Water security: from abstract concept to meaningful metrics

An initial overview of options

Nathaniel Mason and Roger Calow

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Results of ODI research presented
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and critical comment

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Acronyms

AMCOW	African Ministers' Council on Water
BIP	Biodiversity Indicators Partnership
CAFOD	Catholic Overseas Development Agency
CGIAR	Consultative Group on International Agricultural Research
CIWA	Cooperation on International Waters in Africa
CMI	Climate Moisture Index
CoFR	Committee on Foreign Relations (US Senate)
CUNY	City University of New York
CVI	Climate Vulnerability Index
DCDC	Development Concepts Doctrine Centre, Ministry of Defence (UK)
DEG	German Investment Corporation (Deutsche Investitions- und Entwicklungsgesellschaft)
DFID	Department for International Development (UK)
DIE	German Development Institute (Deutsches Institut für Entwicklungspolitik)
DRC	Democratic Republic of Congo
DRR	Disaster Risk Reduction
ECDPM	European Centre for Development Policy Management
EG-IMD	Expert Group on Indicators, Monitoring and Databases
FAO	Food and Agriculture Organization (UN)
GAR	Global Assessment Report (on Disaster Risk Reduction)
GEMI	Global Environmental Management Initiative
GEMS	Global Environment Monitoring System
GIS	Geographic Information Systems
GLAAS	Global Annual Assessment of Sanitation and Drinking Water
GTN-H	Global Terrestrial Network for Hydrology
GWP	Global Water Partnership
GWSP	Global Water System Project
HDR	Human Development Report
ICF	International Climate Fund
ICOLD	International Commission on Large Dams
IGRAC	International Groundwater Resources Assessment Centre
IISS	International Institute for Security Studies
INBO	International Network of Basin Organisations
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
JMP	Joint Monitoring Programme
MDG	Millennium Development Goal
MEWINA	Monitoring and Evaluation for Water in North Africa
MRI	Mortality Risk Index
N-AMCOW	North African Ministers' Council on Water
NGO	Non-Governmental Organisation
NIC	National Intelligence Committee
ODI	Overseas Development Institute
PSI	Pilot Study on Indicators
RBO	River Basin Organisation
SDG	Sustainable Development Goal
SEEA(W)	System of Environmental-Economic Accounting (for Water)
SSA	sub-Saharan Africa
SWAR	Surface Water Runoff
TARWR	Total Actual Renewable Water Resources
TF-IMR	Task Force on Indicators, Monitoring and Reporting

UN	United Nations
UNCSD	United Nations Conference on Sustainable Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children’s Fund
UNISDR	United Nations International Strategy for Disaster Reduction
UNSD	United Nations Statistics Division
USACE	US Army Corps of Engineers
WASH	Water Supply, Sanitation and Hygiene
WBCSD	World Business Council on Sustainable Development
WDPA	World Database on Protected Areas
WEF	World Economic Forum
WHO	World Health Organization
WPI	Water Poverty Index
WRI	World Resources Institute
WRM	Water Resource Management
WWAP	World Water Assessment Programme
WWDR	World Water Development Report
WWF	World Wildlife Fund

Executive summary

With renewed global awareness of planetary boundaries and resource constraints, water's vital role in underpinning equitable, stable and productive societies, and the ecosystems on which we depend, is undisputed. Water security has emerged as a powerful concept to encapsulate the many competing objectives of water resource management, and is increasingly gaining traction in global debates and the agendas of governments, businesses and NGOs. While deliberation continues about exactly how far the scope of the term extends, the emphasis to date has been at a theoretical, qualitative level. While this is vital, we have to be able to measure progress in more rigorous terms if we are to translate water security from abstract concept to a meaningful tool to guide policy and practice.

This paper is a first attempt to meet this need. It responds simultaneously to two concerns. On the one hand a political concern, to articulate the objectives of water management in aspirational terms. On the other hand, a technical or operational concern, to know what we are dealing with and how much progress we are making on water management, in clear, measurable terms.

Bridging between these political and technical concerns is becoming increasingly urgent as 2015 approaches, by which point a global framework of goals, targets and indicators needs to be defined to succeed the Millennium Development Goals (MDGs). The move to develop Sustainable Development Goals (SDGs), potentially applying to all countries and placing greater emphasis on the natural capital underpinning human development, could provide greater room for water than the current MDG targets, which focus on drinking water supply and sanitation. The process to define SDGs is only now beginning, in parallel to the UN Secretary General's existing initiative on the Post-2015 Development Agenda. The integration of these parallel processes, and the place of different resources including water within them, is therefore of increasing interest. Water security is emerging as a possible unifying concept for the different things water managers are trying to achieve, which could therefore be relevant in thinking about how to frame global goals and targets on development and the environment. At the same time, irrespective of global policy agendas, developing country governments and donors continue to be faced with pressing challenges about how best to manage and develop water resources for the benefit of people, ecosystems and economies. There is, then, an acute need to identify appropriate water security metrics at national level also.

The paper is written primarily from the technical perspective, with a pragmatic focus on what can be measured: the emphasis is therefore on indicators and the availability and quality of underlying data. At the same time it retains the political perspective, with attention to the aspirational debates about what should be measured. The concept of water security is relatively young, and carries different associations with longer-established concepts, notably national security and human security, as well as food and energy security. While there are a number of definitions, overall consensus on what water security means has not yet been reached. The related concepts of water scarcity and water risk have also generated considerable debate. After setting out the rationale for the research in greater detail, the paper reviews the three concepts of water scarcity, risk and security. Building on this analysis, it identifies five key themes which are arguably encompassed by the emerging concept of water security, and which can help structure the development of a pragmatic, yet aspirational, metrics framework:

- Water security goes beyond immediate physical availability: water in the atmosphere, on the surface and below ground interacts in complex ways, with different responses to human impacts; availability in any given period or place is furthermore moderated by the economic and social capacity to access water.
- Water security requires us to address variability and risk: while water security implies permanence, spatial and temporal variability is inherent to water systems. As variability amplifies, and where we do not have the capacity to adapt, it translates into water-related risks, including flood, drought and pollution.

- Water security needs a human focus: to be real and meaningful, beyond technical and policy circles, water security has to focus on the needs of individuals, especially the poor and vulnerable. The water security of all matters equally, irrespective of social, economic or political disparities.
- Water security also requires us to meet environmental needs: whether viewed as intrinsically valuable, or valuable for the services they provide, freshwater ecosystems require protection. Ecosystem water requirements may vary over time, and must be met in terms of both quantity and quality.
- Water security requires management of competition and conflict: given the breadth of human and environmental needs which must be met, there are inevitable tradeoffs, particularly in those areas where water is intensively used, or where withdrawals are rapidly accelerating. The institutional capacity to avoid or resolve these tradeoffs, and mediate between the claims of competing users through rules-based systems rather than force or coercion, is therefore essential.

Each of these themes presents different challenges in terms of measurement, which are considered in turn. Physical availability of water is, at first sight, the fundamental concern, and appears relatively straightforward to measure. But even the most basic indicators for availability are fraught with conceptual and methodological difficulties, including accounting for complex interactions of ground and surface water, and in any case omit how water security is mediated by demand for and capacity to access water. Variability and risk are difficult to measure in and of themselves, whether in probabilistic or more qualitative terms, as are corresponding concerns, such as society's capacity to adapt. Human-focused measures of water security have been comparatively well-developed, particularly in relation to health via the drinking water and sanitation targets of the current MDGs. But there has been less attention paid to measuring the extent, costs and benefits of other human uses of water, particularly those associated with agriculture and industry. Environmental requirements are highly context-dependent and likely to vary seasonally, making generic measurement difficult. Measures of institutional capacity, required for example to allocate across competing uses, have tended to be conceived in terms of process, which may not lead directly to substantive outcomes.

Methodological difficulties in defining appropriate indicators are compounded by gaps in the availability and quality of underlying data. Even for key data items like average renewable water resources (flowing in and out of a country or falling as precipitation) internationally consolidated data is not available for all countries, especially for key components such as groundwater, and is rarely updated. Data quality and availability are further constrained by reluctance of countries and other entities, such as corporations, to share information on water. Important initiatives have been undertaken, notably by the World Water Assessment Programme and UN-Water, but overall the architecture for water monitoring is marked by a lack of coordination and collaboration.

But while political and technical challenges around data and indicators abound, this paper does not focus only on constraints. Consideration is given to the positive lessons of other initiatives on metrics – for example monitoring of progress on water supply and sanitation up to and beyond 2015, and efforts to develop targets and indicators on energy. The potential role of innovative methods is also considered – for example placing more emphasis on proxy indicators, or utilising new technologies such as remote sensing. Above all, the paper closes by identifying a range of indicator options in relation to each of the five identified themes, a selection of which could feasibly be employed for recurrent monitoring of different aspects of water security at national and global level. Looking beyond what is currently, pragmatically possible to measure, for each theme a second, more aspirational set of indicator options is also proposed, which would require further effort in data collection and interpretation. For each of the proposed indicators data sources, calculation methods, technical notes and an assessment of the potential policy implications of their use are given. The options are proposed to prompt debate about which indicators are appropriate, in the knowledge that only a selection of the proposed indicators is required, and alternatives or additional options may be available. This technical debate needs to evolve on a parallel, iterative basis to political debates about how water security should be defined, to ensure pragmatism does not limit aspiration, and aspiration does not ignore what is pragmatically possible.

1 Introduction

This paper outlines options for the development of a set of metrics for monitoring water security, principally at the level of countries. Multiple definitions have been proposed for water security, reflecting the desire to articulate, in a few words, the objectives of water resource management in general, as well as reflecting interest in other related 'security' agendas including food, energy, national and human security. This paper does not propose another 'definitive' characterisation of water security. Rather, it considers existing definitions of water security and related terms, notably water scarcity and risk, to identify the themes in relation to water security that recur in ongoing debate (Box 1). From there, workable options for measuring progress on each component are identified, as a first step in moving from an abstract concept, to measurable policy targets.

Outside drinking water and sanitation coverage, which have become the focal indicators for the water sector as a whole due to the prominence of Millennium Development Goal (MDG) target 7c, there is little consensus, nor any unified international architecture, for monitoring progress on water security, broadly conceived.

Box 1: Water security: the right norm for water management?

This paper responds to the increasing prominence of water security in policy and academic usage (Cook and Bakker 2012). However, it should be noted that the term does not have the endorsement of all those working on water issues. Even if understood broadly, there is an argument that the word 'security' will always carry militaristic overtones, or will imply that solutions to water problems will be achieved by force, rather than negotiation and cooperation. Proponents of the term therefore need to monitor the way it is being interpreted by different actors – its place as a useful and universally endorsed term is not yet assured. At the same time, the remainder of this paper proceeds on the assumption that 'water security' is currently the simplest and most widely accepted term to articulate the outcome of sound water management, and therefore the mission of the water management community.

Combined with other challenges, such as the low economic value placed on water as a resource, and the complexity of natural and anthropic water systems, the absence of clear indicators and targets has militated against government and donor attention to water resource management. Assessment of water resources to date has tended to provide either broad measures focusing on availability (Falkenmark, Lundqvist and Widstrand 1989; Seckler et al. 1998); complex composite indicators for human and ecological water threats (Vörösmarty et al. 2010); or has focused on process rather than outcomes, for example the number of countries that have developed Integrated Water Resource Management (IWRM) plans or instituted river basin organisations (AMCOW 2012a; UNEP 2012). Routine monitoring of these measures has been constrained by data availability and a fragmented institutional architecture.

At the same time, awareness of the importance of the resource base for human development and the ecological systems on which we depend is growing. Global meetings such as the UN Conference on Sustainable Development in Rio (Rio+20) have flagged the need to frame new goals, targets and indicators beyond 2015. There is a re-emergent desire to unite, or at least not to further polarise, the spheres of environment and development (Melamed, Scott and Mitchell 2012), notably under a framework of Sustainable Development Goals (SDGs) that could go significantly beyond the current MDGs in scope and application (potentially applying to all, rather than just developing countries). A broad conception of water security should therefore allow for recognition of our universal dependency on water as a fundamental form of natural capital, in a way that recognises both an environmental dimension (protecting the resource for our own and future generations) and a developmental one (providing access to sufficient water to permit all to fulfil their capabilities).

The paper provides a number of options that could form part of a framework of metrics for assessing progress on water security, at national and global level, to help focus attention and potentially to direct finance and capacity for water security to those countries most in need. The focus is on water security outcomes rather than intermediate outputs or processes. The paper starts from the recognition that a metrics framework comprises a family of components (Box 2) and requires attention to the scientific, objective and empirical, as well as the political, moral and normative.

Box 2: Metrics terminology

The following definitions clarify the terminology around metrics used in this paper:

- Goal. A broad statement of a desired, usually longer-term, outcome of a program/intervention.
- Target. The objective a program/intervention is working towards, expressed as a measurable value; the desired value for an indicator at a particular point in time.
- Indicator. A quantitative or qualitative variable that provides a valid and reliable way to measure achievement, assess performance, or reflect changes connected to an intervention.
- Monitoring. Routine tracking and reporting of priority information about a program/project, its inputs and intended outputs, outcomes and impacts.

The UK Department for International Development (DFID), in its guidance on monitoring for the projects and programmes it funds, describes a 'Results Chain' which moves from input, through process activities, to output, to outcome, and thence impact. Indicators or specific deliverables are used to track progress at each link in the results chain. Impact can be broadly associated with Goal in the sense outlined above and is described by DFID as 'a higher-level situation which the project will contribute towards achieving'. Although Goal is used throughout this paper for consistency with the hierarchy of goals, targets and indicators established with the MDGs, the DFID thinking around a 'results chain' may also be useful.

Source: For general definitions, UNAIDS (2010), for DFID-specific terminology, DFID (2011)

The paper is structured as follows: The rationale for re-examining water security and related metrics is established in Section 2, with reference to key applications in policy and practice, for example around the SDGs, the green economy and the continued need to provide guidance to policy makers and practitioners at different levels on whether water resource development and management is moving in the right direction. These potential applications are likely to influence the perceived need for, and shape of, any water security metrics framework. Section 3 further sets the scene, providing a simplified overview of the main framings of water security, current among different constituencies, as well as the related terms water scarcity and water risk. The section closes by identifying five constituent themes and a working definition, which provide a reference point for subsequent analysis. Section 4 examines how different aspects of water security are being measured by existing indicators and approaches. In the light of the preceding analysis, Section 5 considers the current architecture for coordinating and undertaking monitoring, with close attention to the serious challenges of data quality and availability. Section 6 concludes with a number of recommendations for potential indicators to underpin a metrics framework. Indicator options are presented according to two levels of aspiration: a scenario in which limited further resources are made available and existing data sources and monitoring systems must be used, versus a more aspirational scenario under which a coordinated international effort is made to strengthen the gathering and interpretation of water-related data.

2 Rationale: opportunities to set the goalposts

This paper is intended to inform a number of emerging, and evolving agendas. Given this aim, the following section is dedicated exclusively to unpacking those agendas and identifying the potential opportunities for engagement around water security and its measurement.

2.1 The Post-2015 Development Agenda and SDGs

Water's place in any post-2015 framework of goals and targets has, to date, been most extensively explored in relation to water supply, sanitation and hygiene (WASH), thanks largely to the efforts of the Joint Monitoring Programme (JMP) of UNICEF and the World Health Organization (WHO) to devise relevant and feasible goal, target and indicator options (Box 3) Meanwhile, the SDGs were a key feature of Rio+20 (20-22 June 2012), with one of the few substantive results from the conference being a commitment to define and agree them. The process on SDGs is initially to be led by a 30 strong panel nominated by member states with inputs from the UN Secretary General, though no deadline has been specified for their agreement (UN, 2012). The Rio+20 outcome document reflects various themes around water, including WASH and others such as 'floods, droughts and water scarcity', and 'the role of ecosystems in maintaining water quantity and quality' (UN 2012: 23-24).

The proposal to develop SDGs came with the UN Secretary General already having initiated a process on the 'Post-2015 Development Agenda', which has a less explicit emphasis on the environmental dimensions of development. There are now two processes running in parrallel, and it is not yet clear as to how they will be reconciled.

Box 3: Efforts to measure WASH and what this tells us about water security metrics

Several working groups of invited experts are convening between 2011 and 2013 to consider how progress on WASH should be measured, once the MDG deadline is reached in 2015. The JMP is able to derive estimates of what kinds of water sources or sanitation facilities are used by what proportion of the population. But attempts to measure other important considerations (for example water quality, the extent of treatment of wastewater, or the sustainability and affordability of services) have faced difficulties, notably around data availability and accessibility. Identifying a window of opportunity in the run-up to 2015, the working groups are tasked with developing options for extending the scope of WASH indicators and targets. There is also a wider public consultation process.

Concerted and well-coordinated efforts around WASH metrics provide an instructive example for the broader water security agenda. In the first place, globally agreed goals and targets for water supply and sanitation have helped direct resources, not only to the subsectors themselves, but also to the monitoring architecture – exemplified by the initiation of the JMP, and now the post-2015 working groups. Simplicity has been a key hallmark of the MDG indicators on water supply and sanitation, which has aided their uptake as policy and communications tools. At the same time the working groups, drawing on the expertise of many different agencies and interests, show that agreement on difficult decisions about what matters, and how to measure it, needs to be obtained as part of a systematic and consultative process. Finally, the JMP and working groups are circumspect about their ability to dictate the place of WASH in any global post-2015 architecture, describing the goal as being to 'pave the path for the menu of options to be offered for consideration by the UN-member States in their deliberations on post-2015 goals and targets' (JMP, 2012). A similar degree of circumspection may be required by proponents of water security, for example in considering synergies with other resource agendas, notably around the water-food-energy nexus.

Source: JMP (2012)

At root, this is a debate about whether social and economic objectives (a developmental paradigm) can be combined with sustainable management of our environment (an environmental paradigm), especially if the latter is perceived as growth-limiting (Melamed, Scott and Mitchell 2012). There are other, related uncertainties, for example around whether the new goals should apply universally or only to developing countries, or should be aspirational or binding (Evans and Steven 2012).

