

Chapter 2

Performance Indicators in the Water Resources Management Sector

Balázs M. Fekete and Eugene Z. Stakhiv

Abstract Governance, i.e., the institutional administrative component of water resources management, in particular and natural resources management in general, is an increasingly complex endeavor that forms the basis of integrated water resources management. Hence, it is very difficult to assess the performance of numerous adopted policy decisions and regulations that guide future water management adjustments. A myriad of interconnected aspirational goals, embedded within various well-intentioned UN Declarations, address desired water resources management improvements (efficiency, productivity) as a mechanism to support a wide variety of economic, social, ecological and cultural objectives. A wide array of performance indicators has been developed to track the relative effectiveness of these policies on water use productivity and efficiency. Any useful water resources management performance index must start with an accurate specification of available resources at various water resources management accounting level (country, region, river basins, etc.). Traditionally, water resources accounting was carried out via statistical surveys (e.g., FAO-AQUASTATS). A major step forward is deploying high resolution hydrological data assimilation along with geographical information systems to develop water resources assessment and link those data to spatially distributed socio-economic information. It is difficult enough to accurately describe the core state variables of a water management system, such as annual renewable water resources at national and river basin scales. The complexity and uncertainty magnifies when these state variables are used in composite indices to assess the performance of a diverse assortment of water related

B. M. Fekete (✉)

Department of Civil Engineering, The City College of New York, CUNY Environmental CrossRoads Initiative, CUNY CREST Institute, City University of New York, Steinman Hall Room #188, 160 Convent Avenue, New York, NY 10031, USA
e-mail: bfekete@ccny.cuny.edu

E. Z. Stakhiv

UNESCO International Center for Integrated Water Resources Management (ICIWaRM), Department of Geography and Environmental Engineering, Johns Hopkins University, Baltimore, MD, USA

investments, or the relative effectiveness of institutional reforms on various components of the water sector (irrigation, water supply, hydropower, etc.). Single indicators are clearly inadequate to guide different aspects of the water management. Composite indices, such as the Water Poverty Index (WPI) or the Environmental Sustainability Index (ESI), which combine aspirational goals with state variables, skew the evaluation outcomes. Furthermore, indices applied uniformly to regions or countries with vastly different hydro-climatological, geographical and socio-economical conditions are prone to lead to misleading comparison. This chapter offers an overview of some of the indicator systems used in the past and discusses some of the challenges in producing resources management indicators. The paper outlines a conceptual framework for indicators that are suitable to guide both water management planning and evaluation of the implementations.

Introduction

The search for meaningful indicators to track progress of various UN initiatives such as the Millennium Development Goals has a long history going back to the United Nations Conference on Environment and Development (UNCED) or Rio Conference (1992). Numerous composite indices have been developed with the intention of assessing the current state of a nation's status with respect to a set of desired objectives—e.g., the Human Development Index (HDI) (UNDP 1990); the Water Poverty Index (WPI) (Sullivan 2002; Sullivan and Meigh 2003) or the Environmental Sustainability Index (ESI). Several variants of these indices have been developed and tested in various countries and river basins (Kemp-Benedict et al. 2011; Cai et al. 2011).

The genesis for this monitoring evolved from the 1992 United Nations (UN) Dublin Conference on Water and the Environment, which established the main principles of modern water management, and which served as the basis of Chap. 18 of the UNCED Agenda 21 (Rio de Janeiro, 1992). These principles included the imperative necessity of reliable information for water resources planning and management. This issue has been repeatedly reemphasized in a series of subsequent UN conferences, such as the World Summit on Sustainable Development (WSSD) (Johannesburg, August–September 2002), the Commission on Sustainable Development (CSD) (2004 and 2005) as well as other international meetings such as the Istanbul Fifth World Water Forum (2009) and the Sixth World Water Forum in Marseilles (2012).

