrological Position 1.1.1' to 'Hydrological Position 1.1.2' (as the basin delineation is refined and lake volume is used instead of lake area) and to 'Hydrological Position 1.1.3' (as the basin delineation is further refined). It spawns a related, new indicator 'Hydrological Position 1.1.4' (which makes use of future projections in runoff and is based on 1.1.3).

Summary of Proposed Indicators

ILBM Theme	No.	Level 1.1	Level 1.2	Level 1.3
Biophysical Conditions	1			
	1.1	Hydrological Position (1.1.1)	Hydrological Position (1.1.2)	Hydrological Position (1.1.3)
				Projected Hydrological Position (1.1.4)
	1.2	Lenticity (1.2.1)	Lenticity (1.2.2)	Lenticity (1.2.3)
				Projected Lake Volume (1.2.4)
				Projected Lenticity (1.2.5)
	1.3	Lake to Basin Area (1.3.1)	Lake to Basin Area (1.3.2)	Lake to Basin Area (1.3.3)
				Projected Lake to Basin Area (1.3.4)
Human Use	2			
	2.1	Relative Population Pressure (2.1.1)	Relative Population Pressure (2.1.2)	Relative Population Pressure (2.1.3)
				Projected Population Pressure (2.1.4)
	2.2	Human Development Index (2.2.1)	Human Development Index (2.2.2)	Human Development Index (2.2.3)
	2.3	Jurisdictional Fragmentation (2.3.1)	Jurisdictional Fragmentation (2.3.2)	Jurisdictional Fragmentation (2.3.3)
	2.4	Linguistic Diversity (2.4.1)	Linguistic Diversity (2.4.2)	Linguistic Diversity (2.4.3)
	2.5	Landscape Alteration (2.5.1)		
			Cropland Extent (2.5.2)	
			Urban Extent (2.5.3)	
				Irrigated Cropland Extent (2.5.4)
				Non-Irrigated Cropland Extent (2.5.5)
				Impervious Surface Extent (2.5.6)
				Forest Extent (2.5.7)
				Alteration of Littoral Zone (2.5.8)
	2.6	Flow Alteration (2.6.1)	Flow Alteration (2.6.2)	Flow Alteration (2.6.3)
				Relative Flow Diversion (2.6.4)
				Water Level Change (2.6.5)
	2.7	Relative Water Stress (2.7.1)	Relative Water Stress (2.7.2)	Relative Water Stress (2.7.3)
Institutions	3			
	3.1	Government Effectiveness (3.1.1)	Government Effectiveness (3.1.2)	Government Effectiveness (3.1.3)
	3.2	Control of Corruption (3.2.1)	Control of Corruption (3.2.2)	Control of Corruption (3.2.3)
	3.3			Lake Basin Specific Institution (3.3)
	3.4			Degree of Coordination (3.4)
	3.5			Local Community Governance (3.5)
	3.6			Degree of International Involvement (3.6)
Policies	4			
	4.1	Rule of Law (4.1.1)	Rule of Law (4.1.2)	Rule of Law (4.1.3)
	4.2			Ambient Standards/Goal (4.2)
	4.3			Effluent Standards (4.3)
	4.4			Zoning Regulations and Bans (4.4)
	4.5			Effectiveness of Implementation (4.5)
	4.6			Transboundary Coordination (4.6)
Participation	5			
	5.1	Voice and Accountability (5.1)	Voice and Accountability (5.1)	Voice and Accountability (5.1)
	5.2			Integration into Decision Making Process (5.2)
	5.3			Level of Education/Awareness Raising (5.3)
	5.4			Role of NGOs/CBOs (5.4)
	5.5			Indigenous and Gender Representation (5.5)
Technology	6			
	6.1	Access to Improved Sanitation (6.1.1)	Access to Improved Sanitation (6.1.2)	Access to Improved Sanitation (6.1.3)
	6.2			Industrial Pollution Control (6.2)
	6.3			Solid Waste Control (6.2)
	6.4			Non-point Source Control (6.3)
	6.5			In-lake Interventions (6.4)
	6.6			Impact from Resource Development Interventions (6.5)

Information	7			
	7.1	Coverage in Literature (7.1.1)	Coverage in Literature (7.1.2)	Coverage in Literature (7.1.3)
	7.2			Extent of Monitoring Programs (7.2)
	7.3			Resident Scientific Institutes (7.3)
	7.4			Citizens/Indigenous Knowledge Input (7.4)
	7.5			Degree of International Sharing (7.5)
	7.6			Sufficiency of Information (7.6)
	7.7			Freedom of Access (7.7)
Finance	8			
	8.1	Gross National Income (8.1.1)	Gross National Income (8.1.2)	Gross National Income (8.1.3)
	8.2	International Development Support (8.2.1)	International Development Support (8.2.2)	International Development Support (8.2.3)
	8.3			Sufficiency of Funds (8.3)
	8.4			Payment for Ecosystem Services (8.4)
	8.5			Local Retention of Funds (8.5)
Planning	9			
	9.1	National IWRM Plans (9.1.1)	National IWRM Plans (9.1.2)	National IWRM Plans (9.1.3)
	9.2			SAP or Equivalent (9.2)
	9.3			Integration of Plans (9.3)

Indicator 1.1: Hydrological Position (ILBM Category: Setting the Stage / Biophysical Conditions)

	Level 1.1	Level 1.2	Level 1.3
Name	Hydrological Position	Hydrological Position	Hydrological Position
Number	1.1.1	1.1.2	1.1.3
Question Addressed	How far downstream is a lake basin within its broader drainage basin?		
Rationale	The farther downstream a lake basin is relative to its broader drainage basin, the more likely it is to receive upstream pressures. Additionally, it is more likely to be seen as 'important' from the broader drainage basin perspective.		
Data (in addition to the data required to delineate the drainage basins)	Annual average precipitation (mm) from 1950-2000 from WorldClim	Annual average runoff (mm) from 1950-2000 calculated based on WorldClim	Projected annual average runoff in 2050 based on composite of various WorldClim scenarios and models
New Indicator Introduced			**Projected Hydrological Position (1.1.4)**
Spatial Resolution	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)
Methods	1. Calculate area of the lake basin (the land draining directly into the lake, including the lake up to the outflowing river). 2. Calculate area of total drainage basin (including the lake basin, and the basin of the outflowing river until it reaches the ocean (most cases) or an endorheic terminus. 3. Calculate total amount of precipitation falling within lake basin. 4. Calculate total amount of precipitation falling within broader basin. 5. Divide the step 3 by step 4.	Same as Level 1.1 except Steps 3 and 4 which use runoff instead of precipitation.	Same as Level 1.2 except values for Steps 3 and 4 are for 2050 instead of 1950-2000.
Interpretation/Notes	It is important to note that this indicator considers not the relative upstream area, but rather the upstream contribution of water (as given roughly by precipitation in Level 1.1 and more accurately as runoff in Levels 1.2 and 1.3). Highly 'upstream' lakes will have values approaching zero. Highly 'downstream' lakes will have a value of 1. Thinking about the LBMI lakes, we know that for some lakes like Bhopal or Dianchi, even though their outlets drain to the ocean, no one thinks of them as exceptionally important for their downstream areas. Their indicator values for 'Hydrological Position' will tend to zero. At the other extreme, we have lakes like Aral Sea and Nakuru that have no downstream areas (i.e. no river or groundwater outlet leaving the lakes). They are truly terminal and have a value of 1. Along this spectrum, we have lakes like Biwa which might have a value of 0.5. For lakes with a temporary connection to 'stem' rivers (rivers that usually pass by the lake basin but sometimes are connected), we need to apply a variation of the above method for each period: (1) when the stem is draining into the lake and (2) when the stem is bypassing the lake. Obviously, stem rivers do not contribute 100 per cent of their flow to these 'satellite' lakes so we need information on what portion of the stem river discharges into the lake.		

Indicator 1.2: Lenticity (ILBM Category: Setting the Stage / Biophysical Conditions)

	Level 1.1	Level 1.2	Level 1.3
Name	Lenticity	Lenticity	Lenticity
Number	1.2.1	1.2.2	1.2.3
Question Addressed	How much of the water in the lake basin is in lentic form?		
Rationale	Systems with a greater percentage of water in lentic form have slower response times to stress. This also generally implies a higher buffer capacity. On the other hand, they respond relatively slowly to positive interventions.		
Data (in addition to the data required to delineate the drainage basins)	Lake Area from SWBD, Annual average precipitation (mm) from 1950-2000 from WorldClim	Lake Volume (from SWBD-based calculation and/or other sources), Annual average runoff (mm) from 1950-2000 calculated based on WorldClim	Lake Volume (modelled change based on projected changes in climate, WorldClim), Projected annual average runoff in 2050 based on composite of various WorldClim scenarios and models
New Indicator Introduced			**Projected Lake Volume (1.2.4)** **Projected Lenticity (1.2.5)**
Spatial Resolution	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)
Methods	1. Calculate the area of the lakes in the target lake basin. 2. Calculate total amount of precipitation falling within lake basin. 3. Divide step 1 by step 2.	Same as Level 1.1 except Step 1 uses lake volume and Step 2 uses runoff instead of precipitation.	Same as Level 1.2 except values for Step 1 are estimates of future lake volume based on modelling results and Step 2 is for 2050 instead of 1950-2000.
Interpretation/Notes	This is similar to residence time (retention time) that we used in the LBMI project to differentiate between slow- and fast-response lakes. However, by looking at the total amount of lentic water in a basin, the 'Lenticity' shows the relative amounts of lotic versus lentic in a given system. For 'fast' systems such as those with abundant precipitation and relatively few (and shallow) lakes, the Lenticity will approach zero. For 'slow' systems with many and/or deep lakes and/or low precipitation, the Lenticity will be a large number. It would be interesting to look at the intra-annual variations in the Lenticity. For a monsoon-dominated climate, the variations would be significant with perhaps lakes/reservoirs being of greater importance to flood and drought management. Finally, ideally, we would like to calculate the amount of water in rivers versus water in lakes for a given basin but that would be difficult given the lack of information on river volumes (especially upstream).		