As elaborated in this paper an expansive and inclusive framing of water security has the potential to synthesise developmental and environmental objectives – for example equitable access to productive uses of water, and protection from water-related disasters, while safeguarding minimum flows to protect ecosystem services. But in reality those objectives can often appear to be in competition, presenting tradeoffs rather than opportunities for synthesis: for example conventional approaches to flood protection may involve heavy engineering (e.g. dams and dikes) which can disrupt natural freshwater flows on which ecosystems depend. This implies the need for a measurement framework that can permit meaningful assessment and comparison of progress against potentially competing objectives. The proposals which have developed from the Sustainable Energy for All Initiative offer an example from another issue at the bridge (or faultline) between environment and development (Box 4).

Box 4: The Sustainable Energy for All Initiative: a chance to integrate developmental and environmental paradigms?

The UN Secretary-General's proposal on sustainable energy for all comprises three objectives (Sustainable Energy for All Initiative 2012). One of these speaks primarily to the developmental paradigm (universal access) while the other two have greater kinship with the environmental paradigm (energy efficiency and renewable energy):

- Ensuring universal access to modern energy services.
- Doubling the global rate of improvement in energy efficiency.
- Doubling the share of renewable energy in the global energy mix.

Importantly, the underlying goals do not necessitate any major trade-offs, in and of themselves. Could the Sustainable Energy for All proposal provide lessons for the identification of metrics for water security or water resource management?

Energy differs from water, in that renewable forms are, to some extent, unlimited (whereas water is theoretically renewable but limited in absolute availability). By rapidly deploying renewable technologies there is potential to increase access, with attendant social and economic benefits, without necessarily exerting pressure on the environment, at least in terms of safe levels of greenhouse gas emissions. This so-called 'triple-win' is particularly open to developing countries that have yet to put in place long-lived, expensive energy generation and distribution capital (ODI, DIE and ECDPM 2012). There are certainly potential trade-offs, for example the water (and land) requirements of renewable technologies such as large scale solar, biofuels and hydropower, or the risk of a rebound effect from increasing efficiency, but these depend on how the objectives are achieved, not on the objectives themselves. The triple-win is less apparent in the case of water, since on first impression every increase in access without an attendant increase in efficiency would appear to create greater pressure on the finite resource. But this would be to frame the challenge in a way that privileges the global limit over local realities. As explored in Section 3, patterns of access and availability are locally heterogeneous. In most countries there is more than enough water to meet basic needs and fulfil the human right to water, i.e. personal and domestic uses (UN n.d.), while highly consumptive uses, such as irrigation, in already water-scarce catchments are of course less likely to be sustainable. In this context increasing water productivity, e.g. 'crop per drop', also opens up the space for a 'triple win' (social, environmental and economic) in water management. However, all objectives are only as good as the metrics that underpin them – Sections 4 to 6 consider what is, and what might be, available to this end.

In reflecting on potential directions for engagement with the SDG and Post-2015 Development Agenda processes, caution should be sounded about when and how to promote issue-specific agendas, such as water, within the overarching negotiations of a new agreement on global goals. There are concerns that premature arguments around the specific content of a new set of goals and targets could distract from the immediate task of building consensus on fundamental questions (e.g. scope and applicability). Melamed (2012) points to the long gestation period for the MDGs, in an era in which there was broad support for multilateralism and long-run prosperity among nations belonging to the Organisation for Economic Co-operation and Development (OECD). It can be argued that the current context is very different, and less auspicious – especially given the limited progress in international negotiations around some of our most pressing environmental challenges, notably climate change (Melamed, Scott and Mitchell 2012). In this context, while work needs to be done now to define options on issue-specific indicators, goals and targets, careful consideration is needed as to how and when to enter the fray with issue-specific agendas. It is worth considering the profusion of parallel processes and events which will help define the fundamental architecture. Annex 1 provides a visual guide to these processes, elaborated by CAFOD.

2.2 The Green Economy

The other theme for Rio+20, the 'green economy', also presents a window to consider how to measure the effectiveness of water resource management and progress towards water security, particularly given a need for monitoring and decision-making tools that can integrate environmental and growth/ poverty reduction objectives (Melamed, Scott and Mitchell 2012). This need is implicit in most working definitions of the green economy, including UNEP's, which describes the green economy 'as one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities' (UNEP 2011).

The concept of the green economy has emerged from a long tradition of thinking on sustainable development, which can be traced back at least to the 70s (Runnals 2011). The economic crisis and renewed realisation of environmental degradation has catalysed a desire to articulate workable, alternative economic paradigms. The green economy featured as one of the themes for Rio+20, alongside the institutional framework for sustainable development. The Rio+20 outcome document included the green economy as 'one of the important tools available for achieving sustainable development', but following concerns from developing and emerging economies that the concept is intrinsically growth-limiting, numerous caveats were added, for example 'each country's national sovereignty over their natural resources taking into account its national circumstances, objectives… and policy space' (UN 2012: 9-10).

Though the green economy can be viewed as qualitatively different to previous articulations of sustainable development, it faces the same problem of being difficult to operationalise. A key realisation has been that we currently lack the monitoring and accounting frameworks to allow policy-makers to evaluate trade-offs between economic, social and, particularly, environmental objectives. With respect to the latter, there has been energetic work on the subject of natural capital accounting, which allows countries to compare their economic progress against their stock of natural capital, for example freshwater or agricultural land. Joseph Stiglitz has pointed out that, to date, countries make their economic decisions on the basis of an income statement (Gross Domestic Product) and, unlike companies, do not have a balance sheet against which to set their economic progress.

Natural capital accounting is more evolved for material resources (e.g. timber and fisheries) than it is for the more fundamental forms of natural capital (e.g. water and land) and ecosystem services (e.g. flood protection, water filtration) which form the basis for material resources. The UN Statistical Commission has recently adopted the System for Environmental and Economic Accounts (SEEA) which includes material resources. But while many countries also wish to apply accounting to ecosystem services, there is little agreement on the methodology for doing so (World Bank 2012a). Nevertheless, although more work needs to be done, the green economy agenda presents an opportunity to frame workable ways to account for society's impact on water – whether in terms of the raw resource (i.e. water quantity and quality), the goods produced from it (e.g. fisheries, or rainfed and irrigated crops) or the ecosystem services dependent on it (e.g. flow regulating capacity of wetlands).

2.3 Understanding water security at country level

Beyond the global debates highlighted above, individual country governments are grappling with the challenge of water resource management, with varying degrees of success – above all attempting to allocate a spatially and temporally variable resource across multiple uses, each with differing social, economic and environmental costs and benefits. Similarly, with a resurgent interest in natural resource management generally, and the prominent place of water in climate change impacts, donors are seeking to understand how they can direct support for water resource management (WRM) to the areas most in need, as well as to assess 'results' and account for the cost-effectiveness of their investments to their own citizens.

For this task reliable metrics are critical, but quality and availability of data in many countries is severely lacking at basin, national and global level in turn (WWAP, 2012). This points to the interconnectedness of metrics frameworks at different spatial scales and for different policy purposes. The issue of what data can reliably be used to frame goals and targets at international level, for global comparison as per the MDGs (and SDGs), is often bound up with what is available at national and sub-national level.

Box 5: A pan-African monitoring and evaluation initiative

The initiative, led by AMCOW, is intended to assist in assessing progress made on the Sharm-El-Sheikh commitments on water and sanitation. As such, the pan-African Monitoring and Evaluation initiative is to some degree focused on policy goals defined at supra-national level. Nonetheless, the Sharm-El-Sheikh commitments were agreed by heads of state and member governments of the African Union and the initiative thus has scope both to respond to, and to potentially help strengthen, the monitoring capacity of African governments facing water management challenges in their own countries.

The initiative guidelines issued to country governments do not specifically refer to water security, but pick up on numerous themes encompassed by a broad understanding of the term (elaborated in this report in Section 3.4), including productive use of water, good management of different water resources (groundwater, rainwater and transboundary resources), improving access to WASH, and institutional aspects. According to the reporting guidelines, the selection of data and indicators have undergone extensive consultation with different institutions working on water-related monitoring, 'taking into consideration the unique situation of the opportunities and challenges in Africa's water sector, especially with regard to data acquisition and analysis' (AMCOW 2012b). Although in its early stages, the ability of the initiative to generate information across 25 performance categories, drawing on 15 discrete indicators, will be a key test of what is currently feasible in terms of water-related monitoring in African countries, whether or not this is framed under the label of water security. This will in turn provide valuable lessons on where countries need support, with a view to monitoring for both domestic and transnational purposes.

Source: AMCOW (2012b)

While intensive use and degradation of water resources has been much debated in the Asia context, accelerating investment in water development in Africa is receiving growing attention, 'with almost all countries lacking the human, economic and institutional capacities to effectively develop and manage their water resources sustainably' (WWAP 2012: 177). As part of its response to this challenge, the African Ministers' Council on Water (AMCOW) has launched an initiative to consolidate numerous indicators across different aspects of water resource management under a 'pan-African Monitoring and Evaluation and Reporting Format' (Box 5). An equivalent initiative is also underway from the North African Ministers' Council on Water - the Monitoring and Evaluation for Water in North Africa (MEWINA) project (N-AMCOW 2012). Although these are regional initiatives they have a strong focus on understanding, and potentially contributing to, monitoring and evaluation capacity at country level and below.

In general donors are inclined to support country governments on water related monitoring and evaluation capacity as an intrinsic part of their efforts to enhance water resource management, for example the initiative described in Box 5 is funded by the German government. But they may also be concerned to enhance WRM metrics with a view to their own programming – identifying priorities and assessing value for money. As an example, DFID estimates that its recent approval and pipleline WRM-related spending totals over £85m, not including contributions to the Cooperation in International Waters in Africa (CIWA) initiative and Nile Basin Initiative. The initiation of the International Climate Fund (ICF), the primary channel for UK climate change finance intended for climate change adaptation (50%), low-carbon growth and tackling deforestation in developing countries, has opened up a further important funding stream for water resources management and water security interventions. The ICF Implementation Plan 2011/12-2014/15 Technical Paper identifies water resources management as one of seven priority sectors (DFID n.d.), and notes that:

> *The evidence base to inform investment decisions is of variable quality, and the results chains to demonstrate impact and value for money are still limited. Building a more robust evidence base will be a priority for ICF spend during the Spending Review period. (DFID n.d.: 4)*

A number of illustrative indicators for measuring impact and results are presented in the plan, but none of these relate specifically to water security outcomes. Like other donors, DFID have few tools at their disposal to weigh up the costs and benefits of different programmes, and thence to guide spending and assess the effectiveness of that spend.

Any assessment of metrics for water security should therefore also be acutely aware of country-level needs, as well as restrictions, in terms of monitoring and data. How water security is defined and measured at community level is also an emerging concern (WaterAid, 2012), with strong links to national and global water security agendas, though detailed review at this level is beyond the scope of this paper.

3 Scarcity, risk and security: competing framings

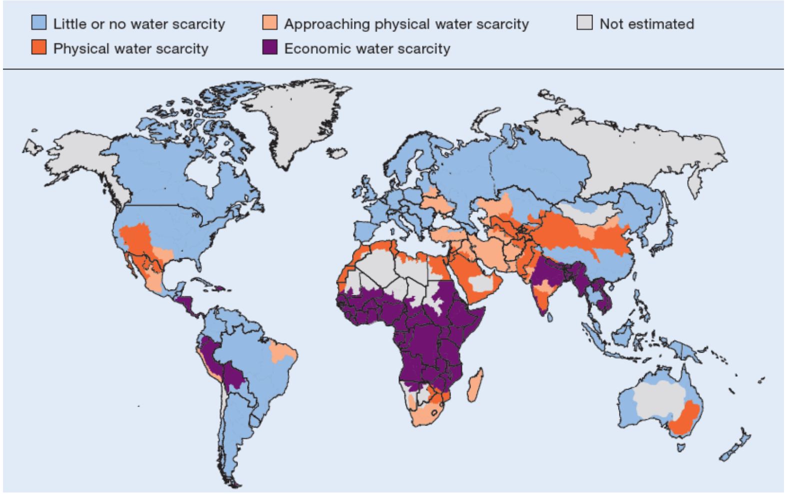
Before turning to a detailed discussion of metrics it is necessary to set out what we mean by water security. As stated, with a number of definitions for water security already proposed, and others forthcoming, another attempt to definitively encapsulate the concept in a few lines is probably not required. But it will be impossible to discuss metrics without an idea of its normative meaning, or the substantive aspects which are of concern in terms of designing a metrics framework. Hence, this section briefly reviews how water security, and the related concepts of water scarcity and risk, are being framed, before identifying 5 key aspects or themes which could be understood to fall under an expansive, inclusive framing of water security. In so doing, a brief 'working definition' is offered, for the purposes of this paper, to provide a reference point in the subsequent, detailed discussion of appropriate metrics (Section 4).

3.1 Scarcity

Across a number of resources, including potentially renewable stocks such as freshwater, limited absolute availability is being set against continuing population growth, changing patterns of consumption and changes in global environmental systems, notably the climate (ODI, DIE and ECDPM 2012). This arithmetic of scarcity - the difference between growing demand and finite (and spatially and temporally shifting) supply - is at first sight compelling, and has captured the attention of the mainstream media, governments and corporations. Certain quantifications of limits or the supply-demand gap have been particularly influential (Rockström et al. 2009; Dobbs et al. 2011). These studies have had the positive effect of galvanising attention around significant global challenges. On the other hand, they tend to privilege a conceptualisation of scarcity as natural fact, rather than as a construct of political, social and economic inequities. But despite resurgent interest in resource scarcity being driven, in many cases, by perceived physical limits, in the case of water divergent views have circulated for some time.

The 2006 Human Development Report (HDR) concluded that 'The scarcity at the heart of the global water crisis is rooted in power, poverty and inequality, not in physical availability' (UNDP 2006: v). Another forceful argument cautions against privileging scarcity - construed at national, regional or global scale and divorced from relational concepts such as need, want and access - over and above scarcities – the multiplicity of realities experienced by local people in local contexts (Mehta 2011) of which physical availability is only one component. A further key intervention in this spirit was made by the International Water Management Institute (IWMI), which characterised the essential distinction as being between areas of the world facing physical water scarcity and those facing what it called 'economic water scarcity'. In this case economic water scarcity is defined as affecting those areas with abundant physical resources relative to current use (25% of available water from rivers withdrawn) but where malnutrition exists, while physical scarcity affects those areas where more than 75% of river flows are withdrawn, accounting for return flows. Despite the simplifications – for example in taking malnutrition as a proxy for insufficient development of supply relative to need, and the focus on surface water only – IWMI's assessment and the resulting map (Figure 1) have done much to underscore that water scarcity needs to be considered in more nuanced terms than physical availability alone.

Figure 1: Areas of physical and economic water scarcity



Source: Molden (2007)

The core finding from IWMI's research has been confirmed by the Challenge Programme on Water and Food's analysis of ten major river basins including the Limpopo, Niger, Nile, Volta, Ganges, Mekong and Yellow rivers, which are home to half the world's poorest people. The analysis highlights that inefficient and inequitable use of water (including rainfed agriculture) is a more widespread problem than physical scarcity (CGIAR 2011) and that the nature of the water scarcity challenge tends to vary according to the nature of countries' economies, from agricultural, to transitional, to industrial. Other forms of water scarcity have been proposed, for example by Molle and Mollinga (2003), including managerial, institutional and political water scarcity. Therefore the term 'economic water scarcity' should not be understood as a reduction of all water management failures to failures of the market. Instead, these other socially generated forms of scarcity should be understood to be implicit.

Framing the scarcity problematic in this way implies that a range of responses are appropriate, including improved management systems and helping the poorest to access water in the first place. It would be a simplification to say that all of the recent interest in the physical dimension of scarcity ignores other forms, or excludes a broad range of solutions, in favour of unilateral action with a focus on developing or securing supplies. However, it is worth considering how far embedded political and economic norms underpin each analysis of the scarcity problem, and responses to it. For example, the management consulting firm McKinsey and Company advocates increased resource-efficiency, spurred by market signals and enlightened, proactive public policy (Dobbs et al. 2011), while the Centre for a New American Security advocates better integration of natural resource issues into the politico-military space (Parthemore and Rogers 2010).

At the same time an emphasis on physical scarcity is not confined to the corporate or national security spheres. The UN's World Water Development Report 2012 argues that 'The world is transitioning to a new era where finite water constraints are starting to limit future economic growth and development. It is becoming clear that even renewable water resources cannot supply enough water if not managed carefully' (WWAP 2012: 124). Although this does not preclude the continued threat of other forms of scarcity, it may yet mark a departure in UN thinking (insofar as this is ever homogenous) from the position adopted in the 2006 HDR.

One final caveat should be added around the way that the physical resource is often conceptualised and, in particular, the frequently implicit assumption that the key flows in time and space (which determine what is available, when and where) are between surface water and the atmosphere. But groundwater and soil moisture are also critical components of the cycle and respond at different rates, both to physical water phenomena on the surface and atmosphere, and to human interventions. Table 1 highlights some of the key differences between groundwater and surface water systems. Of critical importance is groundwater storage, which may be many times greater than annual renewable freshwater resources, and which provides a vital buffer against rainfall variability (Box 6 and Figure 2).

Table 1: Comparison of groundwater and surface water resources

Key features and characteristics	Groundwater resources and aquifers	Surface water resources and reservoirs
Storage volumes	Comparatively large	Small to moderate
Resource area	Widespread	Restricted to water bodies
Flow velocities	Low	Moderate to high
Residence times	Often decades/centuries	Generally weeks/months
Evaporation losses	Low and localised	High for reservoirs
Resource evaluation	High cost, significant uncertainty	Lower cost, less uncertainty
Resource monitoring, data availability	Very limited, especially rural	More comprehensive
Public perception, awareness	Very limited	More visible
Development cost, risk	Often modest	Frequently high
Style of development	Mixed public and private	Largely public

Source: adapted from Tuinhof et al. (2002)

Box 6: Groundwater storage: a missing piece in water security assessments?