One of the main outcomes of the United Nations Conference on Sustainable Development or Rio + 20 Conference (2012) was the agreement by member States to launch a process to develop a set of Sustainable Development Goals (SDGs), which will build upon the Millennium Development Goals and converge with the post 2015 development agenda. It was decided to establish an *“inclusive and transparent intergovernmental process open to all stakeholders, with a view to developing global sustainable development goals to be agreed by the General Assembly”*. It was further agreed that SDGs must be:

- Action-oriented
- Concise
- Easy to communicate
- Limited in number
- Aspirational
- Global in nature
- Universally applicable to all countries while taking into account different national realities.

The development of SDGs will be followed by calls for developing a corresponding set of performance indicators to track the implementation of various SDG initiatives. It is one thing, however, to ask for basic information for status reports on a set of key indicators, as a way of conveying a ‘snapshot’ overview of a nations’ status as a comparative exercise. It is quite another matter to use these indicators and composite indices to determine the relative effectiveness of various UN targets and initiatives, particularly complex ones. The basic reasons are that:

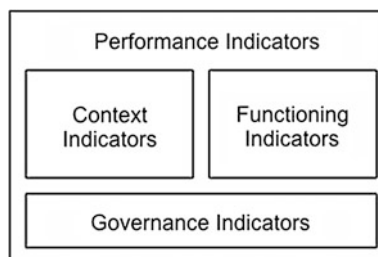
- water resources management comprises many different sectors (irrigated agriculture; municipal water supply, hydroelectric power, flood control, ecosystems, navigation, etc.), each with a different array of management objectives and guiding legislation and regulations;
- many of the water sector reforms deal with a complex array of governance and institutional reform issues, whose direct effects are difficult, if not impossible to evaluate collectively, much less individually;
- national level, aggregate, time-averaged indicators are simply too coarse to be of use for evaluating the relative effectiveness of individual policies on a particular water sector;
- there are too many higher-order national or exogenous global factors that dominate and often catalyze water sector changes, such as trade agreements, globalization, political change or instabilities and lack of financial resources, which are not taken into account in the composite indicators.

Utility of Indicators

Indicators by definition are simplified abstractions of the real world. Some indicators, such as the GDP (Gross Domestic Product) or CPI (Consumer Product Index) are used routinely to summarize the changes in a nation’s production and consumption patterns. A great deal of technical effort and resources are devoted to these composite indices so they are often deemed to conceptually and practically reflect key economic trends at the national level.

Traditional one dimensional indicators expressed as a simple ratio of some resource with respect to socioeconomic conditions often lack correlation in a statistical sense (Chenoweth 2008) with policy relevant states of the managed

Fig. 2.1 Performance indicators structured around context and function indicators underlined by governance indicators



resources. Indicators structured to address efficiency or productivity in the sense of getting more for the investment ('crop per drop', or an increase in yield) have a bit more success, but there is a great degree of variability between different countries (Kemp-Benedict et al. 2011; Cai et al. 2011).

In a broader sense, resources management needs to consider the '**context**' with respect to the '**function**' of the management activity and its alignment with the prevailing '**governance**' approach (e.g., federal systems vs centralized control). These three dimensions, when structured appropriately may enable a more practical assessment of the relative **performance** of the managed sector (Fig. 2.1).

Context Indicators relate to the natural context (e.g., water availability, rainfall), to infrastructure (such as water treatment capacity, or storage), or to human and economic capitals. 'Context indicators' are required to act as benchmarks when assessing the achievements of another territory with a comparable context. Chenoweth (2008) demonstrated that simple context indicators (e.g., Falkenmark (1986) Water Scarcity Index), and other comparable indices that use per capita water availability as key metric) as a means to evaluate performance are inadequate. "The common sense definition of water scarcity being a state of insufficient water to satisfy normal requirements is of little use to policy makers as it fails to acknowledge degrees of water scarcity and how different societies adapt to this scarcity." In other words, those indices that describe predetermined thresholds are essentially inadequate for policy formulation purposes, or even as descriptors of the current state of scarcity. Chenoweth (2008) also noted, the problem arises because composite indices such as the WPI or the ESI (with the exception of the HDI) often try to link vaguely defined concepts such as IWRM or sustainability with particular desired water resources management outcomes.

