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The green-to-blue water continuum: An approach to improve agricultural systems' resilience to water scarcity

This paper explores two examples from the CGIAR Challenge Program on Water and Food research on resilience along the green-to-blue water continuum. A threatened floodplain wetland of the Mekong Basin has been shown to provide many direct and indirect benefits and services that are more resilient and less vulnerable to shocks than externally introduced agricultural systems of various types and intensity occupying the same land–water interface. Multiple-use water systems (MUS) assessed in five large basins show that, wherever water is available, people use water for greater resilience, domestic and productive purposes, including livestock watering, horticulture, irrigation, tree growing or small-scale enterprise.

Keywords: water productivity, wetlands, multiple-use water systems, resilience, green water, blue water

Introduction

All around the world, agricultural systems have never been strictly rainfed or irrigated. The history of Mesopotamia teaches us that even if farmers were mastering some level of irrigation technology, they were not operating under full irrigation, nor were they cultivating using just rainwater. Between irrigated and rainfed agriculture, farmers' reality has been that they simply have never grown any crop without water which they have stored, mobilised and applied to plants through a variety of different methods depending on the nature of the resource available. Irrigated systems typically also use green as well as blue water, and rainfed systems sometimes also use blue as well as green water, even in the absence of formal irrigation systems. In a nutshell, farmers' coping strategies worldwide have always been to deal with a green-to-blue water continuum. Their dependency on this continuum has inspired them to innovate, and to extract the best productive value, not only from crops, but also from aquatic resources, livestock, and many other productive water uses.

Following this long history of combined rainfed and irrigated agriculture, more recent historical paradigms have emphasised a stronger opposition between rainfed and irrigated agricultures. The global surface area under irrigation has dramatically increased since the 1960s, practically doubling from 160 to 300 million hectares. Most policies have kept rainfed and irrigated agricultures distinct from one another, hence trying to negate the existence of this continuum. However a large majority of "new" irrigation farmers – those who were given land to irrigate and crop after the green revolution – were historically rainfed farmers, if not breeders (e.g. in Morocco), or their parents and relatives were. In other words, half of today's irrigated surface is cultivated by farmers who traditionally practised rainfed systems. Figure 1 shows the overall dominance of green-water use in agriculture, with a few exceptions in the arid and semi-arid areas where irrigation has expanded over the last 50 years (and significantly left Africa and South America relatively sparsely irrigated).

The CGIAR Challenge Program on Water and Food (CPWF) initially aimed to increase water productivity and to ensure more equitable use of water among users and the environment. However, and in common with resilience "science", it has considered agricultural and natural resource systems as coupled to social ecological systems, thus emphasising not only the dynamics in each domain, but also the nature and dynamics of the linkages between the two. Therefore, most of the

