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Exploring the Concept of Green Water.
Bridging Science and Water Resources Management

Thesis submitted in partial fulfilment of the requirements of the
Master's Degree in Environmental Studies and Sustainability Science

Author: Olga Agaponova, MPA
222 21 Lund, Sweden
E-mail: agaponova@hotmail.com

Supervisor: Johanna Alkan Olsson, PhD
LUCSUS, Lund University
Lund, Sweden
E-mail: johanna.alkan_olsson@lucsus.lu.se

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Abstract

There is a scientific polemics that humans may rapidly approach the global freshwater crisis, which is driven by the population growth, and exponentially increasing water demands for water supply, food production and in general for socio-economic development that falls far behind from being sustainable at the moment. The issue is even more striking when not only human needs for water should be recognized and addressed but also the factor of dependence by ecosystems on water should be appropriately apprehended and acknowledged. The concept of green water has been proposed in the early 1990s to highlight certain water flows critical for crop production; and further developed to explore linkages within the water cycle, between the water cycle, ecosystems, other natural cycles and human activities.

The present paper pursues the objective to systematize the contemporary knowledge on the concept of green water and analyze if the concept of green water creates a breakthrough for the water resources management. The systematization of present knowledge is made with intention to unravel the evolved green-blue water discourse and attract more attention to water issues. The analysis of available green water related knowledge was performed across contextual categories. Instances of practical utilization of the concept were summarized and presented separately.

The concept of green water is transdisciplinary in its essence and serves to interface the hydrology with other natural and social sciences. Contextual categorization and study of relational aspects between the green-blue water cycle and other phenomena of natural and human reality revealed the similarity of the green water related discourse with the conceptual model of interaction of sustainability's dimensions and the potential to enrich the knowledge within the sustainability/sustainable development paradigm.

As analysis showed the practical utilization of the concept is not easy yet due to a limited consensus reached by scientific community as well as not least limited diffusion of the concept in the realm of water politics and management. Despite the quantitative properties of green water are not well defined as there is a variation in the definition of the concept between disciplines and in the methodologies to measure green water flows; none the less the concept has a proven qualitative value to change the existing freshwater accounting system. It is unlikely that the green water concept will help to simplify delineation of water management levels however it has the potential to facilitate the understanding for water policy-makers and managers of important links between water, land, ecosystems and human activities, and provoke conceptual changes in how to approach water management across different scales.

Keywords: green water, hydrologic cycle, water resources management, sustainability

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I express my sincere gratitude to the Swedish Institute; its support made my studies at Lund University sustainable in all economic, environmental, and social senses!

List of Figures and Tables

List of Abbreviations

CDM	Clean Development Mechanism
CDM-AR	Clean Development Mechanism – Afforestation, Reforestation
FAO	Food and Agriculture Organization of the United Nations
GWC	Green Water Credits
GHG	Green-House Gases
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
LULUCF	Land-Use, Land-Use Change and Forestry (IPCC reporting)
MDG	Millennium Development Goals (UN)
PES	Payments for Environmental Services
SEI	Stockholm Environment Institute
SIWI	Stockholm International Water Institute
SSA	Sub-Saharan Africa
SSI	The Smallholder Systems Innovations Research Program
SWC	Soil Water Content
SWM	Sustainable Water Management
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO-IHE	UNESCO-IHE Institute for Water Education
UNFCCC	United Nations Framework Convention on Climate Change
WF	Water Footprint
WMO	World Meteorological Organization
WWAP	World Water Assessment Program (UNESCO)

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1 Introduction

Water is vital for natural and human systems on the Earth. To make the water resources management truly integrated and sustainable, humans should account for the complexity of the hydrologic cycle and its interaction with the biosphere. The concept of green water has evolved in the literature in connection to the forecast of global freshwater crisis in the future under pressure of population growth, unsustainable socio-economic development and the need to secure food production for the most water-stressed regions (Falkenmark, 1995 in Rockström, 2003; Falkenmark, 1997; Rockström, 2003). It was concluded that human water withdrawals increase exponentially in the course of development (Rockström, 2003).

The proponents of the concept of green water (Falkenmark, 1995, 2004, 2007; Rockström, 1998, 2003; Jewitt, 2002; van der Zaag *et al.*, 2002 and many others) argue that water policies are most frequently based on data of withdrawals from surface water sources (rivers, lakes) and groundwater but at the same time there are water flows which sustain vegetation in grass and croplands, forests and wetlands which are highly important when it comes to the food production from rain-fed agriculture. At present these water flows are not accounted for appropriately and this, according to the Green Water proponents, hampers adoption of sound water and development policies, implementation of water planning and management.

Appeared in the transdisciplinary context of FAO's activities in the beginning of the 1990s, the concept of green water keeps on developing by academia and development practitioners but seems to be stuck in the debates rather than became normative and operational in water resources management. Being guided by the objective of water policy developments of Agenda 21 adopted at the 1992 Earth Summit in Rio:

> "Water is needed in all aspects of life. The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water-related diseases" (Chapter 18, UN, 1992);

as well as objectives for science for sustainable development:

> "to improve and increase the fundamental understanding of the linkages between human and natural environmental systems and improve the analytical and predictive tools required to better understand the environmental impacts of development options" (Chapter 35, UN, 1992);

This paper explores the concept of green water and pursues the goal to systematize the knowledge on it and analyze if the concept of green water creates a breakthrough for the water resources management. Systematization of knowledge is made from the evidence reported in scientific literature and documentation of international development agencies. The paper consists of three main parts. The first part is a content analysis of selected literature related to the concept/phenomenon of green water. The second part is focused on cases of how the concept is practically applied, what are the purposes and status of application. The third part of the paper is discursive in its nature, and it attempts to grasp how the concept of green water relates to the transdisciplinary discussion and process within the science domain to solve complex social-ecological problems. The matter is seen relevant for two reasons.

First, it is argued that transdisciplinarity is considered necessary "in fields of great human interactions – such as agriculture, forestry, large technical interventions, industry, traffic, and megacities – with natural systems – such as water, soil, vegetation, atmosphere; and in the management of those natural resources (Guichun et al.; Robledo and Sell; Vahtar)" (Thompson Klein *et al*., 2001: 10). Secondly, the concept of green water is a piece of knowledge involved in the science-society communication process. When the society faces the problems, it needs adequate knowledge to cope with problems. If the knowledge is well "understood, conceptualized and explained" (Scholz and Marks, 2001, in Thompson Klein *et al*., 2001: 243-244) scientifically and translated to the society, it is more likely that more sound solutions can be applied to persistent problems. Furthermore, better knowledge available to various strata of society is most likely to catalyze changes required to proceed with sustainable development.

Thus, the third part includes the discussion in which the issue of transdisciplinarity of the green water-related research is analyzed; and the concept of green water is explored in relation to sustainability/sustainable development paradigm and water resources management.

1.1 Aim, scope and research questions

This paper performs a scientific literature review to present a more systemic scientific outlook of the concept of green water. At first look the concept seems to stem from natural sciences with foresighted potential of transferring to social sciences in particularly development studies and of application in the integrated water resources management and development programs focused on poverty alleviation in areas with arid and semi-arid climates. The concept has the most prominence in academic literature and perhaps as a consequence the practical application of the concept remains largely on paper and within the debates among water and land professionals dealing with research and expertise for international and national development agencies despite the aim of its initial creators to be useful in practical water management.

Speaking about water and humans implies multiple aspects, the core of which would be development and environment. To give a clearer understanding of the green water concept and to explore the possibilities to expand its utilization for settling water-related problems faced by the humans in the course of evolution as well as in the pursuit of sustainable development it is essential to research on what has been already developed and present the findings in a coherent manner.

The paper therefore raises the following research questions and sub-questions:

1. What is the present discourse on the phenomenon/concept of green water?
   - How has the concept been pronounced in scientific literature?
   - What are the properties of the green water as phenomenon?
2. What is the practical application of the concept?
3. How transdisciplinary is the research on green water?
4. How does the green water discourse relate to the sustainability/sustainable development discourse?
5. How can the concept of green water contribute to water resources management?

1.2 Research methods, material, limitations

1.2.1 Research methods

The scientific and practical significance of the research lies in the comprehensive review of the concept of green water by doing a content analysis of peer-reviewed literature and documentation; in the categorization of the green water concept, and the identification of the practical use potential of this concept in water resources management. The conceptual/theoretic platform of this research is within the sustainable development/sustainability paradigm which implies the consideration of three essential pillars: environmental, social, and economic. Such consideration may be achievable if there is understanding of the complexity of the natural and human systems and hence the intention to seek solutions to scientific and practical problems of high complexity by using the transdisciplinary approach. (e.g. Max-Neef, 2005; Steiner and Posch, 2006).

The paper uses qualitative methods of research. The main steps of qualitative research within this paper can be presented as follows:

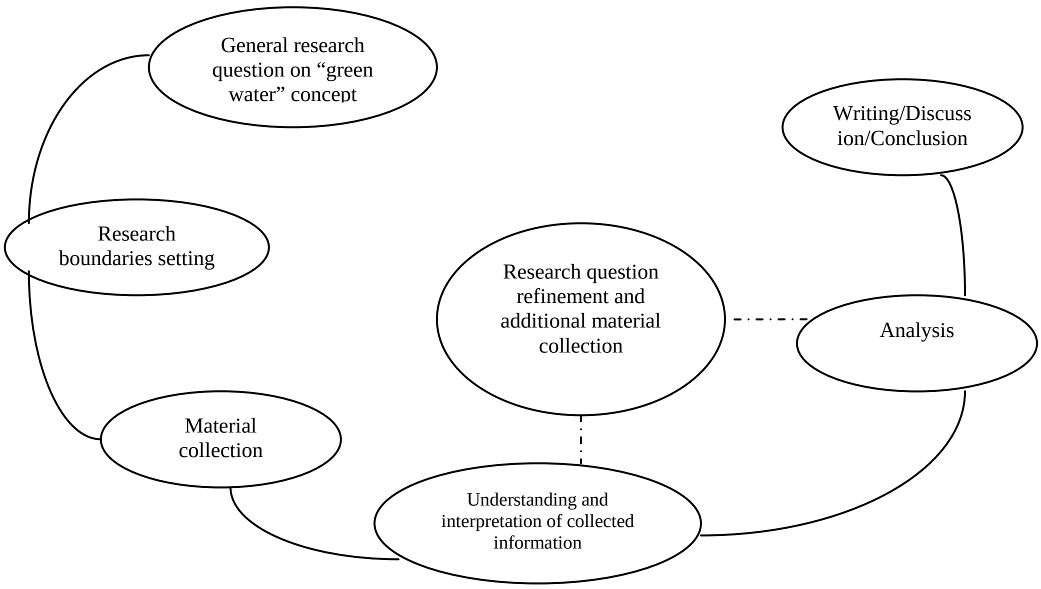


Figure 1.2.1. Steps of conducting research for the present thesis (Adapted from Bryman, 2004: 269)

The development of paper proceeds mainly through the understanding of the concept of green water as conceptualized and theorized by academia as well as being applied in practical settings. In order to discuss the potential contribution of green water concept for sustainable development one should understand this knowledge, how it was produced and how the theoretical assumptions can be/were translated into praxis. Max-Neef notes succinctly: “The knowing has grown exponentially, but only now we begin to suspect that that may not be sufficient, not for quantitative reasons, but for qualitative reasons. Knowledge is only one of the roads, only one side of the coin. The other road, the other side of the coin, is that of understanding (Max-Neef, 2005: 15).

The ontology of the research is based on constructivism. In practice that means that exploring the concept of green water includes an introduction of some categories which would help to understand it as phenomenon belonging to the natural and social world created by people indeed and thus turning to be the social product (Bryman, 2004). Even though the soil moisture and evapotranspiration as physical phenomena are parts of the existing natural scientific model/natural reality, the concept of green water is a pure social construct, evolved from the shift in the thinking or the identification of a gap in the dominant way of interpreting the flow of water by some individual academics.

Touching upon the epistemological stance, it is therefore critical to question if the green water concept is an acceptable knowledge for social and natural sciences. The dilemma lies in the emergence of the concept at the interfaces between natural and social sciences. The value of the concept comes from its dual role to describe the natural phenomena of soil moisture and evapotranspiration in (inter)relation to other natural and social phenomena, to understand the processes within the hydrological cycle in order to change the behaviour of people in terms of shifting from one mode of natural resource management to another. This preliminary assumption confirms the necessity to apply the research strategy of interpretation following the hermeneutic tradition.

The research employing hermeneutics is featured by “dialectics between interpretation as part and whole”, “the particular outlook of the interpreter and the special character of the matter interpreted” (Alvesson and Sköldberg, 2000: 60). “Interpretation implies that there are no self-evident, simple or unambiguous rules of procedures and it matters how researcher is capable of judging, intuitively revealing something, making clear dialogue with the research subject… (cf. Maranhao, 1991 in Alvesson and Sköldberg, 2000: 248). This research consists of processes of thinking, understanding and discussing arguments and counterarguments in order to get deeper insights from existing knowledge on the concept of green water with a plausible hope of its refinement and further practical utilization.

1.2.2 Research material

In order to make this interpretation of the concept of green water I use secondary data including scientific articles, development project reports/documents, books published in the English language since the concept has evolved in 1993 and till present. The temporal reference points are set from 1993 to present. The content analysis method is employed to select study material and interpret natural phenomena turned by epistemic community into artifact called the concept of green water. The drawback that might appear is that secondary sources of material are interpreted and thus subjectivism is inevitable (Marshall and Rossman, 2006).

The search of material was undertaken within the academic library system available at Lund University (including electronic databases of ELIN at http://elin.lub.lu.se.ludwig.lub.lu.se/elin, JSTOR at http://www.jstor.org.ludwig.lub.lu.se/) in the first place and at Google search engine in the second place. The selected pool of literature cannot be proven exhaustive considering the computer search approach across academic and public databases and is also a subject to limitations by the researcher taking into account the available time and resources.

The material selection criterion employed by the author is "the publication must necessarily contain the concept of green water in the text, its definition, and must involve the concept in the discussion implying the meaning of the concept in terms of existing meanings of natural phenomena/concepts (the soil moisture and water flows of evapotranspiration process)". To note: screening showed that the concept of green water can have totally different meanings in various literature sources. Publications using the concept of green water with the meaning describing the effect of eutrophication process as well as with the meaning of green water area between the blue water and brown-water zones (from the discipline of maritime geography) were excluded during the material screening for further consideration. It is most likely that a lot of literature was unintentionally omitted during the screening process due to the fact that many scholars do work for instance with concepts of water vapour, soil moisture, hydrological processes of evapotranspiration but do not use the concept of green water. The final sample of 33 sources was identified and rigorously studied within the present research.

Collected material covers the period from 1997-2007. The number of authors in the selected publications are from one to many with the mean of 2,9. Notably, the analysis revealed that the same academia were the authors of various sources published in different time. For example, the names of M. Falkenmark, and G. Jewitt have been met six times each, J. Rockström – five times. The analyzed pool of literature can be approximately divided in three categories: general discussion (39 %), research (33 %) and case studies (27%).

Appendix 1 presents the material collected and analyzed. The analysis proceeded in three phases:

1.screening of material by checking the definition of the concept and engagement of the concept in the discussion;

2.analysis of material: by looking at

- type of material (general discussion; research; case study),
- its general relation to the sustainability/SD paradigm,
- number of authors, their disciplinary affiliation,
- transdisciplinarity of knowledge presented in terms of 'going beyond disciplines' and producing knowledge to address complex social-ecological problems,
- 'real-world' problem discussed/general topic(s) of scientific debate presented, and based on that,
- developing the context categories of the concept use to make systematic literature review;

3.assessment of the concept

- by analyzing the definition, and classifying it according to hydrologic systems typology in terms of stocks and flows,
- by using categories for the context in which the concept was applied,

- by presenting and making summary of the cases where the green water concept is practically utilized in policies and management field,
- by discussing and concluding on the field of knowledge represented by this concept.

The content of the material was studied to see which ‘real-world’ problems are under consideration and what the general topic(s) of scientific debate are of high attention in publications. In that particular course of analytical work it became evident that context in which the concept was used is categorizable. Categories facilitate the understanding and systematization of already existing knowledge on the concept of green water. This means that the researcher establishes an analyst-constructed typology grounded in the texts but not necessarily used by the authors of the original publications (Marshall and Rossman, 2006) which contain the concept of green water. Context category was elaborated as outcome of publication’s context screening and outlining the major relationship in question for scientific inquiry in the context presented in a single publication in order to seek solutions to ‘real-world’ problems. Finally the following context categories were defined: green water, demographics and agriculture; green water and ecosystems; green water and land use changes; green water and transboundary water resources management; green water and climate change; and multicontextual category.

The systematization of the use of concept beyond scientific boundaries is made through the content analysis and presented in the summary table in which main parameters to clarify the practical application of the concept are: objective, practical realm, boundaries, who and how. The table includes examples which further presented in Part 2 in both narrative and debatable manner.

Part 3 discusses several questions. If the green water concept is scientifically acceptable knowledge, can it be turned into ‘socially robust knowledge’ (Thompson Klein *et al*., 2001), applied across-the-board in the policy and management sphere? Does it truly bridge science and water resources management? The discussion has 1) the scope of understanding and reflecting upon the transdisciplinarity of research on green water, the relationships connecting the green water discourse, sustainability/sustainable development paradigm and water resources management; and 2) the objective to unravel the practical significance of the concept and the potential to play a more considerable role as knowledge useful in application and foreseeing implications.

This paper does frequently use the term ‘system’ for natural and human systems (inferring system as a set of interacting components interdependent from one another) for the purpose of simpler explanation of a complex reality (Thompson, 1999). This is in line with the language of many authors of publications constituting the research material of this paper. The hydrologic cycle represents one of the subsystems of the natural systems with its components and processes, mutual interdependence and feedbacks between components (Thompson, 1999: 3). Representation of the world systems wise is only one of the options to look at it and attempt to comprehend it (Thompson, 1999). Systems analysis terminology in terms of stocks and flows is useful for better articulation and understanding of processes of the hydrologic cycle and its interaction with other natural (sub) systems. The definition of the green water concept is analyzed in terms of hydrological systems topology of stocks and flows for the purpose to see definitional inconsistencies and better capture hydrological boundaries of the concept. The concepts of “the hydrologic cycle’ and “the water cycle” are equally interchangeable in this paper.