Function Indicators relate to inputs, outputs and outcomes (e.g., water use intensity). A number of indicators relate to describing the dynamic functioning of the water sector at the national level (e.g., water withdrawals, water depletion or wastewater actually treated). The WPI and ESI are examples of such formulations. The WPI (Sullivan 2002) intended to provide links between poverty, social deprivation, environmental integrity, access, water availability and health) was applied to 147 countries in 2002. It showed that some of the world's richest nations such as the United States (32nd) and Japan (34th) fare poorly in water ranking, while two developing countries (Guyana, Suriname) score in the top ten. The WPI grades 147 countries to show where the best and worst water situations exist. The

Environmental Sustainability Index (ESI) has similar puzzling outcomes. In the 2012 survey, the US ranked 49th, below Spain (32), Greece (33), Nicaragua (35), and just above Cuba (50), Zambia (57) and Egypt (60).

These composite indices focus on abstract goals and lack the ability to take into account improvements in management, technological adaptation, or globalization (trade and economic changes throughout the globe). The absence of a significant correlation between water availability—either *internal* renewable water resources (the amount of water generated entirely within national boundaries), or with *total* renewable water resources, contradicts the expectation embedded in these indicators that per capita water resources availability play a significant role in determining the ability of a country to satisfy basic water and other human needs (Chenoweth 2008).

Governance Indicators offer possible explanations behind the different levels of performance achieved through the intervention of various policies, programs and regulations intended to improve water use effectiveness, and between a given territory or river basin in comparison with different benchmark territories. Management and governance are sometimes mistakenly considered synonyms, their distinctions is important (Pahl-Wostl 2009). While management refers to activities to keep the state of the resources within desired bounds, governance takes into account the different actors in charge of regulating those who carry out resource management decisions. Depending on the complexity of the inter-relationship between formal and informal institutional hierarchies ranging from state to non-state actors steering resource management objectives faces different challenges. Multi-level, polycentric governance that is characteristic for Western democracies leads to complex interaction between the various governing actors with different level of jurisdiction and degree to influence on management decisions (Pahl-Wostl 2009). The breadth of governance indicators must embrace territorial water resources and a wide variety of water use management improvements to provide an insightful diagnosis of possible weak spots in need of further investigation and possible improvement or reforms (Saleth and Dinar 2004).

Performance Indicators synthesize the three core indicators (context, function, governance) as a targeted consideration of the functioning of a particular sector in relation to its objectives, within a given context. Issues of efficiency/ productivity, effectiveness and impact can be considered (e.g., access to water supply and sanitation or value added in agriculture or industry). Only performance indicators can serve an evaluation function—i.e., to provide insights as to general effectiveness or cost-effectiveness of a particular course of action or a set of policies or combination of investments. Performance indicators are not ‘state variables’ that describe some existing or desired condition. Rather they are meant to illuminate whether a strategy of prescribed actions achieve their intended effect—i.e., they meet the desired outcomes. Water productivity (WP) defined as the ratio of net (economic) benefits from water use (crop, forestry, fishery, livestock or other mixed agricultural systems) and the amount of water utilized in its production (Cai et al. 2011), appears to be a more relevant metric that measures how the system converts water and other resources to goods and services. It is a

performance metric relating two state variables (economic output and resources utilization) and assesses existing conditions that could be tracked over time to determine relative changes and improvements.

