CPWF Project Report

Nile Basin livestock water productivity

Project Number 37

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Program Preface

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface

PN37 (*Increasing Water-Use Efficiency for Food Production through Better Livestock Management - The Nile River Basin*) set out to improve food security, reduce poverty and enhance agroecosystem health by managing livestock for more effective overall use of water. PN37 responded to water challenges posed by the CPWF, to the Nile Basin Initiative's goal of better sharing benefits of water use, and to global need for the livestock sector to use agricultural water more efficiently and effectively. PN37 identified opportunities to increase livestock water productivity (LWP) in key production systems of Ethiopia, Sudan and Uganda. In all countries and systems, the research revealed important opportunities to increase LWP through site-specific sets of interventions including improved feed sourcing, enhanced animal production, water conservation, and strategic provisioning of drinking water. It concludes that better integration of livestock, crop, water, and land management can sustainably enhance livelihoods of many poor people throughout the Nile Basin and beyond that across much of sub-Saharan Africa.

CPWF Project Report series

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1 RESEARCH HIGHLIGHTS

Availability and access to agricultural water are prerequisites to satisfying global demand for food and poverty reduction. Yet inappropriate and excessive water use threatens the natural environment and human livelihood assets. Recent research identified important gaps in past efforts to effectively use water for agriculture. First, livestock use of and impact on water resources was almost completely ignored. Second, until recently, water use in rainfed pastoral and mixed crop-livestock systems received little emphasis. The CGIAR Challenge Program on Water and Food's project, ***Nile Basin livestock water productivity (PN37)***, set out to determine the extent of water use and degradation of water and adjacent land resources and to identify intervention options that deliver more effective, productive and sustainable use of water resources in diverse major agro-ecosystems of the Nile and to draw globally relevant inferences.

The first major PN37 output was a Livestock water productivity (LWP) assessment framework that identified four strategies to increase, LWP. These are: 1) selection of feeds that require relatively little water and produce enough quality dry matter and nutrients to meet animal requirements; 2 integration of existing Animal Science knowledge into water development; 3) water conservation associated with livestock keeping; and 4) optimally distributing livestock, feed and drinking water resources over large areas to maximize animal production through access to underutilized pasture far from water while preventing overgrazing and water degradation near watering points. Evidence indicates that animal production could be doubled without depleting additional water.

The second major output was a set of three country studies in Ethiopia, Sudan and Uganda that included pastoral, large scale irrigation, and rainfed mixed-crop livestock systems. They confirm the applicability of the four LWP enhancing strategies. Basin wide, LWP is much lower than what is possible; integrated approaches to water, crop and livestock management are needed; and changes in policy and institutional arrangements are necessary to bring about increased agricultural water productivity. In all cases, constraints to and opportunities for increasing LWP are highly gendered. Taking gender into account can help ensure more equitable development. Unique country-specific intervention opportunities to increase LWP exist.

PN37 concluded that the greatest opportunity for increasing agriculture water productivity in the Nile lies within rainfed productions systems. We emphasize that agricultural production includes both crops and livestock and not just crops alone. Overall, six rainfed livestock-dominated and mixed crop-livestock production systems cover about 1.9 million km^2 or 63% of basin land area and receive about 1.68 trillion m^3/year of rain of which about 1.27 trillion m^3/year is lost as evapotranspiration (ET). Transpiration (T) drives plant production. Evaporation (E) does not. PN37 did not disaggregate ET into E and T. However, the project estimated that livestock use of water for feed amounts to about 0.06 trillion m^3/year or about 4.7% of ET within these six major livestock production systems. Domestic animals use much less water for drinking (<600 million m^3/year) than for feed. Separately estimating E and T will greatly facilitate better agricultural and water management in future. Even without this refinement, PN37 research suggests that huge opportunities exist to shift billions of cubic meters of water from non-productive evaporation to productive transpiration and plant growth by increasing vegetative cover essential for nature and crop and animal production. Such action would greatly increase availability of agricultural water in the Nile Basin without competing with demands for the Nile's blue water resources. Improving both livestock and crop husbandry and value added marketing can help increase benefits derived from this more available source of agricultural water.

PN37 research suggests that new institutional arrangements and policy are required to foster inclusion of livestock options within water development planning and water options (beyond provision of drinking water) within livestock management organizations. Because governance structures among the Nile countries are diverse and unique, general recommendations for change are not helpful. However, one overriding principle emerges. Integrating livestock, crop and water development will lead to higher agricultural water productivity and more effective and environmentally sustainable human development than independent sector specific approaches can deliver.