1.2.3 Limitations

Limitations exist on the methodological level. The use of qualitative methods implies subjectivism especially when it comes to interpretation of the secondary sources and researcher’s judgment. The selected material is nevertheless assumed scientifically robust knowledge because it has been already peer-reviewed before publications. The quality of knowledge produced during this study is subject for further assessment by peers, reflection and contestation by a wider circle of members of scientific community and general public.

2 Part 1. Exploring the concept of green water in the scientific discourse

Part 1 goes deep in the meaning and conceptual details of the concept of green water. The description of the water cycle is given in a comparative manner to highlight the difference in two conceptual models. At present both models can be found in the scientific literature but the shift of water resources management paradigm at its practical level seems to occur very slowly. The indicator to this is that the UNESCO World Water Assessment Program has introduced the Green-Blue Water Cycle only in its latest 2006 WWAP publication (Figure 2.1.2.1 below). This may be explained by the fact that transdisciplinarity of hydrological and ecological knowledge has been acknowledged by the wider pool of water-related experts for the past decade and thus the consensus within this community has been achieved to accept the conceptual model of the Green Blue water cycle.

Part 1 proceeds further with findings of the literature analysis. There will be a discussion on the concept definition. Major findings on the existing knowledge on the concept of green water are organized in context categories listed chronologically from the moment of appearance in the discourse as it was identified by the analysis of the present study. The purpose to deliver findings is to provide multifaceted overview of the present green water discourse, to pose questions and comments and create a bridge for the next step of study, namely research on the concept's usefulness for practical actions in the water resources management.

2.1 Hydrologic cycle in two representations

2.1.1 Conventional representation of the hydrologic cycle

The hydrologic cycle is the description of the movement of water in forms of liquid, vapour and solid between land, ocean, and the atmosphere. Water transfer occurs through physical processes of evaporation, evapotranspiration, condensation, advection, precipitation, deposition, runoff, infiltration, percolation, groundwater flow by means of energy and matter (Figure 2.1.1.1). Heat causes water to evaporate from oceans and land into atmosphere, where vapour continues circulation with the air. The further from the earth surface vapour gets, the more cooling air forces it to condense. Turning into rain, snow or ice, water precipitates. Depending on landscape, water continues its way by evaporating, running off into surface water bodies, depositing on glaciers, being absorbed by vegetation and further transpired, percolating to the aquifers and reaching the surface again when the cycling goes further on (Mackenzie, 2003: 99). The runoff pattern vary significantly across different regions (temperate, arid, semi-arid or monsoon zones in tropics).

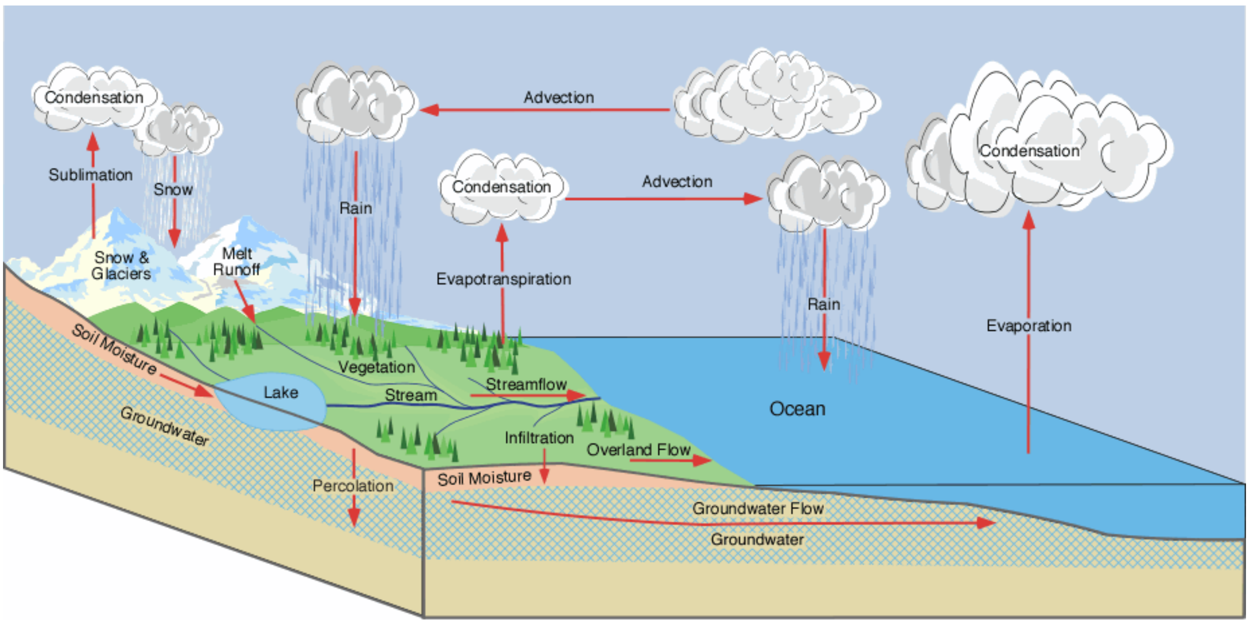


Figure 2.1.1.1.The Hydrologic Cycle (Pidwirny, 2006)

The movement of water through land is much more complicated than that through the ocean as more storage/ inhibiting agents become available: lakes, rivers, soil, aquifers, glaciers, plants. Usually hydrologists use watersheds (catchments) to study on-land water systems. Watershed hydrology is regulated by multiple topographic, edaphic (soil-related) and ecological factors. The common formula to estimate water balance in the watershed is P = ET +R, where P – precipitation, ET – evapotranspiration, and R- run off. (para. from Bonan, 2002).

The water cycle as a physical process might be described in a very detail way as many peculiarities occur with water when water is transported due to the fact that the climate on the Earth varies. It is important to keep in mind, that water like energy in terms of circulated amount "remains the same" within the Earth system (Falkenmark and Lannerstad, 2004: 9). To add, water movement is tightly bound with other cycles. Water movement through plants gets into contact with carbon cycle (Bonan, 2002). By carrying nutrients water plays a big role in their cycling on the Earth too (Bonan, 2002).

Global water pool consists of 97.5 % of water in oceans and 2.5 % of freshwater (UNESCO-WWAP, 2006). Freshwater estimate is approximately 12 500 Gm3/year out of which 4 000 Gm3/year are currently withdrawn for human needs (industrial use of 23 %, household and public sector use of 9 % and agricultural use of 69 %) (Shiklomanov, 2000 in Rockström, 2003). The human water withdrawal projection for 2025 is estimated at the level of 5200 Gm3/year (ibid.) which is roughly equal to the half of available freshwater resources on the Earth. It gets clear that the trend of water consumption by global population is fraught with serious consequences for human and natural systems, thus the consumption patterns should be critically evaluated and the reasonable changes in water use be attempted.

2.1.2 The Green-Blue hydrologic cycle

The main idea of the Green-Blue Hydrologic Cycle lies in separating two types of water flows (Figure 2.1.2.1). If to question why the flows of water in hydrological cycle have to be divided in green and blue water (there are also white and grey flows which are not considered in this paper), the answer lies in practical expediency. This differentiation simplifies analytical analysis of water partitioning on various spatial scales (Falkenmark, 1995(2) in Rockström, 1998: 376). Green water flows going through soil moisture storage available for plant uptake and water vapour in the process of evapotranspiration (I return to the issue of concept definition in the next section) are highlighted to *stress the high importance of water as physical substance for biomass production, terrestrial ecosystems and the biosphere* in general.

Only considering visible water stored in glaciers, rivers, lakes, oceans and aquifers as freshwater resources leads to a distorted perception of the water cycle and incomplete accounting of freshwater volumes (Rockström and Gordon, 2001; Jewitt, 2002). Facing at present the complexity of environmental problems the need for the humans is to understand and know more about water flows' dynamics within the water cycle and in relation to other natural cycles and human activities. Therefore the transdisciplinarity of knowledge seems to be an approach that could help to articulate the relational aspects of the water cycle. Water flows are classified into productive and non-productive routes of green water flows (with major focus on significance for plant growth), and groundwater and surface water routes of the blue water flows (FAO, 2000).

When water gets into the soil, it partitioned to runoff, infiltration and water supply for plants in the form of soil moisture. Soil moisture is conditioned by precipitation, evaporation, slope, vegetation type and qualities of soil (soil type and depth are not usually homogenous in catchment basins) (Lundqvist and Steen, 1999; UNESCO-WWAP, 2003). Most of soil moisture is located in the upper two meters of the soil layer which are also mainly preoccupied by plant roots (Korzun, 1974 in UNESCO-WWAP, 2003). One of the estimates suggests the global volume of soil moisture totals approx. 16 500 km3 (Korzun, 1974 in UNESCO-WWAP, 2003).

The first attempts to operationalize green water flows were made by M. Lvovich in 1979 who studied and estimated partitioning of precipitation for main Earth-known biomes (Falkenmark and Lannerstad, 2004). By 1996 the FAO technical report contained figures of available 70 000 km3 green water globally if green water was considered as evaporation flux (FAO, 1996). Appropriation of green water was estimated in two fractions: human use for agricultural purposes (18 000 km3), and use by Earth's ecosystems (52 000 km3; "all other land-based species and natural communities") (FAO, 1996: 4).

The most particular relationship cited with regard to the green water is that increases in green water flows (mainly due to increase in biomass of vegetation) affect the blue water flows in terms of reduced run-off (Lundqvist and Steen, 1999; Falkenmark and Lannerstad, 2004). Land use and the water cycle is tightly bound in terms of reciprocal impact however when discussion is location specific, other factors (topography, soil characteristics and climate parameters) embrace the great force too (Lundqvist and Steen, 1999).

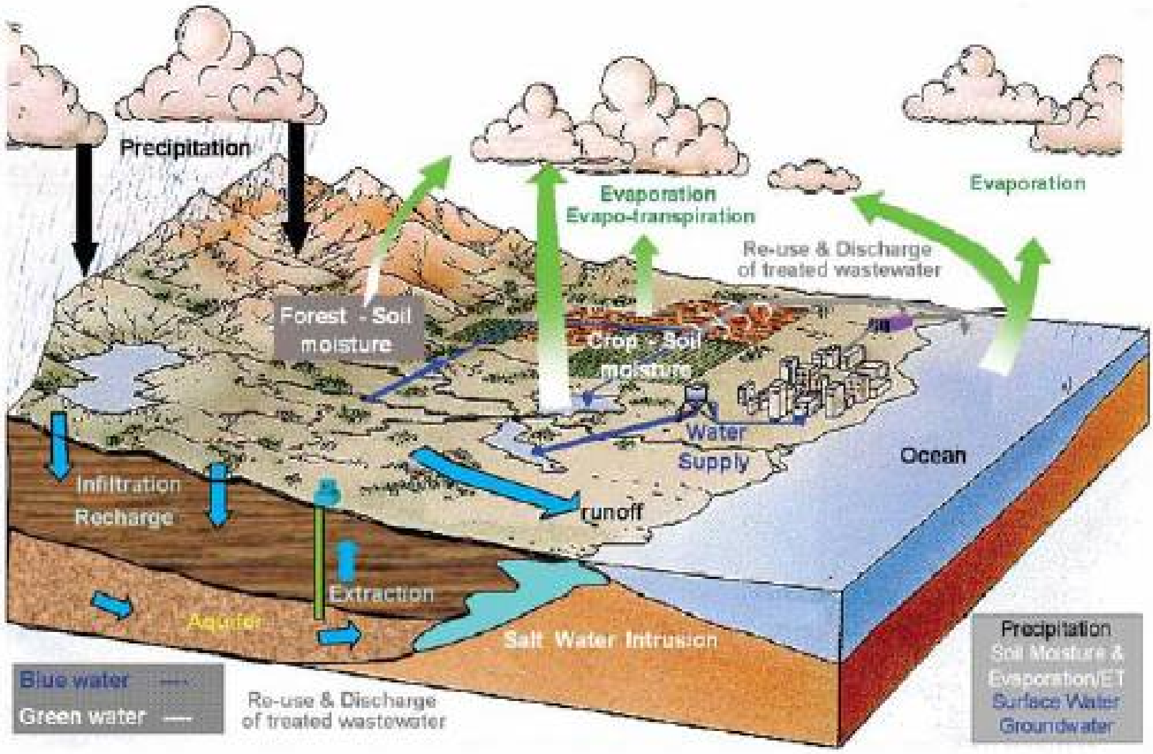


Figure 2.1.2.1 The Green-Blue Hydrologic Cycle (UNESCO-WWAP, 2006: 122)

2.2 On the concept of green water in detail

2.2.1 Definitions of 'green water'

The concept of green water meant originally the soil moisture when introduced at one of the FAO meetings in 1993 (FAO, 2000). Professor Malin Falkenmark coined the concept for the deliberate purpose to attract more attention to the part of water available for biomass growth and participating in evapotranspiration and deepen the understanding of the hydrologic cycle where the consumptive use takes place, by those who exercise water management (Falkenmark and Lannerstad, 2004). Later FAO updated the definition of the green water by considering it as the vertical water flow (the blue water meant the horizontal flow respectively) (FAO, 2000).

By using the hydrologic systems typology of stocks and flows introduced in the course of content review my further analysis of concept definitions showed that in a sample of 33 definitions, 25 definitions can be considered as flow-based (hydrologic processes of infiltrated rain and/or evaporation and transpiration), 2 – as stock-based (water stored in soil), and 6 definitions have combined attributes.

Examples of the operationable 'green water' definitions may be seen in Table 2.2.1.1.

Table 2.2.1.1 Examples of ‘green water’ definitions.

“Water availability in the root zone”; “soil moisture” (Falkenmark, 1997: 929-936).

“Return flow of water to the atmosphere as evapotranspiration (ET) which includes a productive part as transpiration and a non-productive part as direct evaporation (I&) from the soil, lakes, ponded areas, and from water intercepted by canopy surfaces” (Rockström, 1998: 375-383).

“The water supply for all non-irrigated vegetation, including forests and woodlands, grasslands and rainfed crops” (FAO, 2000: 3).

“The water used by ecosystems to uphold “the generation of ecosystem services” (Jansson and Nohrstedt, 2001: 361–370).

“Green water (vapour) flow that supports terrestrial ecosystems”; green water flow reflects the consumptive water use by both natural vegetation and agro-ecosystems” (Falkenmark, 2004: 275–282).

‘‘Green-water’’ is water that is lost from the catchment through evaporation processes, whether transpired by vegetation or evaporated from open water bodies and other surfaces, and escapes from the catchment in gaseous form” (Gerten *et al*., 2005: 334–338).

“Green water is the water held in soil and available to plants. It is the largest fresh water resource but can only be used *in situ*, by plants” (Droogers *et al*., 2006. (ISRIC Green Water Credits Report).

“Green water is the productive use of rainfall in crop production, which, in general, has a lower opportunity cost compared to the blue water use”; “effective rainfall” (Chapagain *et al*., 2006: 455–468).

Green water is what supplies terrestrial ecosystems and rain-fed crops from the soil moisture zone, and it is green water that evaporates from plants and water surfaces into the atmosphere as water vapour” (UNESCO-WWAP, 2006: 122).

Basically the definitions (with rare exception, i.e. a quasi-definition by Chapagain *et al*., 2006) are hydrologically-based with a description of processes of the water cycle with a weak or strong relation to biomass and ecosystems. It has to be noted that the variation among definitions exists both within hydrological boundaries and in the relation to other natural systems.

2.2.2 Contextual categories

Evolution of the green water concept starts in the context of ‘green water, demographics and agriculture’ in 1993 historically (in present analysis in 1997). A new strong emphasis is put on the concept as appeared in the context of ‘green water and ecosystems’ in 2001 followed by the more specialized focus given to land use and impacts on water cycle in the context of ‘green water and land use changes’ in 2002 and later on. In 2002 the concept has been proposed for consideration in the context of transboundary water resources management as having potential to achieve more equitable allocation of shared water resources between riparian countries. Since 2004, scientific publications attempt frequently to treat the concept in a multi-contextual manner which may convince to conclude that complexity of relations between natural and human systems requires more integrated approaches to scientific inquiry and research. Finally in 2006 the concept of green water found its profound place in the context of climate change mitigation.

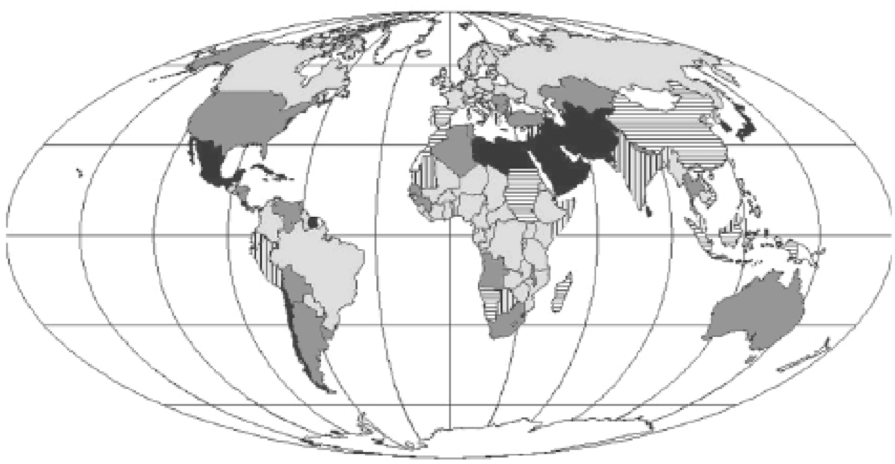
Context distribution across categories can be approximately estimated at a following ratio: ‘green water, demographics and agriculture’ – 30 %; ‘green water and ecosystems’ – 15 %; ‘green water and land use changes’ – 12 %; ‘green water and transboundary water resources management’ – 3 %; ‘green water and climate change’ – 3 %; and multicontextual category – 36 %.