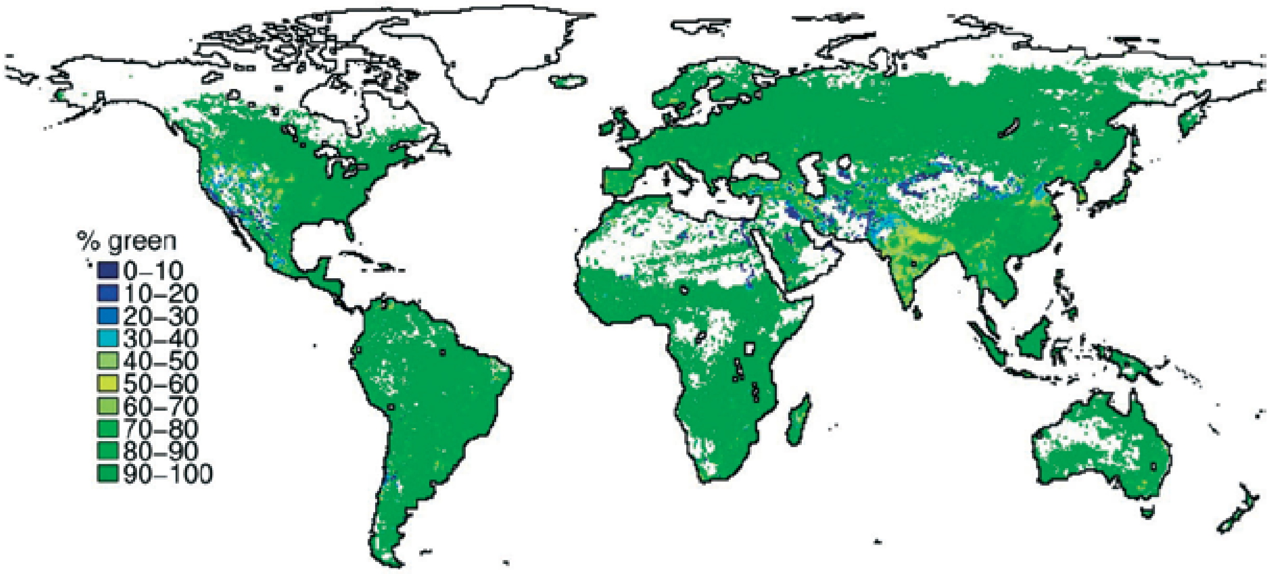

Figure 1. Share of green water in agriculture
Source: Hoff and Rockström (2008)

CPWF Phase 1 projects (2003–2008) have tried to bring greater resilience to the livelihoods of the rural poor who are the ultimate research beneficiaries, as are the natural resource systems upon which they depend. The present paper reviews results from two of these projects: one developed in a "green-water dominated" system, namely a threatened wetland of the lower Mekong Basin; and one developed in "blue-water dominated" systems, looking at multiple-use water systems (MUS) in the Andean, Nile, Limpopo, Ganges and Mekong Basins.

The paper aims to demonstrate that increasing water productivity and improving farmers' livelihoods should be done alongside, and in recognition of, the existing green-to-blue water continuum, and that significant progress can be achieved by learning from the resilience of various systems along this continuum.

The resilience concept and its linkages with agricultural water productivity

In ecology, resilience has long been defined as "a measure of the ability of systems to absorb changes of state variables, driving variables, and parameters, and still persist". It has since broadened to include people, emphasising not only the dynamics in the ecological and social domains, but also the nature and dynamics of the linkages between the two. Walker and Meyers (2004) provided a widely cited definition of the resilience of a social–ecological system as "the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks". Alternatively, it is "the ability of the system to maintain its identity in the face of internal change and external shocks and disturbances" (Cumming et al., 2005). These resilience concepts have to be applied in the context of enhancing, or at least maintaining, the multiple economic, social and environmental benefits that societies derive from natural resource systems.

The Walker and Meyers (2004) paper identifies three attributes of a system that constitute an overall resilience approach: (1) resilience, in the sense of persistence, (2) adaptability, the capacity to manage resilience, and (3) transformability, the capacity to transform into a different kind of system. The essential point about resilience has to do with limits, or thresholds, to change. If a system follows linear dynamics, it is always smoothly reversible within current technology and resource constraints. If a mistake is made, or the managers change their minds, there is no fundamental difficulty in moving to another state of the system. In systems with non-linear dynamics, however, the likelihood of alternate system regimes is high. A shift (intended or unintended) from one to the other can be irreversible or very hard to reverse.

Conventional natural resource management policy and management institutions have tended to assume that ecosystems, agro-ecosystems and social–ecological systems are predictable and controllable, and follow smooth and linear trajectories (i.e., they don't exhibit discontinuous changes). Management has focused on average conditions and on particular time and space scales. Such an assumption is represented in Figure 2, showing what most agricultural and irrigation engineers imagine as a continuous transition from a green-water dominated rainfed system to a blue-water dominated irrigated system.