2 EXECUTIVE SUMMARY

Within the CGIAR *Challenge Program on Water and Food* (CPWF), PN37 (**Nile basin livestock water productivity**) set out to assess the contribution of livestock water productivity at scales ranging from households to the entire basin while taking into account the great diversity of countries, cultures, landscapes and agricultural production systems that make up the Basin. The project was premised on literature review that indicated a huge knowledge gap existed at the nexus of water and livestock management. To a large degree, water research and development has given little attention to livestock while livestock research and development have largely ignored the importance of water with the exception of some work on animal drinking requirements. Thus, PN37 aimed to fill this void and, in doing so, to contribute to the CPWF's goal of improving agricultural water management for the purpose of ensuring environmentally sustainable food security and reducing poverty.

PN37 consisted of four major components. These were:

- Development of a livestock water productivity (LWP) framework to enable project partners and stakeholders, more widely, to systematize thinking about complex livestock-water interactions that underpin actual LWP and potentials to increase LWP.

- Nile basin wide spatial analyses integrating livestock and human demography, climatic patterns, land use systems, cropping patterns, water resources, and hydrology to identify hotspot areas where opportunities exist to improve management of water, land and livestock resources with the intent to improve food security and livelihoods and reduce poverty and land degradation.

- Three case studies (The Blue Nile Highlands of Ethiopia, The Central Belt of Sudan and Uganda's Cattle corridor) intended to identify local and national priority livestock-water management options relevant to national partners.

- Capacity building and dissemination of research results.

This report summarizes the first three of these four components.

Major partners in PN37 were:

- Agricultural Economics and Policy Research Center, ARC, Khartoum, Sudan,
- Animal Resources Research Corporation, MOST, Khartoum, Sudan,
- Animal Science Department, Makerere University (MU), Kampala, Uganda,
- Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia,
- International Livestock Research Institute (ILRI), Addis Ababa and Nairobi, Ethiopia,
- International Water Management Institute (IWMI), Addis Ababa, Ethiopia.

The project could not have achieved success without participation by many other people and institutions especially in Nakasongola (Uganda), Sudan, and Ethiopia. The partners conducted project research from June 2004 to June 2009. Some reports and follow up activities with stakeholders continued beyond the formal end of the project.

Principles of water accounting developed in previous research on water use by crops were extended to accommodate domestic animals within a livestock water productivity (LWP) framework. The project defined LWP as the ratio of net benefits derived from livestock keeping to amount of water directly and indirectly depleted during the process of producing these benefits. This process revealed four basic strategies that could enable increased LWP in diverse Nile basin agricultural production systems. These are:

- Feed sourcing: Selecting animal feeds that have low water requirements while maintaining adequate levels of production. Within mixed crop-livestock farming systems, the use of crop residues is an example of practice already important to farmers.

- Enhancing animal productivity: Adoption and integration of already known Animal Science interventions within agricultural water development enables more effective and productive use of water resources. For example, provision of veterinary services reduce animal mortality and morbidity, the principle being that water used for feed is completely wasted if animals subsequently die from water-borne or other diseases.

- Conserving water: Inappropriate land management, often involving livestock, leads to high rates for runoff, reduced vegetation cover, erosion risk and high levels of evaporation that all contribute to water depletion, reduced water quality and low water productivity. Managing vegetation in ways that increase transpiration and infiltration will help increase both crop and livestock water productivity.
- Strategically allocating water resources across landscapes: Large areas in the Nile Basin have low LWP because animals cannot access under-utilization feed resources due to lack of drinking water. Trekking long distances between drinking and grazing sites imposes high energy costs and reduces animal production and LWP. Near watering points, LWP is low because animals concentrate around drinking water and overgraze adjacent pasture. They suffer from feed shortages, nutritional deficits and exposure to health risks that result in higher morbidity, mortality. Optimal balancing of spatial distributions of animals, feed, and water resources can help increase LWP, but limits to stocking densities are essential.