2.2.2.1 Green water, demographics and agriculture

The concept of green water was born and received its most acclaim within the interrelationship of water availability for crop production to feed the growing human population. The concern on the water deficiency in many regions with dry climates and characterized with high demography was propelled in the 1990s. At this time scientific community had available the results of extensive assessments, such as global water resources assessment under auspices of the UN Commission on Sustainable Development (Shiklomanov, 1996 in Falkenmark, 1997); water requirements for self-sufficient food production (Falkenmark, 1993 in Falkenmark, 1997); and demographic estimates for global/national population based on UN statistics. The concept appears in the same line with the concepts of ‘population pressure’, ‘water stress’ and ‘food security’ (Falkenmark, 1997). Physically the importance of green water is highlighted as it is one of the major factors for food production along with agricultural factors (Falkenmark, 1997).

Predominant use of blue water for irrigation purpose to intensify agriculture produces water stress and causes water scarcity. If this externality seems to be obvious in many regions as assessments suggest (Falkenmark, 1997; 2007), this calls to pay greater attention to the potential of green water for more effective rain-fed agriculture. In this case the challenge comes for both science and management implementation as the cooperation across water, land and plant-related disciplines and management practices will be required.

It is important to discuss the blue water bias as argued by FAO (2000), Rockström (2003), Falkenmark (2007) because global water statistics rely on blue water withdrawals, overlook the green water flows and skew the estimates of human dependence on water especially if water crisis publicity is based on demographic and food security issues. The statement appears to be well-grounded because rain-fed agriculture depends on the blue water only partially when irrigation is required, the rest of water needs are covered by natural precipitation. In attempt to correct the actual hydrologic statistics in terms of water dependence for food production, Rockström *et al.* (2003: 148) mapped countries and showed the most critical water sources for food production (see below Figure 2.2.2.1.1).



Predominant source of water flow – green or blue – to produce cereals (grain) at country level. ☐: Countries with > 80% green-water dependence, i.e. > 80% of water used to produce cereal foods originates from rain-fed agriculture. ■: countries where 60–80% originates from green water. ■: countries with > 80% blue-water dependence, i.e. where > 80% of water withdrawals for cereal-food production originates from blue water. ▥: countries where 60−80% originates from blue water. ▤: countries with 40−60% green-water dependence. Countries where some component of source data was lacking are marked in white.
Source: Rockstroem et al., 2003.

Figure 2.2.2.1.1. Blue and green water sources for food production. Rockström *et al.*, 2003: 148

If looking at the human water need from this angle it appears that the share of human dependence from green water is much higher than from blue water. The reservation should be made that the assessment used the crop production only as a proxy. These assessment results should be kept in mind and accordingly accounted by development professionals, water, land, and food experts. Though other factors impacting on water scarcity (water mismanagement, climate change and changing pattern of droughts and dry spells, physical depletion of blue water resources) may not be however withdrawn from an account as well (Rockström, 2003). As it will be discussed in this paper, water needs are not peculiar to the humans, ecosystems have them too. Hence the fatal competition stemming from the food production expansion over water between natural and human systems should be prevented in the future (Rockström, 2003). There is a rhetoric question of how to make it if present scenarios draw the gloomy picture that future water needs to feed humanity on an acceptable nutritional level will be meeting severe conflicts of interest with environmental flow requirements" (Falkenmark and Lannerstad, 2004: 22; Falkenmark, 2007) ?

When the discourse tries to cope with the complexity of human interventions and the behaviour of nature, more relationships become visible to foresee implications. In fact, rain-fed agriculture occupies around 83 % of arable lands; its share in food supply totals approximately 70 % (FAO, 1995 in Rockström, 1998). In general, food means at most crops and crops require water for growth. Crops take up soil moisture and release through the transpiration process (transpired water is a part of green water). When soil moisture is insufficient for crop growth, the modern agriculture uses irrigation to cover water needs. At present irrigation accounts for about 70 % of blue water withdrawals on the global scale (Rockström, 2003). By integrating knowledge one understands transpiration is both the hydrological process and biological function of plants. The implication of expanding agriculture is assumed in both increase in food production and evapotranspiration (Rockström, 1998). This means that more food will benefit more the society, but more water vapour will result in change of water cycle behaviour with hardly predictable patterns. The issues of scales and variations for further research become a priority.

It should be noted, the use of the green water concept in the context of water-agriculture nexus is often regionally specific (e.g. Rockström, 1998, 2003; Falkenmark, 1997; Mutabazi *et al*., 2005). The bulk of research has a tight link with the African continent and particularly countries of Sub-Saharan Africa (SSA) due to the huge gap between relatively low crop yields and large water losses, i.e., the general vulnerability of the region to secure adequate food supplies for population under high hydro-climatic deficiencies. The data states that most of food producers over there are small holder farmers who compose around 60 % of entire population (Rockström, 2003). Despite the water deficiency may appear to be the biggest limiting factor for crop production in this region, research instead show that the soil fertility factor is much more important for yield increase than water availability (Lundgren, 1998 in Rockström, 1998).

As a consequence several of the articles dealing with green water, demographics and agriculture argues that, the effort should be made to increase both soil and water productivity (Rockström, 2003; Cai and Rosegrant, 2005). Unconditionally, climate factors play a great role in planning and management of agriculture in dry areas like Sub-Saharan Africa. But many existing land cultivation and water management techniques should be practiced and reintroduced (if lost) on the farm level to raise crop production despite the agrarian crisis seems to be settled down there permanently (Rockström, 2003). According to Rockström (2003), water productivity can be improved if blue and green water is integrated in policies and management (including the institutional level); if water harvesting systems (surface and sub-surface), supplemental and drip irrigation are used. Soil and water productivity can be increased in SSA countries if tillage practices have little disturbance on soil and prevent water losses (e.g. zero-tillage, minimum tillage), and soil productivity would be even higher if fertilizers are applied (Rockström, 2003). The management of soil moisture is also desirable for the root zone because it helps during the periods of seasonal water stress to prevent negative impact on growing crops (Kongo and Jewitt, 2005).

At the same time, the discourse surrounding water-food relationship has another perspective for consideration. Such perspective shifts the focus from the point of 'not-enough-water for food production due to multiple biophysical and socio-economic factors' to the point of the acute necessity to change consumption patterns that feature human systems for the sake to justify the human-right-to-food (Falkenmark and Lannerstad, 2004: 7-40). The more in-depth exploration of human systems behavior on the socio-economic level with regard to attitudes to water, water use, innovations and investments in water-related technologies is required. The human systems remain a part of the biosphere and since the human being has not yet taken a new advanced life form independent of biotic environment as, for instance, the noospheric theory predicts on the creation of a so-called noetic environment (V.Vernadsky, 1945 in Trubetskova, 2004); so the anthropocentric bias to appropriate water resources up to its final drop should be reduced to the level of natural capacities to sustain the life within the Earth's biosphere.

To sum up: The purpose to discuss the green water flows in context of green water, demographics and agriculture is to change the format of existing water policies and management and to seek sustainable solutions for the use of water and land in particular in water scarce areas. Remarkably, many authors of the analyzed scientific publications are also the propagators of applied research and policy initiatives who call for integration of management across water/land/ecosystems management from the local to global scale, to involve more science for testing the management techniques for socio-ecological viability.

Such a broad discourse with focus on population, water, land, food production could not develop consistently in isolation from ecological considerations. Further developments on green water has been continued in the contexts of green water and ecosystems and specifically green water and land use change to capture more knowledge on the inter-linkages between the water cycle and other natural and social phenomena.

2.2.2.2 Green water and ecosystems

In this context the concept of green water is used in relation to the interaction of water and ecosystems. From the ecology's perspective the concept of green water defines concretely the roles of different water flow types which those play for ecosystems and biodiversity. Terrestrial biomes (forests, grassland, wetlands, deserts, lakes, agriculture) depend on green water in the first case because green water determines its ecological status (Rockström and Gordon, 2001). The hydrologic balance between green water flow, blue water flow and water stored in soil profile play a key-role in the ecosystem for production of ecological services (Constanza *et al*, 1997 in Rockström, 1999: 376; Jewitt, 2002). Changes in landscapes due to changes in land use, like intensification of agriculture, forestry expansion of diversion of water bodies will lead to changes in water balance and thus the alteration of ecological status is inescapable. This also means that human-induced impacts on land and water change the capacity of ecosystems to produces goods and services on which human systems depend (Daly, 1997).

Most of publications of this category emphasize that ecosystems are complex, dynamic and variable systems. Ecosystems are also adaptive but vulnerable (Moberg and Galaz, 2005). They become vulnerable when their capacity to withstand changes (resilience) decreases (Moberg and Galaz, 2005). The same may be applied to the human systems. Their resilience is well noticeable when people have to withstand floods, droughts or tsunamis or their consequences in terms of lost harvests or damaged infrastructure. We have a lot of similarities in common including the dependence on freshwater.

Ecosystems boundaries may transform, as well as their structure and functions may change over space and time (Jewitt, 2002). It is well defined by now that ecosystem functions are of four kinds: provisional, supporting, regulating and cultural (The Millennium Ecosystem Assessment, 2005). These nuances of dynamic interaction between water cycle and ecosystems are vital for policy and management purposes within social systems as alteration in one component of natural systems will cause alteration in some other component(s).

According to Rockström and Gordon (2001) the human is a part of the complex natural system, but is not an independent resources expropriator. Rockström and Gordon (2001), Moberg and Galaz (2005) argue that it is not enough anymore to secure water for people only. Environment and ecosystems in particular which are also life-support systems for human beings have their water needs and have to be satisfied. The water cycle is also a natural trader of goods and services and those may be distinguished according to the processes within the water cycle (e.g. precipitation, infiltration, evapotranspiration) and interrelation with ecosystems.

Indeed many scholars claim that modern integrated water resources management fails to cope with complexity of the water cycle and still largely preoccupied by human needs and consumption (Rockström and Gordon, 2001; Jewitt, 2002). The elimination of the 'blue water' bias has been also stressed in the context of green water and ecosystems; and therefore the proposition for management is to integrate water (including the vivid distinction and accounting of different water flows), human activities and ecosystems. Despite a common approach on the necessity to eliminate the 'blue-water' bias, there are however practical deficiencies to introduce changes.

In the opinion of Rockström and Gordon (2001) the problem of accounting both green and blue water for the benefit of health of ecosystems and the humans lies in invisibility of green water for the naked human's eye. Basically the problem is twofold. First, it is still problematic for non-specialists to rethink the attitude to nature as the generous provider of free services and goods which are not valued in most cases (nutrient cycling, carbon sequestration, pollination, pest regulation, timber, crops, animals and fish, recreation opportunities, etc.). These goods and services are commonly produced by the enterprise of natural cycles fuelled by the sun energy and available across the globe and over long period of time (Jewitt, 2002). Secondly, it is also equivocal for the majority to make step further and recognize the complexity of water cycle and the cumulative dependence on water.

Luckily science goes up front. The attempt to quantify green water engaged in production of ecosystem services resulted in the estimates presented in Table 2.2.2.2.1.

Biome	**Estimates of Global Annual Green Water Flows (Gm3_y1)**				
	Min.	**Low**	**Mean**	**High**	**Max.**
Croplands	4 900	5 100	6 700	8 500	9 800
Forests and woodlands	32 400	35 300	40 000	45 000	46 700
Grasslands	9 300	10 700	15 100	19 500	21 700
Wetlands	1 050	1 100	1 400	1 650	1 700
Total	**47 650**	**52 200**	**63 200**	**74 650**	**78 900**

Table 2.2.2.2.1. Global annual green water flows for major biomes (Rockström and Gordon, 2001: 847)

The estimate represents the calculation of actual evapotranspiration flow across major biomes. The actual evapotranspiration is conditioned by climate factors and genetic and physiological profile of biomass in the biome (the method of calculation is explained in Rockström and Gordon, 2001: 845-847). It is seen that there is quite a big range between the total minimum of 47650 Gm3 yr-1 and the total maximum of 79900 Gm3 yr-1, nevertheless it is attributed to variations in data which accounts many factors influencing the behavior of natural and human systems to be proxied in indicators.

Jansson and Nohrstedt (2001) conducted the valuation of freshwater flows within the Stockholm County in conjunction with the potential of local ecosystems to assimilate CO2 emissions. To see the dependence patterns between natural and human systems, they separated water flows into green water (appropriated by ecosystems at most) and blue water (appropriated by the humans through withdrawal of water from surface and underground water sources). It is indicative that the research was applied to the area classified as urban which eventually has the trend of growing population and urban sprawl, and hence the potential to increase the anthropogenic load on environment.

The results concluded that the Stockholm County ecosystems depend primarily on green water and at much higher proportion than population depends on blue water: "The forests, wetlands, lakes and agricultural ecosystems of Stockholm County depend directly on a flow of green water that is about nine times the direct human blue-water appropriation (Jansson and Nohrstedt, 2001: 366). This knowledge has a double side value. First, it can be used for water resources planning and management in the County. Secondly, it becomes immediately trans-disciplinary as required for urban planning and management at large. Alteration of landscapes driven by socio-economic demands will impact on the water cycle and the ecosystems, their capacity and finally the volume of ecosystems services that make the contribution to the welfare of people living in the county (Jansson and Nohrstedt, 2001).

To sum up: Multiple issues from qualitative and quantitative points of view are addressed by these scholars to push for a change in water policies. Noticeably, within this context there is a slight interdisciplinary variation depending on the goals of research. Ecological economics' proponents consider water together with ecosystem services. The claim is that people's attitude towards ecosystems services is so indifferent because any price signals do not penetrate their minds. Valuation of ecosystems services would be a move in the right direction so that the population could recognize the value of what nature provides for free on a routine basis (Daily, 1997). As water resources policies do still rarely address the ecosystems issue as important, the scientific community appears to be the generator of findings that may push policy-makers to change rigid policies and turn human water planning to a more responsible one.

2.2.2.3 Green water and land use changes

The understanding that the relationship between water and land in the process of land use is complex as it is seen in terms of reciprocal influence brought to the formation of a specialized context of green water and land use changes. The changes in land use may vary from little to large across scale and from insignificant to total in terms of purpose. Jewitt (2002) distinguishes functional and structural complexities in land uses, which in anyway produce impact on water flows: on blue water (horizontal water movement), on green water (vertical water movement), and the water quality. Changes in land use cause changes in patterns of water cycle work and have long-term implications for ecosystems and climate (Jewitt, 2002; Savenije, 1995).

It has been defined that there are terrestrial and aquatic ecosystems. But only recently they were hydrologically colorized in the following way: terrestrial ecosystems are green and blue water-related; aquatic ecosystems are blue water-related (Falkenmark, 2004). This categorization emphasizes the dependence of ecosystems on a particular type of water and also gives the sign to humans on how to plan the economic activities related to land use and development to address social demands. Any human intrusion into landscapes have produced and continue making disturbances for land, water and eco-systems, nevertheless the question is always of what scale these disturbances may overhaul the natural systems followed by irreversible implications for human systems.

In order to solve the food issue, for instance, (we speak in general and briefly without going deeply in MDG regarding poverty and hunger alleviation), the nations (most prone to the population growth) have to attempt different measures: to increase food production and/or import deficient amount of foodstuffs; and/or change water consumption patterns, and/or impose demographic control. Options related to domestic food production exist through modification of landscapes (agriculture expansion vs. natural biomes) or modernization of existing agriculture through increase of water and soil productivity. In both cases water resources will be affected as well as ecosystems will be altered and most likely in diminishing the availability of water. What makes the story interesting is that the concept of green water helps in understanding of the process of impact and alteration of landscapes, ecosystems and water resources when there will be an increase of the anthropogenic load on blue and green water flows. Expansion of agriculture may lead to the substantial changes in landscape, ecological succession, depletion of surface and groundwater, increase in evapotranspiration followed by plausible alteration of precipitation patterns, etc. (Falkenmark, 2004).

The concept of green water used in this context elucidates how the water flows' inventory changes over time if the land change occurs mainly due to human encroachment. The change in volumes of green-blue water flows is visible when agriculture expands (ex. implications of Green Revolution) and consumptive use increases (green water flow increases), but at the same time when deforestation takes place green water flow decreases (Gordon, 2004 in Falkenmark and Lannerstad, 2004; Gerten *et al*., 2005). Even the replacement of vegetation varying in depth of roots and water transpiration potential may change the balance in blue-green flows. Infrastructural development of blue water flows (dams, hydropower stations) impact on the water cycle by making green water flows more saturated as evaporation more intense. (See examples and references in Falkenmark and Lannerstad, 2004).

To sum up: The context of green water and land use seems to be tightly bound with both green water and ecosystems, and green water, demographics and agriculture. However the delineation of this context allows to highlight specific relationships that occur when central focus is on land use changes followed by implications for the water cycle. Knowledge on impacts and feedbacks in natural systems when social action intervenes gives more room for making and revision of management decisions on land development and hence better anticipating of adverse environmental consequences.

2.2.2.4 Green water and transboundary water resources management

A surprising application of the concept of green water is found in the scientific literature with regard to the issue of transboundary water resources cooperation and management. As it is well known, boundaries of natural water systems do not coincide with political borders of sovereign states. At present there are 263 transboundary river basins; territories of 145 nations are located within these basins (UNESCO-WWAP, 2003). Such a systems dichotomy forces the humans driven by water needs to cooperate and establish concords for equitable use of shared water resources. When cooperation among nations fails the conflict over resources causes or even exacerbates even more both social instability and environmental problems (the Euphrates, the Dan and the Jordan rivers, the Parana River, the Zambezi/Chobe River, etc.) (Gleick, 2006).