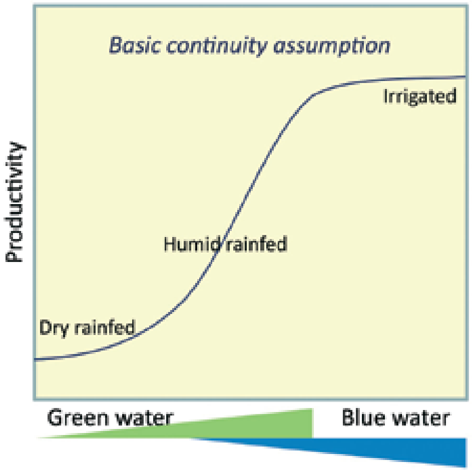

Figure 2. A theoretical " engineering" vision of the green-to-blue water continuum based on the assumption that water productivity of agricultural systems increases continuously when evolving from dry rainfed to humid rainfed, then to irrigated.

In contrast, a resilience approach to management assumes that social–ecological systems can exhibit threshold-type changes, which may move them towards some new state. Examples occur in agricultural, forestry and fisheries systems which are able to recover after being changed by human use and natural disturbances, but beyond some critical level of change can no longer recover. The existence (and the likelihood) of alternate stable states is what makes the concept of resilience so important. The bigger the difference between the levels of the two states, and the bigger the hysteresis effect (i.e., the more the controlling variable needs to be reversed before the state of the system "flips" back), the greater is the significance of that particular aspect of resilience.

The present paper assumes that, under water-scarce conditions, such alternate stable states exist along the green-to-blue water continuum, and correspond to quite high and stable water productivities made possible through better water management, be it green, blue or a combination of both (i.e. respectively left, right or centre of the X-axis in Figure 2).

In the following, water productivities will be approached through the estimated or measured income of poor households generated through the system considered (be it based on agriculture, livestock, fisheries or other productive water uses). Incomes per household are indeed strongly related to income per cubic metre of water (a strict measure of water productivity). And since higher incomes provide the rural poor with a buffer against market, environmental and climatic variations, they logically make them more resilient; hence household income can be considered as a good resilience indicator.

Lessons learnt from two CPWF projects

A wetlands ecosystem and resilience in the lower Nam Songkhram River Basin, Thailand

The Nam Songkhram Basin in Northeast Thailand is a medium-sized (13,128 km^2) sub-basin of the Mekong Basin encompassing a wide range of agro-ecological zones, from forests in the upper watershed to vast floodplain wetlands that experience a three to four month period of annual flooding in the lower basin. The total area of inundation varies from year to year, but averages at approximately 960 km^2, doubling in area during a one in fifty year flood (Blake et al., 2009). Annual rainfall varies within the basin from 1,200 to 2,800 mm, with 90% falling in the wet season. The natural eco-hydrological pattern of the lower Nam Songkhram Basin is complex and mirrors that of the better-known Cambodian Tonle Sap system's annual "flood pulse" phenomenon (Lambert, 2008), albeit on a much reduced scale. Studies have shown that these wetlands are strongly influenced in the wet season by the hydrology of the Mekong River, including occasional backflow events in July–August when Mekong waters may spill over onto the floodplain up to 100 km upstream from the confluence (Sarkkula et al., 2006). In the dry season, water levels fall by around 12 m from their peak and the floodplain reverts to a mixed habitat wetlands complex, dotted with permanent water bodies (natural and artificial), and interspersed by a mosaic pattern of remnant natural forest stands, land converted to agriculture (mostly rice paddy) and, increasingly, industrial tree species (e.g. rubber and eucalyptus) monoculture. In the 1980s and early 1990s, large areas of forested land were cleared of natural vegetation for cash crop plantations (e.g. tomatoes, sweetcorn and sunflowers) by several influential agribusiness companies, most of which failed commercially following the 1997 Asian economic crash and have subsequently been abandoned (Blake and Pitakthepsombut, 2006b).


Photo Credit: D. Blake

Figure 3. Capture fisheries in the Nam Songkhram Basin wetland represent an average catch of 207 kg/household/annum, generating a household income of around US$1,100 per annum.