Groundwater accounts for roughly one-third of the world's total freshwater, and the vast majority (96%) of all freshwater not bound up in ice (Shiklomanov 1998). It also plays a fundamental role in supporting human and environmental systems: groundwater abstraction probably accounts for about one-quarter of total water withdrawals; between 1.5 and 2.8 billion people (nearly half the world's population) rely on groundwater as their primary source of domestic supply; and large-scale groundwater use has brought massive benefits to millions of impoverished farmers, particularly in South Asia and the North China Plain (Morris et al. 2003; Shah 2007; Giordano 2009).

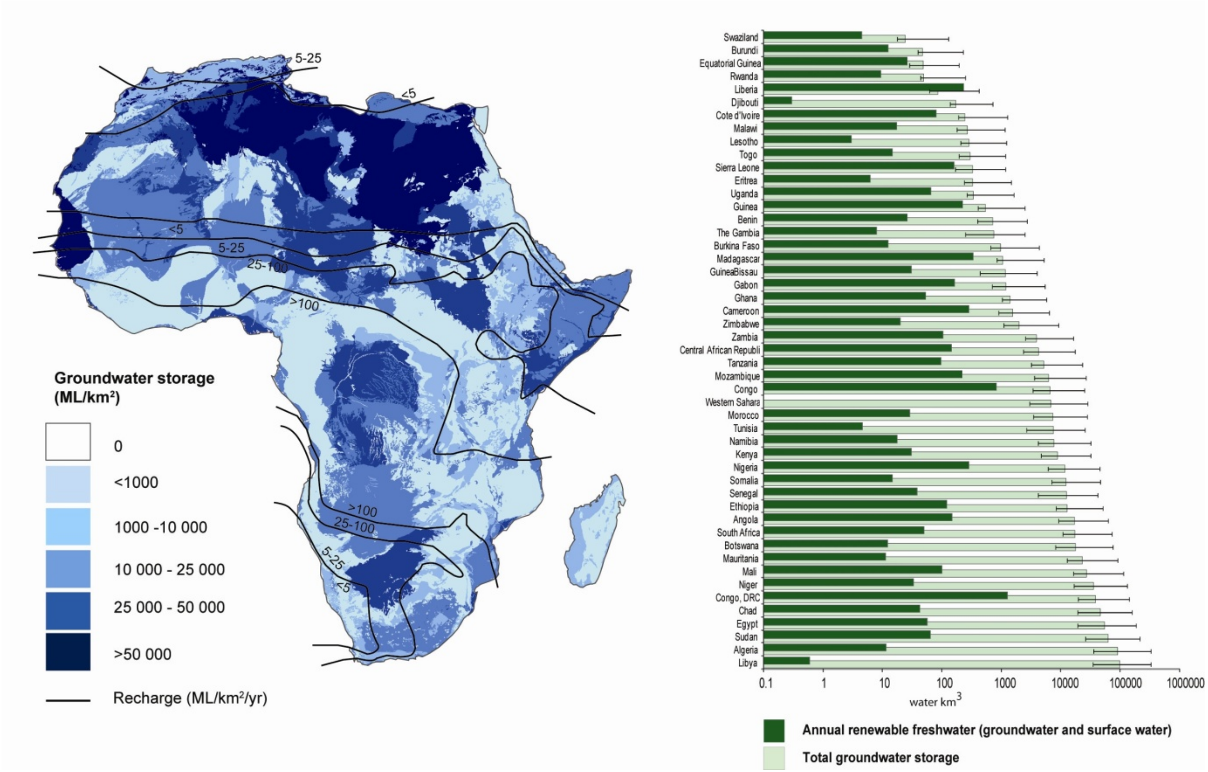
In view of its significance, we would expect to see groundwater figure prominently in assessments of global, regional and national water availability, and in the growing literature on water security. Surprisingly, it does not. As Taylor (2009) and Gleeson et al. (2012) note, most assessments of global resources have focussed on surface water only, or have failed to differentiate between the fraction of freshwater that is well distributed as groundwater with long residence times (years to decades, or longer), or that which is relatively ephemeral and concentrated in river channels. Crucially, this means that while groundwater may implicitly be included in freshwater assessments through its contribution to surface water baseflow (see e.g. Vörösmarty et al. 2010), the significance of groundwater storage is overlooked. Yet as MacDonald et al. (2012) highlight in the African continent, estimated groundwater storage represents a water resource of a different magnitude to all other freshwater sources and many countries designated as 'water scarce' in terms of annual flows have significant groundwater reserves (see Figure 2).

Why the consistent omission or under-emphasis? Giordano (2009) refers to hydro- schizophrenia: the inappropriate differentiation of the natural connection between surface and groundwater, and the creation of separate surface and groundwater governance, policy and bureaucracies. On the supply side, this relates to the fact that groundwater is 'out of sight and out of mind'; a hidden resource whose location, quantity and function in natural and human systems is poorly understood. On the demand side, the rapid acceleration in groundwater exploitation over the last five decades or so has been described as a silent revolution, with massive increases in groundwater withdrawals, particularly in south Asia, occurring largely outside the public realm, and self-financed by millions of farmers (Shah et al. 2003; Shah 2007). In Sub-Saharan Africa (SSA), the imperative to extend drinking water access to the 344 million without safe water will depend overwhelmingly on groundwater (MacDonald et al. 2009, 2011; Calow et al. 2010). However, in most circumstances data on groundwater availability are patchy at best, and data on use are even less reliable (Giordano 2009).

The particular characteristics of groundwater, beyond its relative ubiquity and use, are also poorly appreciated (Table 1). Of particular significance in a discussion of water security is groundwater storage highlighted above - specifically the large storage volume per unit of inflow - as this makes groundwater less sensitive to annual and inter-annual rainfall variation (and longer-term climate change) than surface water. The buffering or stabilisation effect this confers is hugely valuable, for example allowing groundwater sources to provide reliable dry season or drought supply for rural communities in Africa, and supplementary or full irrigation for farmers in the Indo-Gangetic plain and semi-arid northern China (Shah 2007; MacDonald et al. 2009; Calow et al. 2010). Moreover, unlike most surface water, self-supplied groundwater can be delivered precisely when needed, with the result that groundwater irrigation is generally more productive than its surface water equivalent (Burke, Sauveplane and Moench 1999; Shah 2007). Storage potential varies significantly between different hydrogeological environments, and the quality of groundwater can also vary. As Moench (2000) notes, in some locations the Ganges basin contains over 20,000 feet of saturated sediment (of variable quality) and while pumping may become uneconomic if water levels continue to fall, the resource is not about to dry up. In contrast, the basement aquifers underlying much of SSA store much less water. While they cannot support the kind of water-intensive Green Revolution witnessed in south Asia, they can still provide reliable supplies for domestic and small-scale productive uses (Calow and MacDonald 2009; MacDonald et al. 2012).

Whether withdrawals are sustainable depends, in physical terms, on the relationship between abstraction and recharge (from rainfall) over a period of time. The terms sustainable yield, safe yield, overdraft and over-exploitation are commonly used to describe this relationship, with any decline in water levels (and/or quality) frequently labelled 'unsustainable'. A key issue here is that some very large aquifers (e.g. in North Africa – see Figure 2) do not receive any contemporary recharge from rainfall, so any exploitation of non-renewable or 'fossil' groundwater is, by definition, unsustainable in these terms. However, taking a broader line on sustainability, exploitation can be justified where there are clear benefits in use and parallel investment in long-term substitutes - what Foster et al. (2003) describe as 'planned depletion'. From a water management perspective, overdraft or over-exploitation of shallow renewable aquifers can also be justified in circumstances where it makes storage available for wet season recharge, reducing flood risk and providing water supply in the dry season, as it does in Bangladesh (Morris et al. 2003). Moreover, some authors (e.g. COMMAN 2005; Moench 2007) argue that 'over-exploitation' of renewable groundwater can also be justified on social transition grounds, for example where it allows farmers to re-invest in less water-intensive and more sustainable livelihoods in the rural non-farm and urban economies. This, in turn, may make pricing or regulatory control over large aquifers easier by reducing the number of resource users and increasing the stake each remaining user has in positive resource outcomes.

Figure 2: Groundwater storage and freshwater availability in Africa



British Geological Survey © NERC 2012.

Source: MacDonald et al. (2012). Note: areas of largest groundwater storage are in sedimentary basins – both renewable and non-renewable. In North Africa, for example, water is stored in extensive 'fossil' aquifers (e.g. the Nubian sandstone aquifer beneath Chad and Egypt, with roughly 150,000 km3 of reserves) that receive no contemporary recharge but offer significant development potential. Aquifers with least storage occur in thin basement rocks across much of SSA, but even these store water from several decades and can support domestic use and minor irrigation. The graph on the right compares groundwater storage with annual renewable freshwater availability (FAO data).

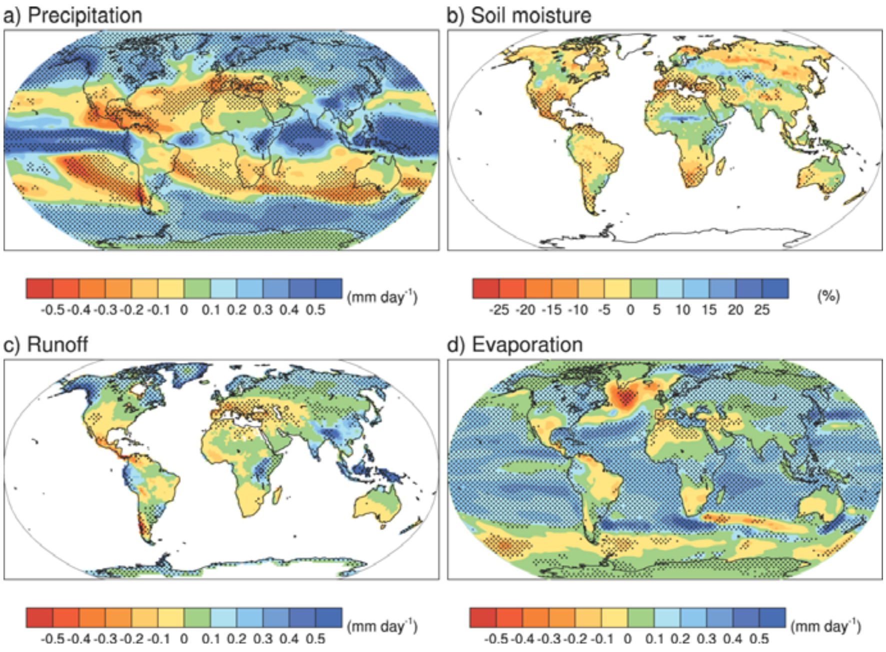
3.2 Risk

Like water security, the concept of water risk is more expansive than even a multivalent interpretation of water scarcity, in that it extends to cover challenges of over-abundance as well as insufficiency. Another key feature of risk, as a general concept, is that it can help us think systematically about uncertainty. 'Risk analysis encourages us to think about a whole range of possible future conditions, from the everyday to the extremely unlikely. That's an important feature in aquatic systems, which are inherently variable.' (Hall 2012)

The concept of water risk has been used extensively in initiatives coming from or intended for the private sector. For example, the latest 'Water Stewardship' report from Coca-Cola refers frequently to water risk and does not use the term water security at all (The Coca-Cola Company 2012). A wide range of water tools developed for strategic and operational managers within corporations, as well as external investors, refer to risk prominently in their titles or straplines (WRI 2012; Batton et al. 2011; WWF and DEG 2011; GEMI n.d.a, n.d.b, n.d.c; WBCSD 2011). This proliferation of water risk assessment and management tools appears to respond to demand – business representatives positioned 'water supply crises' second in terms of impact and fourth in terms of likelihood in the World Economic Forum's 2012 survey of 50 global risks (WEF 2012).

In responding to water risk, private sector actors can seek to address their internal operations, for example by reducing water use in industrial processes. This is often harder than it first appears, for example the hidden disincentive of needing to guarantee a minimum flow for effective functioning of most wastewater treatment technologies. A second area for engagement is in the supply chain, where large corporations may have considerable contractual leverage. In a third emerging but important development, corporations appear increasingly keen to mitigate 'external' risks arising from the wider environment, hence interest on the part of some corporations in convening stakeholders and engaging in broader water resources management - a role traditionally reserved for public agencies (Newborne 2012; 2030 Water Resources Group 2012).

Figure 3: Fifteen-model mean changes in (a) precipitation (%), (b) soil moisture content (%), (c) runoff (%), and (d) evaporation (%) for the last decade of the 21st century, relative to the last decade of the 20th century



Source: Bates et al. (2008)

The World Water Development Report (WWDR) 2012 *Managing Water under Uncertainty and Risk* (WWAP 2012) offers a number of important insights as to how risk can be usefully employed to identify, assess and respond to water resource management challenges. The report distinguishes several sources of uncertainty in relation to water systems and their management, including inadequate or unreliable data, and disagreement or ignorance about natural, physical and human processes which underpin hydrological cycles and our relationship to them. Climate change increases uncertainty, as illustrated by the Intergovernmental Panel on Climate Change (IPCC) maps of expected future change in, respectively, precipitation, soil moisture, runoff and evaporation. In Figure 3, it is only in the stippled areas that more than 80% of models agree even as to the overall direction of future change. A significant improvement is required in modelling of precipitation as well as better integration of climatic and hydrological models. Recently the EU funded Water and Global Change (WATCH) project has sought to develop a multi-model approach to assess impacts of climate change on the water cycle, bringing together the hydrological, water resource and climate research communities (Harding and Warnaars 2011). However, the authors of the WWDR 2012 also point out that even if we can improve our understanding of these processes and the quality of data that describe them, perception of risk – moderated by a number of factors, including likelihood of harm, magnitude of harmful effects, ability to moderate those effects and, critically, trust in the source of information – will determine how far individuals and society as a whole are willing to respond.

Together, these features of water risk test the capacity of all decision makers, in both public and private sectors, to respond effectively. Uncertainty and risk have long presented a challenge to water managers, but the fundamental paradigm has been to calculate future variability on the basis of statistical analysis of historic data. Climate change and other complex manifestations of society's interaction with physical and biological processes have led to a fundamental re-evaluation of this paradigm, with recognition of the non-stationarity of hydrological systems (Milly et al. 2008) and the fact that the past may not alert us to emergent future change, particularly if there is a risk of trespassing tipping points.

In response to the challenging new water risk paradigm, the WWDR 2012 recommends a number of strategies. One option is to plan in an adaptive manner – avoiding commitment to infrastructure or decision pathways that may be irrevocable. The aim here is to enhance resilience, 'the ability to adapt to changes and recover from disturbances, while providing options for future development' (WWAP 2012: 240). An alternative where adaptation is difficult, for example with major capital infrastructure on the scale of reservoirs and flood control structures, is to aim for robustness, or 'how well a system performs over a range of possible input scenarios pertaining to what is uncertain' (Ibid.). This means taking account of an expanded range of possible scenarios, beyond what the historical data suggests. Options to operationalise these approaches include scenario development (for example 'back-casting' to better account for radical changes than conventional, incremental approaches to envisioning the future) and the increased use of the natural adaptive capacity of ecosystems (for example wetlands) to buffer against change.

3.3 Security

With water's significant social and cultural importance, its intersection with the already loaded term 'security' results in some alarmist responses. For example, the World Economic Forum describes water security as an emerging 'headline geopolitical issue' that may 'tear into various parts of the global economic system' (WEF 2011). Like water risk, the concept of water security implies mitigating the effects of overabundance as well as scarcity. Indeed, one widely quoted definition of water security embraces the concept of water risk as one side of the coin – the other being availability:

> *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: 547f)

Compressing this definition further, Professor David Grey has referred to water security as 'tolerable water-related risk to society' (Hope 2012). But while this definition has the advantage of brevity, it is ambiguous – one must still ask what risks matter, and to whom. 'Society' means different things to different people, and may leave room for the privileging of some interests over others.

While the concept of water security is not new, the term appears to have gained greater profile recently, judging from a range of reports and conferences that have considered water security in isolation or in relation to the security of other resources, notably energy and food/land (WEF 2011; NIC 2012; Martin-Nagle et al. 2012; Oxford University Water Security Network 2012).

Compared to water scarcity, there has been more limited problematisation of water security discourses, notwithstanding some important interventions (Tarlock and Wouters 2009; Wouters 2010; Cook and Bakker 2012) and debates about the significance of the term have had less time to evolve and polarise. The definition of water security quoted above privileges availability of the resource. To some degree this underplays issues of access and allocation and aligns more with the concept of physical water scarcity than with other manifestations. A definition giving greater emphasis to these issues was in fact offered in the Ministerial Declaration of the Second World Water Forum in the Hague in 2000, whereby providing 'water security in the 21st century means':

> *Ensuring that freshwater, coastal and related ecosystems are protected and improved; that sustainable development and political stability are promoted, that every person has access to enough safe water at an affordable cost to lead a healthy and productive life and that the vulnerable are protected from the risks of water-related hazards.*
> Ministerial Declaration of the Second World Water Forum, The Hague.

But while the discourses on water security have not been extensively interrogated in their own right, there has been considerable thinking around longer-established security concepts with which water security is inevitably associated – notably national and human security.

In relation to national security, concepts of climate security and resource security in general have featured more prominently in foreign policy and defence communities' portfolios than water security per se (DCDC MoD 2010; CNA Corporation 2007; IISS 2011). However, there has been longstanding consideration of water's potential role in conflict, often with reference to water scarcity (CoFR, US Senate, 2011). Clear examples of international conflicts with water as a central causal factor, or as a weapon of war, are in fact rare (Yoffe, Wolf and Giordano 2001: 64). Nonetheless, there are well-documented instances of water playing a part in more localised unrest, terrorism and political oppression into recent history (Pacific Institute 2011), and commentators reflect that this is likely to be an ongoing and intensifying phenomenon (IISS 2011). The World Bank has attempted to identify potential water conflict hotspots based on physical risk and ability, at least on paper, to manage that risk, matching projected change in hydrological variability against the presence of relevant institutions, notably treaties and river basin organisations, for different transboundary river basins (de Stefano et al. 2010).