Riparian nations normally negotiate allocation of water in order to prevent conflicts. Allocation of shared water resources is made according to jointly set criteria and mostly applied to the surface water which is essentially blue water. Van der Zaag *et al.* (2002) challenge the water allocation criteria based on measurements of blue water and suggest the criteria and algorithms accounting for both, blue and green water. The estimates in proportional terms are made for the Orange River, the Incomati River and the Nile River, all located in Africa. The prevailing criterion is employed to meet the equity principle (to note here: which is a pure human-designed value and hence normative concept in fact) that "all blue and green water generated in the international river basin should be shared by the riparian countries in proportion to the population" (van der Zaag *et al.*, 2002: 23).

The value of green water in this mathematical exercise is assumed at "one unit of green water is equal to half a unit of blue water" (van der Zaag *et al.*, 2002: 23) but the value is variable upon agreement by riparian states. According to van der Zaag *et al.* (2002) the approach of accounting green and blue water for the shared water allocations helps to safeguard water needs of population living downstream and thus to ensure equitable use of shared water resources. The calculations for three river basins show a similar pattern for this statement.

To sum up: Certainly, the proposed methodology has strengths and weaknesses as pointed by its developers and it is simply an available tool for riparian nations to seek equitable water allocation scheme. However, it is important to note in the context of present discussion on green water that this method gives a new possibility to account for a so-called invisible share (green water flow) of the hydrologic cycle that previously remained unrevealed. It can be nevertheless questioned if this method makes sense in terms of facilitation of water problems resolution and relations between riparian states in the long run. This paper leaves this question outside the scope of the present research however assumes it to be discursive and contested as many other issues of the social domain.

2.2.2.5 Green water and climate change

The discussion on the connection of the hydrologic cycle with the climate can be met in any of above presented contexts as the physical relationship is obvious. Nevertheless one publication deserves a particular attention because the concept of green water plays a new role of a 'revealing reagent'. It appears in the context of climate change debate while assessing the feedbacks from curbing CO2 emissions. The recent research by IWMI explores 'hydrologic dimensions of climate change mitigation through afforestation and reforestation" if the Clean Development Mechanism (CDM) is launched (Zomer *et al*., 2006). CDM is one of the three instruments in particular for developing countries to pursue the targets set by the Kyoto Protocol related to GHG emission stabilization. Recognizing the importance of forests, for their substantial capacity to retain a lot of carbon it has been concluded by the IPCC Special report on Land-Use, Land-Use Change and Forestry (LULUCF) that carbon sequestration in terrestrial ecosystems can be expanded "through afforestation, reforestation and improved forest, cropland and range-land management activities" (Watson, 2000). Any of these activities under CDM-AR would imply land changes and as it has been discussed in section 2.2.3 lead to alteration of landscapes and eventually to alteration of the water cycle.

The IWMI report found that on the global scale there are 760 Mha of land that can be considered for afforestation/reforestation. The estimation was done according to the biophysical suitability criterion and UNFCCC requirements. The authors however argue that the actual available area for CDM-AR is much smaller if local aspects (economic, legal, infrastructural, etc.) are properly accounted (Zomer *et al*., 2006). When it comes to the water, under land use changes, the impact on the water cycle will occur in changes of blue and green water flows' dynamics. If the lands found to be suitable for CDM-AR are appropriated the consequence may be expected in a significant rise of vapour flow (green flows) and or decline in runoff of similar magnitude. Scenarios identify that dry and semi-dry areas as well as lands turned from grasslands and subsistence agriculture to forests are the most responsive to this relationship (Zomer *et al*., 2006).

This prediction requires further careful exploration in terms of increases in vapour flows (green water) which is already a concern in the climate change discourse as well as in terms of decreases in water run-off which may have negative implications for water users, both ecosystems and the human beings. The first remark is substantiated by IPCC report stating the latest changes of the Earth's climate system: "The average atmospheric water vapour content has increased since at least the 1980s over land and ocean as well as in the upper troposphere. The increase is broadly consistent with the extra water vapour that warmer air can hold" (IPCC, 2007: 7). If so; the increased evaporation may intensify the water cycle, followed by the change in precipitation patterns around the globe. The same IPCC Summary puts "The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour" IPCC, 2007: 8), however the difficulty remains to predict the precipitation distribution under accelerating climate change, and foresee the new speed of the hydrologic cycle in order to adapt to and possible mitigate implications of climate change coupled with the alteration of the water cycle.

One of the main arguments of the IWMI report developers is that the better captured reality of the natural world is site-specific (Zomer *et al*., 2006). In fact, local scale scenarios (two sites in Bolivia and two sites in Ecuador) show a big variation in results of climate change mitigation efforts. Results of impact on water resources from land use change depend largely on the local biogeophysical peculiarities and land practices.

Project Site	Ecological Zone	Elev (m)	Precip (mm/yr)	Temp (°C)	Pop	Project Type
Tunari NP, Bolivia	Sierra	2,800-5,100	900	7-18	22,000	Ecological Restoration
Chapare, Bolivia	Amazon	200-1,000	3,000	23-26	9,000	Small Farm Agroforestry
Guamote, Ecuador	Sierra	2,900-3,700	700	7-12	5,300	Community Plantations
Coastal Ecuador	Tropical Coastal	0-500	1,300	23-25	8,900	Mixed Species Agroforestry

Table 2.2.2.5.1. Socio-ecological specifications of selected sites (Zomer *et al*., 2006: 13)

CDM-AR Project	Project Area (ha)	CDM-AR Area (ha)	Precip (mm/yr)	Aridity Index (Mean AI)	Vapor Flow Increase (%)	Runoff Decrease (%)	SWC Decrease (%)
Tunari NP, Bolivia	32,142	9,873	900	0.8	7.1	27.7	7.3
Chapare, Bolivia	40,604	11,077	3,000	1.8	15.1	12.4	1.1
Guamote, Ecuador	15,104	13,327	700	0.6	4.7	54.0	32.0
Coastal Ecuador	41,878	26,564	1,300	0.9	23.4	47.4	13.4

Table 2.2.2.5.2. Results of modelling of impacts on water from the implementation of CDM-AR projects (Zomer *et al*., 2006: 26)

From reviewing tables 2.2.2.5.1 and 2.2.2.5.2: the most contestable benefits from CDM-AR in terms of hydrological impacts appear at the site of Guamote, Ecuador taking into consideration its Sierra-ecological zone and changes that pine plantations brought. Substantial decreases in run-off and soil water content are expected due to cash pine forestry having high potential to water consumption for growth (Zomer *et al.*, 2006). The other three projects show that the impacts on local water resources are not crucial nevertheless they take place and cannot be disregarded. This means that land use changes – hydrologic changes considerations should be included in the assessment before the climate change mitigation project is initiated.

To sum up: projections of hydrologic cycle alteration of the global scale due to massive land use change to combat global warming have to be improved due to lots of uncertainties implied in the functioning of the natural systems including human-made impacts on them. As far as the local scale is concerned, it is the most plausible scale to assess reciprocal interference between human and natural systems, when the framework includes the climate system, the water cycle, landscapes and ecosystems, land and water use, and to explore feedbacks of natural systems on human activities.

2.2.2.6 Multicontextual category

The above discussion on green water and climate change shows vividly that any of the contexts in which the concept of green water is present has no strict contextual boundaries. In fact, relational aspects among natural and socio-economic phenomena are tightly intervened. Eventually consideration of climate change mitigation issue is likely impossible from the consideration of feedbacks on the water cycle from land use changes. At the same time issue of land and water use is largely dependent on human demand and where the human demands are high and the natural resources (water, land, ecological services, etc.) are scarce, the socio-ecological conflicts may easily arise as human and ecosystems enter the fight for biological survival. Not surprisingly that 36 per cent of analyzed publications could be placed in the multicontextual category. The multi-context appears with ease especially when the discussion touches upon water policy and management because a multitude of aspects have to be immediately taken into consideration.

One of such publications is by Rockström *et al*. (2004: 1109) which represents the effort of the transdisciplinary team of scientists with backgrounds in natural sciences and management to develop "a watershed approach to upgrade rain-fed agriculture in water scarce regions through Water System Innovations: an integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions". The source appeals to the reader that the social problem of agrarian crisis in many African countries (with vulnerable dry and semi-dry climates) cannot be solved without changing approaches to water and land management, without recognition of new hydrological knowledge such as the distinct ecological functions of green and blue water flows vital for both ecosystems and human beings, without acknowledgement of social and technological factors particular to local cultures, wider participation of various stakeholders in decision making regarding natural resources and understanding of economic dependencies on the state of local livelihoods.

Considerations presented here show that the transdisciplinary approach in science and management might cope with the socio-ecological complexity and trade-offs as well as the more rigorous field research and the vigorous interaction of policy-makers, implementers and technical expertise providers would produce a change for balanced resources use. The next section – Part 2 – is entirely devoted to looking at how the concept of green water is placed on ground.

3 Part 2. Applying science into praxis

3.1 Practical water management initiatives/activities using the concept of green water

This section gives the summary of concept diffusion at the terrain of practical application, when the discourses settle down on the policy and management levels and are attempted to be operationalized for real actions. Table 3.1.1. presents the taxonomy of practical application of the green water concept.

Ultimately the practical use of the green water concept is mostly linked to 1) modelling of global water trends based on observation and estimation data; 2) hands-on field research with focus on various types of land use and its changes including e.g. rain-fed agriculture and activities on how to increase the productivity of water and land in order to produce more food particularly in the areas with high climate variability and prone to droughts; to alleviate poverty and improve local environment. Most of practical initiatives are research programs, development projects and policy forums supported by international and national development agencies.

Table 3.1.1. Taxonomy of practical application of the green water concept.

Objective	Modelling of global biophysical processes to assess trends in natural and social systems	Poverty alleviation and livelihood improvement	Ecosystem/watershed protection/restoration	Water Policy and Management improvement
Practical realm	Earth Studies Research and development. Climate Change Mitigation.	Rural and Urban Planning & Management. Rural water management (Rockström, 2003). Economic development. Rainwater Management (Mutabazi *et al*., 2005)	Rural and Urban Planning & Management. Ecohydrological landscape management (Rockström and Gordon, 2001; Rockström *et al*., 2004). Ecosystem management (Jewitt, 2002). Adaptive co-management (Moberg and Galaz, 2005). Valuation of Ecosystem Services in Urban Landscapes (Jansson and Nohrstedt, 2001).	Integrated Catchment Management (Falkenmark *et al*., 2004) "Philosophy of land/water integration in a catchment-based ecosystem approach" (Falkenmark, 2004)
Boundaries	Global / Regional / National / Local	Local / River basin	Local / Global (potential)	Local (catchment) / Global
Who?	Researchers, Engineers	Donors/National governments and authorities of various kinds / local stakeholders / communities and individuals	Local authorities/resources managers/local stakeholders /communities and individuals	Water experts, policy, law experts / Managers / Water users
How?	Calculation / modelling / simulation	Development and Research Programs, Partnerships, Green Water credits	Projects / Regulation mechanisms	Science-governance dialogue and consultation, Global network of catchments, Multi-stakeholder advocacy, Partnerships
Examples	Global green water for biomes (Rockström and Gordon, 2001). Global green water flows (LPJ model, Gerten *et al.*, 2005). Global water productivity (IMPACT-WATER model, Cai and Rosegrant, 2003). Global water savings (Chapagain *et al*., 2006). Water footprints of nations (Hoekstra and Chapagain, 2006). Impact of CDM-AR projects on the water cycle (Zomer *et al*., 2006).	The Catchment Management and Poverty project in the Luvuvhu catchment, South Africa (Hope et al., 2004), Economic sustainability of Rainwater Harvesting in the Makanya watershed in Pangani river basin (Tanzania), (Mutabazi et al., 2005).	The permit system in South Africa (internalization of river depletion from afforestation (Rockström and Gordon, 2001, Jewitt, 2002). The SSI Research Program (SSI site).	HELP project (Falkenmark *et al*, 2004, Falkenmark, 2004). The SSI Research Program (SSI site) (Kongo and Jewitt, 2005). IWMI-TATA project in the Narmada River (Kumar and Singh, 2005).

The geographic diffusion of the concept within research and management activities is mapped below (Figure 3.1.1.).

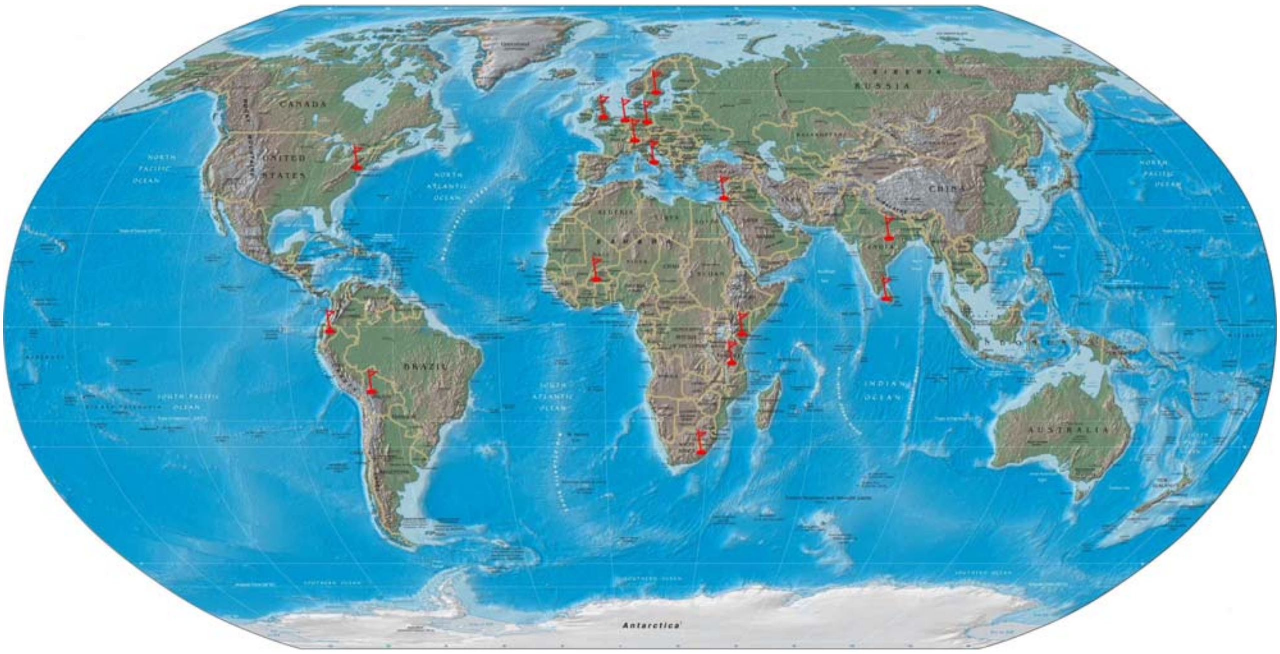


Figure 3.1.1. Mapping operationalization of the green water concept by scientific community and development agencies

The bulk of research (where the green water concept plays a significant role) is produced by European experts. The dissemination of the concept is best performed by the environmental research and international development agencies located in Europe, Sri Lanka, and Africa (i.e. FAO, The UNESCO-IHE Institute for Water Education, The International Water Management Institute, ISRIC – World Soil Information, the Potsdam-Institute for Climate Impact Research, The Stockholm International Water Institute, The Swedish Water House, UNESCO-WWAP, etc.). The efforts of integration of the concept into policies and management are made mostly in Sub-Saharan Africa and India (see also Table 3.1.1.).

3.1.1 Estimation and modelling of global water-related trends

During the analysis the concept of green water has been observed in latest projections of various global water-related trends at least three times. Those global estimates are presented below as claimed by their authors to be useful to see the more complete inventory of the Earth's water resources, to quantify the interactions between natural and human systems and to plan the future by accounting for human and ecological demands. One estimate is the recent quantification of global green water flows for biomes and crop-cover land made with the purpose to trace changes in hydrological cycle on the global level. Two other estimates (in which the green water is a component) shed a light on the human consumption behaviour regarding water use and consequently rising possibilities to control undesirable trend of water deficit, and in a more general sense the negative impact on environment.

1. The Lund-Potsdam-Jena transdisciplinary model based on bio-geographic, biochemical and hydrologic variables from the longitudinal data set (1961-1990) was applied to project available green water flows (Gerten *et al*., 2005). Estimates were for global transpiration at 41 370 km3 yr_1 (about 39 % of total precipitation over land); for total evapotranspiration at 63 906 km3 yr_1." Gerten et al. (2005: 336-337) conclude: "globally, simulated transpiration is reduced by 7.4 %, i.e. by 3 032 mmyr_1 (average 1961–1990) due to land cover change"; and "the total evapotranspiration is decreased by 1.4 %" (mostly due to the increase of arable land). The decreases in green flows are coupled with increases in blue water flows: "2.2 % increase in global runoff, though with considerable regional variation". Soil moisture is characterized by high variation and can be traced by using precipitation patterns" (Gerten *et al*., 2005: 336-337).

2. Water use accounting has different indicators but mostly based on data of water withdrawals for households and various economic sector applied by traditional economics. However it is argued that blue water withdrawals do not reflect actual water demands by population. More ecologically driven economic indicator for water consumption was needed to trace better the demands for fresh water. The water footprint concept was born in 2002 in parallel to the concept of ecological footprint which counts the land needed to sustain the human population. The purpose of the water footprint (WF) creation is to quantify the volume of water required to sustain the human population (i.e. total water consumption). The use of blue and green water is calculated separately. The water footprint concept has also a tight link to the concept of virtual water as basically "the flows of virtual water leaving and entering the country" are at the core of the water footprint estimate (Hoekstra and Chapagain, 2006: 2).