Indicator 1.3: Lake to Basin Area (ILBM Category: Setting the Stage / Biophysical Conditions)

	Level 1.1	Level 1.2	Level 1.3
Name	Lake to Basin Area	Lake to Basin Area	Lake to Basin Area
Number	1.3.1	1.3.2	1.3.3
Question Addressed	How large is the upstream basin relative to the lake?		
Rationale	Lakes with relatively large basins are more susceptible to outside influence than lakes with smaller basins.		
Data (in addition to the data required to delineate the drainage basins)	Lake Area from SWBD	Lake Volume (from SWBD-based calculation and/or other sources)	Lake Volume (modelled change based on projected changes in climate, WorldClim)
New Indicator Introduced			**Projected Lake to Basin Area (1.3.4)**
Spatial Resolution	3 arc seconds (0.01 km^2)	3 arc seconds (0.01 km^2)	30 arc seconds (1 km^2)
Methods	1. Calculate the area of the lake 2. Calculate area of the lake basin (including the lake) 3. Divide step 1 by step 2.	Same as Level 1.1 except Step 1 uses lake volume.	Same as Level 1.2 except values for Step 1 are estimates of future lake volume based on modelling results.
Interpretation/Notes	This is similar to what we did with the table in chapter 1 of the LBMI report by reporting lake area and basin area. However, lake volume, while more difficult to obtain, is a better indication of how much 'buffering' a lake might have for impacts from its basin. Lakes with large basins relative to lake area/volume will have higher values (think of Tucurui); lakes with very small basins relative to lake area/volume will have values approaching zero (think of Crater Lake in the US). Regarding airsheds: (1) the sensitivity of a lake to its airshed depends on the lake's surface area but (2) the relative sensitivity of a lake to its airshed or watershed depends on surface area and basin area. If we wish to deal with the airshed problem more comprehensively, we will need to add some other data like 'biomass burning in airshed'.		

Indicator 2.1: Relative Population Pressure (ILBM Category: Setting the Stage / Human Use)

	Level 1.1	Level 1.2	Level 1.3
Name	**Relative Population Pressure**	**Relative Population Pressure**	**Relative Population Pressure**
Number	2.1.1	2.1.2	2.1.3
Question Addressed	How many people are affecting the lake?		
Rationale	The more people upstream, the greater the potential stress on a given lake. Additionally, the stress is related to the lake size (area, or preferably, volume)		
Data (in addition to the data required to delineate the drainage basins)	Lake Area from SWBD, Population from Landscan	Lake Volume (from SWBD-based calculation and/or other sources), Population from Landscan	Lake Volume (modeled change based on projected changes in climate, WorldClim), Population from Landscan with Projected Population change to 2050 from UN.
New Indicator Introduced			**Projected Relative Population Pressure (2.1.4)**
Spatial Resolution	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)
Methods	1. Calculate the area of the lake. 2. Calculate population in lake basin. 3. Divide step 2 by step 1.	Same as Level 1.1 except Step 1 uses lake volume.	Same as Level 1.2 except values for Step 1 are estimates of future lake volume based on modelling results, and population is projected based on UN country-level estimates.
Interpretation/Notes	The units for this indicator are not common (persons/km^3 of lake volume) but higher values imply a greater stress than lower values. A technical difficulty arises when applying the country-level population projections to the km^2 level Landscan population data. There is a clear possibility that the population change in one country's portion of a basin will not be the same as the change in the country as a whole. Two possible variations on this indicator may be interesting: (1) Calculate the population in the lake basin versus the population in the total basin. This would indicate the relative importance of the lake basin within the broader basin. (2) The location of a person in the basin is important for two contrasting reasons. First, with everything else being equal, the closer people are to the lake, the more direct their influence will be. Conversely, it is possible that the further away they are, the less likely they are to have an immediate interest in the lake (or the benefits from it) and therefore more difficult to include in management. This could be called the Distance-weighted Population Pressure indicator.		

Indicator 2.2: Human Development Index (ILBM Category: Setting the Stage / Human Use)

	Level 1.1	Level 1.2	Level 1.3
Name	**Human Development Index**	**Human Development Index**	**Human Development Index**
Number	2.2.1	2.2.2	2.2.3
Question Addressed	What is the capacity (economic, educational and health) of the basin population to deal with lake basin management issues?		
Rationale	The lower the level of human development in a given basin, the less ability the population will have in preventing and responding to lake basin management challenges.		
Data (in addition to the data required to delineate the drainage basins)	HDI from UNDP, Population from Landscan, International Borders from GADM	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Join the HDI data to GADM national polygons 2. Clip the GADM file to the lake basin extent. 3. Calculate population for each country in the lake basin. 4. Multiply 3 by HDI for the respective countries. 5. Sum all values in 4. 6. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	It is assumed that country-level HDI values are applicable to the sub-national basin level. Also, it is assumed that national HDI values can be summed and averaged. The only change this indicator undergoes through the three levels is refinement due to more precise basin delineation. It may be possible to use this indicator only in Level 1.1 and perhaps Level 1.2 and remove it from Level 1.3 because in Level 1.3 other more specific indicators will be available.		

Indicator 2.3: Jurisdictional Fragmentation (ILBM Category: Setting the Stage / Human Use)

	Level 1.1	Level 1.2	Level 1.3
Name	**Jurisdictional Fragmentation**	**Jurisdictional Fragmentation**	**Jurisdictional Fragmentation**
Number	2.3.1	2.3.2	2.3.3
Question Addressed	To what degree is control over the basin resources fragmented by international borders?		
Rationale	The existence of international borders intersecting a lake basin adds a layer of complexity to integrated lake basin management. The degree to which the basin is fragmented along borders is dependent on the number of countries sharing the basin, their relative percentage of the area and population in the basin, as well as their history of cooperation and/or conflict. In short, basins that have higher degrees of jurisdictional fragmentation will require more effort and coordination to manage properly.		
Data (in addition to the data required to delineate the drainage basins)	Population from Landscan, International Borders from GADM	Same as Level 1.1 but also weighted by Annual average runoff (mm) from 1950-2000 calculated based on WorldClim	Same as Level 1.2 but additional information on history of cooperation and/or conflict among basin countries is included (Basins at Risk; Questionnaires)
New Indicator Introduced			**None**
Spatial Resolution	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)
Methods	1. Clip the GADM file to the lake basin extent. 2. Calculate population for each country in the lake basin. 3. Apply most appropriate method of aggregating values from 2 into a single number (still under investigation).	Same as Level 1.1 except annual average runoff is also weighted.	Same as Level 1.2 except the history of cooperation and/or conflict is also weighted.
Interpretation/Notes	The key issue is quantifying the degree of fragmentation, or more specifically, the relative difficulty that results from fragmentation along population, water resource, and historical lines. We are still testing several methods. It would also be possible to examine the extent of sub-national jurisdictional fragmentation if deemed necessary.		

Indicator 2.4: Linguistic Diversity (ILBM Category: Setting the Stage / Human Use)

	Level 1.1	Level 1.2	Level 1.3
Name	**Linguistic Diversity**	**Linguistic Diversity**	**Linguistic Diversity**
Number	2.4.1	2.4.2	2.4.3
Question Addressed	How linguistically diverse are the peoples living in the basin?		
Rationale	The existence of one or more international borders in a basin is seen as a factor that can complicate lake basin management. Often unexplored but equally challenging is the existence of various language groups in the basin. In theory, the greater the linguistic diversity, the more effort and coordination it will take to manage the basin properly.		
Data (in addition to the data required to delineate the drainage basins)	Population from Landscan, International Borders from GADM, Linguistic Groups from GMI	Same as Level 1.1 but weighted for the linguistic distance (not spatial distance) between the various language groups	Same as Level 1.2 but additional information on history of cooperation and/or conflict among linguistic groups is included (Questionnaires)
New Indicator Introduced			**None**
Spatial Resolution	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)
Methods	1. Clip the GMI file to the lake basin extent. 2. Calculate population for each language group in the lake basin. 3. Apply most appropriate method of aggregating values from 2 into a single number (still under investigation).	Same as Level 1.1 except the linguistic distance is also weighted.	Same as Level 1.2 except the history of cooperation and/or conflict among the groups is also weighted.
Interpretation/Notes	The key issue is quantifying the degree of diversity, or more specifically, the relative difficulty that results from needing to manage across linguistic lines. We are still testing several methods.		

Indicator 2.5: Landscape Alteration (ILBM Category: Setting the Stage / Human Use)

	Level 1.1	Level 1.2	Level 1.3
Name	**Landscape Alteration**	**Landscape Alteration**	**Landscape Alteration**
Number	2.5.1	2.5.2	2.5.3
Question Addressed	How much has the land in the lake basin been modified by humans?		
Rationale	The higher the level of landscape alteration, the greater the potential pressure on the lake.		
Data (in addition to the data required to delineate the drainage basins)	Human Influence Index ('Human Footprint' by WCS, CIESIN)	Global Land Cover Classification (USGS)	Land Use/Land Cover change through time based on classification of Landsat images (from 1970s to near-present)
New Indicator Introduced		**Cropland Extent (2.5.4)** **Urban Extent (2.5.5)**	**Irrigated Cropland Extent (2.5.6)** **Non-Irrigated Cropland Extent (2.5.7)** **Impervious Surface Extent (2.5.8)** **Forest Extent (2.5.9)** **Alteration of Littoral Zone (2.5.10)**
Spatial Resolution	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)	1 arc second (0.001 km^2) for recent data
Methods	1. Clip the Human Influence Index raster file to the lake basin extent. 2. Calculate the average Human Influence Index for the lake basin.	Different from Level 1.1. 1. Clip the GLCC raster file to the lake basin extent. 2. Calculate the total area of cells valued as Cropland and Urban for the lake basin.	Different from Levels 1.1 and 1.2. Image classification of Landsat images with groundtruthing and accuracy assessment using auxiliary imagery and anecdotal information.
Interpretation/Notes	Human alteration of the natural landscape in a lake basin (including the lake shoreline) is an important driver of water quantity and quality issues. To the highest spatial extent possible, we would like to know how the landscape has been altered. This category on Landscape Alteration uses three different levels of effort to gradually arrive at a more refined and exact measure of the human impact. If possible, it would be appropriate to include more detailed information such as amounts of fertilizer and pesticide application.		