In any case, water security may increasingly be referred to in articulating water's role in national and international peace and stability due to water's strategic significance as both a 'fugitive resource' that often traverses borders (UNDP 2006: vi) and, in its 'embedded' or 'virtual' form, a globally traded commodity (see Section 4.3). A report on Global Water Security was recently commissioned by US Secretary of State Hillary Clinton from the US National Intelligence Council (NIC). The report considers the implications of water (in)security, understood in terms of national security, for US interests – identifying not only threats but also opportunities, for example in relation to the US's status as a major global food exporter (NIC 2012), picking up on the emerging theme of the interconnections, or 'nexus', between water and food security (as well as, elsewhere, energy security). The report concludes that within 10 years water insecurity could be a contributing factor to state failure, and increasingly feature as a mechanism for contestation and leverage between states. Beyond 10 years, the report has high confidence that water is more likely to be used as a weapon by states or terrorists.

Observing governmental concern with the global water crisis, and a narrow interpretation of water security aligned closely with national security, some commentators express unease that responses are more likely to be unilateral and backstopped by the threat of force, rather than multilateral and based on cooperative legal forms and management regimes (Tarlock and Wouters 2009). But it can equally be noted that in announcing the NIC commission in 2011, Clinton chose to counterbalance 'the potential for unrest, conflicts, and instability' with the rejoinder that 'the water crisis can bring people together… on water issues, cooperation, not conflict, is and can be the rule' (US Department of State 2011). The report itself includes a further headline conclusion that improved water management (including pricing, allocations and virtual water trade) and investments 'afford the best solutions for water problems' (NIC 2012: 6). This goes some way to temper concerns that the defence and foreign policy communities will necessarily co-opt the concept of water security in support of unilateral military responses.

Beyond transboundary water resources, the national security implications of water extend also to how a country manages its own internal water resources for its economic development and stability. The economic significance of water is clear, in spite of the fact that the resource itself is often under-priced or not priced at all. One influential paper suggests that economic growth is much more closely correlated to an even temporal and spatial distribution of water (i.e. low rainfall variability) than it is to high physical availability overall, and that many agricultural low-income countries are particularly vulnerable to intra-annual variability (Brown and Lall 2006). However, this may underplay the importance of groundwater storage and its potential to provide a buffer against shorter-term variability, especially as groundwater replenishment is unlikely to correlate directly with precipitation (Box 6). Growth is unlikely to be so sensitive to fluctuating rainfall in groundwater-dependent economies, for example in parts of South Asia and the North China Plain where agricultural yields have increased largely on the back of small-scale, farmer-financed irrigation from boreholes (Shah 2007). A further argument around the issue of hydrological variability proposes that vulnerability is exacerbated where countries lack a minimum platform of hydraulic infrastructure (for conveyance and storage), leaving them 'hostage to hydrology' (Grey and Sadoff 2007) – a predicament that applies to some extent in the case of groundwater also, in terms of infrastructure to access, if not store, the resource.

There are clearly both politico-military and economic imperatives at the intersection of water security and national security, which may yet influence future paradigms for WRM. The current dominant paradigm IWRM has been extensively promoted (if not applied) at national level, but as a recent report highlights, more work needs to be done to make its goals relevant in a transboundary context where national security discourses tend to play out, and where more heterogeneous legal and institutional regimes and greater disparities of power and interest may be at play (GWP and INBO 2012).

Human security is the second of the existing major security concepts which is likely to influence interpretations of water security. Since its origins, human security has been conceptually opposed to a narrow, conventional interpretation of national security. The 1994 HDR, which brought the term to popular attention, recognised that the scale and nature of many threats to peace and sustainable development cannot be tackled solely through a territorial paradigm of the nation-state backed by force of arms (UNDP 1994). The 1994 HDR represents a landmark in a narrative which continues through to the water-focussed 2006 HDR and beyond, whereby security is conceived in multidimensional terms, rooted in individual rights and cognisant of insidious disparities in power and resources between individuals and groups. Water security is not mentioned by the 1994 HDR as a category in its own right, but aspects are subsumed within the categories of health and environmental security. Furthermore, its conception of food security requires that 'all people at all times have both physical and economic access to basic food' (Ibid.: 27) foreshadowing some of the thinking which has developed on different forms of water scarcity (and by extension, water security).

Because it places the emphasis on individuals, the concept of human security aligns most naturally with human-centred interpretations of the water crisis, and principle among these is the concept of 'water poverty'. In turn, water poverty tends to be a concept most often deployed in relation to drinking water hygiene and sanitation (WASH). For example, WASH is the focus of the international End Water Poverty coalition of 180 civil society organisations and networks. Water poverty also chimes naturally with the MDGs – not only with Target 7c on drinking water and sanitation, but also with Goal 1 'Eradicate extreme poverty and hunger'. The association of water security with national security agendas may make water poverty a more palatable option for rights-oriented organisations, though UNICEF refers to 'household water security' as a synonym for water supply, specifically (UNICEF 2010).

A WASH-focussed interpretation of water poverty or indeed of 'household' or 'human' water security directs attention to some of the most pressing water challenges. Despite the achievement of the MDG target for water at a global level in 2012, huge geographical and social disparities remain, especially when the many non-functional water points are discounted – as many as 40% of the total in rural Liberia, for example (Hirn 2011). But an exclusive emphasis on WASH may risk overlooking the other ways in which water interlinks with people's livelihoods. In fact, earlier definitions of water poverty do not necessarily restrict themselves to WASH. Black and Hall's categorisation of the water poor (Box 7) puts the headline emphasis on broader relations between water and the ‘livelihood base’ (Black and Hall 2004: 24), including water for cultivation – though water for other productive purposes, such as small scale manufacturing and industry, is not mentioned directly. Another important feature of water poverty as articulated by Black and Hall is its clear emphasis on gender dimensions. The greater impacts of inadequate water on women has been well-articulated around WASH, for example in terms of caring for children and others affected by water-related diseases, and the time costs and personal security risks involved in collecting water (UNICEF 2003). But gender dimensions of wider water use and management should also be considered, for example the tendency for water access for irrigation and livestock to be dependent on land rights – which are limited for many rural poor people, but especially women (IFAD 2007). While Black and Hall propose a number of quantitative and qualitative thresholds in their definition, it should be noted that applying these collectively would result in double counting in many contexts. The thresholds would therefore need some attention if they were to be applied as part of a water-related target.

Box 7: Water poverty as human insecurity

Black and Hall define the water poor as:

- those whose livelihood base is persistently threatened by severe drought or flood
- those whose livelihood depends on cultivation of food and natural products, and whose water source is not dependable
- those whose livelihood base is subject to erosion, degradation, or confiscation (e.g. for construction of major infrastructure) without due compensation
- those living far (e.g. >1 km) from a year-round supply of safe drinking water
- those obliged to spend a high (e.g. >5%) percentage of household income on water; slum dwellers obliged to pay for water at well above market rates
- those whose water supply is contaminated bacteriologically or chemically, and who cannot afford to use, or have no access to, an alternative source
- women and girls who spend hours a day collecting water, and whose security, education, productivity, and nutritional status is thereby put at risk
- those living in areas with high levels of water-associated disease (bilharzia, malaria, trachoma, cholera, typhoid, etc.) without any means of protection.

Source: Black and Hall (2004: 11)

But even if availability of, and access to, water for various needs and productive purposes is included in a human-oriented framing of water security there is a risk of overlooking non-human users. This returns us to the debates about integrating environmental and developmental agendas discussed in Section 2. The original framing of human security in the 1994 HDR acknowledged ‘environmental security’ as one of seven key categories, with threats to water highlighted as ‘one of the greatest environmental threats’ in developing countries. However, partly due to the subsequent alignment of the human security agenda with the poverty and social development focused MDGs, environmental issues have tended to be somewhat squeezed out. There is a natural concern that meeting ecosystem needs will inevitably necessitate trade-offs with human needs. The concept of ecosystem services as fundamental building blocks for human development has helped to reframe apparent tensions between human and environmental water security, as necessary synergies (Carpenter 2005; UNEP 2009).

On the other hand, others refer to water security in a way which treats the resource base as an intrinsic good, separately from any status as an instrumental good which provides a variety of services to humans. For the Global Water Partnership (GWP), ‘the essence of water security is that concern for the resource base itself is coupled with concern that services which exploit the resource base for human survival and well-being, as well as for agriculture and other economic enterprise, should be developed and managed in an equitable, efficient, and integrated manner’ (GWP 2009: 1). Elsewhere, GWP refer to a water secure world as integrating ‘a concern for the intrinsic value of water with a concern for its use for human survival and well-being’ (GWP 2012).

3.4 An expansive and inclusive framing of water security

Taking account of the above discussion, key aspects or themes which could be included under an expansive and inclusive characterisation of are identified in Box 8. Water security differs from both water scarcity and water risk in that it is inherently a positive ideal for water resources management whereas scarcity and risk, as things to be averted or avoided, need to be reframed in positive terms. Any attempt to characterise water security in a few words could therefore be read as an attempt to define a goal, in the manner of the MDGs or SDGs. But there are already a number of definitions and proposing another in an already crowded space is unlikely to add much. Rather, the purpose of identifying five key themes for water security is to frame subsequent discussion of metrics. Understanding of metrics is, in turn, critical for discussion of goals and targets, in order to provide a technical basis to inform discussions at the normative or political level (as these proceed through multilateral fora such as the UN General Assembly Working Groups on the SDGs – see Annex 1). Integrating the technical and political will need to done on an iterative basis, to retain a measure of ambition while retaining a goal, target and indicator set for which sufficient data, of sufficient quality, can be obtained.

This said, a working definition or framing of water security is needed for the purposes of this paper, to provide a reference point and encapsulate the five themes. This can be proposed in two parts – one relating to the physical dimensions of the resource, the other pertaining to issues of economic, social and political capacity, drawing on IWMI’s distinction between physical and economic water scarcity, and adapting existing definitions of water security including Grey and Sadoff (2007) and ODI, DIE and ECDPM (2012). Thus for the purposes of this paper:

> *Water security means having sufficient water, in quantity and quality, for the needs of humans (health, livelihoods and productive economic activities) and ecosystems, matched by the capacity to access and use it, resolve trade-offs, and manage water-related risks, including flood, drought and pollution.*

Box 8: Key themes for a water security metrics framework

From analysis of the concepts of water scarcity, water risk and water security it is evident that an expansive and inclusive framing of water security should:

- Look beyond immediate physical availability. While physical availability is likely to assume increasing localised importance under demographic, socio-economic and environmental drivers, there is a risk of oversimplification. First, conventional measures of physical availability have a number of problems, including limited attention to groundwater and soil moisture, which can be key parts of the resource base but which often react to climate, hydrology and human intervention in complex ways. Second, such measures overlook the economic, institutional, managerial and political inequities which mediate access to the physical resource. Such inequities can also give rise to water insecurity by reducing the ability to manage water-related risk (see below). In this regard the idea of capacity to access the resource, or manage risks associated with it, may be useful.
- Address variability and risk. Being ‘water secure’ intrinsically implies a state of being that will continue in perpetuity. But water resources, and the ways they are used by society (e.g. for agriculture) are subject to wide temporal and spatial variations. The implications of this variability and uncertainty therefore need to be articulated explicitly. Water-related risks, both from hydrological hazards (associated with insufficiency and overabundance of water) and anthropic hazards (e.g. pollution or over-exploitation) should also be addressed for water security – this implies reducing exposure and vulnerability, the two factors which determine our ability to manage or adapt to hazards (IPCC 2012).
- Have a human focus. An inclusive framing of water security should, at root, be human-focused, with an emphasis on individual livelihoods, especially for the poorest and most vulnerable, including women. Framings that are concerned only with higher levels (for example the nation-state) may make it easier to privilege some peoples’ water security over others’, both within and outside a country’s borders. Paramount are the fundamental needs associated with water, sanitation and hygiene, which in turn underpin health and opportunity, though water security also implies access for productive purposes (in terms of individual livelihoods and broader economic activities).
- Acknowledge environmental needs. Though water security is a human-centred concept, it must be framed in such a way that the dependence of human society on the wider natural environment, through ecosystem services, is acknowledged – even if this implies viewing environmental needs as instrumental to human needs.
- Manage competition and conflict. There are justified concerns that ‘securitisation’ of water will privilege competitive management strategies over cooperative ones, or even the use of force rather than negotiation. However, it is important to acknowledge that, given the ultimately finite nature of the resource and the many inequities in terms of access, use, and protection from harmful effects, trade-offs are likely to arise and tensions between competing needs will need to be managed. An expansive and inclusive framing of water security must therefore also emphasise the ability to manage such tensions at different levels through appropriate governance, negotiation and the rule of law, rather than force (Wouters 2010).

4 Metrics and meaning: key considerations for measuring water security

The following subsections take the requisite 'themes' of water security identified in Box 8 in turn, analysing existing datasets and indicators which touch on each. This provides an overview of the water metrics landscape, while critically interrogating current approaches to measuring different aspects.

As intimated in the following subsections, there are important pragmatic considerations of data availability and quality which will inform what is realistic and relevant to measure. There are also important political considerations – reduction to numerical indices may be administratively and politically useful, but also means political and administrative agendas invariably shape the selection of data and use indicators as interpretative tools (Molle and Mollinga 2003; Kaczan and Ward 2011). Moreover, pragmatic and political considerations are not mutually exclusive in that data availability can be enhanced with greater political priority and resourcing, as Box 3 (above) illustrates in an example from the WASH subsector. In the case of this paper, the identified underlying themes of water security (Box 8) are an attempt to be explicit about what is being promoted as important. While such issues are touched on in this section, they are considered in greater detail in Section 5.

4.1 Beyond the physical resource: capacity to access, use and manage

Water availability and our capacity to access, use and manage it are central to the conception of water security, and have been a major focus of water resource metrics developed to date. Total Actual Renewable Water Resources (TARWR) is a key measure of the physical availability of water resources, estimated by a number of institutions, notably the FAO as a national-level long-term average, from data collected over 15 to 25 years. There are significant challenges associated with calculating and interpreting TARWR, as well as the many other indicators for which it is a component, which are discussed extensively in this and subsequent sections. However, the cost of obtaining data at greater spatial or temporal resolution has meant that the FAO estimates of TARWR remain their 'best estimate' and are in widespread use.

TARWR is often compared to population statistics to give an idea of water competition (m3 per person). On the basis of TARWR per person per year, Falkenmark et al. (1989) proposed thresholds for water stress (countries with less than 1700 m3 /person/year), water scarcity (<1000 m3/p/y) and severe water scarcity (below 500 m3/p/y). These thresholds, known as the Falkenmark Index, are widely accepted as crude but straightforward measures of physical availability relative to human demand – as exemplified by their prominence in UN-Water's new Key Water Indicator Portal.

There are a number of concerns with the TARWR indicator and Falkenmark index, however. It tends to obscure in-country variability, and estimates are derived from data spanning a 25-30 year period which may not account for climatic or anthropic changes that could affect the water cycle. While the per-capita measure of TARWR is revised to show trends over time, changes tend to reflect population growth rather than changes in the underlying resource (the FAO updates the water availability estimates only when new data becomes available from countries). Furthermore, TARWR statistics are computed from a number of component indicators, including water flowing into the country from outside, the subsurface component of which (transboundary groundwater flows) is difficult to estimate. The FAO points out additional issues: dependence on government estimates of differing accuracy and reliability; no distinction on water quality (particularly brackish or saline water); crude adjustment for interaction of ground- and surface-water; and omission of 'green water' stored as soil moisture and critical for rainfed agriculture (prevalent in Sub-Saharan Africa), as well as non-conventional sources such as desalinated water and water re-used through drainage of agricultural water to rivers and seepage to groundwater (Margat, Frenken and Faures 2005). Box 9 explains how TARWR is calculated, and highlights recent efforts to address some of the above issues with an enhanced methodology for its estimation.

Box 9: Enhancing estimates of TARWR: Pilot Study on Indicators (PSI)

'The World Water Assessment Programme (WWAP) pilot initiative is a collaboration with the City University of New York (CUNY) and the Global Water System Project (GWSP) to produce a dynamic estimate of the basic data item, TARWR. TARWR is the fundamental measure of water resource availability (in a country, river basin or region) and is used in many indicators. It is defined as the maximum theoretical amount of water actually available for the country (or other unit), calculated from:

- Sources of water within a country itself
- Water flowing into a country
- Water flowing out of a country (treaty commitments)

Availability, defined as the surface and groundwater resource volume renewed each year in each country, means the amount of water theoretically available for use on a sustainable basis. In more specific terms, TARWR is the sum of:

- External water resources entering the country
- Surface water runoff (SWAR) volumes generated in the country
- Groundwater recharge (GAR) taking place in the country

Less:

- The volume in the country of the total resource effectively shared as it interacts and flows through both the groundwater and surface water systems - not to subtract this volume would result in its being counted twice (it is also referred to as 'overlap')
- The volume that flows to downstream countries based on formal or informal agreements or treaties.

The WWAP Pilot Study on Indicators (PSI) is being undertaken at the CUNY by Charles Vörösmarty in partnership with the Global Terrestrial Network for Hydrology (GTN-H) and GEO/IGWCO (Water Community of Practice), with support from the US Army Corps of Engineers (USACE). The group has developed an innovative methodology for estimating country-level TARWR. This approach is based on (but not limited to) a combination of hydro-meteorological and high-resolution (6 minute river network and ESRI country boundaries) surface elevation data, which will allow the identification of TARWR trends (e.g. if certain countries are getting wetter or dryer) and variability (e.g. variation of water supply from one year to the next).

This 'dynamic TARWR' is used to produce an alternative set of countries' per capita water availability. This data item will be further developed. Given its observational basis and dynamic nature, it is hoped that it will eventually become the primary point of reference, as it enables longer-term variations in water availability to be tracked over time. This will overcome some of the current constraints imposed by the assumption of stationary hydrology, which is considered to be inappropriate in the face of climate and related challenges.'