At present there are both national water footprints and the global water footprint. The water footprint of the nation consists of the internal and external water footprint and consequently can differentiate between the use of domestic water to produce goods and services for domestic consumption and the water use by other countries for production of goods and services which will be consumed by the country in question (Hoekstra and Chapagain, 2006: 2-3). The main determinants of the water footprint score are "volume of consumption; consumption patterns; climate; and agricultural practice" (Hoekstra and Chapagain, 2006: 7-9; see some of the national WF scores there too). To conclude for the whole globe, the aggregated findings are 7 450 Gm3/year for the global water footprint, and 1 240 m3/year for per capita water footprint (Hoekstra and Chapagain, 2006). The share of agriculture in total water use is the dominant in the WF score due to the full accounting of the water flows. Between green and blue water flows, the green flaws account for two thirds of the total quantity of water use. The water footprint makes visible that the agriculture is most vulnerable in terms of water dependence in the human economy.

3. Tracing water consumption patterns by humans through the water footprint is not the only recent effort to improve accounting of ecological economics. The concept of green water is central in calculation of national and global water savings and losses when agricultural commodities are traded. It gives the opportunity to transcend on the dynamics between green and blue water flows on the national/global scale as well as to be used in planning of measures to increase water use efficiency domestically. Recent estimate of global water savings from trade of agricultural commodities for the 1997-2001 period is 352 Gm3/year (Chapagain *et al*., 2006). The estimate is in physical units, not in economic units. It has been estimated that 16% of global water use is not consumed nationwide but export-oriented in the form of globalized trade of agricultural products (Chapagain *et al*., 2006). Optimization of water use in the context of water scarcity for human systems may be coupled between water productivity domestically with water savings by virtue of smart water import-export relations (the latter is discussed in the literature through the concept of virtual water which is the water requirement for production of the good or service); the concept in not discussed in the paper).

In conclusion: two questions may arise: How robust are these figures on the one hand and how practically useful are these estimates on the other one? In fact, authors as Gerten *et al*., (2005) ask for caution in treatment of these estimates due to uncertainties related to natural processes and data. From the practical side, little evidence suggests that these estimates have strong convincing power in the practitioners' circle and help generate consensus among water managers over a new type of water accounting in physical terms. Though they might be the reference points for further replication or transdisciplinary scientific research improving accounting methods and consequently results.

3.1.2 Initiatives by The International Water Management Institute

The International Water Management Institute advocates the change of water management approach to the one which would recognize the entire hydrological cycle and establishes tight connection between agriculture and water (green water) (IWMI, 2006). Rijsberman (2006) argues that people know "fairly simple technologies" which can effectively help to utilize water in an optimal manner in small-scale food production even without huge investments and large-scale development communications which disrupt environment (IWMI, 2006/2).

One of the ongoing IWMI projects takes place in the Limpopo Basin (South Africa/Mozambique) and is focused on the upgrade of current farming systems with target on smallholder farmers. The project emphasizes the importance of green and blue water as well as linkages between them for increasing of water and soil productivity. Expected implications are that more management focus on green-blue water use efficiency will result in higher yields followed by improvement of rural livelihoods in the basin. The project time is 2004-2008 and at the moment of writing this paper, no interim findings were available for public access on the IWMI site. (IWMI, 2006/3).

A study by Mutabazi *et al*., (2005) reports that research carried out in the Makanya watershed in Pangani river basin (Tanzania) assessing if rainwater harvesting for crop production (here maize and lablab) has economic benefits and improves rural livelihoods turned with positive results. The study concludes that the returns to labour and land were considerable (especially in the case of intercropping of maize and lablab) when invested in rainwater harvesting; but the actual yields remained low (Mutabazi *et al*., 2005: 11). Despite that the two-year-yield monitoring justifies the rainwater harvesting practices to be economically sustainable, the authors argue that it is not fully clear how "to maintain the integrity of eco-hydrology and other natural systems" (Mutabazi *et al*., 2005: 11). Their recommendation was to continue research on "eco-hydrogeology and human dynamics" on the level of the Makanya watershed and the entire Pangani river basin in order to improve knowledge vital for policy making and management (Mutabazi *et al*., 2005: 11).

IWMI-Tata Water Policy Program/Project: Blue and Green Water Use and Productivity in the Narmada Basin (India) made a cross-cutting assessment of green and blue water use in agronomic and economic terms. Departing from the facts of increasing blue water withdrawals due to changes in land use and agricultural cropping pattern, and as a consequence, decrease in water resources in the Narmada river basin, the research was undertaken to shift the water policies in connection to land and agri-policies in the transboundary context. Four Indian states share the Narmada River and compete over water resources respectively.

It is assumed that economic valuation of hydrological processes speeds up the policy-change process to effectively respond both human and ecological needs. In case of Normada river basin, human needs are not limited by small-scale agriculture to secure food. A big share of land in the river basin is designated for cash-crop production which appropriates the bulk of blue water (Kumar and Singh, 2005). It was observed that for the past 30 years, the volume of water for irrigation increased from 0.62 bln.m3 to 4.53 bln.m3 (Kumar and Singh, 2005).

It is known that crops have naturally different water requirements. Intensification of agriculture leads to more consumptive use of blue (through irrigation) and green water (through change of cropping systems: longer crop growing/high yield seed varieties) (Kumar and Singh, 2005). And this inevitably affects water resources in the basin. Thus, differentiation of water flows into blue and green is useful to see how the water productivity in agriculture can be enhanced in order to increase crop production as well as efficiency of water use, and essentially to raise economic benefits.

The assessment highlights the importance of green water that it plays in the crop economy (61.7 %) in overall; at the same time its productivity is less competitive to the productivity of blue water: Rs. 1.03/m3 vs. Rs. 2.5/m3 respectively (Kumar and Singh, 2005). Significant variation in water use rates across administrative regions of the river basin has been observed due to different soil-moisture budgets and evapotranspiration requirement which various crops have. The results in general called for continuation of research as spatial factors, crop-water interplay affect the estimates. Considering that green water dependence of agriculture is high in the basin it is advised to the river basin management to introduce measures of water conservation, i.e. rainwater harvesting and mulching as assumed effective to increase water availability for rain-fed crops in particular when dry spells threat the yields (Kumar and Singh, 2005).

3.1.3 The Applied Research Program: The Smallholder Systems Innovations

The Applied Research Program: The Smallholder Systems Innovations in Integrated Watershed Management (SSI) has been commenced in 2004 and is focused on rural livelihoods improvement, preservation of ecosystems providing the most important ecological services and agriculture upgrade to increase food production. Spatial boundaries of the program are the Pangani Basin in Tanzania and the Thukela Basin in South Africa. The program implementation approach is the "integrated agricultural watershed management" where agro-water-ecosystems make the whole for the research and development of policy/management recipes.

The SSI program recognizes the drawbacks of the 'alien' technologies brought by development projects in the 1960-1970s to the agriculture in the South and supports the participatory approach that based on the respect of indigenous knowledge and technologies. Nevertheless the SSI program looks for integration of local and foreign knowledge and experiences and application of hybrid solutions that would be capable of addressing the agricultural crisis (Rockström *et al*, 2004; SSIP, 2006).

To note, the rain-fed agriculture holds for 97 % of the river basins areas under SSI program and this is the driver to apply water management based on distinction of green and blue water flows for freshwater use by human and natural systems (Rockström *et al*, 2004: 1112). What is practically new in this program? With regard to study of biophysical and socio-economic interlinkages the scientific ambition is to use methods and tools by which more simplistic representation and deeper understanding of complexity can be achieved with more efficient implications for water and land management.

The concept of green water is accentuated in three ways:

1) technically, by estimating direct green water flows in terms of non-productive evaporation and productive transpiration (instead of an aggregated vapour flow) as this knowledge is assumed vital because green water flow is essential for biomass growth. Heat-pulse techniques and scintillometer methodology are used);

2) theoretically-experimentally, by assessing green water productivity at multiple scales especially when the upstream land use changes may lead to the hydrological and land use changes downstream;

3) linking research, policy, legislation and institutional arrangements, by giving place to green and blue water functions to be adequately addressed by land and water planners and managers (Rockström *et al.*, 2004: 1111-1117).

A case study has been recently completed in the Potshini catchment, a sub-catchment of the Thukela Basin (South Africa). The main research question of the project was to assess the impact from water use innovations for agricultural activities on catchment hydrology and ecology (Kongo and Jewitt, 2005). The water use innovations included rainwater harvesting techniques "for concentrating, storing and collecting surface runoff water in different mediums, for domestic or agricultural uses" (Kongo and Jewitt, 2005: 4).

The water harvesting was coupled with conservation tillage practices. Conservation tillage (zero- and reduced tillage) is considered in some way as a water harvesting technique because it contributes to the increase of infiltration (it prevents compaction and crust build-up) and the potential to retain water in the soil and thus minimize the loss of water (Kongo and Jewitt, 2005). Water use innovation diffusion has been achieved by implementing "farmer-to-farmer participatory learning" (Kongo and Jewitt, 2005).

The monitoring network to make hydrological and weather measurements (methods are described in Kongo and Jewitt, 2005: 5-11) was established to study impacts from agriculture (under change of land and water use practices) on hydrology in the catchment. Interestingly, the green water flows were distinct in soil moisture and their vapour equivalent; the latter was mainly assessed through total evaporation by applying one of the remote sensing methods, called the SEBAL algorithm (Kongo and Jewitt, 2005).

Even if taking into consideration all possible local geophysical variations the research experiment made in the Potshini catchment revealed that in comparison to conventional tillage techniques, conservation tillage practices reduce surface runoff volumes and influence the retention of soil moisture by increasing it at greater depth; and rates of total evaporation increase under active biomass growth (Kongo and Jewitt, 2005).

The scientific challenge as posed by researchers is to continue strengthening the quantification of water flows and capturing spatial variations in order to provide sound recommendations for the catchment water resource management and agriculture upgrade in specific geographic places.

3.1.4 The CAMP project in the Luvuvhu catchment, South Africa

The Catchment Management and Poverty project was implemented within the Forestry Research Program (DFID, UK) in the Luvuvhu catchment, South Africa. The aim was to assess the linkages between land use, rural livelihoods and ecological services coming from the water cycle precisely from green water. The project assimilated the ACRU Agro-hydrological modelling system to the soil water budget of Mutale river (study area at the catchment) and all the variables related to the local dry land and water use (Hope e*t al*., 2004, Jewitt *et al*., 2004). Tools included also the HYLUC hydrologic model and GIS software (Jewitt *et al*., 2004). The tools and methods applied proved to be effective to capture the impacts of land cover and use on the hydrological behaviour in the study area.

Considering the fact that rural communities are very dependent on natural resources in areas like South Africa (figures suggest: South Africa has around 50 % of rural population, 72 % of which are poor (May, 1999 in Hope et al., 2004) it was imperative to get better understanding from the livelihood analysis (based on household questionnaires) how the human and natural systems interact on the catchment level and how to make rural socio-economic activities (small-size farming, commercial agriculture, commercial irrigation and forestry) more viable and of better quality for local people but less environmentally destructive.

Scenarios run by the modelling system showed that the least effect on natural resource base (including the local water cycle) as well as better poverty reduction potential would be from ‘small-scale dry land production’ making the reservation that upstream/downstream socio-economic relations in the catchment would be mutually balanced which is the task of planning and management authorities to resolve these legal-economic issues (Hope *et al*., 2004). With regard to the balance of blue-green-water flows, it has been observed that both irrigated agriculture and forestry would lead to the increase in evaporation and decline in blue water (Jewitt *et al*., 2004).

The implications of this project may be useful for the rural planning and management agency as well as water resources management authority responsible for the Luvuvhu catchment. At the same time the question is open, would they be used? Another aspect relating to the development debate rises from the findings. If the study proves the environmental and social sustainability based on small-size farming systems, this means that economic development of catchment communities proceeds still along the pre-modern path.

3.1.5 UNESCO-WMO Project: HELP

The Project: Hydrology for Environment, Life and Policy is a co-initiative by UNESCO-WMO since 1998 to establish the global network of catchments which connect the water with social needs. The initiative embraces a wide range of discourses and activities surrounding hydrology and socio-economic aspects. Nordic water experts participate in the initiative discourse related to issues of water availability and human needs and argue that the global water discussion and the current water management paradigm is shallow and does not address fundamentals of the hydrologic cycle in the first place by omitting green water from consideration which has the primary importance for terrestrial ecosystems and people’s food production (Falkenmark *et al.*, 2004). Increasing socio-economic demands on water and thus competition between natural and social systems are the driving forces to change the approach to deal with water resources.

People have substantial hydrological knowledge (though gaps remain due to complexities and uncertainties of natural systems). At the same time this knowledge is usually diffused across disciplines and institutions which rarely focus on multiple phenomena holistically. Falkenmark *et al.* (2004) posit that only truly interdisciplinary approach within sciences and collaboration among diverse array of stakeholders (researchers, the public, politicians, water managers, other actors) can positively change the human management of water resources and landscapes if it is assumed for long run. To return to hydrology *per se*, the starting point is that both scientists and practitioners would recognize the necessity to establish commonly accepted boundaries like catchments for research and management of water resources followed by the incorporation of complexities related to functioning of human (society-economy) and natural (ecosystems) systems. It can be assumed that the concept of green water may appear a single element of the professional jargon, since it is succinctly stressing the peculiarities of the hydrologic cycle in relations to other natural phenomena and helping both water professionals and non-professionals to simplify the complex reality.

If the human concerns floating through the present water discourse created a so-called ‘security triangle’ composed of environmental, food and water securities (Falkenmark, 2004), then the feedback from those who act as specialists in these fields should not be by no means a procrastination with cooperation, fresh look at well-known problems of population and consumption growth, urbanization and global migration, resources depletion and environmental degradations, etc. and synthesizing solutions which may curb the problems and better to say their drivers.

This fresh look may come from the use of transdisciplinary approach to see intrinsic links between natural and human systems. Undoubtedly, the knowledge within the mono-discipline, like hydrology should be enhanced and research be advanced but both should be open for other disciplines to capture what make lead to new findings across disciplines. Scientific networking and communication in research and knowledge generation across disciplines will improve the capacity to build the dialogue with those who deal with practical management issues and get feedbacks on what should be researched extra and thus the gaps between science and practical world will be less but the understanding of salient issues be much better.

3.1.6 The Green-Blue Water Initiative

A new initiative with a clear-cut link between green and blue water, so-called “The Green-Blue Water Initiative”, has been introduced at the 4th World Water Forum in 2006. It is pioneered by a number of scientific and research and nature conservation institutions, including the Stockholm Environment Institute, the Stockholm International Water Institute, The International Water Management Institute, The International Food Policy Research Institute, The Association for Strengthening Agricultural Research in Eastern and Central Africa and The World Conservation Union.

It has the aim to stress the importance of green water fluxes of the hydrological cycle for better function of integrated water resources management which will integrate land and rainwater resources management. The popular scheme of water cycle within the green-blue water paradigm is presented on Figure 3.1.6.1, where one can notice a significant difference between shares of water types: 65% (green) vs. 35 % (blue). Technically speaking, the proposal is to optimize the use of rain-fed soil moisture by decreasing unproductive evaporation. It is believed by the initiators that it is imperative if local rural policies have the targets to improve livelihoods and ensure ecosystem sustainability. Besides, such approach will contribute in the process of poverty reduction by allowing farmers to produce more (SWH, 2006/1).

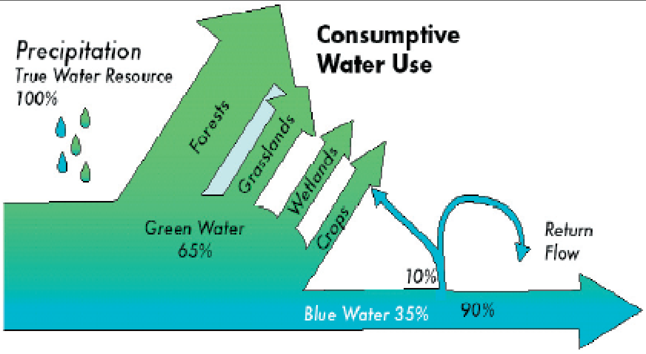


Figure 3.1.6.1 Green-Blue Water Resources (SWH, 2006/2)

As declared by The Stockholm International Water Institute (SIWI) and The Stockholm Environment Institute (SEI) at World Water Week in Stockholm in 2006, the Initiative will be piloted at some river basins together with local counterparts to study “governance approaches” for integration of green and blue water management and “local level mechanisms needed to benefit more from the green water potential to alleviate poverty” (Falkenmark and Rockström, 2006: 2).

Still, it is written on paper little on how the initiative will be implemented on site and in the end will help to alleviate poverty of local small-size farmers. As the consequence more conceptualization of the concrete measures is required to analyze the socio-economic potential of the proposed approach.

3.1.7 Green Water Credits

Green Water Credits is a new concept developed by the members of several research and development agencies and put into a 'proof-of-concept project' to assess its feasibility (Grieg-Gran *et al*., 2006; Droogers *et al*., 2006). Green Water Credits is an economic mechanism to reward rural land users "for specified land and soil management practices which affect the provision of watershed services" (Grieg-Gran *et al*., 2006: ii). The conceptual model of Green Water Credits scheme is presented in Figure 3.1.7.1.

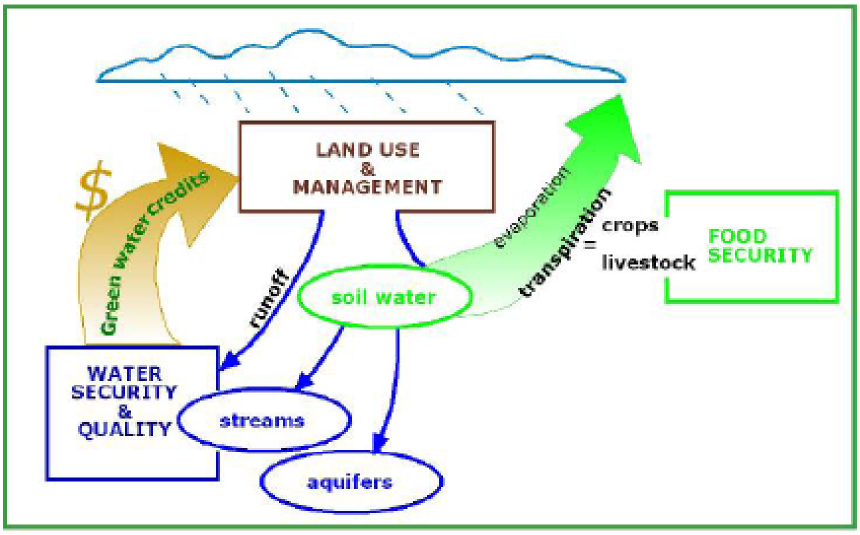


Figure 3.1.7.1. Conceptual model of Green Water Credits scheme (Droogers *et al*., 2006: 1)

It is argued that the Green Water Credits mechanism may create better opportunities to raise incomes of rural people as well as help them to strengthen the natural capital by improving soil quality, water availability, agricultural practices and rural livelihoods in general (Grieg-Gran *et al*., 2006). It is deemed that Green Water Credits may have the potential to contribute in achieving of two of the "Millennium Development Goals: Goal 1, to eradicate extreme poverty and hunger, and Goal 7, to ensure environmental stability" (Grieg-Gran *et al*., 2006: 1).