PN 37 undertook spatial analyses of livestock and human demography, climatic conditions, land-use and agricultural production systems and available water resources and identified key hotspots where opportunities exist to increase LWP, improve livelihoods and reduce land and water degradation. At national and sub-nation levels in Ethiopia, Sudan, and Uganda, PN 37 researchers examined production system specific conditions affecting current levels of LWP. At both the basin and sub-basin levels, the four strategies proved to be applicable. The research team concluded that:

- Historically, water management has focused on water resources observable in the Nile's rivers, lakes, reservoirs and irrigation schemes. Yet the total rainwater for the basin amounts to about 2 trillion m^3/year of which about two thirds is lost as evapotranspiration from major livestock and crop-livestock production systems. One of the greatest opportunities for making gains in basin level water productivity and production is in rainfed area by shifting evaporative loss to productive transpiration. The key to this is better management of vegetation at local and landscape scales involving diverse complexes of plant species of value to people and the environment.

- LWP in the region tends to be higher than crop water productivity when taking into account the highly valued multiple monetary benefits animals provide. Yet, huge opportunities exist to further increase LWP.

- A comparison of LWP among pastoral and rainfed and irrigated mixed crop-livestock systems suggests that LWP increases with agricultural intensification, but the results do not suggest which is cause and effect.

- In many cases, integration of off-the-shelf animal science technologies (e.g. veterinary services) into water resources development show promise of increasing LWP and sustainable returns on investments in water.

- In Uganda, the Makerere University team developed an innovative approach to control of termites on degraded pasture. This breakthrough reversed land degradation and desertification and increased LWP and animal production in the Cattle Corridor.

- One purpose for increasing agricultural water productivity is to help reduce poverty. While accepting this premise, PN37 research indicates that farmers may require minimal asset levels for effective adoption of many interventions. Inputs such as water harvesting and veterinary care along with better health and education are correlated with increased LWP. Enabling farmers to engage in livestock markets that help meet rapidly increasing demand for animal products provides one option for generating cash that they can use of purchase of farm inputs and other livelihood assets.

- PN37 research developed a gendered livelihood approach to assessing LWP. Men and women (and various age classes within these groups) differ in the degree to which they benefit and bear the costs associated with livestock keeping. The four strategies for increasing LWP are highly gendered in their potential impact. Thus, gender is important especially if inequitable consequences arise from efforts to increase LWP.

- Some of the major challenges and constraints to increase LWP center around inappropriate institutional, organizational and policy environments. The historic lack of integration of livestock and water development partly explains why LWP is much lower than its potential throughout the basin.

Outcomes of PN37 research first appeared within the participating research community. Researchers started thinking more pro-actively water productivity of livestock and the implications for improving water management through better livestock keeping practices. This change of thinking led to specific re-adjustments of research priorities within ILRI, IWMI, and the second phase of the CPWF. Publication of several key peer-reviewed papers (Special issue of the Rangeland Journal, June 2009; and Peden et al. 2007) plus exposure through international conferences (e.g., Stockholm world Water Week (2006), CPWF 2nd International Forum on Water and Food (2008) and the Nile Basin Development Forum 2008) extended the reach of PN37 outcomes. One key outcome was the launch of a BMZ funded project led by IWMI intended to integrate LWP concepts into improving food security and livelihoods in Ethiopia and Zimbabwe.
At a broader level, the term, "*livestock water productivity*", was not used prior to 2002. By the end of the project, a simple Google search on this phrase generated about 200,000 hits indicating substantive uptake of LWP concepts globally.

Outcomes are easier to document than impact. When PN37 ended in June 2009, embryonic signs of potentially sustainable impact emerged in Nakasongola, Uganda. Technical interventions involving construction and management of valley tanks (water harvesting based on small reservoirs) accompanied by upslope pasture management demonstrated potential for improving livelihoods of pastoralists and agro-pastoralists while opening up opportunities to rehabilitate large areas of desertified rangeland. To the keep the momentum going, the Ugandan project team continues to support local and district efforts to establish and enforce bylaws designed to make these interventions sustainable. Often research projects find initial success through adoption of promising research but subsequently fail in due to inadequate follow-up. Herein is the challenge ahead. In Ethiopia and Sudan, further effort to apply research findings in their development efforts is needed. At the basin level, opportunity exists for collaboration among the Nile Basin Initiative and the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) to increase water productivity aimed at reducing poverty among poor farmers.

The prime international public good arising from PN37 is the *livestock water productivity framework* that underpins location specific opportunities identified in this project. This concept evolved into several tools involving spatial analyses and spreadsheet models. Modest effort remains needed to package these into products that include guidelines for their use so that they can be applied in research and development globally.