Local livelihoods are closely tied to the floodplain wetland ecosystem and traditionally relied heavily on the harvest of wetland products, including both terrestrial and aquatic biodiversity (Blake and Pitakthepsombut, 2006a). In particular, there has long been an important freshwater capture fishery, which targets both non-migratory and migratory species using a wide variety of gear. In a recent study, capture fisheries were estimated to involve up to 93% of households with an average catch of 207 kg/household/annum (Hortle and Suntornratana, 2008). Non-fish wetland biodiversity harvested by villagers for local consumption and sale include numerous species of edible and medicinal plants, fungi, insects, birds, mammals, amphibians, crustaceans, molluscs and reptiles, as well as a wide range of non-consumptive plant and animal products. Relatively few detailed socio-economic studies of the ecosystem values for Northeast Thailand have been conducted. A study found that the average gross economic benefits derived from wetland products per household in 2006–2007 was around US$1,100 and that approximately 92% of households participated in the collection of wetlands products (Pagdee, 2007).

Much of this natural biodiversity originates in the "paa boong paa thaam", or seasonally-flooded forest, a highly biodiverse and ecologically productive wetland habitat according to multi-disciplinary research conducted under the Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme (MWBP) between 2003 and 2006 (Blake et al., 2009). The annual flood pulse is recognised to be the principal driver of the immense aquatic and terrestrial productivity of the Mekong wetlands floodplain ecosystem, as observed in other major lowland tropical river systems (Junk and Wantzen, 2004; Lambert, 2008). The paa boong paa thaam of the lower Nam Songkhram Basin has been steadily reduced in extent and quality over the past 50 years of modern "development". A study estimated that between 2001 and 2005 alone, the remaining paa boong paa thaam reduced in size from 89.6 km^2 to 73.2 km^2 due to various kinds of human encroachment (Suwanwerakamtorn et al., 2007). A number of ongoing threats to the integrity of the wetlands ecosystem have been identified (Blake and Pitakthepsombut, 2006a), including:

- Construction of large-scale water infrastructure projects, particularly irrigation schemes, including transboundary/basin transfer plans e.g. a proposed "water grid" project,
- Intensification of agriculture, including greater agrichemical inputs, large-scale agribusiness model application, and industrial tree monocrop plantations,
- Use of unsustainable fishing gear and methods,
- Expansion of existing salt and proposed potash-extraction activities,
- Industrialisation and urbanisation with associated local over-abstraction and water pollution,
- Release and spread of alien and potentially destructive plant and animal species,
- Changes in hydrology and sediment transfer from upstream Mekong mainstream and tributary dam construction, adversely impacting the flood pulse regime.

These factors have added to a general decline in the water productivity and resilience of paa boong paa thaam, reflected in numerous reports of reduced aquatic organism catches and other wetland product harvests (Blake and Pitakthepsombut, 2006a and 2006b), which have a low associated opportunity cost compared with agriculture. Research by Pagdee (2007) showed that the relative proportion of net economic benefit from harvesting wetlands products was 82.65% compared with 14.70% for rice cultivation. If protected and left undisturbed, paa boong paa thaam has the potential to provide high direct and indirect economic benefits from provisioning, supporting and providing cultural ecosystem services, which have rarely been considered by regional policymakers and planners.

As the paa boong *paa thaam* is essentially a common property resource, reliant on a complex eco-hydrological regime partially independent of in-basin run-off patterns, then its resilience to changes in water and land use patterns (both within the sub-basin and wider Mekong Basin) can be called into question. To date, a few remnant forested patches remain intact due to local protection measures and have shown a degree of resilience to some external shocks (e.g. rapid regrowth of bamboo forest post-clearance for rice fields) but not to others (e.g. severe physical and chemical forest clearance by agribusiness companies), suggesting highly uneven resilience at the local level. Also, the future resilience of these wetlands is as much dependent on future hydrological scenarios for the Mekong mainstream as much as it is on in-basin developments. On the one hand, blue water is now nominally more available due to the construction of numerous shallow reservoirs on the floodplain, but paradoxically there is little evidence that these sources are being used for agricultural purposes, and irrigation systems cover only 5% of total land area. On the other hand, natural seasonal flooding (green water) limits agriculture to a greater extent than absolute water scarcity, yet is simultaneously the main driver of natural wetland product diversity and abundance.

