Science and management of transboundary lakes: Lessons learned from the global environment facility program ☆

- Mark R. Servos[a],
- Kelly R. Munkittrick[b],
- Gheorghe Constantin[c],
- Raymond Mngodo[d],
- Nikolay Aladin[e],
- Sansanee Choowaew[f],
- Navy Hap[g],
- Karen A. Kidd[b],
- Eric Odada[h],
- Oscar Parra[i],
- Geoffrey Phillips[j],
- Sergei Ryanzhin[e],
- Roberto Urrutia[i]

- [a] Department of Biology, University of Waterloo, Waterloo, Canada
- [b] Canadian Rivers Institute, University of New Brunswick, Saint John, NB, Canada
- [c] Romanian Ministry of Environment, Clinceni, Ilfov, Romania
- [d] Lake Victoria Basin Commission, Kenya
- [e] Russian Academy of Sciences, St. Petersburg, Russia
- [f] Faculty of Environment and Resource Studies, Mahidol University, Salaya, Nakhonpathom, Thailand
- [g] Inland Fisheries Research and Development Institute (IFReDI), Phnom Penh, Cambodia
- [h] Department of Geology, University of Nairobi, Nairobi, Kenya
- [i] Centro EULA-Chile, Universidad de Concepción, Concepción, Chile
- [j] Marsh House, Rotten Marsh, Acle, Norwich, UK

- http://dx.doi.org/10.1016/j.envdev.2013.04.005, How to Cite or Link Using DOI

- Permissions & Reprints

Highlights

- Management of transboundary lakes is complicated by complex governance structures.

- The unique characteristics and natural variability in lakes and their watersheds must be considered.
- The linkage of science to economic and policy frameworks needs to be strengthened.

Abstract

The International Waters Science Project Lakes Working Group reviewed 58 Global Environment Facility (GEF) projects that addressed serious environmental and human development issues in transboundary lakes. The lessons learned from the review of these projects were integrated with the intention to contribute to the design and success of future projects. Issues that will continue to impact lake ecosystems and their management include changing agricultural practices, resource extraction, emerging contaminants, energy policies, and water allocation. Future lakes projects addressing these issues must also consider the potential confounding effects of changing land use and climate on watershed processes, water quality, food web structure and biodiversity. Current and future scientific challenges include developing strategies for climate adaptation, improving the capacity to detect change and enhancing the application of an ecosystem approach within lakes management. Failure to consider the unique physical and biological features and processes in lakes can be a barrier to effective remediation. The spatial and temporal variability in lakes and their often slow response to remedial actions need to be considered in the design of monitoring programs. Factors that improved the success of GEF transboundary projects included early and strong communication, engagement of stakeholders, rigorous peer review and international science teams linked to local capacity building and policy development. The application of both natural and socio-economic science based assessment, and adaptive management were essential for full project implementation and led to optimization of water resources allocation while sustaining ecosystems on which social and economic systems depend.

Keywords

- GEF IW Science;
- Transboundary waters;
- Lake ecosystems;
- Lake management;
- Policy development

---

1. Introduction

Water resources in lakes are impacted by many activities both within (e.g., overfishing) and outside of the lake (e.g., changing land use) or its watershed (e.g., climate change). The poor management of water resources in lakes and their watersheds has resulted in major shifts in the quantity and quality of water resources and altered ecosystems, limiting the benefits available for humans that depend on them (WWAP (World Water Assessment Programme), 2012). Lake systems and their corresponding watersheds often cross political boundaries, making the governance and management of these critical resources very difficult. Serious issues have arisen in lakes that cross political boundaries (transboundary), especially in developing countries where governance structures, scientific capacity and integrated approaches to water management, have been weak or lacking. This has led to environmental degradation and limitations on human development and well-being (WWAP (World Water Assessment Programme), 2012).

The Global Environment Facility (GEF) has made a major international investment in projects focused on improving the management of transboundary waters in developing countries. The goal of the International Waters focal area of the GEF is "the promotion of collective management for transboundary water systems and subsequent implementation of the full range of policy, legal, and institutional reforms and investments contributing to sustainable use and maintenance of ecosystem services" (GEF, 2013a). The GEF therefore plays a strategic role in catalyzing multinational institutional reforms to address these issues. GEF, in cooperation with several other organizations (led by the United Nations University Institute for Water, Environment and Health, UNU-INWEH), conducted a review of all of these past GEF projects on transboundary international waters. This GEF International Waters (IW) Science Project included a focus on "understanding and documenting for future analysis and reference, the scientific experience and scientific best practices from the IW project portfolio" (Mee et al., 2012). The examination of how science has been incorporated into these large transboundary water projects was done in order to increase the benefits and likelihood of success of future GEF investments.

This paper highlights the results of the review of the GEF projects that included a transboundary lake related component. Although only four GEF projects focused exclusively on lakes, 58 projects included lakes as a major component. The intention here was not to provide a critique of the individual projects but to explore the role of science in the past projects and how it can better contribute to the design, implementation and sustainability of the outcomes of future projects both within the GEF and in other programs. Examples from the projects are provided that highlight the observations and conclusions. The process used to review the GEF funded lakes projects is first summarized, and then the general trends and issues, as well as difficulties and challenges encountered in projects, are highlighted. This is followed by an assessment of the factors that contributed to successful implementation of the transboundary lakes projects and identification of future challenges. The objective is to integrate the lessons learned through the review of the transboundary lakes related projects and present it in a way to support future GEF and broader lake management programs.

2. Review of the transboundary lakes related projects

Over the last two decades the GEF has funded 58 projects that deal, in some capacity, with pressing issues in transboundary lakes and their drainage basins (Table 1). The lake projects listed in Table 1 are used as examples throughout this paper by referring to the project location. The IW Science review process included the formation of an international working group of scientists and practitioners who examined the available documents for each project against a series of questions (Lakes Group Synopsis Report; Munkittrick et al., 2012a) and then integrated the observations across the projects into a report that focused on the application of science within the projects (Lakes Group Analysis Report; Munkittrick et al., 2012b). A major focus of the Lakes Working Group was also to identify critical emerging science issues, the application of science for adaptive management, and the development and use of indicators that support monitoring and assessment of the progress toward project outcomes. The conclusions of the six working groups (groundwaters, rivers, lakes, coastal areas, large marine ecosystems and global oceans) were incorporated into a Synthesis Report (Mee et al., 2012) that integrated the conclusions of each of the major areas of focus. The results were presented and discussed further by an international network of experts at the GEF International Waters Science Conference in Bangkok held in September 2012 (Lange, 2012). The purpose of the Bangkok meeting was to build on the key findings of the IW Science Project that assessed the use of science in the GEF International Waters (IW) portfolio, including ways of enhancing the use of science, responding to emerging issues, and identifying innovative solutions.

Table 1. International Waters Science, Global Environment Facility, projects included in the Lakes Group review.