Cai et al. (2011) assessed WP across 10 major river basins, in several continents, at different stages of development and in various hydro-climatic zones with varying proportion of irrigated land from a high (78 %) to low (1 %). Crop yields were highest in the river basins with the highest proportion of irrigation and lowest in rain-fed systems. The authors ultimately concluded that there was too much variability in the river basins and factors other than water availability were at least as important in WP—especially the availability of markets and highly variable prices for commodities. Kemp-Benedict et al. (2011) studying the same 10 river basins from a different perspective arrived to similar conclusion. They tried to make the link between water availability and poverty. This approach differs from the obverse of the water availability—water-specific forms of deprivation, which forms the core of the Water Poverty Index (Sullivan and Meigh 2003). Kemp-Benedict et al. (2011) found that defining poverty itself is difficult, as it covers such tangible concepts as income, assets, as well as sociological conditions of relative deprivation and well-being (education, mortality, life expectancy) and a sense of empowerment and control over one's life.

The Water Performance index appears to be a step in the right direction, but it still misses the essence of acknowledging the differences in the value of water. Water rich countries like Canada or Japan, will rank poorly in terms of return on each “drop of water”, since their agriculture tends to produce crops that are water intensive. In contrast, countries with limited water resources such as Israel are likely to invest in high value crops (e.g., fruits, vegetables) providing high return on investment in water infrastructure.

Indicators developed, so far, rarely take into account the inherent temporal variability of the underlying natural, human induced and socioeconomic processes, although a considerable number of studies were carried out to assess how certain indicators would change under future climate conditions (Arnell 1999, 2010; Schewe et al. 2013)

Since performance indicators are expected to be able to track the changes over time and evaluate if the overall performance is heading in the right directions, all the underlying indicators have to be expressed in a time-varying manner. The core (context, function and governance) indicators need to provide some metrics reflecting those changes that occur outside of the control of the policy makers or managers, in order to distinguish changes in the performance indicators over time that are due to exclusively to policy and management decisions.

Governance and IWRM

One of the most difficult evaluations is the performance assessment of institutional changes (laws, policies, regulations) that are considered key to effective water

resources management. *Saleth and Dinar (2004)*, in their pioneering study of institutional performance in the water sector, note that “...*water scarcity whether quantitative, qualitative, or both—originates more from inefficient use and poor management than from any real physical limits on supply augmentation.*” According to their analysis, the crisis in the water sector is mainly a function of limitations of contemporary institutions, which allocate and manage water and they advocate a series of institutional reforms that are key for successful implementation of IWRM.

Governance reforms are very difficult to implement, and more difficult still to evaluate their relative effectiveness on improvements in water use efficiency, economic productivity, poverty reduction or improvements in environmental sustainability. *Saleth and Dinar (2004)* tried to develop a mechanism for evaluating these important institutional changes. The quantitative results were quite mixed and in most cases inconclusive. The reason was that effective water governance is predicated on a series of prerequisites, beginning with a well-defined system of water rights or water law and enforcement. Other related water policies, administrative changes and water extraction regulations, including those for privatization, cost recovery, water transfers—were all intertwined with the fundamental requirement to define and enforce water rights.

Governance can be defined as the web of policies, institutional arrangement and management instruments mobilized by the actors making decisions impacting the functioning of the production system on a territory. These instruments, or measures include:

- *Technical* measures used in resource assessment and design of structures used to control, store and supply water for different purposes.
- *Economic* measures used to encourage efficient and responsible allocation and use of water resources including pricing, charges, subsidies and penalties.
- *Administrative* information systems, maps/models, plans, guidelines and other decision support and management tools.
- *Legal* measures, which prescribe restrict or prohibit different water uses including abstraction/discharge permits, codes of conduct and minimum standards.
- *Institutional* regulatory bodies, management arrangements, planning procedures, coordination and partnership mechanisms
- *Social/Participatory* measures to increase awareness of water issues and mobilize users to participate in planning, management and financing of water resource development

IWRM, of course, is the fundamental comprehensive management platform for attaining what is termed ‘water security’ and sustainable development. The most widely acceptable definition of water security would read as “the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies” (Grey and Sadoff 2007). The definition is firmly embedded in the concept of sustainable development, with its aim to ensure a triple bottom line of social, environmental, and economic development outcomes. A somewhat more useful categorization for ‘water security’ was proposed by Turton