Indicator 2.6: Flow Alteration (ILBM Category: Setting the Stage / Human Use)

	Level 1.1	Level 1.2	Level 1.3
Name	**Flow Alteration**	**Flow Alteration**	**Flow Alteration**
Number	2.6.1	2.6.2	2.6.3
Question Addressed	To what degree have humans altered the natural flow regime of the drainage basin?		
Rationale	The construction of dams, weirs, levees and embankments all have effects on the natural flow regime of rivers draining into and leaving lakes, and consequently on the timing of water availability and water level. Additionally, large-scale water diversions in and/or out of a basin affect water balance.		
Data (in addition to the data required to delineate the drainage basins)	Dam locations from Vorosmarty (2010) method based on GWSP-GRAND and ICOLD, inventory assigned to SWBD polygons, Annual average precipitation (mm) from 1950-2000 from WorldClim	Dam locations from Vorosmarty (2010) method based on GWSP-GRAND and ICOLD but refined based on a shape-based algorithm using SWBD polygons, Annual average runoff (mm) from 1950-2000 calculated based on WorldClim	Same as Level 1.2 but additional information on diversions included from Questionnaires. For Water Level Change, use information gathered under Indicator 2.5.3 (Landsat) and/or lake elevations from USDA Global Reservoir and Lake Monitor (OSTM Jason-1 Satellite Topex/Poseidon Satellite Mission GFO ERS-1 and ERS-2 ENVISAT)
New Indicator Introduced			**Relative Flow Diversion (2.6.4)** **Water Level Change (2.6.5)**
Spatial Resolution	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)
Methods	1. Match the Vorosmarty dam location with the SWBD polygons to identify which of our lake basins are 'reservoir' basins. 2. Calculate area of the basin (done for Indicator 1.1) 3. Calculate total amount of precipitation falling within the basin (done for indicator 1.1) 4. For a given basin, calculate the percentage of flow that comes from regulated basins (reservoir basins) and from unregulated basins ('lake' basins).	Same as Level 1.1 except the identification of reservoirs is augmented by performing a shape-based classification on the high-resolution SWBD (1 arc second) dataset.	Calculate the percentage of flow that is diverted in or out of a given basin using information from questionnaires. For lake level/area change, the method follows 2.5.3 for Landsat (classification, groundtruthing, accuracy assessment) and a more involved modelling framework for lake levels based on satellite altimetry.
Interpretation/Notes	Level one shows what percentage of the total water in a given basin flows through an impoundment. For reservoir basins, this will be 1, for lake basins with no impoundments, this will be zreo. Although the timing of changes in flow is important for ecosystem processes, it seems impossible to collect such information except on a case-by-case basis. Given the difficulty in predicting the future locations and sizes of reservoirs, we do not make any future projection. However, for a given case, it is possible to model the effects of a proposed reservoir (knowing its proposed location and height) using the SRTM and WorldClim data.		

Indicator 2.7: Relative Water Stress (ILBM Category: Setting the Stage / Human Use)

	Level 1.1	Level 1.2	Level 1.3
Name	**Relative Water Stress**	**Relative Water Stress**	**Relative Water Stress**
Number	2.7.1	2.7.2	2.7.3
Question Addressed	How scarce is water within the lake basin relative to human uses?		
Rationale	The higher the level of relative water stress, the more likely is conflict among stakeholders as well as threats to ecosystem health and biodiversity.		
Data (in addition to the data required to delineate the drainage basins)	Relative Water Stress Index (RWSI) from Water Systems Analysis Group at University of New Hampshire	Population from Landscan, International Borders from GADM, Estimates of Domestic, Industrial and Agricultural Water Demand (Various sources)	Same as Level 1.2 but modelled change based on projected changes in climate (WorldClim), Population (Landscan) with Projected Population change to 2050 from UN, and changes in water demand (not clear how to project this).
New Indicator Introduced			**Projected Relative Water Stress (2.7.4)**
Spatial Resolution	30 arc minutes (~2500 km^2)	30 arc seconds (1 km^2)	30 arc seconds (1 km^2)
Methods	1. Clip the RWSI raster file to the lake basin extent. 2. Calculate the average RWSI for the lake basin.	Same as Level 1.1 except index is calculated from high-resolution population data.	Same as Level 1.2 except values are estimates based on modelling results for 2050.
Interpretation/Notes	The greatest challenge to using this indicator in Level 1.1 is the lack of spatial resolution. Additionally, country-level data on demand are downscaled to the basin level. For Level 1.3, projections of population, climate and water demand are highly uncertain in the RWSI data.		

Indicator 3.1: Government Effectiveness (ILBM Category: Meeting the Governance Challenge / Institutions)

	Level 1.1	Level 1.2	Level 1.3
Name	**Government Effectiveness**	**Government Effectiveness**	**Government Effectiveness**
Number	3.1.1	3.1.2	3.1.3
Question Addressed	How effective is the government at addressing societal issues?		
Rationale	The perceptions of how effective a government is can be applied as a rough proxy for how effective government institutions are at lake basin management.		
Data (in addition to the data required to delineate the drainage basins)	Government Effectiveness Indicator from Governance Matters VIII Report (World Bank), GADM, Landscan	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Assuming the Government Effectiveness values have a normal distribution (and mean = 0, SD = 1), convert to percentile ranks. 2. Join the percentile-rank Government Effectiveness values to GADM national polygons 3. Clip the GADM file to the lake basin extent. 4. Calculate population for each country in the lake basin. 5. Multiply 3 by percentile-rank Government Effectiveness value for the respective countries. 6. Sum all values in 4. 7. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	The World Bank defines it this way: 'capturing perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.' This overlaps with the Policy indicators (4.1). We weight the values for each country based on the percentage of the population in that country's portion of the basin. Also, because the global values are scaled so that the mean is zero and the SD is 1, we assume a standard distribution and convert the values to percentile ranks to allow comparison.		

Indicator 3.2: Control of Corruption (ILBM Category: Meeting the Governance Challenge / Institutions)

	Level 1.1	Level 1.2	Level 1.3
Name	**Control of Corruption**	**Control of Corruption**	**Control of Corruption**
Number	3.2.1	3.2.2	3.2.3
Question Addressed	To what extent is corruption being controlled?		
Rationale	The higher the level of corruption, the less likely that lake basin management will be economically effective and socially equitable.		
Data (in addition to the data required to delineate the drainage basins)	Control of Corruption Indicator from Governance Matters VIII Report (World Bank), GADM, Landscan	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Assuming the Control of Corruption values have a normal distribution (and mean = 0, SD = 1), convert to percentile ranks. 2. Join the percentile-rank Control of Corruption values to GADM national polygons 3. Clip the GADM file to the lake basin extent. 4. Calculate population for each country in the lake basin. 5. Multiply 3 by percentile-rank Control of Corruption value for the respective countries. 6. Sum all values in 4. 7. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	The World Bank defines it this way: 'capturing perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as 'capture' of the state by elites and private interests.' We weight the values for each country based on the percentage of the population in that country's portion of the basin. Also, because the global values are scaled so that the mean is zero and the SD is 1, we assume a standard distribution and convert the values to percentile ranks to allow comparison.		

Indicator 4.1: Rule of Law (ILBM Category: Meeting the Governance Challenge / Policy)

	Level 1.1	Level 1.2	Level 1.3
Name	**Rule of Law**	**Rule of Law**	**Rule of Law**
Number	4.1.1	4.1.2	4.1.3
Question Addressed	To what extent are rules upheld and enforced?		
Rationale	The more strongly the rule of law is upheld and policies enforced and seen as legitimate by the governed, the more likely it is that lake basin management will succeed.		
Data (in addition to the data required to delineate the drainage basins)	Rule of Law Indicator from Governance Matters VIII Report (World Bank), GADM, Landscan	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Assuming the Rule of Law values have a normal distribution (and mean = 0, SD = 1), convert to percentile ranks. 2. Join the percentile-rank Rule of Law values to GADM national polygons 3. Clip the GADM file to the lake basin extent. 4. Calculate population for each country in the lake basin. 5. Multiply 3 by percentile-rank Rule of Law value for the respective countries. 6. Sum all values in 4. 7. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	The World Bank defines it this way: 'capturing perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.' We weight the values for each country based on the percentage of the population in that country's portion of the basin. Also, because the global values are scaled so that the mean is zero and the SD is 1, we assume a standard distribution and convert the values to percentile ranks to allow comparison.		

Indicator 5.1: Voice and Accountability (ILBM Category: Meeting the Governance Challenge / Participation)

	Level 1.1	Level 1.2	Level 1.3
Name	**Voice and Accountability**	**Voice and Accountability**	**Voice and Accountability**
Number	5.1.1	5.1.2	5.1.3
Question Addressed	To what extent can stakeholders meaningfully participate in the decision making process?		
Rationale	The easier it is for stakeholders to participate, the more legitimacy and effectiveness the resulting policies will have.		
Data (in addition to the data required to delineate the drainage basins)	Voice and Accountability Indicator from Governance Matters VIII Report (World Bank), GADM, Landscan	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Assuming the Voice and Accountability values have a normal distribution (and mean = 0, SD = 1), convert to percentile ranks. 2. Join the percentile-rank Voice and Accountability values to GADM national polygons 3. Clip the GAADM file to the lake basin extent. 4. Calculate population for each country in the lake basin. 5. Multiply 3 by percentile-rank Voice and Accountability value for the respective countries. 6. Sum all values in 4. 7. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	The World Bank defines it this way: 'capturing perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.' We weight the values for each country based on the percentage of the population in that country's portion of the basin. Also, because the global values are scaled so that the mean is zero and the SD is 1, we assume a standard distribution and convert the values to percentile ranks to allow comparison.		