Location	**Region**	**Major themes addressed**[a]	**GEF project number**[b]
Lake Victoria	Africa	BD, C, E, Eu, F, IS, M	88, 2405
Gulf of Guinea	Africa	BD, C, Eu, F, M	393
Lake Manzala	Africa	BD, CC, C, DD, E, Eu, F, Fw, M, S, W	395
Lake Tanganyika	Africa	BD, C, Eu, G, F,	398, 1017
Lake Chad	Africa	BD, C, E, F, G, H, IS, W	767
Okavango Delta	Africa	E, G, H	842
Nile River	Africa	BD, C, Eu, F, G, H. IS, M, S, W	1094, 2584, 2602
Lake Ohrid	Africa	BD, Eu, ,F, G, H	113
Water Governance	Africa	BD, C, G, M	3341
Caspian Sea	Asia	BD, C, F, H, M, S, W	596
Mekong River	Asia	BD, CC, C, DD, E, Eu, F, Fw, G, H, M, SI	615
South China Sea	Asia	BD, CC, C, E, F, Fw, G, H, M	885
Yangtze River	Asia	BD, C, DD, E, H	1353
Aral Sea	Asia	BD, CC, C, DD, E, G, H, M	1375

Location	Region	Major themes addressed[a]	GEF project number[b]
W. Indian Ocean	Asia	C, E, F, M	2098
East Java	Asia	BD, C, E, Eu, G, H, M, SI, W	2760
NW. Pacific	Asia	G, M	2961
East Asia	Asia	Eu, f, G, M, W	3025
Shantou Wetland	Asia	Eu, M, W	3309
Lake Baikal	Asia	BD, C, E, Eu, G, M, W	3521
Mediterranean Sea	Europe	BD, C, Eu, F, Fw, M, SI, W	461
Lake Peipsi	Europe	Eu, F, H	1444
Prespa Lakes	Europe	BD, C, Eu, F, G, H, IS, M SI, W	1537
Sistan Basin	Europe	DD, E, F, G, SI, W	2130
Trebisjica Basin	Europe	C, DD, E, Eu, F, M, W	2132
Lake Skader	Europe	BD, C, DD, F, H	2133
Dnipro River	Europe	BD, C, DD, E, Eu, F, G, H, M, SI	2544
Danube River and Black Sea	Europe	BD, C, Eu, F, G, H, IS, M, SI, W	806, 1074, 1123, 1159, 1351, 1355, 1580, 2141, 2143, 2263, 2970, 3148
Lerma-Chapala	N. America	BD, C, DD, E, Eu, F, SI	2540
Rio Paraguay	S. America	BD, C, Eu, H, M, W	583
Rio de la Plata	S. America	BD, CC, DD, E, Eu, F, H, M, W	2095, 3519
Amazon/Igarape	S. America	BD, CC, C, Eu G, M, SI	2136, 2364
Sao Francisco River	S. America	BD, DD, F, M, W	3128
Transboundary Waters	Global	All	584, 1665, 2722, 3181, 3342

a

BD, biodiversity; CC, climate change; C, contaminants; DD, dams or diversions; E, economics; Eu, eutrophication/nutrients; F, fisheries; Fw, food webs; G, governance; H, hydrology/water balance; IS, invasive species; M, management and restoration; SI, social impacts; W, wetlands.

b

See Lakes Group Synopsis Report (Munkittrick et al., 2012a).

Table options

The majority of the 58 GEF projects reviewed were focused on transboundary lakes distributed across Europe (21 projects), Africa (13), Asia (8) and the Americas (8) (Table 1). Examples of the lakes and watersheds include large lakes (e.g., Lake Tanganyika, Lake Victoria, Lake Chad, Lake Baikal, Black Sea, Caspian Sea, Aral Sea), smaller lakes (e.g., Lake Ohrid, Lake Peipsi, Prespa Lakes), and their associated drainage basins (e.g., Mekong River, Yangtze River, Rio de la Plata, Danube River). Although many of these projects were related to river, estuary and groundwater systems, the Lakes Working Group focused specifically on the lake issues and the relationships to their associated drainage basins. The projects covered a diversity of issues but there were some common themes including eutrophication and nutrients (38 projects), biodiversity (33), governance (30), and contaminants (28). The readers are referred to the Working Group reports for specific examples and details of the transboundary lakes projects (Munkittrick et al., 2012a and Munkittrick et al., 2012b).

3. General trends and issues

The GEF projects on transboundary lakes have enhanced the scientific knowledge base and contributed to the overall understanding of how management and governance interventions can alter lakes and their associated ecosystems. The review of the projects emphasizes the importance of incorporating scientific knowledge and results into the design, implementation and reporting of projects. A major limitation of many of the projects was an absence of baseline data on the system that could be used as a basis of comparison. This is of course a major issue for many studies, not only those of the GEF, but was highlighted in many projects because it made it difficult to assess the effectiveness of the remedial actions. In addition, the lack of pristine reference environments for comparison also made it difficult to assess the effectiveness of the various interventions. Baseline studies were conducted in several of the Black Sea projects and the results were used for identifying better management practices. Studies such as those in Lake Skadar/Shkoder and the Black Sea suffered, at least initially, from a lack of background data upon which they could develop rigorous indicators or base assessments of ecological change. The failure to establish a robust monitoring design early on within many projects also made it difficult to separate natural variability and/or confounding factors (other sources) from the impact of the management actions (e.g., Danube River). This was addressed, at least to some extent, in several projects in their later stages (e.g., Lake Victoria). These issues highlighted the need for more rigorous study designs and more effective long-term monitoring of anticipated project outcomes. The regular and effective evaluation of project deliverables would highlight the benefits of future management investment and enhance the application of adaptive management (i.e., the systematic, rigorous approach for deliberately learning from management actions with the intent to improve subsequent management policy or practice; GEF, 2013b). Again the Lake Victoria projects are examples of where early scientific results led to improvements later in the project, including more focused science and the establishment of more effective governance structures.

Although most of the projects related to lakes also had a major component that recognized the importance of the watershed, the unique characteristics of lakes were often not incorporated into the design of the projects. Many projects did not consider lake-specific physical processes (e.g., stratification, sedimentation) as a component of the system or as a possible modifier of impacts. They often also failed to consider the past history of lakes, including other confounding factors that may represent additional sources of pollution, environmental stressors, or activities that contribute to environmental degradation. In some cases the projects did not consider confounding sources from other parts of the drainage basin or the lake and limited their focus to a specific area of the watershed or of the lake. The Aral Sea (Micklin and Aladin, 2008) and Lake Chad (Coe and Foley, 2001) are clear examples of how critical watershed processes and water demand are for lake ecosystems. Water extraction and diversions for irrigation in the watershed have led to most of the Aral Sea drying up, resulting in massive reductions in biodiversity and a major impact on the health and economy of the local communities. By not recognizing lakes as unique components of a complex and dynamic watershed, with differing hydraulics, ecological function and biodiversity, projects may have limited their scope and therefore potential for success. However, many of the GEF projects learned from these early issues and broadened their scope to consider these important sources and processes.

Projects related to the Black Sea, and others, focused on agricultural practices in the watershed as a way of reducing nutrients in the Danube River and ultimately in the Black Sea (Borysova et al., 2005). More than half of the nutrients entering the Black Sea are from the Danube River and more than half of that nutrient load is from agriculture. By identifying the major causes/sources at the watershed scale that were impacting the lake (Black Sea), local and national programs could then be implemented that directly addressed the issue of concern (eutrophication). Lakes are often very sensitive to external drivers such as changing land use in the watershed increasing sediment loads (e.g., Lake Tanganyika; Donohue et al., 2003), but sources such as aerial deposition may be important in many lakes such as those in central Africa, e.g., Lake Victoria (Tamatamah et al., 2005). By altering the hydrology, climate change may alter the temporal and spatial transport of nutrients and other contaminants within watersheds, potentially leading to new issues in lakes. This makes it essential that projects integrate potential threats and consider the temporal and spatial scales of the whole watershed, while also considering factors outside the watershed (e.g., atmospheric inputs).