The mechanism is economically determined by the opportunity cost of environmentally better-off practice and the buyer's willingness-to-pay for this management practice. The benefit-cost analysis for catchment's upstream land-water managers and downstream water users predetermines the economic feasibility of this payment-for-environmental-services scheme. The social perceptions and clear peoples' understanding of the proposed mechanism play the substantial role for implementation. Contractual relations with cash or in-kind payments are assumed to be most plausible under local conditions. Violations by upstream land managers can be ruled by sanctions. (para. from Grieg-Gran *et al*., 2006).

When it comes to water, the environmental and economic focus of GWC is on green water, the water which is available for plant production, so that land use practices utilize green water more effectively in the first run and make available more blue water for downstream part of the catchment. Hence the management practices should primarily target land (soil), water and links between them upstream with positive implications for downstream water users. (para. from Grieg-Gran *et al.*, 2006).

The area of mechanism introduction is the river basins in Africa prone to droughts and floods and characterized by low degree of economic development. The proof-of-concept project was carried out in four river basins to identify if this PES scheme may be viable and feasible taken into account social, institutional, economic and environmental aspects of development. The basins under assessment were the Great Ruaha and Ruvu in Tanzania, the Tana in Kenya, the Volta in Ghana and Burkina Faso. The assessment found that the Tana river basin has the highest potential for GWC according to the assessment criteria: biophysical parameters for climate, soils, water, ecosystems, availability of upstream/downstream participants of the PES scheme in terms of understanding of GWC mechanism, financial and institutional capacity to maintain it. (Droogers *et al*., 2006).

To sum up: Several comments arise along the presentation of this PES scheme developed and assessed for feasibility by environmental economists, land and water experts. Apparently concepts within this scheme are defined very broadly depending on local conditions. The ambiguity starts however from the concept of green water. Two available reports use two different definitions of the green water (see Droogers *et al*., 2006:1 and Grieg-Gran *et al*., 2006:1). It also appears that water resources *per se* are considered a part of land use and management domain (as the conceptual model suggests: Figure 3.1.7.1) and this factor should luckily coincide with the legal and institutional set-up governing land and water in a particular river basin. The assessment results presented in Droogers *et al.*, 2006 give only preliminary indication that the PES might work in a given river basin. Practical significance of this initiative cannot be assessed now because neither this PES scheme works nor any impact on water quantity and quality is produced within the scheme(s) yet. Therefore there is a need to lunch a pilot project with clearly identified and institutionalized buyers and sellers of environmental services as well as preliminary but legible goals to improve the water situation in the river basin.

4 Part 3. Discussion

The paper's focus is the concept of green water. The definition by UNESCO-WWAP (2006: 122) - "Green water is what supplies terrestrial ecosystems and rain-fed crops from the soil moisture zone, and it is green water that evaporates from plants and water surfaces into the atmosphere as water vapour" – appears to be the most latest one and accepted by a great number of scientific and development experts working if not in the transdisciplinary field then in the interdisciplinary one. This definition reflects the hydrological essence of the natural phenomenon as well as shows links to other natural systems of the biosphere: altered landscapes (natural and man-made) and terrestrial ecosystems.

The findings of the literature analysis were reported in Part 1 to show and discuss the peculiarities of the present discourse on the concept of green water, and the summary of practical application of the concept was presented in Part 2. The Discussion Part has the aim to elucidate on the transdisciplinarity of the research involving the concept of green water, to track the relationship of the green water discourse to the sustainability/sustainable development paradigm as well as to discuss on how the concept of green water can contribute to water resources management and sustainability of water use.

4.1 Transdisciplinarity of research involving the concept of green water

Gibbons *et al.* (1994 in Bryman and Bell, 2003: 5) proposed two modes for the process of knowledge production which can be presently observed. The first mode is employed by academic circles following academic agenda and cultivating knowledge based on the existing one and mostly within the same discipline. This knowledge can be both theoretical and applied. However the great demand on it is expected from the same academic environment. The second mode of knowledge production may operate beyond a single discipline and thus becomes the transdisciplinary. This type of knowledge can be produced by academia and practitioners and has multiple layers of dissemination and application. (Gibbons *et al.,* 1994 in Bryman and Bell, 2003: 5). It is expected that by having wider opportunity for dissemination and application the knowledge is likely has bigger potential for getting benefits at practical application, in our case the potential to contribute to sustainable water management.

In the present discourse on knowledge generation if the knowledge is not unidisciplinary, the discussion is frequently focused on three different approaches: multidisciplinary, interdisciplinary and transdisciplinary. Nicolescu (1999) differentiates them in the following way. Multidisciplinary and interdisciplinary approaches "overflow disciplinary boundaries while their goals remain limited to the framework of disciplinary research" (Nicolescu, 1999: 2). However, the critical difference between two lies in the feature of inter-disciplinarity to import and apply methods from one discipline to another at one or the other degree: "the degree of application", "the epistemological degree" and "a degree of the generation of new disciplines" (Nicolescu, 1999:2).

The brief characteristics of the transdisciplinarity is that it “is at once between the disciplines, across the different disciplines, and beyond all discipline; and its goal is the understanding of the present world, of which one of the imperatives is the unity of knowledge. The three pillars of transdisciplinarity that originally stem from quantum physics – i.e. multiple levels of reality; the logic of the included middle; and complexity – determine the methodology of transdisciplinary research” (Nicolescu, 1999: 2-3). To say otherwise there is a need to dismiss from a binary logic approach of ‘either –or’ in research and management sphere and accept the fact that processes are going within and among several dimensions. All in all, the transdisciplinary approach is frequently suggested nowadays as the most promising to establish better communication among knowledge producers and users; to facilitate the creation of a shared vision which is critical for real implementation of sustainable actions.

The content analysis of discourse presented in Part 1 allows concluding that the concept of green water is transdisciplinary in its essence and essentially serves to interface the hydrology with other natural and social sciences. The concept of green water appeared and most frequently utilized in a transdisciplinary manner by connecting pure hydrology with land-related disciplines studying interrelations between water cycle and vegetation growth, landscapes, ecosystems and land-based human activities. The concept is not used for the goals of a single discipline; it serves as a basic term (label) with specific meaning to simplify communication between a multitude of actors from various disciplines who address complex, influenced by many factors, problems of the real world, like water scarcity, degradation of ecosystems, land use, hunger, poverty, climate change.

Appendix 1 contains the information on disciplines (represented by respective authors of publications) participating in the advancement of the knowledge on green water. The analysis of the literature shows that the concept of green water has been picked up and promoted by experts from a variety of disciplines like hydrology, ecology, soil science, geophysics, geosciences, law, economics; interdisciplines like agriculture, ecological economics, eco-hydrology, crop production science, agro-forestry, environmental engineering, bioresources engineering, environmental hydrology; and transdisciplines, i.e. environmental science, development studies, natural resources management, urban and rural planning, etc.

There is a portion of criticism though. Despite the concept has already a high degree of diffusion across disciplines in general, the natural sciences’ disciplines dominate the research domain. Especially this disciplinary disparity is seen when discourse is on problems of population growth, poverty, food production and security, water security. Disciplines such as policy science, sociology, anthropology, traditional economics are not involved in the discourse. Such under-representation of social sciences in the discourse diminishes the fertilizations of the knowledge in the nexus of water and humans in which we should be side with the major interest in. Furthermore, it hampers translation of knowledge in the terrain where the focus on people who nevertheless depend on and make decisions on water.

Green water context analysis and categorization revealed that one of the major purposes of scientific discourses and applied research involving the concept of green water is to change policies governing water resources, to integrate management across hydrologically and landscape coherent management units, to soften competition between humans and nature over ecological goods and services. But those discourses are mainly generated by natural scientists trying to transgress the concept into social sciences and water politics. The scientific green water discourse has a shortage of contributions of peer views on the issues of water regime changes, development of relevant institutions governing water resources, other natural resources and human economic activities in relation to water; landscape planning and development by involving wide range of interest groups; regulation issues (water use and property rights), etc.

Moreover, the dialogue among scientists and researches should be extended to that with the water policy-makers, managers, and the general public if the transdisciplinary collaboration has to be achieved. Only this dialogue would lead to the desired water policy changes. New concepts especially those which are clear to establish common language between scientists and non-scientists are of high importance. Part 2 provided a spectre of recent initiatives aiming to broaden this dialogue, to conquer the policy arena with the new concepts including the concept of green water and to challenge the water governance for changes. It is hardly likely that goals of sustainable development can be reached without changes in the water governance.

4.2 Green water concept and sustainability/sustainable development paradigm

As the analysis shows the concept of green water differs in its definition. It can be explained by intention of researchers to meet scientific objective within their original disciplines or going beyond them in attempt to achieve the goals of interdisciplinarity or transdisciplinarity as well as ambition to link discourse involving the concept of green water to sustainable development paradigm. The concept of green water has some similarity in this sense with not least contested concept of sustainability which is "open for appropriation by vested interests in society, and indeed by various disciplines" (Barnet *et al.*, 2003: 54). This corresponds also to the view on the concept of sustainable development: "The concept is sufficiently rich and protean to refract the full diversity of human interests, values and aspirations" (Raskin *et al.*, 1998: 2).

The diversity of competing definitions for both sustainability and sustainable development may be easily captured from two instances. Raskin *et al.* (1998: 2) argue that "the sustainability of socio-ecological systems is a dynamic process of development", in its turn, sustainable development aims at "the integrity of combined human and natural systems as they interact and condition one another over time". And for example, Dover's definition of sustainability is "the ability of a natural, human, or mixed system to withstand or adapt to, over an indefinite time scale, endogenous or exogenous changes" (Dovers, 1997: 304).

Despite there is a variety of definitions, most of them for both concepts remain relatively clear in literature but still vague for practical life. This is because of high degree of complexity of and uncertainties within the processes taken place in the natural and human systems. Nevertheless these facts do not hide the main practical purpose of the original discourse and the famous report "Our Common Future" which was to accentuate for the global mankind the way to go in the long run and to create the framework of sustainable development in which economy and environment had to be synergically reconciled (Al-Jayousi, 2003). Since Our Common Future (WCED, 1987) academic and popular publications tend to represent sustainable development ongoing in three interconnected dimensions: environmental, social and economic.

Based on the assumptions on sustainability and sustainable development discussed by Raskin *et al.* (1998), argued and presented by Huber-Lee and Kemp-Benedict (2003: 33) I graphically express the interactive state of three dimensions (environment, society and economy) including linkages triggering the impacts among dimension on each other (Figure 4.2.1.). At the same time it is vital to admit that all the activities on the Earth are still subject to the physical activity of the Sun and its energy as a primary driving force of bio-physical life on the Earth. In case of water: "Water circulates in the solar-driven cycle from ocean to land using the atmosphere as transport medium" (Falkenmark and Rockström, 2004: 20).

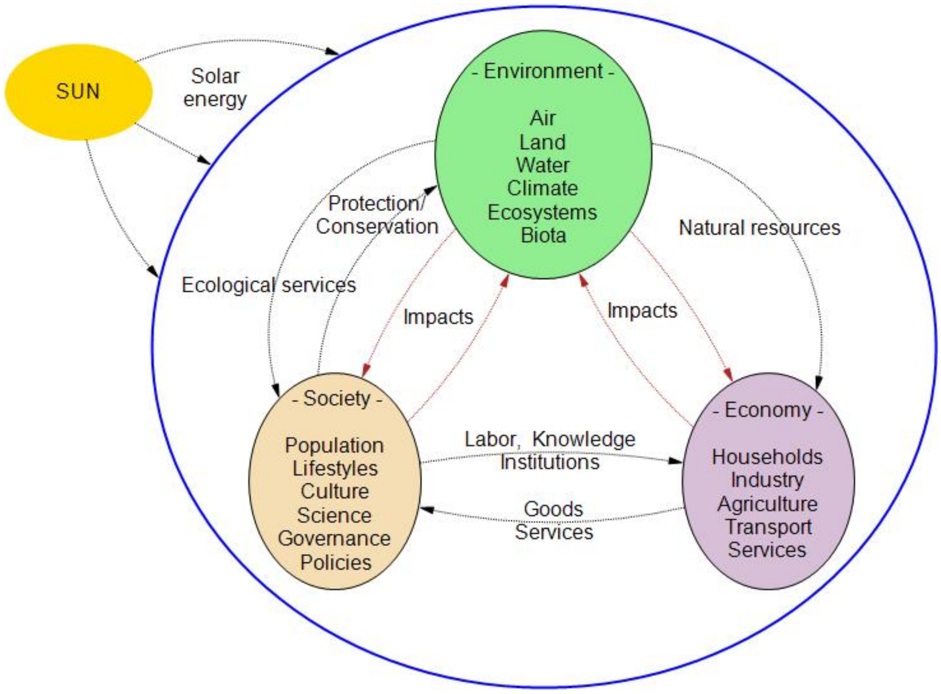


Figure 4.2.1. Conceptual model of interaction of sustainability's dimensions.

To return to the content of literature analyzed I cannot confirm that all publications have the explicit link to the discourse of sustainability/SD. Though the best examples of explicit connection to sustainability in a publication are available in Falkenmark (1997); Lundqvist and Steen (1999) in the context of green water, demographics and agriculture, Jewitt (2002) in the context of green water, ecosystems and land use change, Hope *et al.* (2004), in the context of green water and land use change, in the multicontextual 2006 UNESCO-WWAP report, articles by Falkenmark and Lannerstad (2004), Falkenmark *et al*. (2004), Rockström *et al*. (2004). Some publications stress environmental sustainability more than other dimensions (e.g. 2000 FAO report; articles by Falkenmark (2004; 2007); the book by Falkenmark and Rockström (2004). Nevertheless, it has to be admitted that all publications are featured by future-oriented objectives for human development.

Ultimately it can be argued that the concept of green water belongs to the sustainable development/sustainability paradigm. The back-up of such statement stems from the analysis across categories which were developed based on the results of the screening of discussed ‘real-world’ problems and topics of scientific debate derived from original publications. The concept helps to depict holistically and explore the interdependencies within the water cycle as well as in connection to natural and human systems in general; continuously study the links, impacts and feedbacks among components of both systems not from the pure hydrological standpoint but finally from the transdisciplinary stance created by the collaboration of natural and social sciences.

The schematic modelling of green water contexts may replicate the similar model of the conceptual understanding and development of sustainability paradigm and its dimensions (D.)(Figure 4.2.2.).

Green Water + **Blue Water** ↔ Climate, Land and Ecosystems (environmental D.)

↙↗ ↖↘

Population/demographics — Water Use
Policies ↔ Land Use
Management (social D.) — Agriculture (economic D.)

Figure 4.2.2. Interrelations of contextual categories within the green water discourse.

The weakest point of this model appears that ‘water governance’ and ‘institutions’ elements cannot be specifically included because there is no substantial focus on them in the green-water related discourse. Presence of ‘policies and management’ elements are determined due to the use of the green water concept in the multicontextual fashion. Falkenmark *et al*. argue: “‘Management’ and ‘policy’ refer increasingly more to society and to relations between people rather than to water as such. Water management, water scarcity and water pollution, of course, do have hydrological, technical and physical dimensions, but the main and probably most intricate challenges lie in society and on its members, institutions and legal systems” (Falkenmark *et al*., (2004: 304). From the pool of scientific articles assessed the only article by Falkenmark *et al*. (2004) has the voice by the representative of international water law and no other voices by policy scientists to speak about changes of governance and institutions which manage water resources.

Policy science itself is a complex terrain. A comprehensive study of policy science approaches formulated five main elements of contemporary governance pointing that they are characterized by their ‘multi’-nature: 1) levels and scales of governance (multi-level); 2) actors in the policy network (multi-actor); problem perception and policy objectives (multi-faceted); strategy and instruments (multi-instrument); responsibilities and resources for implementation (multi-resource-based) (Bressers *et al*., in Bressers and Kuks, 2004: 27-28). Why has not then the concept of green water been appropriated by policy science which has such a diverse pool of research niches? I argue it is definitely more focused on humans than on humans and nature because by and large water for the society is the object of competition and the policies are formulated and management is established to satisfy interests of various societal interest groups that is why issues such as property rights, water use, structures and functions of institutions have primary significance for policy science, and "hydrological, technical and physical dimensions" remain the second point of departure for social scientists.

Sustainability/sustainable development paradigm challenges the anthropocentric approaches of knowledge inquiry and appeal to any member of scientific community, human institutions and the general public to join the process of knowledge creation and human problems solution. Transdisciplinarity argued by many scholars is the tool for sustainability but transdisciplinary research takes time to produce outcomes (Thompson Klein *et al*., 2001). Despite the green water-related discourse is still limited with views of social scientists; this section concludes with the standpoint that the concept of green water has the strength to contribute within the sustainability/sustainable development paradigm itself and to bring conceptual changes into water policy and management domain. Here is the bridge to the question "how can the concept of green water contribute to water resources management?"