At the promotion peak of the Nam Songkhram Project in the mid 1990s, rural people were steadily migrating out of the locale, partly because of natural resource degradation and loss of wetland productivity, but also because of better wage earning opportunities elsewhere. Around the same period, it was estimated that 80% of total cash income was earned off-farm in Northeast Thailand, including 43% from wage work in cities (Blake et al., 2009), which cannot be considered as a resilient evolution. Hence, given the continual attempts by certain state agencies, private interests and Mekong regional water resources planners to overcome a perceived regional water scarcity and control floods (often termed "natural disasters") through engineering approaches, there is an urgent need to re-evaluate the present value and ecosystem services of existing natural and artificial wetlands, while recognising issues of equity and rights in common property regimes. Figure 4 below graphically indicates the likely shift in water productivity that may occur when a "tipping point" is reached in terms of ecosystem stability through external shocks such as vegetation clearance or hydrological changes resulting from a dam.

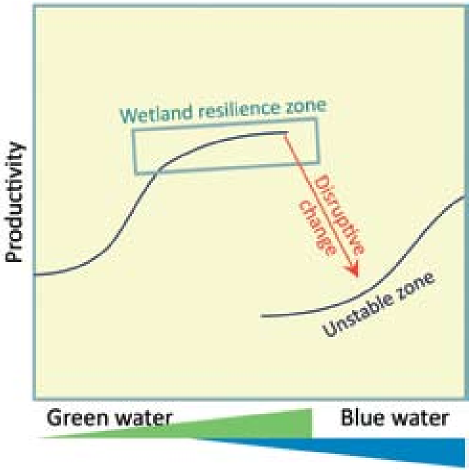

Figure 4. Schematic evolution of water productivity along the green-to-blue water continuum of a productive wetland of the Mekong Basin, and its likely evolution (red arrow) as already observed in past attempts to regulate floods and water flows through infrastructure or massive agricultural land conversion and enclosure schemes.

In summary, the paa boong paa thaam wetland production ecosystem may provide many direct and indirect benefits and services that are more resilient and less vulnerable to shocks than agricultural systems of various types and intensity occupying the same land–water interface, partly because it is fully adapted to and a product of the local ecological conditions related to the flood pulse phenomenon. However, the ecosystem is nevertheless vulnerable to external shocks such as changes to the flood pulse itself (for example, by built and planned Mekong mainstream dams in China) or wholesale forest clearance for agriculture, and thus its long-term resilience is limited in the face of multiple threats. At the same time, it should be noted that smaller-scale, farmer managed and controlled irrigation systems have proven more resilient over the last few decades to external socio-economic and ecological shocks than the larger state or private controlled irrigation systems, which in many cases have been abandoned within a decade. Whether the remaining fragments of paa boong paa thaam can be saved for the benefit of future generations in the face of environmental threats, stakeholder conflict and ongoing waterscape transformation, is a matter that Thai society is currently wrestling with.