Indicator 6.1: Access to Improved Sanitation (ILBM Category: Meeting the Governance Challenge / Technology)

	Level 1.1	Level 1.2	Level 1.3
Name	**Access to Improved Sanitation**	**Access to Improved Sanitation**	**Access to Improved Sanitation**
Number	6.1.1	6.1.2	6.1.3
Question Addressed	How widespread is access to improved sanitation?		
Rationale	One of the greatest stressors on water quality (and consequently, health) is human excreta. The extent to which excreta are treated in the drainage basin (either on-site or through a sewerage system) is a simple but clear indicator of the amount of likely human stress on a given water body.		
Data (in addition to the data required to delineate the drainage basins)	Access to Improved Sanitation (World Bank using WHO, UNCF, JMP), GADM, Landscan	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Join the Access to Improved Sanitation values to GADM national polygons 2. Clip the GADM file to the lake basin extent. 3. Calculate population for each country in the lake basin. 4. Multiply 3 by Access to Improved Sanitation value for the respective countries. 5. Sum all values in 4. 6. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	The World Bank states: 'Access to improved sanitation facilities refers to the percentage of the population with at least adequate access to excreta disposal facilities that can effectively prevent human, animal, and insect contact with excreta. Improved facilities range from simple but protected pit latrines to flush toilets with a sewerage connection. To be effective, facilities must be correctly constructed and properly maintained.'		

Indicator 7.1: Coverage in Literature (ILBM Category: Meeting the Governance Challenge / Information)

	Level 1.1	Level 1.2	Level 1.3
Name	**Coverage in Literature**	**Coverage in Literature**	**Coverage in Literature**
Number	7.1.1	7.1.2	7.1.3
Question Addressed	How many times does a given lake appear in the scientific literature?		
Rationale	The more times a lake appears in the literature, the more likely it is that policy-relevant information is available.		
Data (in addition to the data required to delineate the drainage basins)	Google Scholar, NGA-GNS	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Basin level	Basin level	Basin level
Methods	1. Determine the lake name from NGA-GNS data (and auxiliary sources if necessary) 2. Search Google Scholar for the given name in both English and in any native languages of the lake area. 3. Tally the results.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	This is a very rough way of determining how much scientific information is available on a given lake. It does not consider the lake basin because (1) that would be much harder to search for because of the vast number of place/feature names and (2) until fairly recently, most studies have focused on lakes and not their basins. If assigning lake names using the NGA-GNS data is too difficult for Level 1.1 lakes, it may be more readily done in Level 1.2.		

Indicator 8.1: Gross National Income (ILBM Category: Meeting the Governance Challenge / Finance)

	Level 1.1	Level 1.2	Level 1.3
Name	**Gross National Income**	**Gross National Income**	**Gross National Income**
Number	8.1.1	8.1.2	8.1.3
Question Addressed	How wealthy are the people in the lake basin?		
Rationale	The wealthier the basin population is, the more funds that will be available for lake basin management programs.		
Data (in addition to the data required to delineate the drainage basins)	Gross National Income per Capita (World Bank), GADM, Landscan	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Join the GNI per capita values to GADM national polygons 2. Clip the GADM file to the lake basin extent. 3. Calculate population for each country in the lake basin. 4. Multiply 3 by GNI per capita value for the respective countries. 5. Sum all values in 4. 6. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	This indicator is a rough approximation of average national-level funds available for lake basin management but scaled to the basin-level and averaged across basin countries. It is also possible to use the relationship between GNI/capita and pollution loading to estimate the effects of a population on a given lake. However, these relationships are not clear enough for complex processes that occur at the basin level so we have not made use of this idea.		

Indicator 8.2: Overseas Development Assistance (ILBM Category: Meeting the Governance Challenge / Finance)

	Level 1.1	Level 1.2	Level 1.3
Name	**International Development Support**	**International Development Support**	**International Development Support**
Number	8.2.1	8.2.2	8.2.3
Question Addressed	How much foreign funding is available on a per capita basis?		
Rationale	The more foreign funding available at the national level (on a per capita basis), the more funds that will be available for lake basin management programmes.		
Data (in addition to the data required to delineate the drainage basins)	Net ODA received per capita in current US$ (World Bank based on OECD), GADM, Landscan	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Join the ODA per capita values to GADM national polygons 2. Clip the GADM file to the lake basin extent. 3. Calculate population for each country in the lake basin. 4. Multiply 3 by ODA per capita value for the respective countries. 5. Sum all values in 4. 6. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	World Bank notes: 'Net official development assistance (ODA) per capita consists of disbursements of loans made on concessional terms (net of repayments of loan principal) and grants by official agencies of the members of the Development Assistance Committee (DAC), by multilateral institutions, and by non-DAC countries to promote economic development and welfare in countries and territories in the DAC list of ODA recipients; and is calculated by dividing net ODA received by the mid-year population estimate. It includes loans with a grant element of at least 25 per cent (calculated at a rate of discount of 10 per cent). Data are in current U.S. dollars.'		

Indicator 9.1: National IWRM Plans (ILBM Category: Meeting the Governance Challenge / Planning)

	Level 1.1	Level 1.2	Level 1.3
Name	**National IWRM Plans**	**National IWRM Plans**	**National IWRM Plans**
Number	9.1.1	9.1.2	9.1.3
Question Addressed	Do countries in the basin have official IWRM plans?		
Rationale	National-level IWRM plans can form basis for ILBM. Their existence implies a certain capacity and willingness of a country to manage resources in an integrated fashion.		
Data (in addition to the data required to delineate the drainage basins)	Global Water Partnership	Same as Level 1.1.	Same as Level 1.1.
New Indicator Introduced			**None**
Spatial Resolution	Country level	Country level	Country level
Methods	1. Determine from GWP information whether or not each basin country has national IWRM plans or not. 2. Join the results (1 for yes, 0 for no) to GADM national polygons 3. Clip the GADM file to the lake basin extent. 4. Calculate population for each country in the lake basin. 5. Multiply 3 by the value determined in step 1 for the respective countries. 6. Sum all values in 4. 7. Divide 5 by total basin population.	Same as Level 1.1.	Same as Level 1.1.
Interpretation/Notes	Simply adopting an IWRM plan is not as important as having one implemented effectively; however, for this indicator, we do not make judgments about the state of implementation or the direct effects that this may have on a given country's portion of a given lake basin.		

Indexes

The wealth of information generated through populating the indicators, answering questionnaires, interactions during the workshops, and any other forms of knowledge generation must be condensed into a form that facilitates the ranking of high-risk transboundary lake basins. It is important that information is not lost in this process. Furthermore, this condensation must take place near the end of each level.

Considering just the indicators first, one traditional approach is the creation of one or more indexes. This is done by:

- Scoring or scaling the value of all indicators to a form that makes them comparable (such as to a fixed scale such as from zero to 1)
- Weighing the indicators against each other to form one or more composite indexes.

While scaling the indicators using a statistical approach based on creating Cumulative Distribution Functions (CDF) is without much controversy, assigning weights is fraught with peril and not recommended because instead of clarifying the evaluation process, there is a risk that important information remains hidden.

Given the vast range of types of information contained in the indicators, we recommend a simpler spreadsheet-based, iterative method. Each indicator will be scaled to a value between zero and 1 based on the CDF of the indicator across all lake basins. For ease of comparison, quartiles (or quintiles perhaps) can be shown in colour from red through yellow to white. The filter and sort commands can be used to browse the results and make decisions that can be executed in the spreadsheet. (We will provide an example of this approach before the end of the MSP, if requested.)

The issue remains, especially for Level 1.3, of how to make use of the non-indicator-based information which is crucial but not easily quantified. We suggest that active participation of the GEF and other stakeholders in the Workshops along with Expert Group Meetings is one possible method for ensuring the gradual development of consensus regarding the final ranking.

Scoring

See discussion on Indexes.

Part IV. Links with Other Water Systems

Links between water systems

Background

The final aspect of project implementation deals with the issue of how each specific water system—groundwater, lake, river, coastal zone/large marine ecosystem, and open ocean—interacts with other water systems. These systems are connected through the hydrological cycle, and the ecosystem services they provide. In addition, many if not all of the systems face some common threats or concerns, including those related to global change. In this regard, the connectivity of water resources needs to be evaluated and understood. This is a major role of the Level 2 analysis.

The Hydrological Connection

Lakes and reservoirs receive and discharge their waters in various ways. The most direct route for receiving water is through direct precipitation onto the lake surface. Precipitation is associated with the global circulation and can bring with it contaminants introduced into the atmosphere by natural events (volcanic activities, for example) and human activities (residue from industrial operations discharged into the atmosphere from smokestacks, for example). In this regard, the introduction of anthropogenic mercury into lakes is a classic example of how contaminants can be found in waters well away from the source areas of the contaminants. In addition, water enters many lakes through overland flow. Such flows, whether directly into a waterbody from the lakeshore lands or indirectly through a stream or river, carry with them a wide range of contaminants from the land surface. Some of these are conveyed into the drainage ways through human actions, such as placement of stormwater transfer systems, while others are generated through natural processes of erosion and decomposition of materials such as leaf litter. Finally, water is conveyed into lakes and reservoirs through groundwater flows. Depending upon the local geology, these can also bring contaminants into surface water systems.

The Human Connection

As alluded to above, humans and their use of the landscape can modify the hydrology and influence the delivery of contaminants to natural water systems. Rooftops, pavements, and roadways all modify the rate at which precipitation can be infiltrated into the groundwater system, for example, as well as affecting the rate at which water runs off into streams and lakes. Pavements also form a convenient collection point for many types of contaminants ranging from metals generated by automobiles, phosphorus from exhaust systems of vehicles, and litter and debris arising from daily human lives. In many countries, such debris is periodically collected through street sweeping or refuse collection programmes. While these reduce the level of contamination of rivers and lakes, they also create other concerns in terms of the concentration of contaminants in dumps and disposal sites. Landfilling is widely used as a means of managing concentrated areas of waste disposal.