4.3 How can the concept of green water contribute to water resources management?

At present the water management is called more frequently sustainable water management in the literature though a myriad of other concepts representing holistic frameworks for water management (the integrated water resources management, the river-basin management, the integrated catchment management, etc) are available on paper and for water policy making on global, regional, national, and local levels as well. The matter is that unfortunately "their effective incorporation and implementation have proved to be extremely difficult, irrespective of the country concerned" (Figueres *et al.*, 2003: 3). One of the problems seems to lie in what can be smooth in theory that can be hard in praxis.

To briefly recall the history, the seeds of sustainable water management (SWM) were sprouted at the UN Water Conference in Mar del Plata (1997) and the debate on SWM is still on-going. The concept of sustainable water management can be literally defined following the Brundland's definition of sustainable development (1987) as management of water resources in a sustainable manner by coping with needs of present generations in freshwater but without undermining water resources for future generations. The broadness of this definition calls again for holistic approach where environmental, social, cultural, economic, institutional, scientific and technological aspects will be taken into account. General principles with respect to freshwater management have been formulated by the international community at the International Conference on Water and the Environment in Dublin in 1992 (UNCED, 1992).

SWM is based on the multifaceted aspects which are intervened among each other. Principle 1 stresses that freshwater is indispensable for human and environment on the whole. Principle 2 emphasizes collaboration of actors that deal with water for more optimal and equitable use of water resources. Principle 3 touches upon the gender-related issues as both freshwater and women are vulnerable from adverse impacts of human technocracy. Principle 4 is focused on economics. Water becomes a matter of economic transactions undertaken by human beings depending on the local social and economic conditions. Among four principles, the fourth one is most contested as some debaters claim that if economic value means full-cost pricing, the social value of water is undermined as the human right for water is endangered (Faruqui, 2003 in Figueres *et al.*, 2003). If these principles are underlying basics of the sustainable water management it means that understanding of the SWM essence and its further application is geographically contextual, and depends on what water means for different cultures/nations. Some authors stress multiple dimensionality of water (spiritual, social, economic), as it may be perceived by various nations especially of non-western culture (Akiwumi, 2003; Stalgren, 2006).

The concept of green water appears a very appealing concept from the mouth of water experts working in science and the development field. To return to why it has been coined it is obvious that the concept of green water contributes to the effort to make water policy and management more socio-ecologically oriented from purely technically-optimal. This discussion should be placed on a more practical ground and turned directly into the realm of management of water resources. Consequently I ask another question "How management should treat green water flows in order to achieve sustainability of water use?" Despite it is 'invisible', it can be however taken into management consideration. The matter is How?

The criticism on the concept of green water published in 2006 by one of its proponent, Graham Jewitt is relevant to the present discussion. In his article he defines the limitations that the concept has especially when it is transferred to a site-specific setting, namely into water resources management and planning and where it turned to be the 'green-water' approach (Jewitt, 2006). The vagueness of the concept when it comes to its application emerges from the continuous debate on the water management paradigm itself, what the type and gist of the management and what is actually managed. If for instance the integrated water resources management is accepted for practice, the management boundaries (institutional and physical (hydrological) and the level of integration have to be explicitly defined. As mentioned this remains a bottleneck for many nations (Figueres *et al.*, 2003).

The following example depicts that creation and maintenance of management system implies many factors to be under consideration and interaction in local contexts. The agricultural research carried out in the Sub-Saharan Africa for the purpose of increasing crop production in light of population pressure made obvious that there is a crucial need for integrated soil and water management (Rockström, 1998; Falkenmark and Rockström, 2006). Besides, findings of many studies showed that indigenous knowledge on rain water harvesting and conservation was indispensable to local agriculture and further to its viability over centuries (Reij *et al.*, 1996 in Rockström, 1998). But that knowledge and techniques were not appropriately acknowledged when conventional agriculture was displaced by the modern one and water and land policies became 'structurally adjusted' and separated in many cases. That caused the reduction in local livelihoods, increase in poverty and environmental degradation. Social and natural systems in this region are tightly interconnected, therefore it is necessary to seek integrity in management but still to distinguish its levels (different hydrological scales (downstream/upstream, catchment/basin); inter-impacts between land, water and ecosystems; social scales (institutional scales, gender peculiarities, others).

If the water management is truly integrated and sustainable the water resources should be co-managed with landscapes, terrestrial and aquatic ecosystems. The human understanding of the water cycle seems to remain inadequate if the human continues to struggle with water use optimization. When the integration goes beyond the water cycle, the management gets even more complex as more links involved in interaction between natural cycles and ecosystems, and human socio-economic activities. Despite the concept of green water is scientifically explanatory it is still ambiguous for water practitioners. Being a part of the hydrologic cycle, the green water flows have more significance and practical utility not in a direct extractive way but in an indirect way, for support of ecosystems and human food production which is in management terms a terrain of conventional land practitioners.

To come back to Jewitt (2006), he stresses the following main limitations of the green-water concept:

- in hydrological terms, green water is still difficult to measure as well as capture the dynamics between green and blue water on the catchment level (not mentioning more complex level) in the temporal and spatial contexts;
- in policy terms, the green water is not a part of the language and normative meanings of water policies written for blue water. It may be seen as inter-sectoral concept at best as required by co-management of water and land use (Jewitt, 2006).

It is hard to argue with the first proposition. In fact the paper may confirm that the concept of green water is not exactly defined by hydrological boundaries, and the authors afford variation in their definitions. From this it follows that 'different' green water flows are measured and different tools and methods are applied (Kongo and Jewitt, 2005, Gerten *et al.*, 2005, Jewitt, 2006). The findings on the dynamics of green and blue water are usually case specific and have low degree of generalization for large scales (estimates of global green water flows are always presented as preliminary: Gerten *et al.*, 2005). Even if the scientific green-water-related findings are presented to be significant for the understanding of complex natural and social reality, there is still a challenge to translate these findings lucidly to those who writes and implements water policies. Falkenmark (2007: 5) puts "In the scientific water community, there is for some reason an astonishingly slow tendency to update concepts and the conceptual framework that interlinks humanity and the life support system that provides human livelihoods". What to say then about the practical field of water resources management?

Despite the measurements of green water are not fully convincing quantitatively for water management use and prone to criticism, still they have qualitative value. First, green water estimates emphasize the importance of water and the green water in particular for ecosystems (their structures and functions) in terms of generation of goods and services as well as "maintenance of sustainable water supplies" (FAO, 2000 in Jewitt, 2002: 891) in the biosphere (again essential for both parts and the whole), secondly, they prevent from underestimation of human systems dependence on freshwater irrespective from its operational colour (green/blue), thirdly, they push people to rethink the place of humans (not above, beyond, apart but within the environment) and upgrade management approaches.

The second Jewitt's statement can be explained by factors as such: still a limited understanding of all processes within the water cycle, and when the water interplays with soil and air; drawbacks described in the first preposition; and essentially a technical difficulty to cope simultaneously with multiple processes and events from the management perspective. If to consider catchments as management units, it is reasonable that water management (if green-water perspective is accounted) should not be isolated from land management as changes in land use (e.g. agriculture/forestry/urban development) cause changes and redistribution in water flows and storages across the upstream/downstream parts of the catchment. At the same time hydrologically logical management set-up gets into contact (becoming often conflict) with the social systems of property rights on land (water), rival water use by different actors, and with the institutional set-up.

Water managers are not those who formulate and adopt laws and policies (though they participate in policy-making process), they are the executive branch of the human governance who need concrete guidance to implement legislative decisions. The quality of these decisions (i.e. water policies) depends on the competence and values of decision-makers. Desire to exercise the integrated water resources management or sustainable water management based on appealing ideas and internationally recognized values is not often realizable in practice as noted before, because those values are frequently abstract for hands-on implementation.

The concept of green water needs a better promotion among policy-makers and water managers. Part 2 presents that several projects (e.g. in Africa, India) have been implemented and several ones are ongoing or planned (e.g. The Smallholder Systems Innovations, The Green-Blue Water Initiative, Green Water Credits). This is one of the ways to test the social robustness of the concept at the science-society interface. Expanding communication of scientists and non-scientists will reveal the lifetime and the value of the concept for society.

It is the most plausible that a transdisciplinary research will continue the development of the concept in contexts prompting changes in water policy and management. Further research on water and people with inclusion of blue-green specifics is recommended to be expanded within sciences (especially related to social domain, which tend to approach water with 'supply-side vision' (the term used by Conca, 2006). Transdisciplinary research collaborators should i) refine the concept's definition and methodologies to measure green water flows to be better understood by policy-makers and water managers and applied in real world contexts, ii) to suggest reasonable and implementable management levels, both physical and institutional, iii) to provide on a rolling basis new findings on natural (including the water cycle) and social systems behaviour and their reciprocal effects so that the society could strengthen the capacity to continue its evolution in harmony with nature.

After completing the present research on the green water I conclude that there are general challenges for integration of scientific knowledge to the practical terrain related to water resources:

- Within the mono-discipline it is still hard to operationalize various hydrological processes within hydrological units (catchments) in terms of clear-cut definitions and robust measurements especially when processes occur on different heterogeneous temporal and spatial scales, to see and account for internal links within the hydrological cycle and be flexible to bridge the water cycle with a lot more complex natural world reality.

- There is still a challenge to give priority to the transdisciplinary research by preserving the strong knowledge capital generated by mono-disciplines as the prerequisite for the water-related science – policy/management interface.
- The translation of scientific information to the wider public audience and for the faster injection of scientifically-proven innovations into water policies and management is hampered in the first place by the lack of relative consensus by the scientists and experts themselves on discoveries and reasonability of practical application for the common good.

5 Conclusion

The constructive dialogue and collaboration between scientists and practitioners is strongly required to ensure that sustainability does not only become a ‘convenient’ scientific and public discourse but the salient issue in solving of accumulated human problems. As evidence as well as the present study suggests sciences generate a lot more knowledge than it is appropriated by politicians and managers who have the mandate from people to develop sound policies and guarantee their implementation for the sake of peoples’ wellbeing. The current challenge for water resources policy and management is to seek dynamic socio-economic-ecological balance for human systems taking into account more profoundly the dependence on natural systems, i.e. hydrologic cycle, ecosystems functioning and their close interrelation in between.

Knowledge on green water generated today by various disciplines is mostly an applied knowledge and deserves to be vastly tested in practical water management domain. So far in practical terms, the green water concept does not yet simplify delineation of management levels and has to be better clarified for a new freshwater accounting system; however it has the potential now to facilitate the understanding for water policy makers and managers of important links between water, land, ecosystems and human activities and provoke conceptual changes in water management across different scales. The most significant features of green water that have to be seriously taken into policies and management considerations, are 1) it is an integral part with all inclusive functions of the hydrologic cycle and the natural systems; 2) the sustainability of terrestrial ecosystems depends primarily on green water; 3) the food production for the human population on a global scale is still mainly based on green water.

The concept of green water as part of human knowledge base requires understanding and assessment from different points of view for both scientific and practical utility purposes. The presented systematization of the knowledge on green water was made with intention to maintain the discourse and attract more attention to the water issues penetrating today’s human agenda.

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Appendix 1

Analytical matrix for literature screening/analysis to explore the phenomenon/concept of Green Water in scientific publications.

Based on citations from the original sources (secondary data). Sorted by year of publication.

Print format- A3

	Source/Year of publication	**Definition of green water**	**General discussion Research Case Study (spatial/temporal boundaries, if any)**	**Can be the source ascribed to the Sustainability / SD paradigm General assumption**	**Number of authors**	**Original discipline (by author affiliation)**	**Potential for knowledge fertilization across Disciplines**	**"Real-world" problem**	**Scientific debate on**	**Concept in the context: Context Categories**	**Definition: Hydrologic Systems typology in terms of stocks and flows Flow-based Stock-based Combined**	**Does the concept used in the transdisciplinary manner?**
1.	Malin Falkenmark, Meeting water requirements of an expanding world Population" Phil. Trans. R. Soc. Lond. B (1997) 352, 929-936	**"Water availability in the root zone"; p.929** **"soil moisture" p. 930**	Research (focus on dry climate regions in Africa and Asia /30 years, i.e. up to 2025)	The article falls within the S /SD paradigm	1	Natural Science Research Council (Multidisciplinary body)	Demography, Natural sciences, Agricultural science, Hydrology Policy Science	Water availability /scarcity for future food production	Food Production (ability of Soil and water provide for the future population). Global agricultural policy and world trade.	**Green water, demographics and agriculture**	**Stock-based**	Yes
2.	J. Rockström. On-farm green water estimates as a tool for increase food production in water scarce regions. Phys. Chem. Earth (B), Vol. 24, No. 4, pp. 375-383.1998	**"Return flow of water to the atmosphere as evapotranspiration (ET) which includes a productive part as transpiration and a non-productive part as direct evaporation (I&) from the soil, lakes, ponded areas, and from water intercepted by canopy surfaces (Rockström, 1997a). p.376**	Research The Samadey watershed, Niger, West Africa (1994-1996)	The article falls within the S /SD paradigm	1	Land Management natural resources management	Agricultural science Hydrology Ecology Environmental and development studies	Food Production Upgrade for water scarce regions	"More crop per drop" optimization of green water. Integrated water and soil management	**Green water, demographics and agriculture**	**Flow-based**	Yes
3.	Jan Lundqvist and Eliel Steen FAO. 1999. The Contribution of Blue Water and Green Water to the Multifunctional Character of Agriculture and Land. Background Paper 6: Water.	**"Water in the root zone" p.5 Plus FAO definition of "... the water supply for all non-irrigated vegetation, including forests and woodlands, grasslands and rain-fed crops" p.5; p.11.**	General discussion	The article falls within the S /SD paradigm	2	Water and Environmental Studies Ecology and Crop Production Science	Water and Environmental Studies Ecology and Crop Production Science	Food security	Food security Role of water for agriculture and land	**Green water, demographics and agriculture**	**Combined**	Yes
4.	Cosgrove W.J. and F. R. Rijsberman. 2000. World water vision. Making Water Everybody's Business. UK: Earthscan Publications Ltd http://www.worldwatercouncil.org/index.php?id=961	**"Green water—the rainfall that is stored in the soil and evaporates from it" (Executive summary, ii) "Green water—the rainfall that is stored in the soil and then evaporates or is incorporated in plants and organisms" R. 2 pp. 6,11,**	General discussion	The report falls within the S/SD paradigm	2	World Water Council	International intergovernmental and NGO network dealing with water policy topics and issues at a high level, including transboundary issues (WWC)	Water-related problems that the humankind faces at present	Water-related issues Water vision for future	**Multi-contextual**	**Combined**	Yes
5.	FAO. 2000. NEW DIMENSIONS IN WATER SECURITY. Report AGL/MISC/25/2000	**"The water supply for all non-irrigated vegetation, including forests and woodlands, grasslands and rain-fed crops." (FAO). P.3 more discussion n definition on page 23.**	General discussion	The report falls within the S /SD paradigm	Team study 7	Under the aegis of FAO (Land and water development) Water and Environmental Studies Systems ecology Social Sciences	Water and Environmental Studies Systems ecology Social Sciences	Water security, food security	Global sustainability, water security, food security	**Multi-contextual**	**Flow-based**	Yes
6.	Asa Jansson, Peter Nohrstedt, Carbon sinks and human freshwater dependence in Stockholm County. Ecological Economics 39 (2001) 361–370	**"The water used by ecosystems to uphold "the generation of ecosystem services". P.362 "evapotranspiration of forests and wetlands and evaporation of inland water bodies (green-water flows)." P.366**	Case study Sweden, Stockholm county	The article falls within the S /SD paradigm	2	Systems Ecology, Natural Resources Management	Systems Ecology, Ecological Economics Urban planning	Environmental problems of urban areas (pollution), ecosystem degradation	Valuation of ecosystem services, Interdependencies of natural and social systems	**Green water and ecosystems**	**Flow-based**	Yes
7.	J. Rockström and L. Gordon. Assessment of Green Water Flows to Sustain Major Biomes of the World: Implications for	**"Vapour or evapotranspiration flows" "Return flows of water vapour from rain-fed crops, grass land, forests, wetland flora and grazing lands." P.844**	Research (major biomes of the world) assessment of	The article falls within the S /SD Paradigm	2	International institute for infrastructural, hydraulic and	Hydrology, Env. studies. Ecology	Recognition of dependence on green water for ecosystems	Ecosystems sustainability Green water and ecosystem services.	**Green water and ecosystems**	**Flow-based**	Yes