Source: verbatim from WWAP (2012: 171)

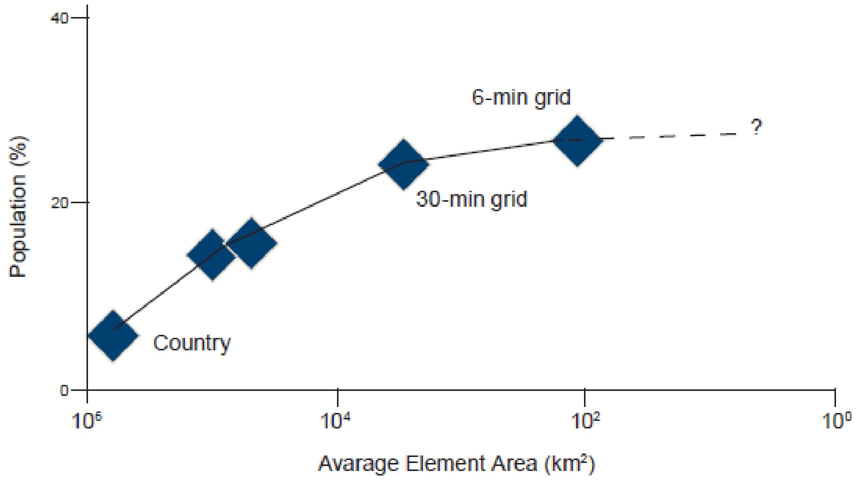
Perhaps most critically, the FAO point out that the theoretical measure of physical availability inherent in the TARWR indicator does not correspond to what is actually exploitable. Their proposed concept of exploitable water resources depends on technical and economic feasibility of development and exploitation, as well as reservation of any amount for environmental needs – calculation methods vary by country and, to date, FAO's database on water, AQUASTAT (FAO 2012a), only provides estimates for a limited number of countries, principally OECD members (Margat, Frenken and Faures 2005). Although comprehensive indices of exploitable water resources by country are not available, the concept adumbrates the wide range of issues relating to capacity to access, use and manage water, which take us beyond the physical resource. Also worth highlighting here is that any metric of exploitable resources should also account for water held in storage, and changes in that storage over time. As Taylor (2009) argues, the continued exclusion of water storage (groundwater, soil moisture, glaciers) from indicators and projections '…critically undermines their ability to adequately represent water scarcity and profoundly constrains scientists' understanding of the global water crisis'. For example, our understanding of available water resources may in some cases need to be extended to include non-renewable ('fossil') groundwater reserves which provide significant sources of water (and water security) in some areas, and where there is an economic logic for their managed depletion assuming time and economic growth will permit development of alternatives (see Box 6).

By setting per capita thresholds for water scarcity, the index proposed by Falkenmark et al. introduces relative human needs to the otherwise exclusively hydrological TARWR indicator. But water stress and scarcity thresholds based on TARWR per capita implicitly assume that all people require the same quantity of theoretically available water, regardless of their geographical location or socio-economic circumstance, and that the required volume can be accessed by those people, either directly (in the case of domestic needs) or indirectly (in the case of the water required for the production of goods and services).

Successive attempts have been made to improve on the Falkenmark index, particularly by comparing availability to withdrawals on a country-by-country basis. A major UN assessment set the threshold for water scarcity where withdrawals are greater than 20% of available water, and severe water stress where withdrawals exceed 40% of availability (Raskin et al. 1997). Subsequent efforts to improve on this include work by the University of New Hampshire Water Systems Analysis Group, using geospatial data to map (surface)water supply and demand across grid cells (6 minute grid cells for Africa; 30 minute grid cells globally). This allows a much more spatially disaggregated comparison of supply (employing data on locally generated runoff as well as the effects of rivers in transporting water from wet to dry areas) and demand (based on irrigated area, population and domestic and industrial water demand). The approach also relies on data derived globally from Earth System Science (GIS, modelling, weather prediction, remote sensing) rather than hydrographic estimates obtained from government (Vörösmarty et al. 2005). A key finding of the more spatially disaggregated approach is that the proportion of the population found to be living in areas subject to water stress tends to increase at greater resolution (Vörösmarty et al. 2000; see Figure 4), which is apparently a function of the fact that populations tend to be concentrated in areas of lower water availability.

However, there is no final agreement on how to calculate a comparison of availability and withdrawals. The UN-Water Task Force on Indicators, Monitoring and Reporting (TF-IMR) proposed using what it called the MDG water indicator, calculated from national figures for TARWR and withdrawals data derived from AQUASTAT, and setting the water scarcity threshold at 75% of TARWR abstracted, rather than 40%, but accounting for return flows (UN-Water TF-IMR 2009). The latest WWDR (2012) focuses on a Relative Water Stress Index derived from the University of New Hampshire geospatial approach, which retains the 40% threshold for severe water stress (UNESCO 2012a).

Figure 4: Water stress in Africa as percentage of the population computed with increasing resolution



Source: WWF and DEG (2011)

While comparison of withdrawals with availability is useful for highlighting that scarcity is a function of society's interaction with the resource, rather than physical availability alone, it does not account for water insecurity that arises from under-exploitation (from weak economic, technical or management capacity, and an inability to convey and store water to address spatial and temporal variability) rather than over-exploitation. The Democratic Republic of the Congo has physically abundant water resources (over 24,000m3/person/year) that appear even more abundant when set against very low withdrawals (0.05% of available water) and yet water insecurity, particularly in terms of clean, safe water for human consumption, is a reality for many Congolese citizens, due to inadequate capacity to abstract and utilize the resource. Seckler et al. (1998) attempted to account for this by projecting demand (based on e.g. increased irrigation for food production and increased population) and supply (infrastructure, irrigation efficiency) to 2025, on a country-by-country basis. On this basis, to satisfy 'reasonable future requirements' by 2025 (1998: vi), DRC would need to develop supply almost four-fold compared to 1990 levels.

Other attempts to account for water insecurity deriving from low capacity and the under-development of water resources have involved introducing other parameters, for example the Comprehensive Assessment's use of data on malnutrition (see Section 3.1). Similarly, Ohlsson (1998) used the composite Human Development Index (HDI) to weight the Falkenmark index. The calculation was undertaken by simply dividing each country's score on a 'hydrological water stress/scarcity index' (essentially the inverse of available water per capita, so high scores indicate greater physical stress/ scarcity) by the HDI score. On this measure, countries such as the UK and Belgium are no longer classed as water stressed, while Niger, Afghanistan and Burkina Faso, which at national level have sufficient water resources relative to population, are re-classified as water stressed.

The Water Poverty Index (WPI) is another composite index designed to be applied at household level. The WPI was calculated most comprehensively by Sullivan et al. (2003) incorporating measures of water quantity, quality and variability, access, uses, capacity for water management and ecosystem requirements. Critics argue that, for all their subtlety, such complex composite indicators are generally 'black boxes' which prevent interrogation of underlying realities (Rijsberman 2006). Vörösmarty et al. (2010) developed the geospatial approaches described above to produce a human water security index, made up of weighted indices for a wide range of 'drivers of stress' including dam density, nitrogen loading and a ratio of population to (river) discharge (a 'localised' version of TARWR per capita). They then adjusted the index to take account of the potential for technology and investment to mitigate the risks: 'areas with substantial technology investments have effectively limited exposure to threat whereas regions with little or no investment become the most vulnerable in a global context' (Vörösmarty et al. 2010: 558). The calculations showed that South East Asia and Sub-Saharan Africa face much higher threats to human water security once the inadequacy of technology and investment is accounted for, while countries in the Global North (notably the US, Western Europe and South-East Australia) are, for the time being, mitigating the threat. But while the Vörösmarty et al. study assimilated a staggering array of data, the application of their index as a regular monitoring tool to track the performance of national efforts to improve water security may be limited, in the near term, by the complexity of calculation and the limits to regularly updated data. Moreover, although the study marshals an array of indicators for quantifying water security, it is completely silent on the contribution of groundwater.

4.2 Variability and risk: spatial and temporal factors

Variability has always been a feature of hydrological systems. Temporal variability in water resources is a concern in terms of both 'ordinary' oscillations and extremes. As mentioned, an influential study suggests that a high degree of intra-annual rainfall variability is a more reliable explicator of GDP growth in agricultural economies than average physical water availability (Brown and Lall 2006), although other research has underscored the complexity of relations between development trends and hydrological variability (Conway and Schipper 2011). The WWDR 2012 identifies the coefficient of variation for the climate moisture index (CMI) - a statistical measure of variability in plant water demand to precipitation - as an appropriate indicator for areas with variable climates that may be subject to periodic water stress and scarcity (UNESCO 2012b; WWAP 2012). The global gridded data set (30 minute grid cell resolution) is compiled by the Environmental Crossroads Initiative at University of New York, computed as a 40-year average (1971-2000). The co-efficient of variation for CMI can therefore give a crude indication of the overall degree of climatic variability although it should be noted, particularly for agriculture, that how variability plays out is a location-specific function of hydro-meteorological factors, water management responses (e.g. storage, groundwater pumping) and crop-water demand at different moments of plant development (Woodhouse 2012). Meanwhile, in spatial terms water is distributed unevenly but also moves with the hydrological cycle. Vörösmarty et al.'s (2000) calculation of water stress at higher resolution on a geospatial grid, and mapping of flows along digitized river corridors, constitute attempts to grapple with the challenge of spatial variability, albeit through a surface water lens only.

Indicators like the coefficient of variation for CMI rely on past experience to give a guide to the lower and upper bounds of uncertainty, particularly uncertainty associated with temporal variability. However, the concern is that with climate change, past experience will no longer be a reliable guide to those bounds of uncertainty (Section 3.2) and the likelihood and magnitude of extreme events. The recent IPCC SREX report finds that 'A changing climate leads to changes in the frequency, intensity, spatial extent, duration and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events' (IPCC 2012: 5). This will further complicate the prediction and management of disaster risk presented by hydrological extremes – principally drought and flood. Even without the additional uncertainty presented by climate change, disaster risk is acknowledged as a complex concept that is difficult to measure, whereby the physical hazard is moderated by exposure (essentially, being in the wrong place at the wrong time) and vulnerability (capacity to anticipate, cope with, resist and recover from adverse events).

Among global indices of disaster risk, the Mortality Risk Index (MRI) developed for the 2009 Global Assessment Report on Disaster Risk Reduction (GAR) and updated for the 2011 report, is notable. This uses GIS data on hazards, vulnerability (computed from statistical analysis of historical events) and modelled population exposure, for a number of different disaster types including floods. The authors argue that the high spatial resolution (1x1km) and potential for comparing risks indicators between countries and over time, makes the MRI particularly useful (Peduzzi et al. 2010). However, a major challenge arises when applying the MRI to drought-risk due to lack of sufficient and suitable datasets, which results in African countries' overall MRI being under-estimated. Additional problems are the lack of clear correlation between population exposed to drought and mortality, due in part to the tendency for impacts to be bound up with other problems such as civil unrest and conflict, rather than purely meteorological conditions (UNISDR 2011a), though drought risks can be computed on a more localized basis where data is available.

It also appears that the MRI, designed to reflect evolving risks in the short term, is not ideally suited to taking account of long-term changes in hazards associated with climate change. This is understandable given the difficulty of projecting climate change impacts, especially at localised scales, due both to uncertainty around future emissions and the complexity of the climate system. The development of scenarios, for example the IPCC scenarios, can be used to help structure thinking around various plausible futures and reduce the number of variables considered in each. This is one premise behind the Climate Vulnerability Index (CVI), a composite indicator to assess local vulnerability to water related risk, drawing on ‘Global Impact Factors’ which include geographical and topographical data (e.g. slopes, proximity to coast), as well as data for water availability, the capacity of people and institutions, ecological impact, access (including property rights) and the economic efficiency of water use (Sullivan and Huntingford 2009). The need for stakeholder-determined weightings of each impact factor, detailed underlying data and (ideally) locally relevant scenarios, mean it may be more relevant to application at local scale – though it has so far been applied to 148 countries (UNESCO 2012c).

A simpler approach to measuring adaptive capacity to hydrological variability is proposed by the TF-IMR, using water storage and conveyance capacity as a proxy, reflecting the idea that a minimum platform of hydraulic infrastructure is required to avoid being held ‘hostage to hydrology’ (Grey and Sadoff 2007). This would primarily involve compiling data from the ICOLD database on large dams (ICOLD 2012), supplemented with information on irrigated infrastructure from the FAO (FAO 2011). To some degree data on irrigated extent would help capture those areas which utilise groundwater and small dams to supply irrigation, although the proxy indicator, as proposed, would still give a possibly undue emphasis to large dams. Furthermore, while the FAO has recently included irrigated area in its annual land-use questionnaire sent to governments, data is not yet available for many countries from the FAOSTAT database. The TF-IMR also proposes that adaptive capacity as measured by storage should also take account of natural reservoirs and aquifers, acknowledging in particular the role groundwater plays in buffering hydrological variability across seasons and between years (MacDonald et al. 2009; Calow et al. 2010). Estimates of groundwater resources at country level are provided by the International Groundwater Resources Assessment Centre (IGRAC 2012) and AQUASTAT. However, data availability and reliability for groundwater are in general limited (WWAP, 2012). Local and regional studies, such as those supported by DFID in Africa (MacDonald et al. 2012: 5) and now South Asia, are contributing to improved knowledge in this regard.

As noted (Section 3.2) water risk is an attractive concept to the private sector and a number of tools have emerged to characterise risks which may damage reputation, impede license to operate, or create threats to core operations by affecting the quantity, quality and/or reliability of available supply (SABMiller, GTZ and WWF 2010; WRI n.d.; WWF and DEG 2011). The World Business Council on Sustainable Development (WBCSD) Global Water Tool, and the equivalent Local Water Tool developed in partnership with the Global Environmental Management Initiative, allow strategic and operational managers to identify water risk at the level of the entire company and specific operational facilities, respectively. Such tools nonetheless tend to provide a customised interface for existing, publicly available datasets at watershed and country level. An exception is the WRI Aqueduct tool, which draws on previously proprietary data on water risk compiled by Coca-Cola to generate maps of global water stress, including projection of water stress over timeframes of more than 80 years using IPCC scenarios to 2095 (Jenkinson, 2011). Given private companies’ interest in water risk and the commensurate resources large companies can bring to gathering and analysing data, initiatives to make proprietary data publicly available are welcome (though the Coca-Cola data in its raw form does not appear to be fully open access).

Neither the principle private sector-oriented tools in the public domain, nor the indices described above in relation to climate change, take a formal probabilistic approach to risk assessment, especially for medium to long-term risks. Probabilistic risk assessment (PRA) approaches are widely used by industries dealing with engineered technologies (such as nuclear power plants) where the causal chains for potential risk events are arguably clearer (USNRC 2007). PRA calculates risk as a factor of the magnitude of an event and its likelihood, with both expressed in quantitative terms (e.g. 1 in 100 year probability of a water-related disaster incurring costs to the business of US$1m). The MRI is one of several water-related indicators with a probabilistic component, in that it quantifies hazards according to their probable frequency, as well as magnitude and spatial extent (Peduzzi et al. 2010). However, it does not seek to project how this frequency may vary long-term with climate change.

But even in its application to engineered technologies, PRA has been criticised for failing to take account of features of complex systems such as nonlinearity, feedback and emergence, as well as for the simple psychological difficulty we face in conceiving of as-yet unprecedented catastrophic events (Ramana 2011). Climatic and hydrological systems, which comprise natural and anthropic interactions, are still more complex. The difficulty of attributing probabilities to long-range climate forecasts is a familiar challenge (Morello and Climatewire 2010). Nonetheless, attempts are being made (Michel-Kerjan et al. 2012), with the insurance industry prominent in efforts to develop probabilistic modelling of climate change impacts, including those relating to water. Synthetic stochastic catalogues of extreme events have been developed to underpin catastrophe models, and are widely used by the insurance industry. These overcome limited historical experience to some degree but still require sound input data, which is generally more limited in developing countries (Ranger, Muir-Wood and Priya 2009).

4.3 Human focus: water for health and livelihoods

Although there is still much progress to be made in relation to the MDG targets for water supply and sanitation, these targets and the indicators against which they are tracked have drawn international attention to the importance of water for basic human requirements, which in turn underpins health, productivity and opportunities including education. The service coverage indicators, compiled by the JMP, are based on household survey data (primarily census, Demographic and Health Surveys and Multi-Indicator Cluster Surveys). Compared to many water resource indicators, data availability is comparatively good, derived from broadly standardised survey questions and updated with reasonable regularity even in many low-income countries. The targets' (relative) simplicity has also contributed to their success. However, as the debate around what should succeed the water supply and sanitation MDGs makes clear, there are still many concerns around data quality, and the JMP's definition (and measurement) of 'sustainable access to safe drinking-water and basic sanitation', which tends to overlook problems with service quality and functionality and, in the case of sanitation, the environmental impacts of inadequate faecal sludge and wastewater management (WHO and UNICEF 2011).

Arguably due to having had an agreed target and monitoring framework for several years around which to focus debate, the discourse on WASH monitoring is more advanced than that for broader water resource management or water security. The work being undertaken by the JMP and the post-2015 working groups, for which regular updates are available (JMP 2012), provides many lessons for the water resource management community (see Box 3).

Other human water requirements, notably food production and other productive uses, are not within the ambit of the MDG target on water supply or the JMP's post-2015 working groups. The aforementioned Water Poverty Index integrates measures of water use for irrigation, livestock and industry, but the data must be gathered using dedicated household surveys, limiting the WPI's utility as a global monitoring indicator.

Indicators to track the relationship between water and industry and agriculture are available at less refined spatial scales. The agricultural sector is a core concern because globally withdrawals for agriculture (primarily irrigation) make up a more than 70% of the total. Various indicators attempt to measure agricultural demand to give an idea of the agricultural sector's vulnerability to water stress and the potential for competition with other uses – based for example on irrigated land compared to total cropland, or agricultural withdrawals as a share of total withdrawals (WWAP 2012). In both cases, data are available from FAO AQUASTAT (in most countries only for a few years) though there are issues with data reliability. In particular, estimating agricultural withdrawals is difficult where many rural users self-supply groundwater, and where the partition between rainfed and irrigated agriculture varies from year to year. In the case of estimates of irrigated area relative to overall cropland, while increasing data is expected via the FAOSTAT annual questionnaires sent to government, remote sensing methods for land-cover and evapotranspiration offer a supplementary estimation approach (WWAP 2012).