Unlike rivers, processes in lakes may respond over much longer time frames. In large or deep lakes, such Lake Baikal, these processes may result in response time frames much longer than the duration of the relatively short-term GEF projects that often have no post-project monitoring plan. This again emphasizes the need for longer term projects and monitoring that fits with the scientific understanding of dynamic processes and responses in lake ecosystems. Sediments can represent a significant source (e.g., re-suspension) of nutrients and contaminants in lakes (e.g., Lake Tanganyika) that, if not considered, may delay or even prevent the desired outcomes of the management actions. Sediments are a key component of lake systems and historical issues may lead to legacy effects that were not anticipated. This is certainly the case for the Laurentian Great Lakes in North America where legacy contaminants have altered reproduction and recovery of fish populations (UNU-INWEH, 2011a and UNU-INWEH, 2011b). Long-range transport in the atmosphere has become recognized as a source of contaminants and nutrients to lake systems (Karlsson et al., 2000). For example, a significant proportion of nutrients entering Lake Victoria are from the atmosphere (Odada et al., 2006). This means that projects must take a broader look at the science to inform them of the factors that may limit the effectiveness of a specific management action (e.g., agricultural practice, reforestation) and look for options (technical, management and political) that may reach well beyond the individual lake or watershed.

Increasing demand for food products, for both local and export markets, continues to put considerable pressure on the inland fisheries that are critical resources for large local populations of people (e.g., Lake Tanganyika). Overfishing is a common issue in transboundary lakes and stock reductions and collapses have had major impacts on ecosystems as well as human development. Deliberate or accidental introductions of new species (e.g., aquaculture, pest control, preferred fishing target) can have dramatic effects on fish stocks and ecosystems. Attempts to introduce biological control agents into lakes have sometimes resulted in severe unintended consequences. For example, the introduction of the Nile perch into Lake Victoria led to a cascade of unanticipated negative effects that changed the food web and altered human behavior (e.g., fishing, firewood collection), subsequently impacting the watershed and the lake (Odada et al., 2006). Our poor understanding of how natural ecosystems function limits our ability to effectively manage and remediate these complex systems.

Lakes and their watersheds are usually influenced by many stressors simultaneously (Heugens et al., 2001). Almost all the GEF lakes projects addressed multiple stressors (Table 1). For example, Lake Victoria has been impacted by intensive fishing, species introductions, species loss, eutrophication, water level changes and climate variation (Hecky et al., 2010). Agricultural practices within a watershed may alter nutrient inputs, introduce pesticides and other contaminants into the system, and alter habitat. Understanding the mechanisms by which multiple stressors alter ecosystems is currently a major scientific need, and attempting to manage complex lake ecosystems with multiple interacting stressors is a major challenge (UNU-INWEH, 2011a and UNU-INWEH, 2011b). Although many of the GEF projects included multiple stressors (Table 1), very few approached them in a systematic fashion and there was often a lack of explicit recognition of their linkages. Failure to consider the interactions of multiple stressors may result in the inappropriate application of remediation or management actions.

There should be a distinction between situations where there are multiple sources of a single stressor (e.g., nutrients from agriculture, urban runoff, atmosphere) versus multiple stressors (e.g., chemicals, nutrients, temperature). This is critical in the context of assessing cumulative effects and therefore for the design of remedial actions. Many basin studies (e.g., Rio de la Plata, Lerma River Basin, Igarape) identified numerous sources of specific contaminants (e.g., organochlorines, metals, phosphorous) arising from agricultural or urban runoff, municipal or industrial effluents, and atmospheric and in-lake processes (e.g., sediments). In comparison the wetland restoration projects on the border of Yugoslavia and Bulgaria (part of Danube River) identified multiple stressors (e.g., nutrients, contaminants) in the system arising from municipal effluents, mining, or industrial activities. This often is further compounded by a failure to recognize the socio-economic realities of the region, the importance of human activities on the landscape, and the linkages between water quality in lakes and their watersheds. Changes in land use, such as deforestation around Lakes Victoria and Tanganyika, influenced water quality through changing the export of nutrients from the watershed. Another example is seen in the Nile River in how the impacts of siltation (sediment) caused by changing land use (e.g., changing agricultural practices) can be exacerbated by flow control (dams) preventing natural hydrologic cycles. Failure to protect wetlands has caused serious issues in many lake basins (e.g., Sistan Basin, Okavango Delta, Lake Manzala, Shantou Wetland) and their role in water balance and quality (environmental services) must be recognized. These examples again highlight the necessity of robust long-term monitoring systems to detect changes in major processes and ecosystems of interest.

Climate change will certainly be a major consideration for water managers as it will alter almost every process that affects the function of lakes and their ecosystems (O'Reilly et al., 2003). It will not only affect processes within the lake but also those in the watershed, potentially altering the availability and quality (e.g., nutrient and contaminant loads) of water entering the lake (Wrona et al., 2006). These changes may eventually alter food web interactions and biodiversity, reducing the resilience of the system to other stressors (Winder and Schindler, 2004 and Woodward et al., 2010). The environment may also become vulnerable to invasive species which may then alter important ecosystem process and species interactions (Rahl and Olden, 2008). The changes in water availability may lead to a variety of undesirable ecological outcomes that have adverse effects on human development.

A lack of consistent environmental indicators for lakes limits our ability to manage these ecosystems and assess the effectiveness of remedial actions. Specific guidelines for collection of consistent information and basic data needed for lake management is desirable. Development of simple and clear environmental indicators of lake status that could be included in baseline monitoring would be very useful and should be developed. An ongoing challenge relates to a lack of regional infrastructure for long-term implementation of remedial actions and a lack of capacity or commitment for continued environmental monitoring to assess the effectiveness and sustainability of these actions. In the Mekong Basin an understanding of the both socio-economic and ecological drivers became the basis of designing sustainable practices to protect the ecosystem and fisheries resources. In contrast, the difficulty of maintaining databases and communication (e.g., websites) after project completion was identified in several projects (e.g., South Coral Sea, Lake Tanganyika) as barriers to fully exploiting the project outcomes and sustaining impacts.

The social and economic linkages are critical to implementation of lake management. Science alone is not sufficient to ensure success of large interventions in transboundary lakes and strong international governance structure must be established (UNU-INWEH, 2011a and UNU-INWEH, 2011b). Lake management needs to include an assessment of tradeoffs for environmental protection, human development, and social and economic costs and benefits. In particular, the value of ecosystem services has seldom been incorporated into the economic assessment and therefore integrated into the management of lake resources. The management actions and incentives must be consistent with the social and economic realities of the situation and the local people expected to implement the desired changes. For example, the need for firewood was a critical factor influencing water quality (erosion) and the ability to implement changes in Lakes Victoria and Anatilia (Turkey: Danube River). Projects such as Lake Victoria incorporated sociological studies on the livelihoods of the communities, revealing linkages among, ecosystem change, local economies, global trade and health outcomes. The Lake Tanganyika and Dnipro Basin studies highlighted the linkages between poverty and continued environmental degradation. The local communities must be empowered to address the water management issues in a manner consistent with their economic needs and capacities. Changes in farming practices in areas far removed from the Black Sea in the headwaters of the Danube River had to be both socially and economically feasible in order to be implemented. Financial incentives as well as pilot scale demonstrations need to be used to convince local land owners of the benefits to themselves as well as to the ecosystems far downstream.