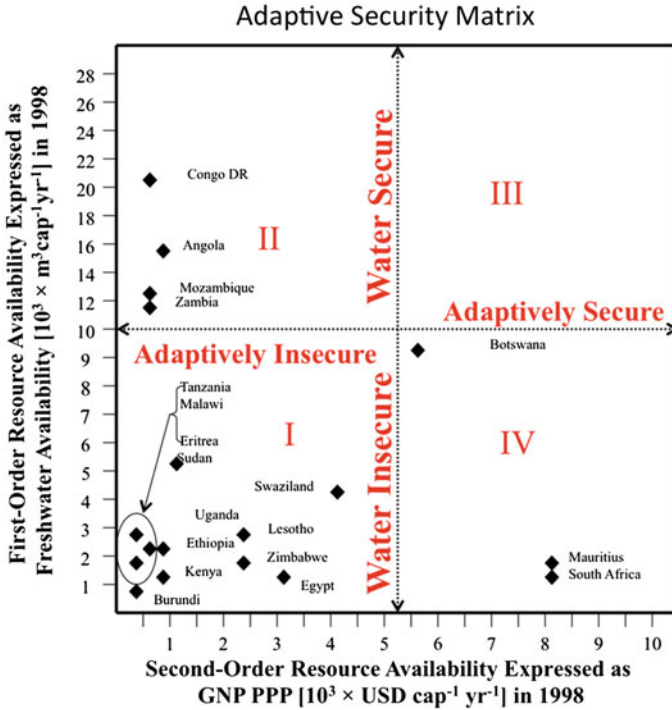


Fig. 2.2 Adaptive security matrix adopted from Turton and Warner (2002) and populated with a wider range of countries

and Warner (2002). They formulated a four quadrant graph of water security/insecurity that is represented by the per capita availability of total renewable water resources versus the relative adaptability of a nation to deal with water scarcity, as reflected by GDP per capita (Fig. 2.2). Both are gross measures, but at least there is a recognition that nations can effectively deal with relative water resources scarcity through improved performance and institutional adaptation. Generally speaking, nations cannot create new water (except for desalination), and cannot readily move from Quadrant I to quadrant II. However, they can become adaptively secure by increasing their GDP. Economic growth will allow investments in technology and infrastructure, and is the key to adaptive water security (towards the quadrants III and IV).

Water Resources Accounting

Reliable water resource accounting is a fundamental basis for establishing any water related indicators. The lack of adequate hydrological monitoring (Hannah et al.

Table 2.1 Global freshwater fluxes to ocean estimates in km³/year

Source	Discharge
Baumgartner and Reichel (1975)	37,713
Korzoun et al. (1978)	46,900
L'vovich et al. (1990)	39,700
Oki et al. (1995)	22,311
Postel et al. (1996)	40,700
Grabs et al. (1996)	42,700
Nijssen et al. (2001)	36,103
Fekete et al. (2002)	38,320
Dai et al. (2009)	37,288
Schlosser and Houser (2007)	36,000
Syed et al. (2010)	32,851
Wisser et al. (2010)	37,405
Haddeland et al. (2011)	42,000–66,000

2010; Fekete et al. 2012) severely hinders optimal design and operation of the water infrastructure and allocation of water resources. Global water resource assessments that could guide international efforts to promote sustainable human developments are in particularly difficult due to inconsistencies in data reporting, obstacles in data sharing and declining monitoring capabilities (Vörösmarty et al. 2001).

Water resource planners often use various statistics (long term mean, extremes, exceedance probability, etc.) in lieu of the time varying records partly as a convenience to reduce the amount of data needed, but as a necessity, when observation records are only available as statistical summaries. Traditionally, these statistics were assumed to be stationary, but this assumption was challenged (Milly et al. 2008) arguing that with changing climate these statistics will no longer remain steady and water managers will need to consider Global Circulation Model predictions to prepare for anticipated changes.