Other relevant indicators include those for water productivity. The World Bank maintains an index of water withdrawals against GDP, which provides some indication of economy-wide water productivity (World Bank 2012b). The TF-IMR proposed two sectoral measures of water productivity, for agriculture and industry, respectively. In the case of agriculture, the measure proposed compares agricultural water withdrawals to value added by agriculture. However, the estimates of agriculture's value added (World Bank data) conflate the contribution of irrigated and rainfed production, leading the Task Force to propose calculating a measure of 'water use intensity in irrigated agriculture' only in those countries where the substantial majority of cropland is irrigated. Cai et al. (2011) point out that agricultural water productivity could also be measured in other terms, for example altering the 'numerator' to a non-monetary value, such as calories or kilograms of agricultural product, or the 'denominator' from water withdrawals to, for example, evapotranspiration or water diverted to irrigation. In the case of industrial water use, an equivalent measure of water withdrawals for industry against industrial value added can be derived. However for the industrial sector the AQUASTAT data on withdrawals is also patchy. In terms of productive use of water, it may also be instructive to compare estimates of current hydropower capacity with potential (International Journal on Hydropower and Dams, 2011), though an increase in this indicator needs to be interpreted in the context of the social and environmental costs of hydropower development. Numerous guidelines have been developed by both independent entities (World Commission on Dams 2000) and the hydropower industry itself (International Hydropower Association 2010), the lessons of which need to be heeded in future.

Virtual water is also a potentially useful indicator in thinking about water's role in productive processes. Countries with apparently low levels of water demand (e.g. on the ratio of withdrawals to TARWR – see Section 4.1) may be reducing their water consumption by importing virtual or embedded water from other countries, effectively displacing their water use or water polluting activities onto other countries (Hoekstra and Mekonnen 2012). This is an extremely complex area, with methodological challenges including tracing water footprints more than one step back in the value chain, estimating grey water footprints associated with freshwater pollution, and the familiar difficulty of deriving time series estimates (insufficient data). However, there is a rapidly growing body of work on virtual water assessment (Liu and Yang 2010; Hanasaki et al. 2010; Fader et al. 2011). The normative implications of national water footprints are also not straightforward, though evidence suggests that they play a strong but rarely acknowledged role in international trade and countries' ability to manage their water and land resources (Fader et al. 2011). Hoekstra and Mekonnen propose that high external water footprints (imports of virtual water) should be explicitly taken into account by countries when considering their foreign and trade policies. Detailed data on water footprints per capita and per unit of product (e.g. kg of beef) can also be used to inform considerations about where to target effort around water productivity. Data on per capita water footprints (blue, green and grey water) of consumption and production across agricultural, industrial and domestic sectors, as well as for international virtual water flows by product and country, are available from the Water Footprint Network (Water Footprint Network 2012). At country level, water footprint data may therefore be useful to cross-reference with other indicators, for example on water productivity, withdrawals or availability.

4.4 Environmental needs: biodiversity and ecosystems

Our economies and societies are fundamentally dependent on ecosystems, including aquatic ecosystems, and the services they provide (Carpenter 2005). Human water use can destabilise the functioning of such ecosystems by reducing water quantity or discharge of emissions. This implies a need for data on environmental flow requirements (quantity, timing and quality), human interventions which may damage the aquatic environment (pollution, flow disruption), and the status of freshwater ecosystems (WWAP and UNSD 2011).

Ecosystem water needs (environmental flows) have often been overlooked, even by metrics and definitions which attempt to ground availability within its social, political and economic context. Smakhtin et al. (2004) attempted to estimate the volumes of water required to maintain freshwater ecosystems and the services they provide across the world's river basins, making an important distinction between low-flow requirement (the minimum for fish and other species through the year) and high-flow requirement (important as a stimulus for migration and spawning, for wetland flooding and other critical processes). The essential aim of the study was to adjust a standard ratio of withdrawals to availability (in their case, mean annual runoff rather than TARWR) with an estimate of the 'Environmental Water Requirement'. Their calculations showed that basins such as the Yellow River in China, and the Orange in Southern Africa, have been developed to the extent that environmental flows are severely disrupted and depleted, and would face much greater water stress/scarcity were this requirement properly accounted for. Smakhtin et al. (ibid) computed the Environmental Water Requirement for river basins rather than individual countries, since ecosystems are not organised along administrative boundaries. Further work would therefore need to be done to calculate the implications for riparian countries of the Environmental Water Requirement of transboundary river basins.

Besides withdrawals, human impacts on the aquatic environment include both emissions and flow disruption. Of the former, phosphorous and nitrogen loading are a particular concern, causing eutrophication and the formation of toxic nitrate, ammonia and cyano-bacteria (Vörösmarty et al. 2010). The nitrogen and phosphorous cycles have together been characterised as one of nine critical planetary boundaries by Rockström et al. (2009). Sampled data and statistics on phosphorous, ammonia, nitrate and nitrite (as well as metals, nutrients, organic matter and physical-chemical characteristics) are available from the UNEP Global Environment Monitoring System (GEMS) Water Programme. The data (including trends where available) are searchable by river basin, major lakes and regions, as well as individual in-country monitoring stations for those countries that have shared their data (UNEP n.d.). However, there are concerns that there are significant temporal and spatial gaps in the GEMS data (UNESCO 2012d). Emissions sources themselves could be monitored but data is limited. The population connected to wastewater treatment, which is only readily available for OECD countries, is one possible proxy indicator highlighted by the TF-IMR (UN-Water TF-IMR 2009), though in terms of nitrogen and phosphorous this would omit the substantial contributions from other processes, notably non-point source pollution primarily associated with fertilised agriculture.

A principal cause of flow disruption is impounding dams. While the potential importance of such dams, and the reservoirs they store, for coping with variability and climate change (Section 4.2) and for energy generation (Section 4.3) has been highlighted, the negative environmental implications of their development also require attention. The fragmentation and flow regulation effects of impounding dams can damage ecosystems through nutrient and sediment retention, prevention of animal migration and invasion by lentic bacteria (UNESCO 2012e). Vörösmarty et al. (2010) modelled dam density and impacts on ecosystem health on a geospatial basis (0.5 degree resolution) using geo-referenced data on large dams from the Global Water Systems Partnership (GWSP-GRanD) and spatial averaging of country-by-country data from ICOLD. The GRanD database makes an important distinction between dams and reservoirs, on the basis that several dams can be associated with a single reservoir, and run-of-the river schemes may not hold reservoirs at all (Lehner et al. 2011). Nilsson et al. (2005) derived their own index of dam impacts for the Biodiversity Indicators Partnership (BIP), accounting for fragmentation and flow regulation effects. Severely affected river systems are characterized as those where less than one quarter of the main channel is dam-free, the largest tributary has at least one dam, and where reservoirs retain a considerable portion of a year's flow (Ibid.). The indicator was prepared at basin and regional level, and a pilot application at national level was undertaken for Sweden, but no further developments are planned by the BIP at this stage (BIP 2011).

The third of the aforementioned data areas is the state of aquatic ecosystems themselves. Data on freshwater species is available in time series from the Freshwater Living Planet Index, though this is calculated at a global and regional level only (WWF 2012). In the absence of a database of aquatic biodiversity by country, proxies are necessary. FAO time-series data on fish catch and aquaculture could be one option (FAO 2012b; Vörösmarty et al. 2010), though this would require some estimate of sustainable yields, which is difficult to achieve.

4.5 Competition and conflict: governance arrangements

Conflict over water can take many forms. Violent conflict between individuals or even countries is the most visible, but far from the most likely, manifestation (see Section 3.3). In response, governance regimes must be capable of mitigating the risks proactively rather than reactively. This means going beyond dispute resolution mechanisms to the whole range of technical, economic, administrative, legal, institutional and social/participatory measures (Plummer and Slaymaker 2007) that underpin water resource management, including equitable and efficient allocation between users, enhanced access for the poorest, and protection of the environment. As such, governance is a domain 'fundamentally different' from those of water availability, uses, access or environmental degradation (UN-Water TF-IMR 2009: 18). It must often be measured in more qualitative, process-oriented terms - what the TF-IMR referred to as 'water governance means' (Ibid.). Effective governance is also a pre-requisite for, or encompasses, the aspects of water security discussed above (Sections 4.1 to 4.4), for example protection of biodiversity or allocation between productive sectors. Furthermore, given the problems highlighted around data availability and reliability, a further key component of governance is effective monitoring, in and of itself.

Efforts to track the evolution of water governance processes have consolidated around the IWRM paradigm, stemming in large part from the target 'To develop integrated water resources management and water efficiency plans by 2005' adopted at the Johannesburg Summit for Sustainable Development in 2002. There is a vast body of literature on IWRM. Box 10 summarises some of the key recent developments in trying to measure progress.

Box 10: IWRM: resourcing and operationalising

The Johannesburg Summit in 2002 gave IWRM additional international sanction and a clear target, but one which focused primarily on putting processes in place, rather than outcomes or the resources needed to achieve those outcomes. This has set the tone for much reporting on IWRM progress, though there is increasing realisation that plans and policies constitute means, rather than ends.

Work following Johannesburg, led by GWP and UN-Water, proposed consolidating reporting around common indicators and extending the focus to management instruments and the institutional framework, as well as the enabling environment of laws, plans and budgets. Increasing emphasis on operationalising IWRM (not least through investment plans and vehicles), as well as change outcomes (e.g. treatment of human waste waters), rather than just putting plans and roadmaps in place, is evident in the GWP and UN-Water reporting framework (UN-Water and GWP 2008; UN-Water 2008).

The latest report in this family was released in June 2012 (UNEP 2012). It remains difficult to interrogate the quality or effectiveness of IWRM institutional or management changes, as reporting is primarily achieved through a questionnaire for countries to self-assess their own progress, with limited independent external assessment. However certain questions, for example on the trajectory of water resource development spending as a proportion of national budgets (53% of countries report an increasing trend in the last 20 years), show that the search continues for pragmatic indicators which assess action rather than words.

The IWRM progress reporting led by UN-Water currently offers the best available assessment of the highly qualitative domain of water resource management capacity at the global level. In future the pathway approach developed for the AMCOW Country Status Overviews on Water Supply and Sanitation might be adapted to the WRM sphere, combining sequential assessment of different kinds of capacity (enabling, developing and sustaining services) with analysis of resourcing relative to need, and how these translate into substantive outcomes (de Waal, Hirn and Mason 2011).

The TF-IMR point out that global and regional agreements and conventions provide their own architecture for monitoring progress, for example wetland areas protected under the Ramsar convention. The World Database on Protected Areas is a useful resource for tracking the progress on this and other global, regional or national initiatives (WDPA n.d.). FAO's legal databases on water (WATERLEX and information on international water treaties) also offer a potential source of data on governance (FAO 2012c), though again it is much harder to establish how far agreements, laws and conventions are being adhered to in practice.

5 Politics and pragmatism: the architecture for data gathering and interpretation

As intimated throughout Section 4, there are significant issues of underlying data availability and quality for almost all of the indicators described. In an ideal world, development of a coherent water security metrics framework would start with what is important, rather than what is opportune or feasible. The paper has sought to explore what is important in proposing five normative themes which might be encompassed by the term water security. However, indicators are only ‘fit for purpose’ if there is reasonable confidence that they are a reliable guide to phenomena in the real-world. The quality and availability of data are thus inevitable constraints to what is feasible. The following subsection (5.1) gives an overview of these constraints, while subsection 5.2 indicates the current architecture for gathering data on water resources and their management, and 5.3 outlines prospects for enhancement.

5.1 Data difficulties: variability, complexity and politics

As noted, hydrological variability presents a particular challenge for determining relevant and reliable metrics (Section 4.2), and indicators are usually only relevant at a particular spatial or temporal scale. At the same time, increasing spatial and temporal resolution for a given indicator invariably increases the time and financial costs of data gathering, analysis and quality assurance. Data for many indicators for describing and tracking important water considerations are simply unavailable at meaningful scale.

Furthermore, the complexity of interactions between human and natural systems mean that even before seeking to improve how water-related data is gathered, important decisions have to be made about what information is relevant. Data on biodiversity is a case in point. While it is possible to devise various biodiversity indicators across the common causal framework for society-environment interactions (driver, pressure, state, impact and response - DPSIR), there is continued uncertainty as to what are the most important concerns and how they relate to each other. For example, the UN-Water Expert Group on Indicators, Monitoring and Data Bases cautions that the Living Planet Index of species biodiversity ‘does not capture the most important species indicators for water-related purposes … [and] it is difficult to link the trend with causes’ (UN-Water EG-IMD 2009: 21-22).

The political economy of data and knowledge management around water can also be a barrier, for example when a country is reluctant to share its water resource data internationally because of sensitivity around transboundary agreements, or when a company maintains data confidentiality for legal or competitive reasons (WWAP 2012).

As already implied, the way data is gathered and presented can inform political priorities, and vice-versa. Despite acknowledged shortcomings with TARWR per capita and the Falkenmark index (Section 4.1) they are widely used and promoted by sources such as the UN-Water Key Water Indicator Portal and the FAO AQUASTAT database. Common usage arguably lends ‘a kind of universal and unquestioned validity’ to the scarcity thresholds, and thence to an implicit definition of water scarcity which privileges physical availability of renewable supplies (Molle and Mollinga 2003: 542). At the same time, data availability should not be viewed as an absolute binding constraint on what it makes sense to try to measure. Presenting a clear case for the importance of certain parameters may increase the likelihood that required data could be obtained in future, either by initiating new monitoring or by tapping into existing but currently unexploited sources of information. Global WASH monitoring by the JMP is an example of the latter, since it has been undertaken on the back of existing general household survey initiatives.

5.2 The existing architecture: databases and initiatives

There is, as yet, no central resource for water security data to cover the broad range of concerns implied by this paper's working definition of the term, or the five proposed themes. Currently most indicators are compiled by different agencies and initiatives on specific water issues and subsectors, for example WASH (the JMP and GLAAS reports), utility performance (IWA and IBNET), water foot printing (the Water Footprinting Network), groundwater (IGRAC) and biodiversity (BIP). Hitherto, FAO has been the agency with the most prominent role in compiling or hosting water-related data across various aspects of water resources, use, development, management and quality (most prominently in its AQUASTAT database). However, across the water monitoring spectrum there remains a high degree of fragmentation leading to gaps, duplication and an inevitable reliance on second or third-hand data which disguises underlying quality problems where it is not made explicit. For the most part the above agencies and initiatives ultimately depend on data derived from national sources, though discrepancies often arise between international estimates and those of government. For example there may be differences between the JMP's estimates of water supply and sanitation access based on household surveys, and government estimates that are derived from service providers. As a result there is a need for vertical reconciliation (between international and national level) as much as horizontal reconciliation between different parts of the international water monitoring system (UNSD 2007).

In response to this fragmentation, UN-Water and the World Water Assessment Programme (WWAP) have taken a lead role in identifying relevant data and key water indicators across different agencies and databases, and initiating a programme to mobilise information. UN-Water's new Key Water Indicator Portal (UN-Water 2012) suggests a desire to take on a role as central repository for data, although to date only TARWR per capita, dam capacity per capita, % of TARWR withdrawn, sectoral withdrawals (all via FAO AQUASTAT) and water supply and sanitation coverage (via JMP) are available.

The Portal is the latest manifestation of an ongoing programme of work for the triennial WWDRs, motivated by continued difficulties in establishing the state of the world's water resources and water management challenges. While 160 indicators were outlined in the first WWDR (published 2003), for lack of new data only 62 indicators were presented in the second report (2006) and only 30 in the third report (2003).

In 2009 UN-Water, UNESCO and the WWAP published the findings of the Expert Group on Indicators, Monitoring and Data Bases (EG-IMD) and the Task Force on Indicators, Monitoring and Reporting (TF-IMR). While the mandate of these initiatives was not framed in terms of monitoring for water security specifically, they touched on numerous issues which could be embraced by the term. The EG-IMD was convened to 'initiate a process to identify the key dimensions and indicators of water resources and their management as well as the work required to be able to produce such indicators on an ongoing basis' (UN-Water EG-IMD 2009: 2). Certain recommendations have had traction to date, for example the programme to enhance estimates of TARWR (Box 9) and collaboration with the UN Statistical Office around environmental accounting for water (see below). However, there has been little progress on the majority of recommendations made by the EG-IMD.

The TF-IMR, meanwhile, developed 15 indicators using the SMART (specific, measurable, achievable, relevant and time-bound) criteria i.e. with specific attention to pragmatic concerns including data availability and quality. But as indicated in Box 11, there were serious constraints when the task-force published their findings. Negligible progress on the task-force's 'medium term (within three years)' ambitions, for example to have reliable sub-national breakdowns on most indicators, underscores the challenge. More generally, the TF-IMR identified particular problems with the data on water productivity, gender-related issues, water quality, wastewater production and treatment, groundwater, biodiversity, and a widespread lack of reliable time-series data for many indicators.

The WWDR 2012 included 49 indicators pertaining to water and related concerns (e.g. energy, health), for which detailed infosheets explaining underlying definitions, computation, data availability, scale of application and other considerations are available from the WWAP website (UNESCO 2012f). Some of these overlap with those proposed by the TF-IMR, though not all, and most encounter data quality and availability problems of their own.