Political differences and priorities can represent real barriers to transboundary lake management and governance. Education and capacity development therefore needs to be across all levels of society, including political leadership, to ensure successful and sustained implementation of policy change to enable action. Although training programs to enhance national capacity were essential in projects such as Lake Prespa, development of transboundary science and political networks, such as those in the South China Sea and Dnieper River, were critical to establishing watershed scale monitoring and integration of project outcomes/goals into national programs (e.g., national development planning). The political commitment to long-term protection of fisheries, wetlands, and biodiversity will be difficult unless the needs and benefits to society can be clearly demonstrated. The Mekong River Commission used project outcomes from a GEF project to establish mechanisms to promote and improve coordinated and sustainable water management. The Lake Ohrid project focused on transboundary cooperation to conserve and protect natural resources and biodiversity that are essential to the long-term sustainability and economy of the region. However, changing political, economic and regulatory requirements may represent new challenges that will need to be addressed as management is adapted to these new situations. These changes may come from the local communities but may also come from outside the watershed boundaries as a result of international trade, changing markets or environmental considerations that are negotiated at the international level. These issues and changing regulations may lead to conflicts among local, national and international priorities and influence the ability of local programs to achieve the desired development and environmental goals.

4. Difficulties and challenges encountered

The 58 transboundary lakes projects reviewed were diverse but there were some common issues that arose. It must first be highlighted that these GEF projects have made a tremendous contribution to our understanding of transboundary lakes as well as having made an enormous contribution to the human communities who share and manage these resources (Munkittrick et al., 2012a and Munkittrick et al., 2012b). However, there were some key observations made across many of the projects that may have limited their success and ability to change policies or practice. It is essential that the projects are based from the start on the best available and up-to-date science. Although this seems obvious it was not always the case. Many projects did accomplish this by involving a science advisory group at the beginning or throughout the project. Scientific knowledge needs to define the causes and scope of the problem and the uncertainties, develop solutions to priority issues, and inform policy responses. It therefore must be carefully integrated into projects so that it supports and contributes to the final implementation of the project outcomes. Unfortunately, poor linkages among science, management and human development objectives in the past projects were often a barrier. The projects frequently did not consider the current state of the science at their onset and seldom considered or integrated approaches with local traditional ecological knowledge. However, in several of the most successful projects there was a balance between these objectives that was achieved through strong communication and integration of the science at international and local levels into the routine aspects of the project operation. Projects that identified the communication needs early and implemented a plan to surmount communication barriers were often more successful (e.g., South Coral Sea project; Pernetta, 2002).

Poor design of a project in terms of adequate sampling or of appropriate data collection and analysis made it difficult to determine if the project was making a difference. Especially in early projects, the QA/QC guidelines for data collection and storage were poor and therefore the interpretation of results was limited. Data were often not collected prior to initiating changes, or after the termination of the project, and therefore unavailable to evaluate the impacts of the changes. The absence of solid conceptual frameworks for some projects also made them difficult to assess. More extensive and appropriate modeling activities are needed that bring current knowledge into the planning and implementation stages. The shortage of reliable and adequate data for modeling and analysis, and a lack of verification and calibration of models will remain a challenge for future projects. There is a need to establish and maintain long-term monitoring programs in major transboundary lakes to ensure the sustainability of these systems, define natural variability, and protect against undesirable effects of diverse human activities. A number of actions were identified to reduce the impacts of the difficulties common to the projects (Table 2).

Table 2. Selected issues for transboundary lakes management and possible actions to address them.

Issues	Specific problems	Possible actions
Data limitations	Baseline data in transboundary lake systems are often unavailable, unreliable or non-comparable	Use the IW Learn platform to link to existing databases around the globe (e.g., International Lake Environment Committee (ILEC) World Lakes Database; Russian Academy of Science WorldBase)
	Difficulty of data access post-project, including that used to formulate the project plans	Develop guidelines for data collection and reporting for transboundary lakes projects, i.e. create a data repository and inventory
	Institutional ability and availability of project data	Needs deliberate investment to ensure institution capacity for project data management
Integration of disciplines	Social, economic and political science have not been well represented	Need integration of multidisciplinary teams that include governance, economic and political considerations
Sustainability of outcomes	Usually few resources to sustain the project impacts	Need to promote early stakeholder ownership and capacity building. Early involvement of policy makers and consideration of sustainable actions to

Issues	Specific problems	Possible actions
		implement project outcomes. Innovative long term funding solutions (e.g., Lake Victoria Fish Levy Trust & Environmental Trust Fund)
External drivers	Integration of external drivers such as contributing drainages, changing land use, aerial deposition, and climate change; Identification of conflicting resource uses: e.g., irrigation needs versus other ecosystem services	Incorporate a review in project planning/implementation stages
Knowledge	Improving our understanding of stressors and remedial action on water resources and ecosystems	Integrate research into project components
Hydrologic linkages	The need for explicit recognition of linkages of water to other watershed components (river, estuaries, atmosphere)	Need an ecosystem and watershed scale approach to project planning and implementation
Indicators	Lack of a basic set of common environmental indicators for lakes	Lake experts should make recommendations about types of data and platforms that should be included in new lakes projects to improve comparability of data across lakes, specific data expectations, including social information and quality of metadata
Integrated methods	Emerging approaches and methodology for integrated lake management	Develop an integrated framework protocol for linking Integrated Lakes Basin Management (ILBM), IWRM and Integrated Coast Zone Management (ICZM) methodologies to enhance hydrological linkages aspects of water studies
Climate change	Implications for changing hydrology, physical properties and water quality	Increased linkages to international efforts to understand climate change impacts and adaptation
	Mitigation and adaptation actions and their implications (i.e. dam storage)	Incorporate the goal of creating resiliency in lake ecosystems to provide ecosystem services
Green Economy	Role of lakes in the Green	Derive economic valuation of lake

Issues	Specific problems	Possible actions
	Economy (Rio +20)	ecosystem goods and services as lakes are major sources of livelihoods in developing countries
Governance	Weak international mechanisms to deliver project outcomes	Establish a robust governance structure that include key stakeholder and policy makers
Communication	Misunderstanding and lack of commitment	Establish communication program that target identified key stakeholders and decision makers

Table options

5. Success factors

There were many positive aspects to every project and the Working Group was able to identify several commonalities that supported the success of these projects (Table 3). Early and meaningful engagement of local stakeholders, early engagement of the science community, respectful interaction with local stakeholders, effective use of traditional ecological knowledge, strong linkages to social, economic, and political scientists (and outcomes), rigorous peer review (e.g., external, independent) and clarity of issues being addressed were all important factors. The involvement of public stakeholders in projects occurred in a variety of ways but consistently improved the project implementation and enhanced outcomes. Effective involvement required a commitment to public engagement, but also acceptance and uptake of the recommendations of these groups. This often led to stronger relationships and improved uptake of the final products and recommendations by the communities. Good science alone was not sufficient to ensure the desired impact. The Aral Sea project is a good example of how scientific research targeted and communicated effectively was used to inform and support decisions of regional policy makers.