Solid waste management is a further example of good practice that has spread throughout human society, related to anti-littering campaigns in many countries. These seek to engage society through education in schools, and through community action such as awareness programmes and sign placement.

Water Quantity

It is axiomatic that all life depends upon water. Access to clean freshwater in appropriate quantities is seen as a fundamental human right, and providing such access has been a major driver of human progress from early times. Some of the oldest known structures created by humans were created for the purpose of water supply and sanitation. However, water of the appropriate quantity and quality is unequally distributed around the world, with large volumes being tied up in glaciers and polar ice. Of the remainder, most usable freshwater is contained in lakes and reservoirs, the latter being structures created for the specific purpose of making the necessary volumes of water available for human use. Freshwater also is subject to contamination, and in extreme cases of pollution can become practically unusable without exhaustive and expensive treatment.

Global-change models suggest that the volumes of available water will become increasingly scarce, with many parts of the world becoming hotter and drier. Rainfall, a major driver of runoff and infiltration, is expected to occur less frequently but at higher intensities, with greater risks of flood flows interspersed by drought. These changes will not only affect the availability of water for human uses, but also modify the habitat needed by other organisms, including fish that form a major portion of the diets of much of the world's population. Some of these modifications in flow regime will also change levels of erosion and sediment transport, affecting water-borne commerce and threatening major urban centres, both from the point of view of damaging or destroying infrastructure and impacting economic activities such as farming.

Under such conditions of change, ensuring adequate water storage in the landscape takes on greater urgency, both from the point of view of ensuring adequate supplies of water of suitable quality for human consumption and for protecting human infrastructure from inundation by floods. In this regard, the role of reservoirs assumes increasing importance not only in terms of new construction but also in terms of maintaining and/or modifying older infrastructure to limit the risk of dam failure in the event of more intense flooding.

Nutrients and Eutrophication

Changing patterns of rainfall and runoff have implications for nutrient loading and dynamics in freshwater systems. Fish and other aquatic organisms need an adequate volume of water in which to grow and an appropriate mass of phosphorus, nitrogen and carbon as a basis for growth. In certain circumstances, nutrient enrichment can spur the growths of blue-green algae which can develop toxic strains that threaten wildlife, domestic animals, and even humans.

Under conditions of enrichment, freshwater resources become less able to serve human purposes without significant treatment. While enrichment may not affect passive water uses such as navigation, and may even benefit some water uses such as irrigation—in the sense that the waters can supply additional nutrients needed to cultivate crops—many other uses are placed at risk. The production of algal toxins has already been noted, while the potential damage to turbines and other infrastructure from anoxic water can have significant negative impacts on ecosystems, as well as on the ability of water to continue to serve economic purposes. Lakes and reservoirs are at greater risk from enrichment than other waterbodies due to their previously-noted integrating nature, long retention time and complex response dynamics. Their retention times are such that there is often adequate time for algal growths to occur, for example, which may not be the case in flowing water systems. In this regard, lakes, large marine ecosystems (LMEs) and open oceans share some of the same characteristics, although algal blooms in coastal seas are usually associated with red algae and not blue-green algae. Nonetheless, the risks to humans and wildlife are considerable.

Vulnerability to Climate Change

All five water systems are at some level of risk from global climate change, and many of the consequences of global change are related to shifts in the open oceans. In this way, there is a feedback loop from open oceans to terrestrial water systems, since the moisture that forms rains over the continents is largely supplied by evaporation from the ocean surface.

As noted above, climatic variability affects runoff to lakes and reservoirs, and as a consequence influences the flushing rate, the rate at which a volume of water equal to the volume of the lake passes through the waterbody. The timing of rainfall events also influences the timing of the flushing. If rainfall becomes more episodic, there is a likelihood that algal growth, and possibly blue-green algal growth, will benefit, increasing human health risks from cyanotoxins.

Changing hydrological conditions may also alter the patterns of stratification in lakes and reservoirs. Many elements are released from sediments during periods of stratification, some of which are potentially toxic while others, such as phosphorus, may alter the essential character of lakes by contributing to alterations in species composition. Changes in the species composition in the primary levels of the aquatic food web can have knock-on effects across the food web, with concomitant impacts on the human communities depending on aquatic resources for survival.

Biological Productivity

It is a general principle of aquatic science that biological organisms respond to changing levels of nutrients and sunlight. In this regard, global change, as noted above, may have a multi-faceted impact on biological productivity, ranging from modifying the timing of delivery of nutrients to aquatic systems, nutrient residence times within aquatic systems, and the internal dynamics of waterbodies affecting nutrient availability, especially from sediment sinks. A further consequence of global change may be changing frequencies of cloudiness and changes in insolation. Such changes would have direct impacts on the ability of primary producers to photosynthesize and reproduce. They could even lead to species shifts. All of these possible impacts would extend across the entire food web.

The consequences of nutrient enrichment in terms of species change have already been mentioned, but alterations in species composition would have further impacts on the magnitude of biological production. Declines in production could reduce outputs of economically valuable species or even contribute to a shift in species such that economically valuable species are overwhelmed by species of less value.

Finally, in indirect terms, changing hydrology may also affect reproduction success in species, especially amongst potandromous and anandromous fishes that require river flows at specific seasons in order to reproduce. Shifts in rainfall periodicity and intensity – such as more intense and less frequent storms - could benefit some species at the expense of others. Such impacts could extend throughout the rivers, lakes and coastal marine systems.

Mercury

For thousands of years, civilizations ancient and modern have found mercury to be useful in many ways. Worldwide industrial use of mercury in mining and manufacturing, and discharges as emissions from power stations, have greatly increased concentrations of mercury in the environment. Unfortunately, knowledge of the health affects has been gained only relatively recently, since the 1950s. Currently, health concerns centre on exposure to methyl-mercury contamination in fish, shellfish, birds, reptiles and fish-eating mammals.

Mercury is in a class of chemicals called persistent bioaccumulative toxins. Mercury persists in the environment for long periods by cycling back and forth between the air and soil surface, all the while changing chemical form. Mercury is never removed from the environment; it just moves to other locations and may eventually be buried under lake sediments. Bacteria can act upon this available elemental mercury and convert it into several organic mercury compounds, collectively called methyl mercury (Me-Hg). This is more toxic and difficult to remove from bacterial systems than inorganic mercury. Any higher-level organisms that consume these bacteria also consume the Me-Hg. This cycle repeats up the food chain, with each higher predator consuming more and more Me-Hg, ultimately arriving in fish. Estimates suggest that Me-Hg can accumulate more than a million-fold in the aquatic food chain. As humans consume fish, the Me-Hg in the fish is also consumed, and if mercury is consumed at a faster rate than our bodies can remove it, humans also bioaccumulate Me-Hg. By consuming less Me-Hg contaminated foods, concentrations in bodies will decrease. This idea has led to the fish-consumption warnings for mercury, particularly for children and pregnant women.

Neurotoxicity is the most important health concern associated with mercury contamination. Methyl mercury easily reaches the bloodstream and is distributed to all tissues; it can also cross the normally protective blood-brain barrier and enter the brain. It will also readily move through the placenta to developing fetuses, and so it is of particular concern to pregnant women. Low-level exposure is linked to learning disabilities in children, along with interference in reproduction of fish-eating animals. Also, both methyl mercury and mercuric chloride are listed by the U.S. Environmental Protection Agency (US EPA) as possible human carcinogens.

The effects of changing patterns of global circulation on mercury distribution and deposition are less clear than the potential effects of climate change on nutrients and runoff. For one thing, the amount of mercury being released into the environment is being reduced and is expected to continue to diminish as replacement products are developed and distributed, and as air pollution control equipment is improved and implemented. Further, there is an increasing body of evidence being developed with respect to mercury of geological origin, suggesting that some mercury inputs are the result of natural processes from igneous rock formations and naturally occurring slightly acidic in-lake conditions in parts of the north temperate zone dominated by coniferous forest. The implications of this situation for future lake management remain unclear.

Input-output analysis

Among the five TWAP waterbody types, the strongest link for lakes is the one with rivers. The most distant is the one with the open ocean. And on a case-by-case basis, lakes and groundwater and large marine ecosystems are linked but often the link is distant.

The relationship with rivers is intimate and two-fold. Almost all lakes receive water from inflowing rivers (although in certain cases, direct precipitation, diffuse runoff and/or groundwater are dominant) and many lakes drain through a main outlet river (except endorheic lakes which have no outlets and are usually saline but of great importance). Therefore, many of the indicators that are suggested here for lakes are equally relevant for rivers. In fact, the only indicators suggested here (apart from the questionnaire which is quite lake basin-centric) which are not readily applicable to rivers are 1.2 (Lenticity) and 1.3 (Lake to Basin Area), but even lenticity relates to rivers in the sense that it represents a measure of the relative amounts of lentic to lotic water in a basin.

The greatest difference between the rivers indicators and the lakes indicators is perhaps that the ones for lakes focus on a much larger size range of systems than the ones for rivers. In general, rivers in TWAP are taken as continental-scale river basins such as the Nile and Ganges. For lake basins, we are looking at all transboundary lake basins (for Level 1.1) numbering tens of thousands with many of the order of less than 100 km^2. This necessitates an approach that includes information available at a sufficiently high resolution to allow the appropriate ranking of even the smallest systems. This has, in turn, prevented the lakes group from making use of some indicators available to the rivers group such as the Global NEWS dataset.

The proposed Level 2 analysis will be an important way in which the links between the various waterbodies are developed with a focus on how the trans-system links affect transboundary water management. We propose that Level 2 is carried out on 4~5 transboundary water systems that have long records that will permit sufficient examination. Possible cases that contain major aquifers, lakes, LMEs, and rivers include:

- Nile Basin (10-11 countries from Rwanda to Egypt draining to the Mediterranean)
- Ohrid-Schkoder Basin (Greece, FYR Macedonia, Albania draining to the Mediterranean)
- San Juan-Cocibolca Basin (Nicaragua, Costa Rica draining to the Caribbean)
- Himalayan Drainage System (to look especially at the role of glaciers on the rivers, lakes, aquifers and multiple LMEs fed by this ‘water tower’)
- Biwa-Yodo Basin (draining to Osaka Bay)

Each of the TWAP working groups (except Open Oceans which is quite distinct) would work together to compare and validate their independent methodologies.