Box 11: Fifteen indicators proposed by the UN Water Task Force on Indicators, Monitoring and Reporting: data challenges

Fifteen key indicators were proposed by the TF-IMR for 'assessing progress in the water sector', across the categories of context, function and performance. Data problems were nonetheless significant for all at the time of publication in 2009, and have yet to improve significantly:

1. TARWR per capita (context – finite resources and population). As noted, while it is possible to calculate this for most countries, only population data is available on a time-series basis. FAO AQUASTAT, the main source for TARWR estimates, updates on an ad-hoc basis when new estimates are available. Other uncertainties persist around the data (see Section 4.1).
2. Storage capacity compared to potential (context – climate change impact and adaptation capacity). Data is available on large and most medium dams, but is less reliable for small dams and irrigated areas.
3. National expenditure for water supply and sanitation as percentage of total budget (context – ability to invest for sustainable management). While budget data is available at country level, there is as yet no central global mechanism to identify sectoral (still less subsectoral) spend.
4. Total water withdrawals/TARWR (function – intensity of use). Problems as above for TARWR. Withdrawals data (compiled by FAO AQUASTAT based on generic country surveys) is generally of poor quality, with differing sector definitions, inadequate trend data, and difficulty estimating sectoral withdrawals especially for agriculture where there are numerous small users.
5. Use by abstraction by main sector as percentage of total withdrawals (function – importance of consumptive uses). Problems as above for total withdrawals and sectoral withdrawals. Accurately establishing consumptive use (taking account of e.g. evapotranspiration and pollution) is even harder.
6. Trends in fish capture and aquaculture production (function – on-stream direct use of freshwater services). Time series data is available (FAO FISHSTAT), though catch data at country level does not always distinguish between marine and inland catches. There is limited data on small-scale fisheries and few reliable estimates of overall fish population to establish sustainable yields.
7. Share of blue, green and virtual water used to produce food in a country (function – trade and water use). Water footprint data is improving rapidly but often requires using a number of proxies and assumptions, e.g. deriving country level virtual water export or import based on scaled-up average water footprints for each major product for which trade data is available.
8. Perentage of population with access to improved water sources (performance – access to improved water supply). Though this is arguably the area where data quality and collection effort have been most sustained, issues persist e.g. with how to capture data on quality, sustainability and affordability.
9. Percentage of population with access to improved sanitation (performance – access to improved sanitation). As for water supply; tends to focus on the containment stage of the sanitation chain and does not consider disposal, treatment and re-use.
10. Change in water productivity of irrigated agriculture, based on agriculture added value compared to agricultural withdrawals (performance – food production). Data on agricultural withdrawals is unreliable (see no. 4); data on agriculture added value conflates irrigated and rainfed systems.
11. Water productivity in industrial sector, based on industrial sector added value compared to industrial withdrawals (performance – industrial production). Data on

industrial withdrawals unreliable (see no. 4).

12. Change in hydropower productivity, based on production relative to potential (performance – energy production). TF-IMR points to annually updated country estimates of potential and installed hydropower capacity from FAO AQUASTAT and the International Energy Agency, but does not give details. Data does not currently appear to be freely available from either source.
13. Change in percentage freshwater of samples meeting quality standards (performance – degradation of key renewable water resources). To be derived principally from GEMS data, but consistency and coverage of sampling stations is uneven.
14. Urban wastewater treatment connection rates (performance – pollution mitigation effort). Data tends only to be available for OECD countries and Europe, and even here detail on the level of treatment is partial.
15. Threatened freshwater species (performance – risk of biodiversity loss). The EG-IMD points out that, while the Living Planet Index estimates of freshwater species biodiversity trends are regularly updated and could be analysed on a country basis, it is difficult to establish causal relationships between detrimental human activities, biodiversity trends and ecosystem services.

Indicators were also proposed around water for improved livelihoods, to be developed in the medium term (three years) - an affordability indicator for urban areas and an indicator around access to water for multiple use e.g. irrigation, or for rural contexts. However, no indicators of sufficient standard were available at the time of publication.

An additional category of indicators was proposed on governance, linking to IWRM objectives. However, specific recommendations on what to measure were not made given the nascent state of monitoring on IWRM progress. The UN-Water reports on IWRM progress show continued effort in this regard (UN-Water 2008; UNEP 2012).

Source: UN-Water (UN-Water TF-IMR, 2009)

5.3 Future aspirations

As noted, UN-Water and the WWAP are at the forefront of emerging initiatives, though progress on implementing the TF-IMR and EG-IMD recommendations has been mixed. The Key Water Indicator Portal and the PSI initiative (Box 9) are currently the most visible. However, the latter has encountered delays in final release because of the need to collectively resolve differences in the present estimates on TARWR and in the new dynamic estimates, before they can be rolled out.

The PSI is one instance of an attempt to harness new technologies in pursuit of more reliable data. Remote sensing is often touted as the answer to challenges of water monitoring, including improved spatial and temporal resolution, as well as monitoring hard-to measure aspects like groundwater (gravimetric sensing) and quality (spectral band analysis). However, there are concerns that this does not obviate the need to ground-truth data acquired remotely with in-situ measurements, and thus to address the worldwide deterioration in hydrometeorological monitoring stations (WWAP 2012). Numerous innovative proxies have been proposed to bridge data gaps, which merit further investigation. For example mobile signal attenuation can be used to estimate precipitation (Ibid.), and employment data can be used to estimate calculate industrial pollution based on a widely observed correlation between number of workers and rates of BOD discharge (UNESCO 2012g). Since the use of proxies represents a contentious, but potentially useful, way to measure progress towards water security or other ‘sectoral’ goals, it is considered in further detail in Box 12.

The wealth of scientific studies estimating the extent of water security challenges (for example the work of Vörösmarty et al. 2010; 2005; 2000) suggests that it is possible to derive estimates across a wide range of variables, albeit on a one-off basis and using a large number of proxies. More can be done to ensure that the most up-to date science and technology informs policy decisions around enhanced monitoring, underscoring the importance of concluding and releasing the results of the WWAP PSI.

The System of Environmental-Economic Accounts for Water (SEEAW) is another key initiative which could increase consistency and quality on water-related data. SEEAW is a subset of the SEEA framework, which the UN Statistical Division promotes to countries in order to move beyond the conventional System of National Accounts, to a better understanding of countries' dependence and impacts on their natural capital. SEEAW 'provides a conceptual framework for organizing hydrological and economic information in a coherent and consistent manner', in such a way as to consider the water flows between the hydrological system and the economy (UN DESA 2012). It will be important to follow uptake of SEEAW, particularly in the context of the green economy (Section 2.2). However, countries with limited capacity in conventional public financial management and accounting are likely to face similar, if not greater, difficulties with SEEAW.

Initiatives driven by global agendas such as the SDGs and green economy must nonetheless retain a focus on the needs of individual countries, to understand their water resource situation and make more informed policy decisions. The regional initiative led by AMCOW to establish a pan-African water monitoring and evaluation format is a positive example in this respect, being closely linked to governments' needs via the ministerial membership of AMCOW and links to the African Union (Box 5).

Box 12: Using proxies to measure progress

Use of proxy indicators for decision making appear to run counter to the objective of evidence-based policy making, on the logic that the evidence in question should relate directly to the issue at stake.

But many broadly-accepted water-related indicators are proxies, especially those which describe progress around normative concepts, for example 'improved' water supply or sanitation. Wherever there is a dearth of directly related data, proxies provide a possible alternative. The different ways in which proxy indicators can relate to the policy issue can offer other advantages. On the one hand, proxies that are somewhat further 'upstream' in the causal chain, relating to processes or inputs, are more likely to be within the direct sphere of influence of the policy community in question. On the other hand, proxies which measure broader 'downstream' outcomes may actually be more significant in a global public goods sense, though they often require simultaneous action by others outside the immediate policy community. This latter category of proxies may be particularly relevant where the policy space is crowded with different issues, with equal claim to decision makers' attention (as is the case with the processes on the Post-2015 Development Agenda and SDGs, for example).

To take the example of a policy maker seeking to increase productivity of agricultural water use: Data for the 'directly relevant' indicator, agricultural water productivity (value added per m3 withdrawn) is collated by the FAO. However, for reasons including patchy data on withdrawals, and the difficulty of separating value added by irrigated and rainfed farming, it is not straightforward to estimate. The policy maker may chose to focus instead on an input or process which it can be reasonably assumed will lead to increased agricultural productivity, for example the area equipped for irrigation (again collated by the FAO). This has advantage of being more within the influence of policy choices, and in this case the data may be slightly better, offering a further pragmatic incentive. On the other hand, it is one (or more) steps back in the causal chain, and there is no guarantee that increasing the area equipped for irrigation will result in an increase of functioning, or productive, irrigation.

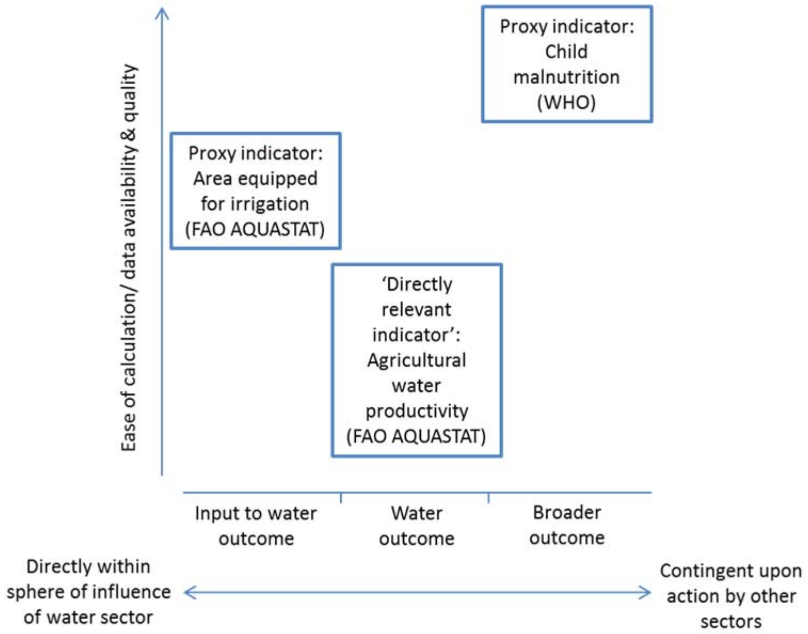
An alternative would be to look further down the causal chain to broader public goods outcomes, which may require inputs from other sectors. This can be a valid exercise in and of itself, to (re)consider what's really important: does agricultural water productivity matter in and of itself, or because it contributes to reduced malnutrition (which depends also on e.g. access to WASH, various infrastructure services and healthcare) or poverty reduction (which arguably depends on action across all sectors). Obviously, choosing such an indicator removes the metric, and perhaps the political and financing attention that come with it, from the direct influence of the sector in question. But some would argue this is a necessary 'sacrifice' where there is a risk of fragmentation across numerous issues, as is inevitably the case in devising global development and environment goals and targets. Malnutrition is nonetheless an extreme example. For most water managers, malnutrition would be seen as simply too far removed from their influence, with agricultural productivity not even being the main concern in many contexts, for example where food distribution systems are inadequate.

Proxies are widely used in the water policy and science communities. For example Vörösmarty et al. (2010) employ numerous proxies in compiling their indices of threat to human water security and biodiversity. It is therefore recommended that any water security metrics framework should make considered use of proxies, taking close account of their different attributes, particularly in relation to the two axes depicted in Figure 4.

The large amount of data collected by private corporations is a further source that could be significantly developed. This will entail negotiating difficult terrain of corporate competition and law to make the incentives for increased openness clear, and remove barriers. Narratives around shared water risk (SABMiller, GTZ and WWF 2010; UN Global Compact 2011) imply an awareness that new modes of governance, public and private, will be required to address water security challenges. Robust engagement is needed to make clear the quid pro quo: shared risk requires shared, transparent data. Investor- and public-relations also provide strong motivations for sharing water data, and investing in data gathering and analysis (see for example Ceres' Aqua Gauge and WRI's Aqueduct tools).

It is important to be realistic about the pace of change: technology is unlikely to yield a sudden revolution in water monitoring; the complex incentives that discourage companies and countries from sharing data will take time to re-orientate; a long decline in capacity and instrumentation for water monitoring in many countries will not be reversed overnight. But beyond making recommendations on the most relevant data and indicators with regards to water security, a take-home message of this paper is the urgent need to improve the availability and quality of data, and the important opportunities to do so.

Figure 4: Positioning proxy indicators in relation to the challenge of increasing productivity of irrigated agriculture: according to pragmatic considerations (y-axis) and relevance to sector decision-making (x-axis)



Source: Author

6 Recommendations

6.1 Introduction to proposed indicators and caveats

Five key themes encompassed by the concept of water security (Box 8) were proposed in order to review existing indicators and measurement approaches in Section 4. Bearing in mind the caveats relating to the practical and political difficulties to obtain sufficient data of good quality (Section 5), this section presents options for a limited number of indicators which could form part of a framework for measuring water security as described by the five themes, on a recurrent basis, at global and national level.

For each of the five themes – titled resource stress, variability and risk, basic human needs and productivity, environmental needs, and governance – two sets of indicator options are proposed in the tables that follow: a first set that could currently be obtained from existing global datasets, and a second, more aspirational set that would require considerable further work in terms of primary data gathering and/or analysis. Effort is made to highlight the coverage (number of countries) of each indicator, relevant data sources, and to identify key issues relating to their calculation, use and interpretation, especially for defining associated policy goals and targets.

More generally, it is important to underscore the following:

- The proposed indicators follow from the underlying themes of water security and working definition proposed in Box 8. Alternative definitions and typologies are of course available (Grey and Sadoff 2007; ODI, DIE and ECDPM 2012; WWAP and UNSD 2011; GWP 2012) and more are likely to emerge as wider debates evolve e.g. around resource security and the SDGs. The definition and typology used in this paper are therefore not proposed as definitive, but are used as conceptual devices to structure thinking around the abstract concept of water security.
- Similarly, indicator options are not proposed as a definitive or necessarily coherent list, in and of themselves. They are intended to promote dialogue on the technical aspects of measuring water security, which needs to evolve on a parallel, iterative basis to political debates about how water security should be defined. Alternative or additional indicator options may be available. Similarly, prioritising different themes for water security might yield different indicators. Even within the options currently proposed, only a selection of indicators would be required – a key lesson from the MDG monitoring framework is the importance of simplicity.
- Among the different windows of opportunity identified in Section 2, the indicator options presented are in general most relevant to the SDG/ post-2015 debates i.e. indicators that can be monitored at global level across most countries. Some of the indicators could also be relevant to thinking on the green economy (e.g. agricultural and industrial water productivity) or orienting the WRM policy and spending priorities of national governments and their donor partners (e.g. flood mortality risk index). However, further work is needed to match indicators to the particular priorities, country focus, and spending time-frames of particular countries.
- In addition to general limitations on data availability, disaggregated data (for example by gender and different socio-economic groups) is particularly weak. A general point is that, for currently feasible and 'aspirational' indicators alike, enhanced disaggregation is needed to improve their usefulness as policy tools and address the much greater water security challenges faced by the poorest and most vulnerable in society.
- Notwithstanding the complexity of water systems and the inadequacy of information, effort has been made to focus on simple indicators where the underlying data is readily apparent, rather than complex, weighted composite indicators. Some of the indicators, and especially the 'aspirational' options, may rely on innovative methods (modelling,

proxies, remote sensing) to fill data gaps, though these do not remove the need for ground-truthing.

- Consideration should be given to how to name and articulate the indicators themselves, recognizing that they are as much political and communications tools, as they are analytical devices.

6.2 Water security indicator options

Resource stress

Key data: renewable water availability (external, groundwater, surface components); withdrawals (by sector); capacity to access (proxies e.g. malnutrition or HDI score)

Indicator name	Calculation method; units	Data sources/ relevant studies	Countries covered[1]	Indicates	Technical notes	Potential implications of use as country/ global targets
			Currently feasible			
Renewable water resources per capita	TARWR/ population; m^3/person/year	FAO AQUASTAT	183	Theoretical renewable water availability per person; inverse (people/ 1000000m^3) gives sense of water crowding	Subcomponents of TARWR, e.g. dependence on external water resources, may also be informative; time series data represents change in pop'n not TARWR; masks spatial variability; does not account for non-renewable sources, e.g. non-renewable groundwater, which may be significant and for which there may be a rationale for exploitation; continued concerns around data quality	Gives sense of the environmental water endowment but privileges physical water scarcity/insecurity over other forms
Social resource water stress	People/m^3 TARWR/HDI; no unit (weighted composite)	FAO AQUASTAT, UN Population Division, UNDP; originally suggested by Ohlsson (1998)	183	Water crowding (people per m^3) adjusted by HDI score as a proxy for capacity to access water; water abundant developing countries still show up as socially water stressed		Explicitly incorporates non-physical forms of water scarcity/insecurity, but HDI may not be reliable proxy for social capacity to access water; unitless composite indicator requires expert interpretation and is not intuitive

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1. Estimate. In most cases, figures taken from UN-Water TF-IMR (2009).