Table 3. Activities identified in GEF projects that contributed to successful implementation and outcomes.

- Integration of international and local knowledge and teams with shared responsibility, understanding, respect and clearly defined roles
- Rigorous peer review initially and throughout the project
- Involvement of multidisciplinary natural sciences as well as social, economic, and political sciences

- Early, sustained and respectful engagement of stakeholders that includes key industry (e.g., local farmer groups), government (at various levels), NGOs, and the public
- Development of a shared vision
- A commitment to local capacity building
- A commitment to public engagement, training and education
- An early, targeted and transparent communication strategy
- Identification of clear, simple scientifically based environmental indicators that inform the decision making processes
- A commitment to long term project performance and environmental monitoring
- Development of partnerships to sustain project outcomes

Table options

Successful projects often completed a scientific peer review or a process to include diverse scientific ideas early in the planning phase and development of project. This was most effective when it included a balance between local and international scientific communities such that a solid dialog of both emerging scientific knowledge and local scientific understanding were included. This could not be a onetime event but was most effective when there was a commitment to regular review and scientific peer review during data collection and analysis. In many studies there was also a goal of balanced participation between governmental, scientific and local/NGO influences. Essentially, involvement of all those affected by the project needs to be done early and regularly throughout the projects.

Diverse groups need to be involved in a way that ensures their voice is heard because each has a role in making the project successful and ultimately sustainable. Successful projects accomplished this in a wide variety of innovative ways. However, this took additional effort and commitment by the project managers. In some cases, the stakeholders needed to be trained to be able to fully participate but the project managers also had to be educated on the realities and complexities of implementing the project at the local level. This partnership appears to be a very important factor in ensuring the integration of science into projects, and the sustainability of their impact. The South China Sea project highlighted the importance of establishing strong governance structures that then enable sustainable outcomes including coordinated and collaborative ongoing monitoring programs. The South China Sea project involved seven countries and its success was helped by the establishment of local science networks at the local level as well as national and international science advisory bodies. Using local, national and international committees focused on specific issues they were able to facilitate more than 31 government agencies, as well as other key stakeholders (linking more than 400 institution), into taking action. Characteristics of effective science networks included the involvement of grassroots, community-based organizations and nongovernmental organizations (NGOs) with balanced representation with consideration of gender, meaningful collaborative roles, balance of power, early engagement, and recognition of traditional and local knowledge. The inclusion of local initiatives, adequate legislative and financial support, and efficient communication are also important factors. This needs to be supported by leadership (e.g., steering committee) that balances governance, and scientific and societal perspectives. The process is enhanced by having a framework or conceptual model that allows for a shared vision, meaningful decision making targets, appropriate multidisciplinary scientific input (local, national international), democratic recruitment and rotation of power, adaptive management capacity and finally, a mechanism for influencing policy change. Often the implementation of change requires institutional change which can be very difficult to achieve. Although institutional barriers can be subtle they can block even the most obvious and necessary actions. Institutional change or acceptance is a transitional process that requires appropriate legal frameworks, harmonization of policy at each level, implementation at the watershed scale and flexibility to enable adaptive management. In the China Sea example, management of demonstration activities, regional harmonization and coordination of national level actions were important for project success.

The project objectives were more likely to be successful when they were linked to clearly defined policy actions, options or development. Identification of what data are needed to support political decisions and how to communicate it is needed early in the projects. Clarity of the issues and goals of the project were essential. The promotion of agricultural practices in the headwaters of the Danube River (e.g., Moldova), with the goal to reduce nutrient discharges into the Black Sea, needed community support and clear communication of benefits to the local farmer. Projects in the Neretva and Bosna Rivers (part of Adriatic and Black Sea drainage) established stakeholder committees at the local level early in the project to review local issues, advise on design and provide continued input, enhancing the project implementation.

Many of the projects established local management committees with stakeholder representation (e.g., Lake Prespa, Lake Ohrid) and/or conducted a variety of stakeholder consultation/meetings (e.g., Nile River, Lake Ohrid) to ensure broad perspectives that included the local communities. Early on projects need to develop priorities for management activities, develop criteria, indicators and milestones for project evaluation, and identify and develop a strategy for dealing with implementation barriers. Although not always required, the inclusion and consultation of a broad base of stakeholders avoided barriers for implementation of the project at later stages.

Although science outputs from projects are very important, dissemination of the knowledge and integration into implementation plans is critical to achieve the broader environmental and societal goals. Success in implementation of sustainable action was facilitated by well-developed project plans that included appropriate statistical design, setting of achievable and measureable targets, and a targeted monitoring program to access progress. The final steps of delivery of the project's outcomes must be considered early in the process and not as an afterthought. For example, demonstration sites used in nutrient control projects in the Danube Basin were very powerful tools to influence stakeholders, but plans for how to expand and influence the uptake of the innovations or practices to the full community were also needed. Linkage to the political and planning processes must be made early. Projects must focus on building or strengthening, capacity, regional cooperation, and involvement (participation). Relationships, understanding and education takes time and is necessary in communicating the project outcomes and ensuring uptake by decision makers and communities. A clear communication of the benefits of the project outcomes will greatly enhance the local and political support for implementation on a wider scale and greatly increase the project impact. Communication must be targeted at key receptors (decision maker, politicians) in an easily understandable format that emphasizes societal goals so that support can be secured for the sustainable implementation of project outcomes. Clear, simple, scientific, environmental indicators are needed that inform political processes.

International science can be more effectively integrated into projects when local and global participants have shared responsibilities, mutual understanding and respect, and well-defined roles. Although local capacity may need to be enhanced, successful projects are implemented at the local level and need to incorporate local approaches and traditional knowledge using mechanisms that eliminate implementation or communication barriers. It should be a true partnership with respect and commitment to the project outcomes at all levels.

It needs to be recognized that the GEF projects are only one mechanism of many that are providing valuable information on transboundary lakes. The scientific literature continues to grow and many of the issues faced by the transboundary lakes in the developing countries are similar to those faced elsewhere (UNU-INWEH, 2011a and UNU-INWEH, 2011b). The GEF projects can therefore use the knowledge learned from the efforts undertaken in other parts of the globe such as the North American Great Lakes, Lake Saroma in Japan, and many others. Other agencies are developing indicators that may be applied within GEF and to other lake projects (European Framework Directive, OECD, UNEP). In addition, numerous other international agencies and local governments are conducting studies in transboundary lake systems on related issues (e.g., Lake Tanganyika, Lake Victoria) and this information can be made available to help direct and inform future GEF programs. Finally, the experience of past GEF IW Science projects should not be lost as many of these past projects have explored innovative approaches to science, management, communication and practice (Munkittrick et al., 2012a and Munkittrick et al., 2012b).