The first global assessments of the global freshwater resources (Baumgartner and Reichel 1975; Korzoun et al. 1978; L'vovich et al. 1990) were solely based on water balance considerations. Later studies included country statistics (Shiklomanov 2000; Shiklomanov and Rodda 2002) or discharge gauge records (Grabs et al. 1996; Fekete et al. 2002). Up until the first decade of the 21st century the different assessments appeared to narrow around the 36,000–39,000 km³/year (Table 2.1) with some notable exception. Both Oki et al. (1995) and Syed et al. (2010) based their water budget assessments on atmospheric water budget derived from the weather forecast model reanalysis from NCAR–NCEP (Kalnay et al. 1996; Kistler et al. 2001) which has known deficiencies in representing the amount of water participating in the water cycle (Fekete et al. 2004).

Before Haddeland et al. (2011), the global estimates appeared within the 36,000–40,000 km³/year that Fekete et al. (2002) suggested as the most plausible range based on the recognition that only 50 % is monitored for discharge recording 20,700 km³/year on average based on the Global Runoff Data Centre's data (Fekete et al. 2002).

The discharge to ocean estimates from Haddeland et al. (2011) were generated as a model inter-comparison exercise under the EU WATCH¹ program where global scale hydrological models were tested with the same bias corrected Global Circulation Model climate forcings, therefore the deviation from previous reported values is not surprising, but the wide range among the tested models is disturbing. Recent effort under the Inter-sectoral Impact Model Intercomparison Project (ISI-MIP) (Schiermeier 2012) arrived to similar spread while testing different large scale impact assessment models with hydrological component (Davie et al. 2013; Schewe et al. 2013).

The large uncertainties in water resource estimates based on hydrological modeling combined with the similar uncertainties in GCM future climate predictions makes (Milly et al. 2008) suggestion to rely more on climate and hydrological simulations for numerical water resources planning questionable. Fekete and Stakhiv (2013) argued that water managers best guidance will remain to use hydrological observations and continuously update of the long-term statistics. Since water infrastructures are typically designed for 30–40 years, when major repairs and upgrades are inevitable, past records with sufficient extra safety buffer will remain viable basis for specifying design criteria, while the continuous update of the long-term statistics allows for adaptation of changing climate (Fekete and Stakhiv 2013).

Conclusions

Improving availability of spatially specific hydro-meteorological, bio-geophysical and socioeconomic data opened new opportunities in supporting water managers and decision makers with up-to-date and comprehensive information. Given the plethora of diverse data available, policy makers will need aggregated information in the form of performance indicators that combine context, function and governance indicators as a single metric providing insights into the effectiveness of a particular course of action or a set of policies or investments. Comprehensive performance indicators need to objectively assess whether given policy decisions lead to desired outcomes without preconditioning or biasing the policy options to a narrowed subset that are preferred “a priori”.

Simplistic context indicators such as the Falkenmark index or function indicators such as the Water Poverty Index or the Environmental Sustainability Index, promoted in the past, are insufficient to substitute for true performance indicators, because they are limited to identifying potential shortages of water without recognizing the capabilities of individual societies to adapt to water resources limitations via the deployment of technology, better water resource management, etc.

In this chapter, a conceptual framework for performance suitable to evaluate water resources management was proposed that distinguishes three underlying core indicators (**context**, **function** and **governance**) to characterize the boundary

¹ <http://www.eu-watch.org>.

conditions (context) within which water resources management needs to operate, the objectives (functioning) of the water resources utilization and the regulatory, institutional and management environment (governance) dictating how policy decisions and implementations are carried out.

Instructive **performance indicators** need to synthesize **context**, **function** and **governance** indicators in order to provide an integrated metric that can guide water managers and policy makers. Context, function and governance indicators need to be able to characterize spatial and temporal variability, while performance indicators are expected to factor in the spatial differences and temporal variations in a manner that would allow performance evaluations irrespective of space and time.