Cross-cutting issues: Transboundary lake-river complexes and ecosystem service framework

See section on Links above.

Part V. Data and Information Management

Data Management

General Issues

The Transboundary Lake Basin Assessment component of the TWAP exercise will generate a considerable amount of information. Most of it will be:

- **New**. The simple act of delineating such a large number of previously un-delineated basins is a major accomplishment and will be of great interest to a wide community of stakeholders. The information contained in the indicators described in Part III will be of even greater value to those concerned with lake basin management even if they never carry out a project with GEF funds.
- **Spatial**. All the indicators discussed in Part III are managed in a geographic information system (GIS). There will be much vital information in the questionnaires that is not initially in the GIS (e.g., answer to questions like 'what is needed to achieve further institutional integration?') but all the information generated in questionnaires for a given lake basin is indeed location specific and can be geo-referenced.
- **Of wider interest**. Although this analysis is focused on transboundary lake basins, the ideas and information generated from the analysis can easily be applied to other sorts of 'transboundary' situations including lake basins that are strictly national but divided by sub-national borders or to lake basins whose management is spread over national sectors and poorly integrated.

During the FSP

During the FSP, this information will be managed in-house at ILEC by the Technical Coordinator. It will be available to the other TWAP working groups, GEF and other stakeholders through a password-protected site. As far as possible, it will be presented as a geo-database, i.e. all information will be geo-referenced, including PDFs, etc. that are generated during the questionnaire and workshop phase. Digital copies will be available on hard media for those with slow Internet connections.

Appropriate links will also be made according to the forthcoming decisions of the Information Management and Indicators Working Group (IMIWG).

After the FSP

The geo-database will be made public and openly accessible through ILEC's server. If convenient, project documents can also be put into IW:Learn although the highly-spatial data will probably require a dedicated solution.

Information Management

LAKES (a knowledge-based search engine specifically developed for ILBM)

To manage lake basins effectively, the meaning of lake basin governance must be well understood by basin stakeholders. The questionnaires to be prepared by the local stakeholders, together with information contained in existing reports on lake basin management experiences and lessons learned, and in the World Lake Database, will help increase understanding of the meaning of lake basin governance, thereby helping to meet its challenges. Such wide-ranging sources of quantitative and qualitative information need to be integrated into various forms of the knowledge base, each serving a specific purpose. Two approaches are currently being pursued. One is the development of the ILBM Training Module. The other is development of the interactive information search and display system called 'Learning Acceleration and Knowledge Enhancement System' (LAKES). LAKES has been refined over several years, in cooperation with the Research Institute for Humanity and Nature.

A great deal of information and knowledge about the world's water systems has been acquired and documented in the past century. An increasing amount of this knowledge is being archived on the Internet, but for many countries the compilation and dissemination of information remains problematic, especially for those countries and lakes located outside the temperate zone. As recently as 1980, it was said that there was little known about tropical lakes, despite significant knowledge being available in regional journals and other publications. Yet even in this situation the impression persists that tropical limnology and lake studies lag behind those of Europe and North America, leading to the introduction of terms such as ‘literary imperialism’ to describe the tendency for ‘mainstream’ journals to publish work from the northern hemisphere.

To address this bias, the University of Shiga Research Center for Sustainability and Environment, in cooperation with ILEC and the Ministry of Education, Culture, Sports, Science and Technology of Japan, have created an innovative document management system and search tool known as LAKES, the Learning Acceleration and Knowledge Enhancement System, to quickly and efficiently store and analyse a range of documents dealing with the full range of lake-related issues. Through the application of this search engine, supplemental data on specific water systems can be accessed and included in the Level 1.3 assessment, providing at times more detailed analysis of specific lake and reservoir systems and issues of concern. Consequently, it is proposed that the Level 1.3 analysis be supplemented by information gleaned from the analysis of regionally and locally relevant documents to be obtained by the regional centres of excellence.

Part VI. Towards Implementation of the Transboundary Lake Basin Assessment

Partnerships and institutional arrangements

ILEC has a broad international network created through its 24 years of existence. It ranges from international agencies such as GEF, the World Bank, and UN agencies (UNEP in particular) to national-level ones especially the Ministry of Environment, Ministry of Foreign Affairs (JICA), and Ministry of Education in Japan as well as a growing network of national government connections garnered through the World Lake Conference and activities of ILEC Scientific Committee members' activities (e.g. the SciCom chair's Governance project with national-level activities in Nepal, Malaysia, Mexico and many other countries). Finally, ILEC has strong roots at the local level in many lake basins around the world. These links have been fostered through a variety of ILEC activities through the years including the JICA ILBM training course and the World Lake Conferences.

The TWAP project will allow a significant broadening and deepening of this network. One major reason will be the interaction among the various Working Groups. In particular, the Rivers and Groundwater working groups have expertise which needs to be applied to many of the crucial questions that arise in Lake Basin Management and ILEC looks forward to maintaining and growing ties during the FSP.

Validation

Validation of the currently proposed methodology will take place through the upcoming discussions in response to this draft between the various working groups and the GEF secretariat. We will provide an example of Africa (Nile Basin and select upstream lake basins) to illustrate the value and practicality of the proposed indicators. The questionnaire and workshop-based information-gathering phase has been well tested in other GEF and non-GEF projects. Suggestions for change will be incorporated in the pre-FSP phase.

Validation of the results of the methodology will be made at the end of each Level (1.1, 1.2 and 1.3) through testing against well-known cases. Evaluation by stakeholders will be a key validation step at the end of Level 1.3 and through Level 2.

Capacity building needs

Regional/Local Needs

One of the most important long-term objectives of TWAP is to have a catalytic effect on stakeholders and institutions working on transboundary basin assessment and management. This requires capacity building of selected individuals/groups, which will be covered partly through the questionnaire/review meeting process (Level 1.3) but, in some cases, will require further activities.

Staffing Needs

We expect that the following incremental personnel capacity will be needed to ensure satisfactory implementation of the Lakes WG portion of the TWAP-FSP.

- **Project Manager**. A part-time, senior position responsible for the overall conduct of the FSP including participation in relevant FSP-related meetings.
- **Senior Advisor**. A part-time position for a global expert with broad experience in ILBM and international policy development responsible for guiding the overall work of the FSP team.
- **Technical Coordinator**. A near full-time position for an expert in both GIS and ILBM to work on the technical aspects of the FSP including populating the indicator geo-database at all three levels as well as designing and interpreting the questionnaire.
- **GIS/Remote Sensing/Hydrology Experts**. We expect to engage 3-4 part-time world experts on a range of technical issues to work with the Technical Coordinator.
- **Technical Assistant**. A full-time technical assistant will be needed to help the Technical Coordinator.
- **Administrative Assistant(s)**. One full-time assistant will be required throughout the whole project and one additional assistant will be needed for the final two years (Level 1.3 and Level 2).

Financial resources necessary for the implementation

Assuming an approximate budget of $2 million for the lakes portion of the FSP, the major categories of planned expenditure are:

- $750 000 for obtaining detailed answers to the questionnaires carried out in Level 1.3. This assumes 75 lake basins identified for Level 1.3 analysis at $10 000 per questionnaire (similar to the LBMI project). These will be mostly experts and other stakeholders from each lake basin with almost all from developing countries. Each questionnaire will have approximately 2 to 5 people working on it depending on the complexity.
- $300 000 for the stakeholder and questionnaire review meetings. This assumes 10 meetings at $30 000 each (again, similar to the LBMI project but providing more focused discussion). The attendees will be key contributors to the questionnaire plus other stakeholders as appropriate. Meetings will be held in convenient locations in developing countries.
- $100 000 for expert group meetings. This will include the main project staff and other TWAP groups as necessary. Most meetings are likely to take place at the ILEC headquarters.
- $800 000 for the staffing discussed in the Capacity Building section above.
- $50 000 for purchase of proprietary data sets and software as well as some dedicated GIS analysis computer systems.
- Additional funds for regional/local capacity building (contingent upon the scale and scope not yet determined).

There figures do not include the in-kind contribution which is forthcoming from ILEC in terms of personnel, logistical and administrative support as well as the contributions from ILEC's global network of experts in the Scientific Committee.

Note that the easiest place to either expand or reduce the required funding is through the number of lake basins identified for Level 1.3 analysis.

Beyond FSP: Development of Regional ILBM Platforms both for TWAP and non-TWAP Lake Basins (Additional Section not in Main Outline)

The final output of the TWAP-Lake Assessment Methodology approach has to be integrated into the global, regional, national and local ILBM 'platforms', the development of which will imminently require a concerted effort by the relevant international and global initiatives. These platforms will have to be developed for a large number of lakes of concern with a focus on lake basin governance which will have to be enhanced through an iterative approach based on continuing adaptation and refinement with relevant data and information (see figure 7). ILEC has begun to explore the possibility of developing and sustaining such ILBM platforms in a number of countries over the past several years, including China, India, Japan, Kenya, Malaysia, Mexico, Nepal, Philippines and Russia. It is apparent that the success of the post-TWAP transboundary water management projects will depend largely on the development and implementation of such platforms for a broad spectrum of local, regional and national stakeholders, including governments, that can be sustained autonomously with catalytic inputs from the international initiatives, transboundary or otherwise.