6. Future challenges for transboundary lakes

Major land use changes, global shifts in population growth and distribution, resource exploitation and extraction, as well as climate change, are all rapidly emerging threats to lake basins (Fig. 1). Integrated water resources management must consider these important changes that are driven by evolving demands for energy, food production, natural resources, urbanization and water. These drivers cause changes in human activity (pressures) that result in major shifts in water availability, water quality, habitat quality and ecosystem function. Environmental stressors resulting from these activities can be very diverse, can interact in complex ways and can limit resources and ecosystems services available. Remediation of these impacts will remain a scientific and water management challenge well into the future. Innovative solutions will need to be developed and policies implemented that will protect ecosystems and optimize the benefits for developing communities. Many challenges remain to be addressed and numerous additional emerging threats are being recognized that will require continued action. The use of water for economic development, including agriculture, resource extraction and industry, needs to be balanced against environmental degradation and the often undefined cost of losing ecosystem services. For transboundary lakes, the additional issues of complex governance structures create a continuing challenge for resource managers, government and society.

Fig. 1. The major factors influencing transboundary lakes (modified from Munkittrick et al., 2012b with permission). The figure depicts the relationships among drivers (outside boxes), pressures (outside circles) state indicators (inside points) and responses (inside box) that influence the sustainability of resource use and ecosystem services (inside circle) and challenge our governance institutions (large circle).

Figure options

There will continue to be shifts in chemical use policies as a result of international and global chemical use restrictions, and these will place pressure on local decisions and lake management. Toxic chemicals arise from diverse point as well as nonpoint sources associated with industry, agriculture, forestry and urban development. In addition, there is a legacy of historical contamination that may have very long term implications. The atmosphere is also a major source of contaminants (AMAP, 2010) that has been recognized widely as important for transboundary lakes. These problems will remain as major international challenge for the foreseeable future and considerable regional cooperation will be required to deal with understanding the significance of these sources and options for remediating the impacts in lakes, often far from the original source. Many chemicals will continue to emerge (e.g., endocrine disruptors, nanoparticles) and our lack of data and understanding of their fate and effects will make assessing their risk and formulating appropriate risk management strategies difficult (WHO/IPCS, 2002, Daughton and Ternes, 1999 and Klaine et al., 2008).

Excessive nutrients from poor land use practices continue to be a major issue that will threaten all lakes, but particularly transboundary lakes where implementation of land use changes (agriculture, forestry, urbanizations, etc.) are a continuing challenge considering the complexities of governance in their watersheds. We have limited understanding of the sources, transportation, and nutrient cycling in transboundary lakes and atmospheric transport may be a growing and important source of nutrients to lakes. The remedial actions required may therefore cross international borders and need international cooperation. Despite decades of research the time scales for recovery of ecosystems from chronic release of nutrients are still poorly understood. Impacts of agriculture, including eutrophication and sedimentation, will continue to limit the opportunities for beneficial uses of water resources unless effective solutions can be found.

Changing agricultural policies and practices will continue to be of growing importance to transboundary lakes in the future. This will include new threats resulting from changing farm practices such as implementation of lower cost growing techniques, altered irrigation practices, and a shifting trend toward new crops that have different water and chemical use requirements (FAO, 2003). The growing demand for agricultural products, especially meat/protein, will be a major factor in driving land use and crop practices. There will be further movement towards consideration of water footprints and the trade of virtual water. Changing foreign investment and trade policies will have an impact on lakes and water resources by changing land use, crops, agricultural practices, and fisheries. The food, energy and water nexus will become an increasingly strong driver of decisions and compromises moving forward (Jägerskog and Jønch Clausen, 2012 and Comprehensive Assessment of Water Management in Agriculture, 2007). Competing demands for limited water resources will lead to conflicts and new models that meet the needs of society as well as ecosystems will be needed.

The effects of changing energy policies, including dams (construction and operation), water diversions, biofuels and resource extraction, on water resources and sustainability of ecosystems, will be critical to understand in the future. The desire for biofuels may alter agricultural and forest practices and impact water resources at the watershed scale (de Fraiture et al., 2008). Energy extraction and use can create pollution that can affect local as well as remote aquatic resources. Expanding hydroelectric developments may create new reservoirs (lakes) that will have a variety of negative impacts on the altered water balance, changing nutrient availability, sedimentation, contamination and biodiversity. Chilean Patagonia is today one of the largest freshwater reserves in the world with large ice fields supporting pristine lake and river ecosystems. Lake General Carrera, O'Higgins and Cochrane are among the largest and deepest lakes in the Americas with characteristics of ultra-oligotrophic waters and very little human presence. Today these ecosystems are threatened by various investment projects related to hydropower development and aquaculture (salmon) production (Goodwin et al., 2006 and Wright et al., 2008). In addition, unprecedented glacial retreat is currently being observed (Araneda et al., 2007, 2009) and primarily associated with global climate change. Multiple stressors, even in these remote areas of the world, have the potential to affect fjords, lakes and streams that are sustained by glacial melt waters and are sensitive to nutrient and contaminant inputs. Climate change will continue to be important in all watersheds, altering both the quantity of water for allocation and water quality (Vörösmarty et al., 2000). Changing temperature and increased variability in precipitation will cause changes in hydrology, sediment and nutrient flows leading to altered ecosystem structure and function. Adapting to these changes in lakes will be critical for resources managers who are challenged with protecting important fisheries and sustaining biodiversity. Altered lake processes resulting from climate change may reduce the resiliency of these ecosystems to the impacts of multiple stressors (Scheffer et al., 2001a and Scheffer et al., 2001b). Climate change adaptation will increase the need to strengthen the linkage of science to economic incentives, policy frameworks, and the development of adaptive management capabilities. Optimized use and allocation of water resources will be essential to sustain ecosystems on which social and economic systems depend.

Better indicators with their ability to predict change at various spatial and temporal scales are needed to support lake management. However, implementing and sustaining environmental and socio-economic monitoring programs that are so crucial is likely to remain a challenge in the future with limited financial resources and political commitment. Meaningful environmental targets need to be supported by robust, scientifically defensible monitoring programs. As comprehensive monitoring is usually not always feasible, there is a need for proxy indicators that support management goals such as water quality, fish productivity, biodiversity, ecosystem resilience and social development. Monitoring must consider the time frames and frequencies that are appropriate to system as well as to the response time of the indicators. This necessitates understanding and consideration of natural variability across both spatial and temporal scales, to support the implementation and assessment of the effectiveness of management actions. In transboundary lakes it important that monitoring activities across the watershed (i.e., different countries, jurisdictions, agencies) are compatible so as to be able to test hypotheses. Transboundary monitoring programs need to be designed to measure progress toward environmental and human development goals while informing decision makers and increasing public awareness and confidence. When people and governments understand how the environmental goals (and indicators) are linked to social and economic impacts it is easier to implement and sustain programs. Innovative solutions and technologies are emerging that can be applied to this growing gap between science and management.