Regardless of the simplicity or complexity of various indicators intended to help evaluation for policy making and management decisions, the validity of any indicators ultimately hinges on the underlying data. The huge uncertainties in water resources estimates severely hinder the application of any indicators. Without adequate monitoring and reliable data, 'tweaking' the existing array of indicators remains a futile exercise that won't improve decision making.

References

- Arnell NW (1999) Climate change and global water resources. *Glob Environ Change* 9:S31–S49
- Arnell NW (2010) Hydrology and global environmental change. In: Malone TF, Roederer JG (eds) *Global environment change*. Pearson, Cambridge, UK, pp 4–6
- Baumgartner A, Reichel E (1975) *The world water balance*. Elsevier, New York
- Cai XL, Molden D, Mainuddin M et al (2011) Producing more food with less water in a changing world: assessment of water productivity in 10 major river basins. *Water Int* 36:42–62. doi:[10.1080/02508060.2011.542403](https://doi.org/10.1080/02508060.2011.542403)
- Chenoweth J (2008) A re-assessment of indicators of national water scarcity. *Water Int* 33:5–18. doi:[10.1080/02508060801927994](https://doi.org/10.1080/02508060801927994)
- Davie JCS, Falloon PD, Kahana R et al (2013) Comparing projections of future changes in runoff from hydrological and biome models in ISI-MIP. *Earth Syst Dyn* 4:359–374. doi:[10.5194/esd-4-359-2013](https://doi.org/10.5194/esd-4-359-2013)
- Dai A, Qian T, Trenberth KE (2009) Changes in continental freshwater discharge from 1948 to 2004. *J Climat* 22:2773–2792
- Falkenmark BYM (1986) Fresh water-time for a modified approach. *AMBIO* 15:192–200
- Fekete BM, Looser U, Roberts RD (2012) Rationale for monitoring discharge on the ground. *J Hydrometeorol* 13:1977–1986
- Fekete BM, Stakhiv EZ (2013) Water management preparation strategies for adaptation to changing climate. In: Charles R, Kumagai M, Roberts RD (eds) *Climate change and global warming of inland waters: Impacts and mitigation for ecosystems and societies*, 3rd edn. John Wiley & Sons
- Fekete BM, Vörösmarty CJ, Grabs W (2002) High-resolution fields of global runoff combining observed river discharge and simulated water balances. *Glob Biogeochem Cycles* 16(15):1–6. doi:[10.1029/1999GB001254](https://doi.org/10.1029/1999GB001254)
- Fekete BM, Vörösmarty CJ, Roads JO, Willmott CJ (2004) Uncertainties in precipitation and their impacts on runoff estimates. *J Climatol* 17:294–303
- Grabs W, de Couet T, Pauler J (1996) Freshwater fluxes from the continents into the world oceans based on data of the global runoff data base. Global Runoff Data Centre, Koblenz
- Grey D, Sadoff CW (2007) Sink or swim? Water security for growth and development. *Water Policy* 9:545. doi:[10.2166/wp.2007.021](https://doi.org/10.2166/wp.2007.021)