The primary recommendations emerging from PN37 are:

- Proactive efforts to increase livestock water productivity will help achieve greater environmentally sustainability, higher rates of return on investments and mitigate or avoid conflicts, but sub-national, national and basin level agencies involved in agricultural water management must collaborate in establishing institutional arrangements and policies that encourage integration of water, agricultural and human development. Such integration will help overcome the perception that livestock production constitutes a wasteful use of water resources.

- Livestock keepers, including farmers, need access to livelihood assets including water, land, farm inputs, credit, markets, education, and health. Appropriate institutional arrangements and policy will help enable these conditions and farmer's adoption of relevant interventions, individually and collectively. Taking a gendered perspective will help ensure equitable access to agricultural water and benefits from crop and livestock derived from it.

- Across diverse scales and production systems, strategic feed sourcing, animal husbandry, water conservation, and allocation of livestock, drinking water sites and pasture across landscapes will help increase LWP. Location specific interventions that address these four strategies are needed. Some examples are contained within this report. More generally, multi-stakeholder teams including farmers', herders', and water users' groups along with representatives of diverse government agencies must collaborate and take an agroecosystems approach to increasing LWP.

- The Nile River Basin includes at least three hot spots or areas where efforts to increase LWP. These are the Ethiopian Highlands, the Central Belt of Sudan, and Uganda's Cattle Corridor. They are located within six major livestock and crop-production systems. Adoption of the four related LWP enhancing strategies and related specific intervention will greatly increase availability and farmers' access to water resources and enhance the sustainability of benefits derived from water. The challenge is to shift emphasis from blue water to green water management, transfer nonproductive evaporation into productive transpiration, and improve livestock keeping and marketing practices resulting in more effective agricultural use of billions of cubic meters of water that currently yield little or no benefit to nature or humanity.

3 INTRODUCTION

The year, 2001, launched the CGIAR Challenge Program on Water and Food (CPWF) and the CGIAR Comprehensive Assessment of Water Management in Agriculture (CA). These two global programs hosted a planning workshop, Water Week 2001, in Wadduwa, Sri Lanka, (http://www.iwmi.cgiar.org/Assessment/About_the_CA/). These events brought together about 80 researchers from diverse institutions and many countries to draft their global research agendas. The overarching goal of the CPWF and CA was to improve agricultural water management to ensure future food security and reduce poverty in developing countries in an environmentally sustainable manner. The only formal mention of livestock at Water Week referred to Goodland and Pimental (2000) who stated one kg of beef, maize, and potatoes required about 100,000 l/kg, 1400 l/kg, and 500 l/kg of water respectively. The implication was that livestock were wasteful users of scarce water resources and production of them was not conducive to improved water management. This widely held view that domestic animals use too much water posed a challenge to the International Livestock Research Institute which participated in Water Week. On one hand, if this excessive use of water by livestock was true, there was urgent need to reduce it. On the other hand, if this was not true, there was critical need for science based estimates of actual levels of water use and degradation in the developing world.

In spite of concern about possible excessive use of water by livestock, livestock have been conspicuously absent in agricultural water research and development. In 2002, the CGIAR Science Council stated that "*traditionally, water productivity concepts have been applied mainly to crop production. Demand for milk and meat is expected to double over the next 20 years. This demand needs to be factored into future assessments of water use and productivity. Water productivity in livestock production systems must be characterized in all of its dimensions … in river basin*(s)" (ISC 2002).

Within the network of river basins included in CPWF, livestock are particularly important in the Nile River Basin where domestic animals outnumber people and their demand for feed was thought to exceed the amount of food required by people. In the two largest Nile countries, Sudan and Ethiopia, animal products and services make up between 25% and 50% of agricultural GDP. Basin wide, the land area covered by livestock production systems is greater than land used for crops, but much of the former is not suitable for other forms of agriculture. One working hypothesis prior to this project is that integration of livestock and water development is a requisite component of any efforts to increase agricultural water productivity in the Nile Basin.

The purpose of this research was to develop concepts and tools to account for livestock use, depletion and degradation of water in river basins, to assess livestock-water productivity in major Nile production systems, and to use this knowledge to improve overall allocation and use of water and land resources for all users and at scales ranging from the household and community levels to the basin scale. The research took place in four locations. Three operated at country level. They were Uganda's Cattle Corridor, Sudan's Central Belt, and the Blue Nile Highlands. Together these areas constitute case examples that represent most of the Nile's diverse livestock production systems. The fourth component of PN37 was located within ILRI and undertook a broad brush basin wide overview of livestock water interactions and livestock water productivity. This report summarizes these four sets of research activities and then draws key lessons from them.