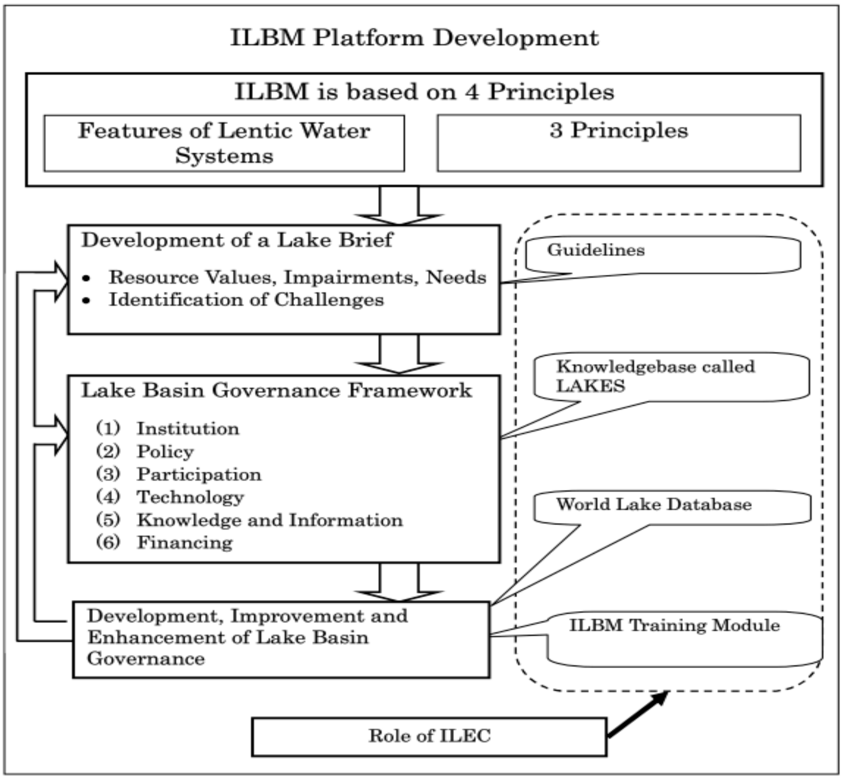

Figure 7. Overview of ILBM Assessment and Management Platform

The procedural details of the approach are given at:

http://www.ilec.or.jp/eg/pubs/ILBM/Guidelines_for_Lake_Brief_Preparation.pdf

Some of the ongoing efforts for the promotion of this approach are given at:

http://rcse.edu.shiga-u.ac.jp/gov-pro/eng/

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Annex I. Working Group Members

Name	Affiliation	Major Areas of Responsibility
Ballatore, Thomas	Visiting Researcher, ILEC	Development of geospatial indicators and their integrated analysis; lead author
Lin, Hebin	Kyoto University	Compilation and synthesis of background information (application of PES framework)
Matsumoto, Satoru	ILEC Secretariat	Secretariat Coordination and Liaisoning
Muhandiki, Victor	Nagoya University	Compilation and synthesis of background information (mainly water quality indicators)
Nakamura, Masahisa	Shiga University, ILEC Scientific Committee	Development and refinement of ILBM-TWAP analytical framework
Rast, Walter	Texas State University, ILEC Scientific Committee	Overall program development and technical coordination on ILBM-TWAP framework
Thornton, Jeffery	Southeastern Wisconsin Regional Planning Commission	Consultative inputs on past GEF experiences and on development of governance framework

Annex II. Data Sources and Partners

Data Sources for Part II Inventory of Transboundary Lake Basins

For the inventory of transboundary lake basins in Part II, we will use the following sources as base data for input and processing in GIS.

For elevation data, we use NASA's SRTM dataset available at

http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/

For waterbody locations, we use NASA's SWBD dataset available at

http://dds.cr.usgs.gov/srtm/version2_1/SWBD/

For the Level 1.1 analysis, we take pre-delineated river basin polygons and a flow direction raster from Hydrosheds (USGS, World Wildlife Fund) available at:

http://gisdata.usgs.gov/website/HydroSHEDS/

Data Sources for Part III Indicators

Building on the drainage basins delineated in Part II with NASA (SRTM, SWBD) and USGS/WWF (Hydrosheds) data, we do calculations in GIS with spatially referenced information from the following sources (described in order as they appear in the indicators list).

For climate-related data (1950-2000 average precipitation and average temperature as well as projections for the same for 2050) we use the WorldClim dataset available at

http://www.worldclim.org/

For 2008 population figures, we use the Landscan data set from the Oak Ridge National Laboratory available at

http://www.ornl.gov/sci/landscan/

For population projections, we use the United Nations Population Fund (UNFPA) data available at

http://www.unfpa.org/public/

Human Development Index values for 2008 come from UNDP at

http://hdr.undp.org/en/statistics/

Administrative boundaries are taken from the Global Administrative Areas dataset available at

http://www.gadm.org/

Basins at Risk data comes from Oregon State University's Program in Water Conflict Management and Transformation available at

http://www.transboundarywaters.orst.edu/research/basins_at_risk/

Information about languages comes from World Language Mapping System (based on Ethnologue) from Global Mapping International available at

http://www.gmi.org/products/gis/wlms/

The Human Footprint data are available from CIESIN (Columbia University) and Wildlife Conservation Fund at

http://www.ciesin.columbia.edu/wild_areas/#

The Global Land Cover Characterization is available from USGS at

http://edc2.usgs.gov/glcc/glcc.php

Landsat images are available from NASA and USGS at

http://glovis.usgs.gov/

Some information on the location of dams will be based on Vorosmarty et a. 2010. *Global threats to human water security and river biodiversity*. Nature **467**: 555–561, which is in turn based on GWSP-GRAND and ICOLD data available from those respective sources.

Lake elevation data will be taken from USDA's Global Reservoir and Lake Monitor (or calculated using the same methods) available at

http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

The Relative Water Stress Index data will be taken from the University of New Hampshire's Water Systems Analysis Group dataset available at

http://www.wsag.unh.edu/

The governance-related indicators Government Effectiveness, Control of Corruption, Rule of Law, and Voice and Accountability are taken from the World Bank Governance Indiators available at http://info.worldbank.org/governance/wgi/index.asp

Information on GNI per capita, ODA, and access to improved sanitation is available from the World Bank at

http://data.worldbank.org/indicator/

Lake and other feature names is available from the National Geospatial-Intelligence Agency's GEOnet Names Server at

http://earth-info.nga.mil/gns/html/

Finally, information about the existence of national-wide IWRM plans will be taken from the Global Water Partnership at

http://www.gwp.org/

Data Sources/Partners for Part III Questionnaire

The questionnaire which forms a large part of the Level 1.3 analysis will need to be filled out by a group of stakeholders within each lake basin. The composition of these teams will depend on the lake basin and will need to be flexible to reflect the inherent difficulty in collecting information of this nature. Although ILEC has an extensive network from which appropriate teams can be identified, it will be desirable to receive suggestions from all TWAP members and beyond.

Annex III. Description of Indicators

See Part III.

Annex IV. Glossary of Terms

Algal blooms – The growth of algae in lakes to excessive levels that can cause a range of negative environmental impacts, including water quality degradation and interference with beneficial human water uses. The decay of large algal blooms can sometimes extract sufficient oxygen from lake waters to lead to fish kills.

Algal toxins – Organic materials associated with microscopic photosynthetic Cyanobacteria in lakes, many of which can be toxic to animals, including humans.

Anthropogenic – Being of human origin, or resulting from human activities.

Aquifer – An underground layer of rock or soil sufficiently porous to store significant quantities of water; major source of drinking water on a global scale.

Artisanal – Referring to a worker or labourer with a particular skill or trade (such as fishermen).

Bathymetry – The measurement of water depths in lakes.

Benthic – Referring to organisms that live at or near the bottom of a lake.

Bioaccumulation – The build-up of material (such as toxic substances) within the body of an organism.

Biocide – A chemical that can kill a large variety of living organisms, including humans.

Biodiversity – A measure of the variety of kinds of animals and plants present in a given environmental compartment (such as lakes) over a given time period.

Bio-manipulation – An inclusive term referring to methods of artificially changing or altering the biological communities living in a waterbody, primarily to improve water quality. It does not involve genetic manipulation.

Biomass – A measure of the quantity of all the living organisms in a waterbody.

Carbon sequestration – Referring to a family of methods, involving both aquatic (oceans) and terrestrial (forests, soils) components, for capturing and permanently removing or isolating atmospheric carbon dioxide and other greenhouse gases that can contribute to global climate change.

Catchment – the area surrounding a lake from which surface water drains into the lake.

CBOs – Community-based organizations (for example, artisanal fishery associations).

Chlorophyll – A green pigment found in all plants, responsible for trapping sunlight energy needed for photosynthesis; chlorophyll concentration is often used as a measure of algal biomass in lakes.

COD – Chemical oxygen demand; a measure of the organic material in water (such as sewage) whose bacterial decomposition can consume oxygen in a waterbody.

Cyanobacteria – A group of microscopic blue-green algae, often occurring in eutrophic lakes in the form of algal blooms; some species can produce organic materials toxic to living organisms, including humans.

Deforestation – Cutting down or removing the trees from a given region; when done at a rate that exceeds the forest growth rate, it can lead to increased soil erosion and associated land degradation.

Desiccation – The process of removing water from a material or substance.

Diagnostic analysis – As practiced by the Global Environment Facility (GEF), refers to the analysis of the biophysical and socioeconomic characteristics of a lake and its drainage basin as a means of identifying environmentally associated development problems and their root causes; serves as knowledge base for subsequent development of basin-scale Strategic Action Program.

Diatoms – A form of microscope algae in a lake; often associated with good water quality.

Diffuse source – Referring to sources that can contribute pollutants to a waterbody in the rain or snowmelt-induced drainage from the land surface (in contrast to effluents entering from a distinct pipeline); often called nonpoint sources, the specific pollutant sources are difficult to identify and quantify, with the pollutant load depending largely on the climate and land uses characterizing a given drainage basin.

Drainage Basin – The area from which surface water drains into a lake together with the rivers and lakes.

Enabling environment/framework – The sum of the institutions, policy framework, financial incentives, informed public participation, and similar components that collectively provide the basis for developing and implementing effective programs and activities for the sustainable use of natural resources.