MUS – multiple-use water systems

The multiple-use water systems (MUS) (sometimes referred to as multiple-use water services) project explored the resilience of humans and of natural resource systems, and, above all, their interfaces (Mikhail and Yoder 2008; Van Koppen et al., 2009). This broader conceptualisation opened up a new practical approach to water services by governments, NGOs, international water and rural development agencies and the private sector: "multiple-use water systems" (MUS). The project realised that water users are invariably quick to transform any system designed for a single use into multiple-use schemes, whether this causes damage and is illegal, or not. As conceptualised by the project, MUS moves beyond the fragmented interventions of single-use sub-sectors: either domestic, or green water, or blue water, or livestock watering, or fisheries, etc. It anticipates and plans for such multiple needs, including domestic water uses, which are often the priority of poor men and women, and mainstreams this priority across the water sector. Thus, MUS takes people's multiple water needs as the starting point of a water intervention. The project pioneered the implementation and scaling-up of this new approach, and found all evidence for its hypothesis that MUS is significantly more effective than conventional sector-based single-use interventions for sustainable rural and peri-urban poverty alleviation.

Photo credit: MUS project

Figure 5. Developing multiple water use systems in Nepal at household and community levels has empowered villagers, especially women, and generated additional income

The merits of MUS lie primarily in the fact that MUS strengthens resilience, both from a people's and a resource perspective. MUS boosts resilience in people's livelihoods by concurrently meeting multiple domestic and productive water needs, and thus simultaneously contributing to health, dignity, food, income and freedom from the drudgery of water fetching, to mention the most important dimensions of wellbeing. The combination of these livelihood benefits strengthens resilience against shocks and extreme events even more than the sum of each dimension. Health enables higher water productivity; more income allows more spending on health care; women can use the time saved for productive activities or rest; and girls can attend school which tends to increase marriage age, income and family welfare, thus breaking intergenerational poverty traps. Indeed, MUS triggers virtuous circles out of poverty, especially in peri-urban and rural settings in low- and middle-income countries where people's agrarian livelihoods are diversified and depend in many ways upon water.

From a resource perspective, MUS combines green and blue water and considers all forms in which water comes at the interface with society. Water is available for humans as multiple interlinked, conjunctively used water sources of rainfall, surface streams and storage, groundwater, and wetlands. Infrastructure, which brings the right quantities of water of the right quality at the right time to the right place, is the single most important trigger for a higher level of equilibrium in which many more water needs of many more people can be met. Water infrastructure development underpins the economic growth of high-income countries. The use and re-use of, and protection from combined natural and human-made water sources are key to resilience in the ecosystem of humans and natural resources as a whole. Significantly, since time immemorial, this is the way in which rural communities themselves have developed infrastructure and managed multiple water sources for multiple water needs, mitigating variability, unpredictability and extreme drought and flooding in often harsh ecological conditions.

The MUS project applied these new opportunities for enhanced resilience to the implementation and scaling-up of two models of MUS: homestead-scale MUS and community-scale MUS. Led by the International Water Management Institute, the project was implemented in 30 sites in eight countries in five basins of the Challenge Program on Water and Food: Andes (Bolivia and Colombia), Indus-Ganges (India and Nepal), Limpopo (South Africa and Zimbabwe), Mekong (Thailand), and Nile (Ethiopia). In each country, the lessons learnt on the ground were scaled up among intermediate and national level water service providers, through learning alliances which encompassed a total of 150 institutions. Advocacy at the global level was undertaken in collaboration with the global MUS Group (www.musgroup.net). The project's ultimate aim of scaling-up MUS was to contribute to providing all people with the water services they need.

For homestead-scale MUS, the project found that the water services ladder commonly used in the domestic sector failed to match reality in peri-urban and rural areas in low- and middle-income countries. Unlike the domestic sector's assumption that people use up to 100 litres per capita per day near to homesteads for domestic uses only, the project found that wherever water is available, people use water for productive purposes as well, including livestock watering, horticulture, irrigation, tree growing or small-scale enterprise. In Northeast Thailand, up to nine water sources were found to be used for intensive use- and re-use of water and nutrients at homesteads for economic self-sufficiency. Ample and flexible choice among homestead-based activities accommodates volatile environments. Moreover, for women, the land-poor, and the sick, the homestead is often the only site where they can use water productively.