- Haddeland I, Clark DB, Franssen W et al (2011) Multimodel estimate of the global terrestrial water balance: setup and first results. *J Hydrometeorol* 12(5):869–884. doi: [10.1175/2011JHM1324.1](https://doi.org/10.1175/2011JHM1324.1)
- Hannah DM, Demuth S, van Lanen HAJ et al (2010) Large-scale river flow archives: importance, current status and future needs. *Hydrol Process*. doi:[10.1002/hyp.7794](https://doi.org/10.1002/hyp.7794)
- Kalnay E, Kanamitsu M, Kistler R et al (1996) The NCEP/NCAR 40-year reanalysis project. *Bull Am Meteorol Soc* 77:437–471. doi: [10.1175/1520-0477\(1996\)077](https://doi.org/10.1175/1520-0477(1996)077)
- Kemp-Benedict E, Cook S, Allen SL et al (2011) Connections between poverty, water and agriculture: evidence from 10 river basins. *Water Int* 36:125–140
- Kistler R, Kalnay E, Collins WD et al (2001) The NCEP/NCAR 50-year reanalysis: Monthly means CD-ROM and Documentation. *Bull Am Meteorol Soc* 82:247–267. doi: [10.1175/1520-0477\(2001\)082](https://doi.org/10.1175/1520-0477(2001)082)
- Korzoun VI, Sokolov AA, Budyko MI et al (1978) Atlas of the world water balance. Gidrometeoizdat, Leningrad
- L'vovich MI, White GF, Belyaev AV et al (1990) Use and transformation of terrestrial water systems. In: Turner BL, Clack WC, Kates RW et al (eds) *Earth as transformed by human action*. Cambridge University Press, Cambridge, USA, pp 235–252
- Milly PCD, Betancourt J, Falkenmark M et al (2008) Stationarity is dead: whither water management? *Science* 319:573–574
- Oki T, Musiake K, Matsuyama H, Masuda K (1995) Global atmospheric water balance and runoff from large river basins. *Hydrol Process* 9:655–678
- Pahl-Wostl C (2009) A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Glob Environ Change* 19:354–365. doi:[10.1016/j.gloenvcha.2009.06.001](https://doi.org/10.1016/j.gloenvcha.2009.06.001)
- Postel SL, Daily GC, Ehrlich PR (1996) Human appropriation of renewable fresh water. *Science* 271(2):785–788
- Saleth RM, Dinar A (2004) *The institutional economics of water: a cross-country analysis of institutions and performance*. Edward Elgar, Cheltenham, UK
- Schewe J, Heinke J, Gerten D et al (2013) Multimodel assessment of water scarcity under climate change. *Proc Nat Acad Sci U.S.A.* doi:[10.1073/pnas.1222460110](https://doi.org/10.1073/pnas.1222460110)
- Schiermeier Q (2012) Models hone picture of climate impacts. *Nature* 482:286. doi:[10.1038/482286a](https://doi.org/10.1038/482286a)
- Schlosser CA, Houser PR (2007) Assessing a satellite-era perspective of the global water cycle, *J Climate* 20:1316–1338
- Shiklomanov IA (2000) Appraisal and assessment of world water resources. *Water Int* 25:11–32
- Shiklomanov IA, Rodda JC (2002) *World water resources at the beginning of the 21st century*. UNESCO, Paris
- Sullivan CA (2002) Calculating a water poverty index. *World Dev* 30:1195–1210
- Sullivan CA, Meigh J (2003) Considering the water poverty index in the context of poverty alleviation. *Water Policy* 5:513–528
- Syed TH, Famiglietti JS, Chambers DP et al (2010) Satellite-based global-ocean mass balance estimates of interannual variability and emerging trends in continental freshwater discharge. *Proc Nat Acad Sci U.S.A* 107:17916–17921
- Turton AR, Warner JF (2002) *Exploring the population/water resources nexus in the developing world*. The Woodrow Wilson Institute, Washington, DC, p 52–82
- UNDP (1990) *Human Development Report 1990*. United Nations Development Programme (UNDP)
- Vörösmarty CJ, Askew A, Barry RG et al (2001) Global water data: a newly endangered species. *AGU EOS Trans* 82:54, 56, 58
- Wisser D, Fekete BM, Vörösmarty CJ, Schumann AH (2010) Reconstructing 20th century global hydrography: A contribution to the Global Terrestrial Network- Hydrology (GTN-H). *Hydrol Earth Syst Sci* 14(1):1–24. doi: [10.5194/hess-14-1-2010](https://doi.org/10.5194/hess-14-1-2010)

The Global Water System in the Anthropocene
Challenges for Science and Governance

Bhaduri, A.; Bogardi, J.; Leentvaar, J.; Marx, S. (Eds.)

2014, XVI, 437 p. 70 illus., 26 illus. in color., Hardcover

ISBN: 978-3-319-07547-1