	Future Ecohydrological Landscape Management. Phys. Chem. Earth (8). Vol. 26, No. 1 l-12, pp. 843~851,2001		global green water flows (data 1992-196)			environmental engineering Systems Ecology,	Eco-hydrological landscape management.	sustainability	New water paradigm.		
8.	Graham Jewitt, Can Integrated Water Resources Management sustain the provision of ecosystem goods and services? Physics and Chemistry of the Earth 27 (2002) 887–895	**“Water vapour”, i.e. flow of water to the atmosphere as evapotranspiration (ET), which includes transpiration by vegetation and evaporation from soil, lakes, and water intercepted by canopy surfaces” p. 891**	General discussion South Africa /current state	The article falls within the S /SD Paradigm	1	Bioresources engineering and environmental hydrology	Ecology, Hydrology, IWRM	IWRM Sustainability of ecosystems	IWRM based on ecosystem approach.	**Green water and ecosystems**	**Flow-based**	Yes
9.	Pieter van der Zaag, I.M. Seyam, Hubert H.G. Savenije. Towards measurable criteria for the equitable sharing of international water resources. Water Policy 4 (2002) 19–32	**“Green water is renewable water that occurs in the soil; it is the part of the rainfall that infiltrates into the root zone and is directly used by plants for biomass production through transpiration.” p.20.**	Case study Estimates are for the Orange, Nile and Incomati rivers.	The article falls within the S /SD Paradigm	3	Hydrology Geosciences	International relations, Int’ Law, Political science and NRM.	Sharing transboundary water resources equitably	Equity. Allocation of international water resources. Valuation of water (green vs. blue). Regime theory. / Development of criteria for allocation of international water resources.	**Green water and transboundary water resources management**	**Flow-based**	Yes
10.	Johan Rockström. 2003. Managing rain for the future. In in Rethinking Water Management. Innovative Approaches to Contemporary Issues, edited by Figueres, C.M., Tortajada, C., and J. Rockstroem. London: Earthscan. Publications Ltd. Copy of the book article	**‘Return flow of vapour in rain-fed agriculture” p. 74**	General discussion (research based) (with some focus of sub-Saharan Africa)	The article falls within the S /SD paradigm	1	Natural resources management	Hydrology, ecology, soil science, agriculture-related studies, development studies	Water-related problems due human mismanagement	Water resources scarcity, food production, optimization of water and rain-fed agriculture	**Green water, demographics and agriculture**	**Flow-based**	Yes
11.	Ximing Cai and Mark W. Rosegrant. World Water Productivity: Current Situation and Future Options 2003. in CAB International 2003. Water Productivity in Agriculture: Limits and Opportunities for Improvement (eds J.W. Kijne, R. Barker and D. Molden)	“Effective **rainfall for rain-fed areas” p. 164 see section “Methodology, data, assumptions” p.164**	Research Assessment of water productivity at global scale (data 1995-2025)	The article falls within the S /SD paradigm	2	Food policy Water management	Hydrology, Water management Economics Agriculture-related sciences	Water management for food production	Estimation of water productivity, water consumption for food production.	**Green water, demographics and agriculture**	**Flow-based**	Yes
12.	John Rockström, Jennie Barron and Patrick Fox. 2003. Water Productivity in Rain-fed Agriculture: Challenges and Opportunities for Smallholder Farmers in Drought-prone Tropical Agroecosystems. in CAB International 2003. Water Productivity in Agriculture: Limits and Opportunities for Improvement (eds J.W. Kijne, R. Barker and D. Molden)	**“The return flow of green water as evapotranspiration” “Green-water flow sustains rain-fed agriculture, as well as all other water-dependent ecosystems, such as forests, woodlands, grazing lands, grasslands and wetlands” p.148.**	Research Sub-Saharan Africa (field research was done in Burkina Faso, Kenia at smallholder farmers in semi-arid rain-fed farming systems).	The article falls within the S /SD paradigm	3	Hydrology Systems Ecology	Ecology, Hydrology, Soil Science Integrated rainwater management. Sociology, demography	Water scarcity Food security	Global food production under population pressure. Productivity of soil. Productivity of water.	**Green water, demographics and agriculture**	**Flow-based**	
13.	J. Rockstroem, C. Folke, L. Gordon, N. Hatibu, G. Jewitt, F. Penning de Vries, F. Rwehumbiza, H. Sally, H. Savenije, R. Schulze. A watershed approach to upgrade rainfed agriculture in water scarce regions through Water System Innovations: an integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions. Physics and Chemistry of the Earth 29 (2004) 1109–1118	**“Vapour flow sustaining crop growth” p. 1109 “green water flows, i.e., non productive evaporation and productive transpiration flow” p. 1115**	Research/project The Pangani Basin in Tanzania and the Thukela Basin in South Africa	The article falls within the S /SD paradigm	10	Hydrology Systems ecology Soil science Bioresources engineering and environmental hydrology	Ecology, Hydrology Sustainable agriculture Adaptive management IWRM Policy Science	Poverty Degradation of rural livelihoods Food security Water scarcity	IWRM Increase of food production in semi-arid areas Rain-fed agriculture upgrading	**Multi-contextual**	**Flow-based**	Yes

14.	M. Falkenmark and J. Rockström. 2004. Balancing water for humans and nature. The new approach in ecohydrology. London: Earthscan. BOOK	**"Vapour flow from infiltrated rainfall" "Green water is the vapour flow in the water cycle over land, or total evaporation, consisting of non-productive vapour flow from foliage, open water or soil, and production vapour flow as transpiration from vegetation." P. 43.**	General discussion (specific cases include the savanna zone)	The book falls within the S /SD Paradigm	2	Systems Ecology Hydrology and NRM	Systems Ecology Hydrology Environmental and development studies, agriculture, economics, political science, law, water and land management, etc.	Water-related problems in the nexus to food production, sustaining livelihoods,	How to maintain food security, eliminate water scarcity, ensure environmental security	**Multi-contextual**	**Flow-based**	Yes
15.	Malin Falkenmark, Lars Gottschalk, Jan Lundqvist & Patricia Wouters. Towards Integrated Catchment Management: Increasing the Dialogue between Scientists, Policy-makers and Stakeholders. Water Resources Development, Vol. 20, No. 3, 297–309, September 2004	**"The invisible water in the soil" p. 298** **"The soil moisture and green water flow consumed in plant production" p.301** **'infiltrated rain' p.298**	General discussion	The article falls within the S /SD Paradigm	4	Hydrology Geophysics Water and environmental studies Water law	Hydrology Policy science Water Law	Bringing together water experts for more coherent water policies development and management	Science and Water Management Integrated catchment management	**Multi-contextual**	**Assumed as Combined**	Yes
16.	Malin Falkenmark, Towards Integrated Catchment Management: Opening the Paradigm Locks between Hydrology, Ecology and Policy-making Water Resources Development, Vol. 20, No. 3, 275–282, September 2004	**"Green water (vapour) flow that supports terrestrial ecosystems"; green water flow reflects the consumptive water use by both natural vegetation and agro-ecosystems". p.276**	General discussion	The article falls within the S /SD Paradigm	1	Hydrology	Hydrology, Ecology Water Policy Integrated Catchment Management	How to find "proper balance between humans and the impacts that their activities cause to ecosystems"	Rethinking of water management	**Multi-contextual**	**Flow-based**	Yes
17.	M. Falkenmark and M. Lannerstad. Consumptive water use to feed humanity -curing a blind spot. Hydrol. Earth Syst. Sci. Discuss., 1, 7–40, 2004	**"Green water flow branch includes vapour flow from different surfaces: from irrigated fields, wetlands and evaporating water surfaces (blue water transformed into green), and from natural vegetation (intercepted and naturally infiltrated rainwater)" p.10, 11**	General discussion	The article falls within the S /SD Paradigm	2	Hydrology Water and environmental studies	Hydrology, ecology Water and environmental studies Development studies Economics	Water scarcity Water mismanagement	Water consumption Addressing water-related problems of scarcity, depletion and pollution Future food needs	**Multi-contextual**	**Flow-based**	Yes
18.	R.A. Hope, G.P.W. Jewitt, J.W. Gowing. Linking the hydrological cycle and rural livelihoods: a case study in the Luvuvhu catchment, South Africa. Physics and Chemistry of the Earth 29 (2004) 1209–1217	**"Return flow to the atmosphere as evaporation and transpiration" after partitioning of rainfall. "water vapour phase". P 1209, 1210**	Cases study Luvuvhu catchment, Limpopo Province, South Africa /Assessment of current practice/ Scenarios for land use (commercial afforestation, dryland and irrigated agriculture rangeland).	The article falls within the S /SD Paradigm	3	Land use and water resources Bio-resources engineering and environmental hydrology	Hydrology, Natural Resources, Landscape management, Agriculture, Rural Development, Economics	Sustainability of rural livelihoods. Poverty Land and water use	"The role of the hydrological cycle in contributing to the livelihoods of rural communities". Assessment of links between "rural livelihoods, land use and the goods and services provided by the evaporation and transpiration components of the hydrological cycle (green water)".	**Green water and land use changes**	**Flow-based**	Yes
19.	G.P.W. Jewitt a,*, J.A. Garratt b, I.R. Calder b, L. Fuller. Water resources planning and modelling tools for the assessment of land use change in the Luvuvhu Catchment, South Africa. Physics and Chemistry of the Earth 29 (2004) 1233–1241	**''Green-water'' is water that is lost from the catchment through evaporation processes, whether transpired by vegetation or evaporated from open water bodies and other surfaces, and escapes from the catchment in gaseous form." p. 1234**	Case study The Luvuvhu catchment, Limpopo Province, S. Africa	The article falls within the S/SD paradigm	4	Bio-resources engineering and environmental hydrology Land use and water resources	Hydrology, Geosciences, Landscape management, Rural Development GIS and modelling tools	Catchment management Poverty	Land use and impacts on water resources, Land use scenarios Hydrological modeling	**Green water and land use changes**	**Flow-based**	Yes
20.	Dieter Gerten, Holger Hoff, Alberte Bondeau, Wolfgang Lucht,Pascalle Smith, Soenke Zaehle. Contemporary ''green'' water flows: Simulations with a dynamic global vegetation and water balance model. Physics and Chemistry of the Earth 30 (2005) 334–338.	**"Green water is the precipitation water stored in the soil and eventually transpired by natural and agricultural vegetation, i.e. used for plant growth and biomass production". P. 334-335**	Research Modeling of Global trend / Period: 1961–1990.	The article may be considered within the S/SD paradigm	6	Climate change research Ecology Environmental studies	Earth studies Climate studies Ecology	Biophysical complexity, Water accounting	Measurement of contemporary global green water flows Dynamics of hydrologic processes	**Green water and ecosystems**	**Combined**	yes

21.	Moberg, F., Galaz, V. Resilience: Going from Con ventional to Adaptive Freshwater Management for Human and Ecosystem Compatibility. Swedish Water House Policy Brief Nr. 3. SIWI, 2005.	**"The water flow that supports plant production in forests, grasslands, rain-fed croplands and wetlands and is responsible for much of the production of wealth in the world" p.4** **"Part of the water is consumed in terrestrial ecosystems by vegetation and evaporation from moist surfaces (green water flow)" p.5**	General discussion	The article falls within the S/SD paradigm	2	Transdisciplinary research, hydrology Ecology	Ecology Adaptive co-management Ecological economics	Need of freshwater management when human and ecosystems are reconciled	Turning to ecosystem-oriented freshwater adaptive co-management	**Green water and ecosystems**	**Flow-based**	Yes
22.	V.M. Kongo, G.P.W. Jewitt. Preliminary investigation of catchment hydrology in response to agricultural water use innovations: a case study of the Potshini catchment-S. Africa Proceedings of the 11th Conference of the South African Council of the Institute of Applied Hydrological Scientists (SANCIAHS). Sept. 2005.	**"the gross return flow of water to the atmosphere-total evaporation (*Et*) in the form of water vapour, which includes a productive part as Transpiration (*T*) and a nonproductive part as direct Evaporation (*E*) from the soil, lakes, and from the part of Precipitation (*R*) intercepted by canopy surfaces." p.9**	Case Study the Potshini sub-catchment, (S.Africa)	The article falls within the S/SD paradigm	2	Bio-resources engineering and environmental hydrology	Hydrology Ecology Environmental Studies Agriculture Development studies IWRM Remote sensing tools	Impacts of human-induced land activities (agriculture) on water	Land use issues. Water use innovations for food production to improve Hydro-ecological balance on the catchment level.	**Green water and land use changes**	**Flow-based**	Yes
23.	K.D. Mutabazi, E. E. Sekondo, D.S. Tumbo, B.P. Mbilinyi H. F. Mahoo, N. Hatibu .2005. Economics of Rainwater Harvesting for Crop Enterprises in Semi-Arid Areas: The Case of Makanya Watershed in Pangani River Basin, Tanzania. http://www.iwmi.cgiar.org/Africa/files/RIPARWIN/05/EARBM_Papers/Theme5/Mutabazi%20Daud.doc	**"Green water resources in forms of rain where it falls" p.2**	Case Study The Makanya Watershed in Pangani River Basin, Tanzania	The article falls within the S/SD paradigm	6	Agriculture-related studies Soil-water management	Hydrology Agriculture-related studies Water economics Rainwater management	Food production in semi-arid areas, water scarcity Poverty	Optimization of farming practices in semi-arid areas Poverty reduction	**Green water, demographics and agriculture**	**Flow-based**	Yes
24.	M. Dinesh Kumar and O. P. Singh. 2005. Which Water Counts? Blue and Green Water Use and Productivity in the Narmada Basin. Water Policy Research. Highlight, 8. http://www.iwmi.org/iwmi-tata	**Assumed as water flows in rain-fed agriculture** **"rainwater in the form of soil moisture"** **see at Quantum of Green Water Crops in the Basin….p. 4.**	Case study Narmada river basin, India	The article falls within the S/SD paradigm	2	Water policy and management	Hydrology Agriculture-related studies Economics Landscape management	Food security vs. ecological security Poverty	Water economics for agriculture Water productivity	**Green water, demographics and agriculture**	**Assumed as flow-based**	Yes
25.	A. Y. Hoekstra, A. K. Chapagain. Water footprints of nations: Water use by people as a function of their consumption pattern. Water Resource Management (2006)	**"Moisture stored in soil strata)" p. 3,** **"soil water", p.7**	Research Cross-country / indicator for the period of 1997–2001	The article falls within the S/SD paradigm	2	Hydrology	Hydrology Ecology Ecological economics, Sustainability science	Global, national water consumption	Water demand management Calculation of global water consumption	**Multi-contextual**	**Combined**	Yes
26.	ISRIC Report 2006/04. Green Water Credits: Basin Identification Green Water Credits Report 1	**"Green water is the water held in soil and available to plants. It is the largest fresh water resource but can only be used *in situ*, by plants"** **p.1**	Case studies of 4 river basins in Africa Proof-of-concept project	The report falls within the S/SD paradigm	5	Environmental studies Soil science	Environmental studies Hydrology Land use-related studies Env. Economics Development studies	Poverty Water availability Sustainable water and land management	Land and water management by using incentive mechanisms Poverty reduction Water resources conservation	**Multi-contextual**	**Stock-based**	Yes
27.	ISRIC, 2006/05. Green Water Credits: Lessons Learned from Payments for Environmental Services. Green Water Credits Report 2	**"The infiltrated water may be used by plants (green water), returning to the atmosphere and coming back again as rainfall, or it recharges groundwater and stream base flow that can be tapped for use downstream (blue water)" p.1**	General discussion	The report falls within the S/SD paradigm	3	Environmental and development studies	Environmental studies Hydrology Land use-related studies Environmental Economics Development studies	Poverty Water availability Sustainable water and land management	Environmental services Operational PES schemes (institutional arrangements, economic feasibility)	**Multi-contextual**	**Flow-based**	Yes
28.	A. K. Chapagain, A. Y. Hoekstra, and H. H. G. Savenije. Water saving through international trade of agricultural products. Hydrol. Earth Syst. Sci., 10, 455–468, 2006	**"Green water is the productive use of rainfall in crop production, which, in general, has a lower opportunity cost compared to the blue water use (i.e. irrigation)." P.456** **"effective rainfall" p.463**	Research Across countries, global / 1997–2001	The report falls within the S/SD paradigm	3	Water Engineering Civil engineering, Geosciences	Earth Science, Hydrology, Ecological Economics Development studies	Food security, water scarcity	Water conservation thru - International trade of agricultural products Virtual water	**Green water, demographics and agriculture**	*Economically-oriented definition* ***Also* Flow-based**	Yes

29.	Robert J. Zomer, Antonio Trabucco, Oliver van Straaten and Deborah A. Bossio. 2006. Carbon, Land and Water: A Global Analysis of the Hydrologic Dimensions of Climate Change Mitigation through Afforestation/ Reforestation Research Report 101. IWMR	**“That portion of precipitation that evaporates into the atmosphere, and is not available as runoff” p.13**	Research	The report falls within the S/SD paradigm	4	Water management Agroforestry	Earth Science Agroforestry Hydrology Development studies Environmental studies Climate Change research	Climate change mitigation	Land use, Climate change and hydrological cycle – interconnections and interdependency	**Green water and climate change**	**Flow-based**	Yes
30.	Graham Jewitt, Integrating blue and green water flows for water resources management and planning. Physics and Chemistry of the Earth 31 (2006) 753–762	**“Flows of water vapor in the form of transpiration, interception and evaporation from the soil and vegetation” p.753**	Research (South Africa)	The article falls within the S/SD paradigm	1	Bio-resources engineering and environmental hydrology	Earth Studies, Hydrology, Water resources management	Integrated Water Resources Management	Integrated Water Resources Management Land use changes and hydrological alterations. Green-blue water integration	**Green water and land use changes**	**Flow-based**	Yes
31.	UNESCO-WWAP.2006. Water. Shared responsibility.	**“Most of the water used to produce food or other crops comes from rain that is stored in the soil (so-called green water) p.247; Green water is what supplies terrestrial ecosystems and rain-fed crops from the soil moisture zone, and it is green water that evaporates from plants and water surfaces into the atmosphere as water vapour”, p.122**	General discussion Assessment report All scales are represented	The publication falls within the S /SD Paradigm	Numerous contributions	Multi-, inter-, transdisciplinary research	Multi-, inter-, transdisciplinary research	Contemporary water-related problems faced and created by humans	Water and Human. Human demands for water Sustainable Development	**Multi-contextual**	**Combined**	Yes
32.	Holger Hoff, Katja Tielbörger. 2006. GLOWA Jordan River Integrated Green and Blue Water Management. Conference presentation. http://www.glowa-jordan-river.de/	**Rockström et al, 1999**	Project Case study The Jordan River Israel	The PPP falls within the S/SD paradigm	2	Water management Environmental studies	GLOWA Project Water and land management Environmental studies Development studies Urban and rural planning	Water scarcity	Integrated Green and Blue Water Management Water productivity	**Multi-contextual**	**Flow-based**	Yes
33.	Malin Falkenmark. Shift in thinking to address the 21st century hunger gap. Moving focus from blue to green water management. Water Resources Management (2007) 21:3–18	**“Naturally infiltrated rain”. P.6**	General discussion. Current state up to 2050.	The article falls within the S/SD paradigm.	1	Hydrology	Development studies. Agricultural science. Hydrology. Ecology. Integrated water resources management. Policy science	Food security Water consumption Poverty Environmental degradation	The food security dilemma. Shift in water policy and management paradigm Natural science perspective. International policy debate. Agricultural upgrading.	**Green water, demographics and agriculture**	**Flow-based**	Yes