The project estimated that these productive activities brought food and additional annual incomes in the order of US$300–500 per household, which is significant for poor households living on one U.S. dollar per person per day. Renwick (2007) found similar amounts and calculated that this income often allows full repayment of investments in the required infrastructure within a half to three years. So, in principle, homestead-scale MUS allows even the poorest to pay for water and cross-subsidise domestic water uses.

Hence, the project recommends replacing the domestic sector's water ladder with a more realistic "multiple-use water ladder" in poor rural and peri-urban areas (Van Koppen et al., 2009). Accordingly, water services policies should allow the poor to "climb the water ladder" by increasing service levels to an "intermediate level" MUS of 50–100 litres per capita per day, or even to more than 100 litres for "high level" MUS. Out of these quantities, 3–5 litres should be safe for drinking and cooking. In this way, homestead-scale MUS contributes cost-effectively to all the Millennium Development Goals, and creates a more productive and stable resilience zone when compared with the instability associated with single-use designed systems, as depicted in Figure 6.

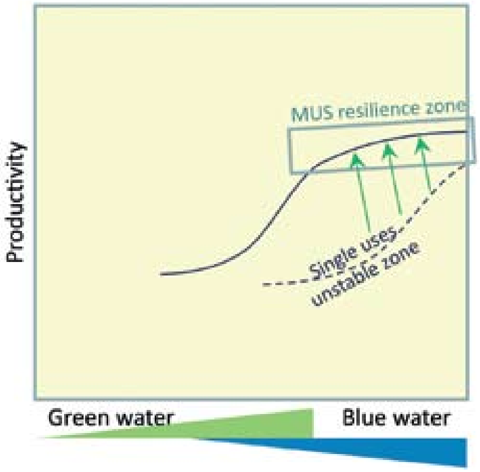

Figure 6. Schematic evolution of water productivity along the green-to-blue water continuum between single-use and multiple-use water systems (MUS), observed in many basins targeted by the Challenge Program on Water and Food

Photo: Mats Lannerstad, SIWI

Conclusions

The two cases reviewed above can be grouped into the same graph (Figure 7) to illustrate how the green-to-blue water continuum can be used to better guide interventions on improved productive water use and management, depending on actual conditions. Different trajectories may hence be drawn according to the productive systems considered: humid rainfed, like in the lower Mekong Basin, or blue-water dominated, like in many places around the world where water infrastructure has been significantly developed.

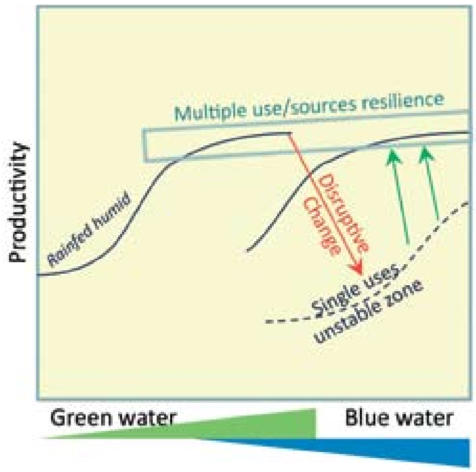

Figure 7. Schematic evolutions of water productivity along the green-to-blue water continuum according to the different productive systems considered by the CGIAR Challenge Program on Water and Food from the two cases described.

Experience from these two CPWF projects shows that, for each system, there is a state of higher household income related to higher water productivity, considered to be more resilient, which is ensured by a combination of multiple water uses, techniques and/or sources, together with a resulting (or accompanying) community organisation. It also shows that neglecting the green-to-blue water continuum creates unaffordable disruptive changes, depicted by the red arrow on Figure 7.

These two examples clearly show that, when increasing water productivity and improving farmers' livelihoods is done along the existing green-to-blue water continuum, more resilient states can be identified, maintained, created or restored by combining multiple water sources and uses. This paper hence suggests a change of paradigm in food production systems where green water is still too often placed in opposition to blue water in a sense that implies that more productive and resilient states are achieved only thanks to well-mastered blue water. ■

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