7. Conclusions

Future projects on transboundary lakes need to consider lakes as part of a linked hydrologic continuum within integrated watershed management. There is a need for increasing the focus on the ecosystem approach and recognition of the interconnected nature of water, land and atmospheric components of watersheds. Human activities alter environmental stressors in diverse and unpredictable ways and seldom in isolation. Adequate scientific assessments must be included early to identify potential effects of both multiple sources and effects of cumulative stressors that could influence the success of GEF investment. More effective ways to monitor the impacts and responses of ecosystems to management interventions are needed especially the incorporation of proxy indicators that can be sustained over long time periods. Successful transboundary lake interventions need to ensure effective capacity development and training, implementation of planning processes which include policy development and harmonization, promotion of the development of strong regional collaboration, linkages to the international/local science communities, as well as early and sustained involvement of all stakeholders. Clear objectives, scientifically robust basin-level assessments (including socio-economic), and setting of achievable and measureable targets will inform and facilitate uptake at each level of decision making (local, national and transboundary). Transboundary lake projects under GEF or other programs will face many challenges but lessons learned from past projects can be applied to ensure the success of future investments.

Acknowledgments

We wish to acknowledge the tremendous work of the GEF projects on lakes that are the basis of this review. Many people participated directly or indirectly to this review through the UNU led Working Groups, the dialog that occurred at the Bangkok Meeting and the various reviewers of the related documents.

References

1.

- Araneda et al., 2009
- A. Araneda, F. Torrejón, M. Aguayo, I. Alvial, C. Mendoza, R. Urrutia
- Historical records of Cipreses glacier (34°S): combining documentary-inferred 'Little Ice Age' evidence from Southern and Central Chile
- The Holocene, 19 (2009), pp. 1173–1183
- View Record in Scopus

  |

  Full Text via CrossRef

  | Cited By in Scopus (1)

2.

- Araneda et al., 2007
- A. Araneda, F. Torrejón, M. Aguayo, L. Torres, F. Cruces, M. Cisternas, R Urrutia
- Historical records of San Rafael glacier advances (North Patagonian Icefield): another clue for Little Ice Age timing in Chile?
- The Holocene, 17 (2007), pp. 987–998
- View Record in Scopus

| Cited By in Scopus (21)

3.
- AMAP (Arctic Monitoring and Assessment Programme), 2010
- AMAP (Arctic Monitoring and Assessment Programme)
- AMAP Assessment 2009: Persistent Organic Pollutants in the Arctic
- Science of the Total Environment, 408 (2010), pp. 2851–3051

4.
- Borysova et al., 2005
- O. Borysova, A. Kondakov, S. Paleari, E. Rautalahti-Miettinen, F. Stolberg, D. Daler
- Eutrophication in the Black Sea Region; Impact Assessment and Causal Chain Analysis
- University of Kalmar, Kalmar, Sweden (2005)

5.
- FAO (Food Agriculture Organization), 2003
- FAO (Food Agriculture Organization)
- World Agriculture: Towards 2015/2030: An FAO Perspective
- J. Bruinsma (Ed.), 92 5 104835 5Earthscan Production Ltd., London, UK (2003)

6.
- Coe and Foley, 2001
- M.T. Coe, J.A. Foley
- Human and natural impacts on the water resources of the Lake Chad basin
- Journal of Geophysical Research, 106 (D4) (2001), pp. 3349–3356

7.
- Comprehensive Assessment of Water Management in Agriculture, 2007
- Comprehensive Assessment of Water Management in Agriculture
- Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture
- Earthscan, and Colombo: International Water Management Institute, London (2007)

8.
- Daughton and Ternes, 1999
- C.G. Daughton, T.A. Ternes
- Pharmaceuticals and personal care products in the environment: agents of subtle change?
- Environmental Health Perspectives, 107 (1999), pp. 907–938

9.
- de Fraiture et al., 2008
- C. de Fraiture, M. Giordano, Y. Lia
- Biofuels and implications for agricultural water use: blue impacts of green energy

- Water Policy, 10 (Supp. 1) (2008), pp. 67–81
-

10.
- GEF (Global Environment Facility), 2013a
- GEF (Global Environment Facility), 2013a. GEF International Waters Strategy. Accessed March 17, 2013 〈http://www.thegef.org/gef/IW_GEF5_strategy〉
-

11.
- GEF (Global Environment Facility), 2013b
- GEF (Global Environment Facility), 2013b. IW: LEARN, GEF IW Project Manuals. Accessed March 24, 2013 〈http://manuals.iwlearn.net〉
-

12.
- Donohue et al., 2003
- I. Donohue, R.W. Duck, K. Irvine
- Land use, sediment loads and dispersal pathways from two catchments at the southern end of Lake Tanganyika, Africa: implications for lake management
- Environmental Geology, 44 (2003), pp. 448–455
-

13.
- Goodwin et al., 2006
- P. Goodwin, K. Jorde, C. Meier, O. Parra
- Minimizing environmental impacts of hydropower development: transferring lessons from past projects to a proposed strategy for Chile
- Journal of Hydroinformatics, 8 (2006), pp. 253–270
-

14.
- Hecky et al., 2010
- R.E. Hecky, R. Mugidde, P.S. Ramal, M.R. Talbot, G.W. Kling
- Multiple stressors cause rapid ecosystem change in Lake Victoria
- Freshwater Biology, 55 (2010), pp. 19–42
-

15.
- Heugens et al., 2001
- E.H.W. Heugens, A.J. Hendriks, T. Dekker, N.M. van Straalen, W. Admiraal
- A review of the effects of multiple stressors on aquatic organisms and analysis of uncertainty factors for use in risk assessment
- Critical Reviews in Toxicology, 31 (2001), pp. 247–284
-

16.
- Jägerskog and Jønch Clausen, 2012
- Jägerskog, A., Jønch Clausen, T. (Eds.), 2012. Feeding a Thirsty World–Challenges and Opportunities for a Water and Food Secure Future. Report Number. 31. SIWI, Stockholm.
-

17.
- Karlsson et al., 2000

- H. Karlsson, D.C.G Muir, C.F. Teixiera, D.A. Burniston, W.M.J. Strachan, R.E. Hecky, J. Mwita, H.A. Bootsma, N.P. Grift, K.A. Kidd, B. Rosenberg
- Persistent chlorinated pesticides in air, water, and precipitation from the Lake Malawi area, Southern Africa
- Environmental Science and Technology, 34 (2000), pp. 4490–4495
-

18.
- Klaine et al., 2008
- S.J. Klaine, P.J.J. Alvarez, G.E. Batley, T.F. Fernandes, R.D. Handy, D.Y. Lyon, S. Mahendra, M.J. McLaughlin, J.R. Lead
- Nanomaterials in the environment: behavior, fate, bioavailability, and effects
- Environmental Toxicology and Chemistry, 27 (2008), pp. 1825–1851
-

19.
- Lange, 2012
- Lange, M., 2012. Conference Report of the 'GEF International Waters Science Conference 2012: Setting the International Waters Science Agenda for the next Decade. 24–26 September 2012, United Nations Conference Center (UNCC) Bangkok, Thailand, IW Science 〈http://iwlearn.net/abt_iwlearn/events/iw-science-conference〉
-

20.
- Contributing authors, 2012
- L.Z. Mee, O.Tujchneider Adeel, J. van der Gun, K. Munkittrick, M. Servos, H. Kremer, R. Ramachandran, M. Babel, E. Karar, A. Cabanban, S. Heymans, A. Dansie, Contributing authors
- Synthesis Report. Science-policy bridges over troubled waters: making science deliver greater impacts in shared water systems
- , 92-808-6034-8United Nations University Institute for Water, Environment and Health (UNU-INWEH), Hamilton, Canada (2012) 〈http://www.inweh.unu.edu/River/IWScience%20Reports/SynthesisReport_Web.pdf〉
-