Relative water stress	Total withdrawals/ TARWR; % ratio	FAO AQUASTAT	160	Intensity of water withdrawals relative to renewable supply	Data on withdrawals are unreliable, especially for agriculture	Explicitly considers the relation between demand and availability as a component of water security, but may conceal social/economic water scarcity/insecurity, e.g. in countries with limited water infrastructure for abstraction and conveyance
				Aspirational		
Dynamic water resources per capita (dynamic)	Dynamic TARWR/ population; m^3/person/year	Dynamic TARWR estimates from WWAP; UN Population Division	Most countries in theory	Dynamic water availability (cross-referenced with remote sensing data; permits trend analysis of TARWR over time) per person	Data not yet released (dynamic TARWR requires reconciliation with standard TARWR estimates)	As for 'standard' water resources per capita above, though has the advantage of greater accuracy and ability to track trends; need for reconciliation indicates that physical water availability may be politically sensitive, especially where transboundary waters are contested
Non-sustainable water use (dynamic/ locally derived version of relative water stress)	Geosptatially derived water withdrawals/ dynamic TARWR; unitless ratio	Dynamic TARWR estimates from WWAP; geospatially derived water withdrawals from Centre for Environmental Systems Research/ GWSP Digital Water Atlas	Most countries in theory	Locally estimated withdrawals relative to dynamic estimate of renewable supply	Data on dynamic TARWR not yet released; grid-cell estimates need to be extrapolated to country level; geospatial estimates of water withdrawals are derived from grid cell-specific estimates of population and irrigated land density with available water modelled through digital river networks	As for relative water stress (above); also note above caveats on reconciling conventional and dynamic TARWR estimates; may discourage temporary use of non-renewable sources and investment in innovation to develop alternatives

Variability and risk

Key data: hydrometeorological/precipitation variability; water storage and conveyance capacity; population exposure and vulnerability

Indicator name	Calculation method; units	Data sources/ relevant studies	Countries covered	Indicates	Technical notes	Potential implications of use as country/ global targets
Currently feasible						
Water storage capacity	Dam storage capacity/ population*100000 [conversion factor]; AND/OR regular renewable groundwater per capita; m^3/person	UN-Water Key Water Indicators Portal (dam storage capacity per capita); FAO AQUASTAT (regular renewable groundwater)	107 for dam capacity; 49 for regular renewable groundwater	Water storage capacity as a proxy for ability to manage rainfall variability between seasons	Validity of storage as proxy for resilience to variability depends on extent and timing of variability and complex hydrological and hydrometeorological interactions (stream flow, recharge etc.); definitions of large dams vary by country; small and medium dams may be omitted, effects of silting not taken into account; GRanD database (GWSP 2012a) may be more accurate than ICOLD (georeferences and specifications); for groundwater availability, estimates are unreliable, infrequently updated and unavailable for many countries	Underscores the importance of a basic platform of hydraulic infrastructure, but insensitive application may encourage ‘hydraulic mission’ and heavy engineering at the expense of other solutions (i.e. if lessons from previous large dam development are not learned)
Flood mortality risk	Risk calculated as function of hazards (GIS data), vulnerability (statistical analysis of historical events), and modelled population exposure; unitless risk index	GAR Global risk data platform, GAR (UNISDR, 2011b)	Almost all countries	Risk of mortality from flood as a function of hazard, vulnerability and exposure	Equivalent drought indicator has not been calculated due to the difficulty of deriving accurate mortality statistics	Captures destructive potential of water as a component of water insecurity, but better ability to estimate flood and other disaster risks may have diverted international attention and funds from tackling more complex drought risk; unitless composite indicator requires expert interpretation

Aspirational						
Rainfall variability	Coefficient of variability for CMI (StdDev(CMI)/Mean(CMI); unitless ratio	Environment CrossRoads Initiative, CUNY	Most countries in theory	Vulnerability to periodic water stress	Currently calculated on grid-cell basis, would require conversion for country-by-country estimates	Emphasises rainfall variability as a more important predictor of economic growth than physical water availability, but unitless composite indicator requires expert interpretation, and underlying data is not intuitive
Climate vulnerability	Risk index based on topographical variability, water resources, water access, water utilisation, human and institutional capacity; unitless composite index	Sullivan and Huntingford (2009)	Most countries in theory	Vulnerability to impacts on water resources as a function of topography, water availability and access, and capacity	Currently calculated on grid-cell basis, would require conversion for country-by-country estimate Note: a general point for all indicators that require estimates of climate change impacts on hydrology for their calculation - improvements in model skill and linkage to hydrological models are required	Can capture stakeholder perceptions of vulnerability across multiple dimensions, but differences in weightings (as well as data availability) across countries may limit usefulness of international comparisons; not a formal probabilistic assessment of risk

Basic human needs and productivity

Key data: access to drinking water and sanitation; agricultural/industrial withdrawals

Indicator name	Calculation method; units	Data sources/ relevant studies	Countries covered	Indicates	Technical notes	Potential implications of use as country/ global targets
			Currently feasible			
Access to drinking water	Population using an improved source of drinking water/total population; percentage	JMP	Almost all countries	Percentage of the population using an improved source of drinking water	Ongoing debates around ability to measure service quality, accessibility, affordability, sustainability etc; ‘aspirational’ equivalent for this indicator to be identified based on findings of JMP Working groups	Existing MDG target on access to drinking water has done much to galvanise political attention and finance around the issue, but this may have come at the expense of wider water resource management
Access to sanitation	Population using an improved sanitation facility/ total population; percentage	JMP	Almost all countries	Percentage of the population using an improved sanitation facility	As for access to drinking water (above)	Existing MDG target on access to sanitation has done much to galvanise political attention and finance around the issue, but risks overlooking environmental/health impacts of poorly managed wastewater or faecal sludge
Irrigated agricultural water productivity	Value added (value of output less value of immediate consumption) by agriculture/ agricultural water withdrawals; US$/$m^3$	FAO/ FAO AQUASTAT	Only countries where irrigated agriculture predominates	Water productivity of irrigated agriculture	Data on agricultural withdrawals may be unreliable, especially where there are numerous small-scale users, and is updated only every 5 years; can only be calculated for countries where irrigation predominates as estimates of irrigation-only value added are not available	Emphasises the importance of water as a contributor to economic growth, but cannot be calculated for countries where rainfed agriculture predominates, including much of Sub-Saharan Africa, where agriculture is also a major economic sector
Industrial water productivity	Value added by industry/ industrial water withdrawals; US$/$m^3$	FAO AQUASTAT, World Bank	162	Water productivity of industry	Data on industrial withdrawals may be unreliable and is updated only every 5 years	Emphasises the importance of water as a contributor to economic growth, but does not distinguish non-consumptive uses of water, where water is not significantly

						polluted or evaporated, e.g. cooling for thermal power
Aquaculture production	Aquaculture production/ population; tonnes per capita	FAO fisheries and aquaculture department	Most countries	Productivity of aquaculture (farming of aquatic organisms) relative to population	Data better for aquaculture of aquatic animals than for aquatic plants, which may still be important for some countries; fisheries (aquatic organisms exploitable by the public as a common property resource) production may be used in addition/instead	Emphasises the increasing importance of aquaculture to diets, especially in providing protein, but intensive aquaculture can have significant negative environmental impacts, and can be difficult to establish and enforce sustainable production thresholds for both fisheries and aquaculture
Aspirational						
Virtual water footprint	Various e.g. dependence on virtual water imports; national blue, green and grey water footprints of consumption AND/ OR consumption; m^3/ capita	Water Footprint Network; Hoekstra and Mekonen (2012)	174	Indicates e.g. dependence of water scarce countries on imports of virtual water to balance water budget; or displacing of water use and impacts to other countries	Time series data is not yet available (average 1996-2005)	Many potential policy applications and implications, e.g. could be used to focus attention on the potential for virtual water trade to mitigate against localised water scarcity, but thinking is relatively young and virtual water footprint data needs careful interpretation

Environmental needs

Key data: key freshwater species populations; water withdrawals; water availability; dam locations and size; remote sensing spectral data; various variables to estimate Environmental Water Requirement

Indicator name	Calculation method; units	Data sources/ relevant studies	Countries covered	Indicates	Technical notes	Potential implications of use as country/ global targets
Currently feasible						
Freshwater species	Annual change in freshwater species; Unitless Living Planet Index	WWF/ZSL Living Planet Index (WWF, 2012)	Global	Status and trends on freshwater species	Currently index is unavailable by country, though LPI concept note implies this is possible (ZSL and WWF 2012); currently focuses on vertebrates only; estimates are derived by tracking a limited number of key species, with data compiled from numerous different sources; interactive open-access data is planned	Focuses attention on the importance of biodiversity for provision of freshwater ecosystem services
Aspirational						
Water re-use index	Aggregate upstream water demand/total water supply; % index	CUNY Environmental Crossroads Initiative, according to UNESCO (2012h).	Most countries in theory	Level of upstream human withdrawals relative to supply; increase indicates greater likelihood that water abstraction will jeopardise environmental flows; note that this is calculated on geospatial grid-cell basis using estimates of national industrial and domestic water demand, population data, irrigated land extent,	Further work is needed to extrapolate grid-cell calculation to country level; environmental flow requirement is not uniform; better data on extent of irrigated areas is required	Emphasises the way water withdrawals impact downstream through natural hydrological flows, but making clear conceptual distinction with relative water stress index (water re-use index looks at upstream use) may be difficult

				discharge fields and digital river networks		
Environmental adjusted water stress	Water withdrawals/ available water, adjusted for estimated Environmental Water Requirement; percentage ratio	GWSP Digital Water Atlas. GWSP (2012b); Smakhtin et al. (2004)	Most countries in theory	Water withdrawals relative to available water, taking into account environmental flows (calculated based on national level TARWR and withdrawal estimates or grid-cell derived estimates of supply and demand – see 'Index of non-sustainable water use' (above)	Broad consensus needed on appropriate method of calculation, using Smakhtin et al.'s study as a starting point (2004)	Integrates environmental water needs which are often overlooked, but estimating these is notoriously difficult
Water quality	Change in chlorophyll/ turbidity/ suspended solids; various units	Spectral data from MODIS satellite, initially for 600+ large lakes monitored by US Department of Agriculture Foreign Agriculture Service; for surface elevation change atmospheric correction required; UN-Water EG-IMD (2009)	In principle most countries where there are large standing surface water bodies (lakes)	Water quality of lakes	While individual studies have been undertaken using this technique, there is no currently available global assessment; UN Water TF-IMD estimate cost for setting up initial analysis at US$100k-US$1m, with annual repetitions at less than US$100k	Draws attention to health of major water bodies (lakes and reservoirs) but potentially overlooks threats to riverine (flowing) systems
River fragmentation and flow regulation	Geospatial estimate	Various sources calculate dam density, e.g. GRanD (GWSP Digital Water Atlas (GWSP 2012a); UMEA University (BIP 2011); ICOLD data on large dams can also be probabilistically distributed (Vörösmarty et al. 2010)	In principle most countries	River fragmentation and flow regulation based on distribution of dams relative to river networks	Overlooks small dams; work needed to extrapolate country-level estimates from geospatial data; impounding dams and run-of-river schemes may have very different impacts in terms of flow regulation and river fragmentation	Emphasises the potential negative implications for aquatic ecosystems of river fragmentation, but does not take account of potential economic benefits of water infrastructure (e.g. dams)
Treated wastewater	% of wastewater flows receiving primary/ secondary/	Currently data is only reliably available for OECD countries	Currently only OECD countries	Percentage of wastewater flows	Even if data can be sourced for non-OECD countries, national wastewater treatment	Draws attention to the importance of wastewater treatment for human and

	tertiary treatment; percentage ratio		methods and standards vary significantly, making comparison difficult; needs to be discussed in context of any post-2015 sanitation monitoring proposal	environmental health, of increasing importance with urbanisation, but potentially overlooks non-point sources of pollution that in some contexts (especially developed countries) are a more significant problem

Governance[2]

Key data: data on IWRM process components (see footnote); RAMSAR wetland status data (qualitative) and remote sensing data on wetland extent (quantitative); data on budgetary commitments to aspects of WRM and sanitation.

Indicator name	Calculation method; units	Data sources/ relevant studies	Countries covered	Indicates	Technical notes	Potential implications of use as country/ global targets
				Currently feasible		
IWRM planning	Based on survey questionnaire sent to national governments (self-assigned into 5 qualitative categories); percentage of countries in each category	UN-Water (2008), UNEP (2012) and AMCOW (2012a)	More than 130 countries	How far countries have progressed in meeting the 2002 Johannesburg summit commitment 'to develop integrated water resources management and water efficiency plans'; other similar indicators, looking at e.g. water quality monitoring, information management or early warning systems, could be selected from the survey results	Survey method – third party verification undertaken for few countries; represents only 'national government perspective' (and often that of the individual completing the survey)	Captures the importance of governance processes and systems, but does not give indication of the quality of those processes, or how they relate to outcomes
International water governance	Proportion of transboundary waters identified as vulnerable to current or future water stress that are covered by a	de Stefano et al. (2010)	Countries with transboundary waters	Extent to which countries are managing potential water disputes through transboundary water management agreements, including	Treaties and institutions (RBOs) indicate only capacity to manage tensions *in principle*; some work needed to translate de Stefano et al.'s basin-	Underscores the need for robust institutional mechanisms to manage tension between countries

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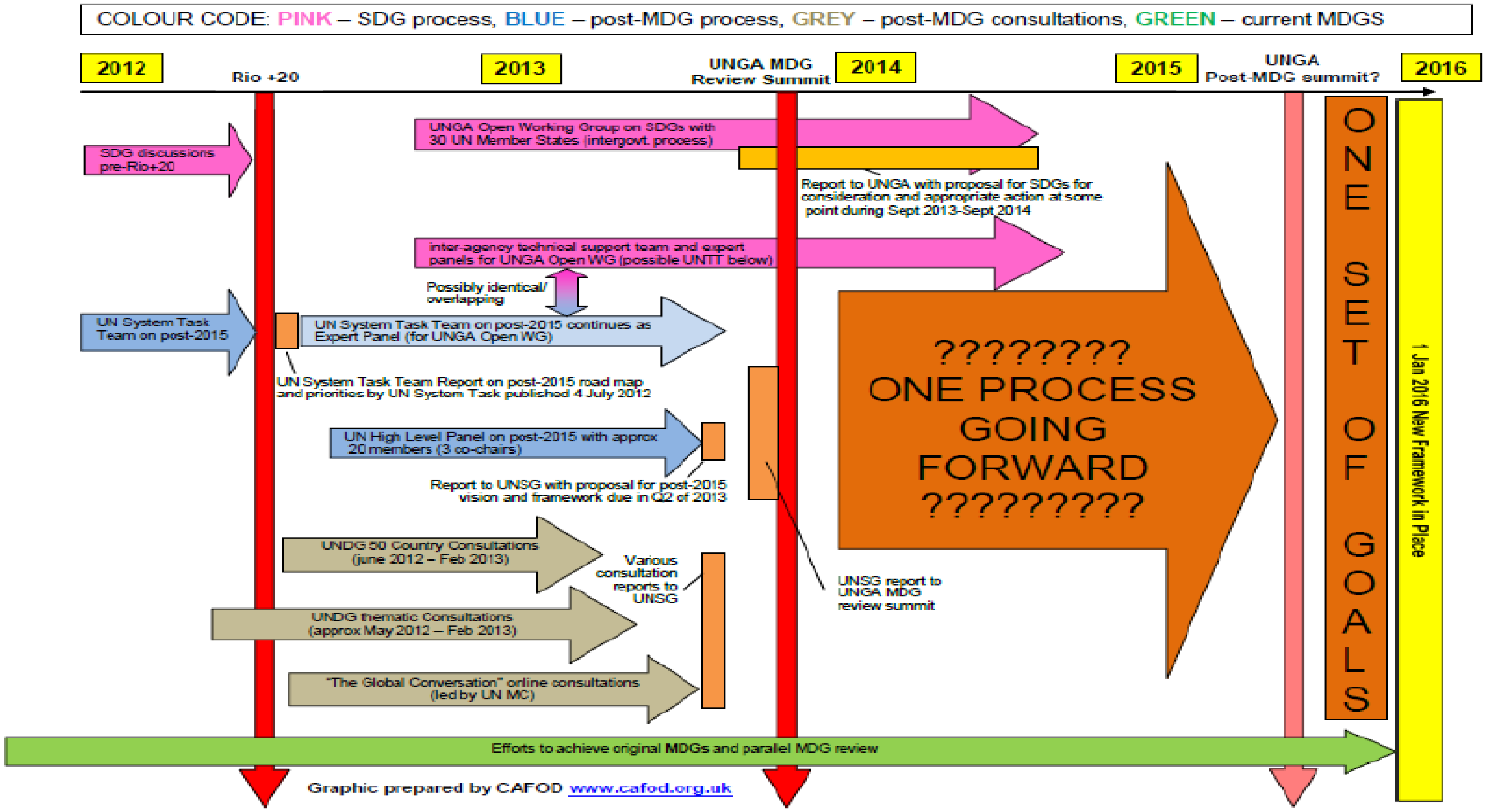
2. Process-oriented indicators such as status of implementation of IWRM policies, plans and mechanisms are nominally outside the scope of this paper, which focuses on water security outputs and outcomes. Existing initiatives are underway to monitor progress in putting in place different aspects of an IWRM architecture. This is principally undertaken through a UN-Water led initiative (UNEP 2012; AMCOW 2012a) to monitor progress against various process components, including the enabling environment (policies, plans); institutional frameworks (institutions, participation, capacity building); management instruments (information, demand management programmes, knowledge sharing); and infrastructure and development financing (investment plans and status of development). The information is derived principally from surveys sent to government, with limited third party verification, so there is potential for inconsistency. However, such process-oriented monitoring remains the current best available option for assessing nominal progress on water governance. Hence in the short term, the paper recommends that a holistic approach to water security monitoring can draw on the UN-Water led initiative, while making it explicit that elaborating a process on paper does not equal progress on the ground, in terms of IWRM outcomes. In the longer term, it is hoped that countries' progress against specific, outcome-oriented commitments (e.g. the RAMSAR convention) can be monitored.

	treaty (with mechanisms for allocation, variability management, and conflict resolution) and one or more river basin organisations (RBOs); percentage			mechanisms and institutions for managing variation and dispute	oriented index into a workable ratio at country level	over water resources, but historic evidence and expert opinion suggests localised unrest and conflict relating to water is more likely than interstate water conflict
			Aspirational			
Water monitoring effort	Percentage of key water indicators reliably tracked by national government; percentage	UNEP (2012); the 2012 IWRM progress assessment supported by UN-Water included an additional 'level-2' assessment undertaken by external consultants for a selected subset of countries, which included assessing whether countries were regularly tracking 42 different indicators	Most countries in principle	Extent of national monitoring effort and need for reconciliation between national and international water monitoring systems	Data reconciliation is an arduous, long-term but essential process; reliably establishing what countries are regularly monitoring is only a first, essential step	Underlines the importance of data gathering and analysis for informed policy decisions
Protection of aquatic environments	Change in extent of wetland areas protected as Ramsar Sites; in addition to qualitative and some quantitative reporting, this indicator would ideally assessed using remote-sensing data on the actual extent of Ramsar-designated wetlands over time, with ground-truthing	UN-Water EG-IMD (2009)	161 parties to the RAMSAR convention	Extent to which countries are meeting their environmental governance responsibilities in relation to wetlands	Could equally be applied as an 'Environmental needs' indicator, especially if non-Ramsar wetlands were included (i.e. not just monitoring 'governance' in terms of adherence to international commitments); wetland extent would ideally be complemented with e.g. data on water quality or Ramsar reporting on key species	Emphasises the importance of wetlands as important loci for freshwater ecosystem services

Water accounting	Compliance with environmental accounting standards/ frameworks e.g. SEEAW; no unit, or percentage compliance with different aspects of framework	UN-DESA (2012)	Most countries in principle	Extent to which countries are monitoring the interaction between water resources and their economies, and how far growth is based on degradation of natural capital		Could incentivise the collation of large volumes of new, standardised data on water and its relation to the economy, but significant capacity building will be required for effective uptake of e.g. SEEAW in many countries

Annex 1: The various UN processes around the SDGs and Post-2015 Development Agenda



Source: CAFOD (2012)

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