Encroachment – Advancing or intruding beyond proper limits or boundaries.

Endemic – Plant or animals native to a given region or waterbody.

Endocrine – Referring to the human hormonal system, particularly sexual hormones.

Endorheic – Term used to describe a lake with water inflows (such as tributaries), but no outflows; water only leaves the lake via evaporation, generally resulting in higher salinity lake water.

Environmental status indicators – Term used by the Global Environment Facility (GEF) to denote agreed measures of actual performance or success in restoring and protecting a target waterbody (for example, measurable improvements in chemical, physical, or biological parameters).

Eutrophic – The nutrient status of a lake receiving excessive nutrient loads (mainly phosphorus and nitrogen), resulting in excessive algal blooms that degrade water quality and interfere with beneficial human uses.

Eutrophication – The natural aging process of lakes; can be greatly accelerated by human-induced excessive nutrient inputs (so-called cultural eutrophication).

Exorheic – Term used to describe a lake that has both water inflows and outflows, thereby ensuring its waters remain fresh (in contrast to endorheic lakes).

Exotic species – Non-native animals or plants accidentally or intentionally introduced into new lakes; in the absence of natural controls, can displace a lake's native species and alter its biological communities; term often used interchangeably with invasive species.

Externalities – Monetary or other expenses associated with the use or utilization of a natural resource borne by someone other than the individual or groups using the resource.

Hydrological – Referring to, or involving, water.

Hypereutrophic – The nutrient status of a heavily nutrient-enriched lake at the extreme end of the eutrophic range, to the extent that its water quality and biological characteristics are essentially completely degraded (also see eutrophic).

Hypolimnion – The bottom water layer in a lake lying below the thermocline.

Hysteresis – A delayed change in a property of a lake, whether in a positive or negative direction, to an altered force or factor acting upon or influencing it.

Incremental costs – Term used by Global Environment Facility (GEF) to denote the costs associated with projects that produce international environmental benefits, as opposed to those that only produce national-level benefits.

Indigenous – Having originated in, or occurring naturally in a particular region or environment.

Infrastructure – The underlying foundation or framework of a system or organization; in the context of water resources management at the lake basin level, this refers to dams and weirs for multiple purposes; water transfer structures; water treatment, wastewater collection and/or wastewater treatment systems; irrigation and drainage; and flood control structures.

Invasive species – Non-native animals or plants accidentally or intentionally introduced into new lakes; in the absence of natural controls, can displace a lake's native species and alter its biological communities; term often used interchangeably with exotic species.

Invertebrates – Animals lacking a spinal column (e.g., insects, clams).

Limnology – The study of the biology, chemistry, and physics of inland water systems.

Littoral – The water in a lake lying near to the shoreline (in contrast to the water in the lake's centre).

Macrophytes – Free-floating or rooted aquatic weeds.

Mediation – Intervention between competing parties to promote settlement, compromise, or an agreed solution regarding a given issue(s).

Millennium Development Goals – A set of time-bound, measurable goals and targets for combating global poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women, agreed to by world leaders at the September 2000 United Nations Millennium Summit.

Millennium Ecosystem Assessment – An international work programme, launched by the UN Secretary-General in 2001, designed to meet the needs of decision makers and the public for scientific information on a global and regional scale concerning the consequences of ecosystem changes for human well-being, and options for responding to those changes.

Mitigation – Activities undertaken between parties to lessen the negative impacts of a given action(s).

NGOs – Non-governmental organizations.

No-net-loss policy – Measures, practices, or processes that do not result in a loss of lake values or uses.

Nonpoint source – Referring to pollutant sources that can contribute pollutants to a waterbody in the rain or snowmelt-induced drainage from the land surface (in contrast to effluents from a distinct discharge point, such as a pipe); also called diffuse sources. Specific pollutant sources are difficult to identify and quantify, with the pollutant load dependent largely on the climate and land uses characterizing a drainage basin.

Non-structural – Referring to management interventions that do not involve structures (such as behavioural changes and education).

Nutrients – Nutritive substances (food) required for the growth and reproduction of algae and macrophytes in a lake; primary nutrients are phosphorus and nitrogen compounds.

Oligotrophic – The nutrient status of a lake receiving small nutrient loads, and containing a small algal biomass; oligotrophic lakes typically display good water quality and can support a wide range of beneficial human uses.

Organic load – The quantity of organic materials entering a lake; lakes with large organic loads can exhibit low oxygen levels associated with bacterial decomposition of the materials, resulting in degraded water quality and interfering with beneficial human uses.

PCBs – Polychlorinated biphenyls; a group of persistent organic pollutants believed to have carcinogenic and other human health impacts.

Photosynthesis – The biochemical process whereby chlorophyll-containing plants utilize sunlight energy to convert carbon dioxide and water to sugars such as glucose.

Point source – Referring to pollutant sources that can be readily identified and quantified, such as effluents from a distinct pipeline (in contrast to pollutants entering a lake in rain or snowmelt-induced drainage from the land surface; also see nonpoint source).

Process indicators – Term used by the Global Environment Facility (GEF) to denote a measure of progress in project activities involving procurement and production (inputs and outputs) of goods, physical structures and services (e.g., formation of high-level steering committee for project preparation and implementation; completion of country-endorsed Transboundary Diagnostic Analysis).

Ramsar Convention – An intergovernmental treaty signed in 1971, which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

Ramsar site – Wetlands designated as internationally important under the Ramsar Convention.

Red tides – Seawater discoloured by the presence of large numbers of certain types of algae, which can produce a toxin poisonous to many forms of marine life and to humans who consume infected shellfish.

Reforestation – The process of replanting areas after the original trees and other vegetation are removed.

Remediation – The act or process of providing relief, whether in the form of money, actions, or other approaches, that can satisfy or rectify conflicting activities or policies.

Retention time – The period of time a given quantity of water may spend in a lake; typically calculated as lake volume divided by the water inflow (or outflow); lakes with short retention times exhibit more rapid water flushing (and associated pollutants) than lakes with long retention times.

Riparian – Relating to, or located on, the bank of a natural watercourse, such as a lake or river.

Runoff – Storm-generated water drainage from the land surface to lakes, rivers, and other watercourses, including the materials dissolved in, or carried by, the water; also called storm runoff.

Saline – Used to refer to water containing elevated concentrations of dissolved salts, mainly sodium, potassium or magnesium.

Salinity – A measure of the quantity of salts contained or dissolved in water.

Sedimentation – The process whereby soil and other particles carried in water settle to the bottom of a waterbody.

Siltation – The process whereby a waterbody becomes filled or choked with soil and other particles carried in water.

Storm runoff – Storm-generated water drainage from the land surface to rivers, lakes and other water courses, including the materials dissolved in, or carried by, the water.

Stress reduction indicators – Term used by the Global Environment Facility (GEF) to denote specific on-the-ground measures implemented by the collaborating countries to produce measurable changes in transboundary water systems (for example, reduced releases of pollutants from point sources; area of eroded land stabilized by reforestation).

Structural – Referring to management interventions that involve structures (such as dams, water treatment plants).

Subsidiarity – Referring to the lowest effective level of management of a waterbody.

Subsidy – A grant or cash award offered by a government to a private individual or company to assist an enterprise deemed advantageous to the overall public good.

Subsistence – Referring to the minimum levels of food, shelter, and other items necessary to support human life.

Super-nationality – The buy-in and agreement by riparian nations to common measures and activities regarding the effective use and management of shared natural resources, including water systems.

Supply-side economics – The economic theory that encourages expanded economic activity (and increased utilization of natural resources), via such measures as reducing tax steps (in contrast to managing demand for the resources).

Sustainable development – Economic development within the constraints of the available natural resources base, in contrast to uncontrolled exploitation of the resources.

Sustainability – A measure of the degree that exploitation of natural resources for economic development can be continued indefinitely without permanently affecting the current resources base or its accessibility to future generations.

Tariffs – Charges, user fees, or duties imposed by governmental entities for goods or services.

Tectonic – Referring to the deformation of the earth's crust by the movement of surface geological layers over a geologic time scale, and the resulting geologic forms (e.g., lakes).

Temperate – Refers to regions of the world that experience moderate climate; generally comprises the earth's surface occupying the intermediate lateral position on both sides of the equator between the tropical zone and boreal or sub-arctic climate of the polar zones.

Tertiary wastewater treatment – An advanced stage of wastewater treatment for removing dissolved pollutants left after primary and secondary treatment are completed; typically used to remove phosphorus and nitrogen from wastewaters.

Total social welfare – Referring to a social welfare approach in economic valuation in which the 'whole' (total social welfare) is equal to the sum of the parts ('individual welfare measures').

Tradable rights – Rights to the use of natural resources that can be traded, in the same manner as goods or services, between individuals or organizations, as a means of influencing natural resources utilization and management.

Transaction costs – The costs or obligations, whether material or otherwise, to the involved individuals or organizations of altering management structures and functions in pursuit of sustainable use of natural resources

Transboundary – Referring to natural resources, including water courses (lakes, rivers) shared or used by two or more countries.

Trophic levels – Specific levels of energy flow through ecosystems and their living resources; often used to delineate organisms in different levels of a food chain.

Vector-borne diseases – Diseases spread from one host to another by organisms that live in, or whose live cycles are associated with, watercourses.

Watershed – the boundary between two catchments. Now more commonly used to refer to the catchment itself.

Water hyacinth – An aquatic weed (macrophyte) that often grows to excessive levels in lakes and interferes with beneficial human water uses; a symptom of cultural eutrophication in many parts of the world.

Wetlands – Areas periodically or permanently covered with water, including swamps, tidal marshes, coastal wetlands, and estuaries.

World Commission on Dams – An independent, international commission convened in 1998, and comprised of representatives of governments, private sector, international financial institutions, civil society organizations and affected peoples, to review the development effectiveness of dams and assess alternatives for water resources and energy development, and develop internationally-accepted standards, guidelines and criteria for decision-making in the planning, design, construction, monitoring, operation and decommissioning of dams.