1.
- Micklin and Aladin, 2008
- P. Micklin, N. Aladin
- Reclaiming the Aral Sea
- Scientific American, 2008 (2008), pp. 64–71
- View Record in Scopus

  |

  Full Text via CrossRef

  | Cited By in Scopus (1)

2.
- Munkittrick et al., 2012a
- K. Munkittrick, G. Constantin, M. Servos, N. Aladin, S. Choowaew, N. Hap, K. Kidd, E. Odada, O. Parra, G. Phillips, S. Ryanzhin, R. Urrutia
- Lakes: A global Synopsis of Lakes Science and Transboundary Management. Synopsis Report of the Lakes Working Group, GEF IW Science
- , 92-808-6021-6United Nations University Institute for Water, Environment and Health (UNU-INWEH), Hamilton, Canada (2012) 〈http://www.inweh.unu.edu/River/IWScience%20Reports/L%20SYN%20Final.pdf〉
-

3.
- Munkittrick et al., 2012b
- K. Munkittrick, G. Constantin, M. Servos, N. Aladin, S. Choowaew, N. Hap, K. Kidd, E. Odada, O. Parra, G. Phillips, S. Ryanzhin, R. Urrutia
- Lakes: A Global Analysis of Lakes Science and Transboundary Management. Analysis Report of the Lakes Working Group, GEF IW Science
- , 92-808-6020-8United Nations University Institute for Water, Environment and Health (UNU-INWEH), Hamilton, Canada (2012) 〈http://www.inweh.unu.edu/River/IWScience%20Reports/L%20ANA%20Final.pdf〉
-

4.
- Scheffer et al., 2001a
- M. Scheffer, S. Carpenter, J.A. Foley, C. Folke, B. Walker
- Catastrophic shifts in ecosystems
- Nature, 413 (2001), pp. 591–596
- View Record in Scopus

  |

  Full Text via CrossRef

  | Cited By in Scopus (1607)

5.
- UNU-INWEH, 2011a
- UNU-INWEH
- Transboundary Lake Basin Management: Laurentian and African Great Lakes
- UNU-INWEH, Hamilton, Ontario, Canada (2011)
-

6.
- 〈http://start.org/download/publications/environment-development.pdf〉
- E.O. Odada, D.O. Olago, W. Ochola (Eds.), Environment for Development: An Ecosystems Assessment of Lake Victoria Basin, United Nations Environment Programme, UNEP/PASS (2006)

7.

- O'Reilly et al., 2003
- C.M. O'Reilly, S.R. Alin, P-D. Plisnier, A.S. Cohen, B.A. McKee
- Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa
- Nature, 424 (2003), pp. 766–768

8.

- Rahl and Olden, 2008
- F.J. Rahl, J.D. Olden
- Assessing the effects of climate change on aquatic invasive species
- Conservation Biology, 22 (2008), pp. 521–533

9.

- Pernetta, 2002
- Pernetta, J.C., 2002. Reversing Environmental Degradation Trends in the South China Sea and Gulf of Thailand. The United Nations Environment Programme and The Global Environment Facility Project No. GF/2730-02-4340. 〈http://www.unepscs.org/Newsflashes/Newsflash/Terminal_Report_of_the_SCS_Project.html〉

10.

- Scheffer et al., 2001b
- M. Scheffer, S. Carpenter, J.A. Foley, C. Folke, B. Walker
- Catastrophic shifts in ecosystems
- Nature, 413 (2001), pp. 591–596

11.

- Tamatamah et al., 2005
- R.A. Tamatamah, R.E. Hecky, H.C. Duthie
- The atmospheric deposition of phosphorus in Lake Victoria (East Africa)
- Biogeochemistry, 73 (2005), pp. 325–344

12.

- UNEP, 2005
- UNEP
- Severskiy, I., Chervanyov, I., Ponomarenko, Y., Novikova, N.M., Miagkov, S.V., Rautalahti, E. and D. Daler. AralSea, GIWA Regional Assessment 24
- University of Kalmar, Kalmar, Sweden (2005)

13.

- UNU-INWEH, 2011b
- UNU-INWEH
- Transboundary Lake Basin Management: Laurentian and African Great Lakes, UNU-INWEH
- Hamilton, Ontario, Canada (2011)

14.

- Vörösmarty et al., 2000
- C.J. Vörösmarty, P. Green, J. Salisbury, R.B. Lammers
- Global water resources: vulnerability from climate change and population growth
- Science, 289 (2000), pp. 284–288

15.

- WHO/IPCS, 2002
- WHO/IPCS, 2002. In: Damstra, T., Barlow, S., Bergman, A., Kavlock, R., Van Der Kraak, G. (Eds.), Global Assessment of the State of the Science of Endocrine Disruptors. WHO/PCS/EDC/02.2 World Health Organization, Geneva, Switzerland 〈http://ehp.niehs.nih.gov/who/〉.

16.

- Winder and Schindler, 2004
- M. Winder, D.E. Schindler
- Climate change uncouples trophic interactions in an aquatic ecosystem
- Ecology, 85 (2004), pp. 2100–2106

17.

- Woodward et al., 2010
- G. Woodward, D.M. Perkins, L.E. Brown
- Climate change and freshwater ecosystems: impacts across multiple levels of organization
- Philosophical Transactions of the Royal Society B: Biological Sciences, 365 (2010), pp. 2093–2106
- View Record in Scopus

  |

  Full Text via CrossRef

  | Cited By in Scopus (66)

18.

- Wright et al., 2008
- Wright, S.J., Parra, O., Bledsoe, B., 2008. Give and take: the toll on ecosystems. Sigma XI. The Scientific Research Society: Critical Issues in Science White Papers.

19.

- Wrona et al., 2006
- F.J. Wrona, T.D. Prowse, J.D. Reist, J.E. Hobbie, L.M.J. Lévesque, W.F. Vincent
- Climate change effects on aquatic biota, ecosystem structure and function
- AMBIO: A Journal of the Human Environment, 35 (2006), pp. 359–369
- View Record in Scopus

|

Full Text via CrossRef

| Cited By in Scopus (60)

20.
- WWAP (World Water Assessment Programme), 2012
- WWAP (World Water Assessment Programme), 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. UNESCO, Paris.
-

☆

Thematic issue: Collaborative Global Management of Water in the Journal Environmental Development. To be published by Elsevier in association with United Nations University's Institute for Water, Environment and Health and the International Waters Learning Exchange and Resource Network (IW: LEARN).

Corresponding author. Tel.: +519 888 4567x36034.

Copyright © 2013 Elsevier B.V. All rights reserved.

Note to users: Corrected proofs are Articles in Press that contain the authors' corrections. Final citation details, e.g., volume/issue number, publication year and page numbers, still need to be added and the text might change before final publication.

Although corrected proofs do not have all bibliographic details available yet, they can already be cited using the year of online publication and the DOI , as follows: author(s), article title, journal (year), DOI. Please consult the journal's reference style for the exact appearance of these elements, abbreviation of journal names and use of punctuation.

When the final article is assigned to an issue of the journal, the Article in Press version will be removed and the final version will appear in the associated published issue of the journal. The date the article was first made available online will be carried over.