Among production systems, gender roles in livestock-water vary. For example, men and children, especially boys, often herd and water animals in pastoral systems, but women and girls assume responsibility for young and sick animals. Decision-making on grazing and trekking routes largely depends on knowledge about water availability, a man's domain. In agro-pastoral and mixed farming systems, herding and watering within limited geographical boundaries also require significant amount of labour, largely provided by children. In urban and peri-urban systems, women and children usually collect drinking water from nearby sources for stall-fed cattle. These roles also vary across ethnic and religious groups and cultures (Tangka et al. 2000). When combined with competing demands for labour of household members for other uses, the ease of access to water source(s) in different production systems may significantly influence gender division of labour for livestock-water interactions, the level of water use and its efficiency in livestock production. Indirectly this has implication for the drudgery and welfare of different household members, especially women and children.

Livestock drink about 25 l/ TLU/day of water (Sileshi et al. 2003), but water for daily feed production can be 100-200 times greater (Peden et al. 2003). This is important because the prime constraint to livestock production in the basin is feed shortage, the production of which is often water limited. Governments and livestock keepers in the basin place high priority on securing water for livestock and on production of their feed. Whether or not the feed comes from irrigated or rainfed plant production, the demand for water is high, but this is normally not considered when looking at water demand for livestock production. In addition, inappropriate feeding and manure management contribute to soil erosion, run-off, reduced infiltration, and downstream flooding and sedimentation. Manure and urine often contaminate surface and ground water. Knowledge about these interactions in the basin is almost non-existent or scanty.

The overarching hypothesis is that better management of livestock-water interactions effectively contributes to increased water productivity for food production and poverty reduction in river basins. The prime goal is to improve food security, reduce poverty and enhance agroecosystem health in the Nile basin with the expectation of out-scaling project outputs to other river basins. The original specific objectives were:

- To identify **hotspots** or problem-specific areas across the Nile basin involving negative livestock-water interactions and to advance policy and targeted innovations enabling more efficient and equitable water resource use for all purposes including livestock production. Within this context, we have included an overview of gender, institutional and policy issues related to livestock and water management in the Nile Basin although many aspects are also relevant more locally.

- To identify **potential technologies**, INRM practices and policies that are feasible, socially acceptable and gender-sensitive for sustainably improving food security and well-being through management of livestock-water interactions across the Nile Basin and to test a sub-set of these in collaboration with participating communities.

- To **increase capacities** for undertaking improved, integrated and gender-equitable livestock-water management of key target groups including selected communities, development professionals, policy makers and researchers.

This report is organized around the first two of these objectives. The third objective is not a research issue, but is summarized in the project completion report for PN37. Once the research had commenced, we realized that the concept of increasing agricultural water productivity underpins much of required investment and effort to use the Nile's water resources in environmentally sustainable ways that foster greater food security and poverty reduction. Consequently a fourth intermediate objective was included in the research: the development of **livestock water productivity framework (LWP)** that could help systematize and help stakeholders understand various livestock-water interactions and the diverse animal production systems of the basin. Because this serves as an integrating tool for the basin and country level studies, it is placed in this paper prior to the sections that describe the other two research objectives.

4 LIVESTOCK WATER PRODUCTIVITY

We define LWP as the ratio of the total net beneficial livestock-related products and services to the water depleted in producing them. Details can be found in Peden et al. (2007, 2008, and 2009). LWP is a systems concept based on water accounting principles that is applicable to diverse agricultural systems and to scales ranging from household to river basin levels (Figure 1). Livestock provide people, especially the poor in developing countries, with multiple benefits derived from diverse animal species and breeds. Estimating LWP requires estimates of the total value of these good and services. We normally use monetary units for benefits and express LWP in units such as US$/km^3 of water.

Water within agroecosystems occurs in lakes, rivers, ponds, reservoirs, and soil moisture, and in water locked up in the tissues of plants, animals, and microorganisms (Falkenmark et al. 1998). Water enters a system as rainfall and surface and subsurface inflow. Water depletion or loss from the system includes transpiration (T), evaporation (E), and downstream discharge. Sustainable water management requires long-term inflow and depletion to be in balance preferably with sufficient storage to offset short-term scarcity due to droughts. Once depleted, water is no longer available and has no further value within the system. Water contamination is a depletion process that makes water less valuable to future users even though it may remain within the system. Estimating livestock-related water inflow, depletion, and storage is a primary requirement of assessing LWP.

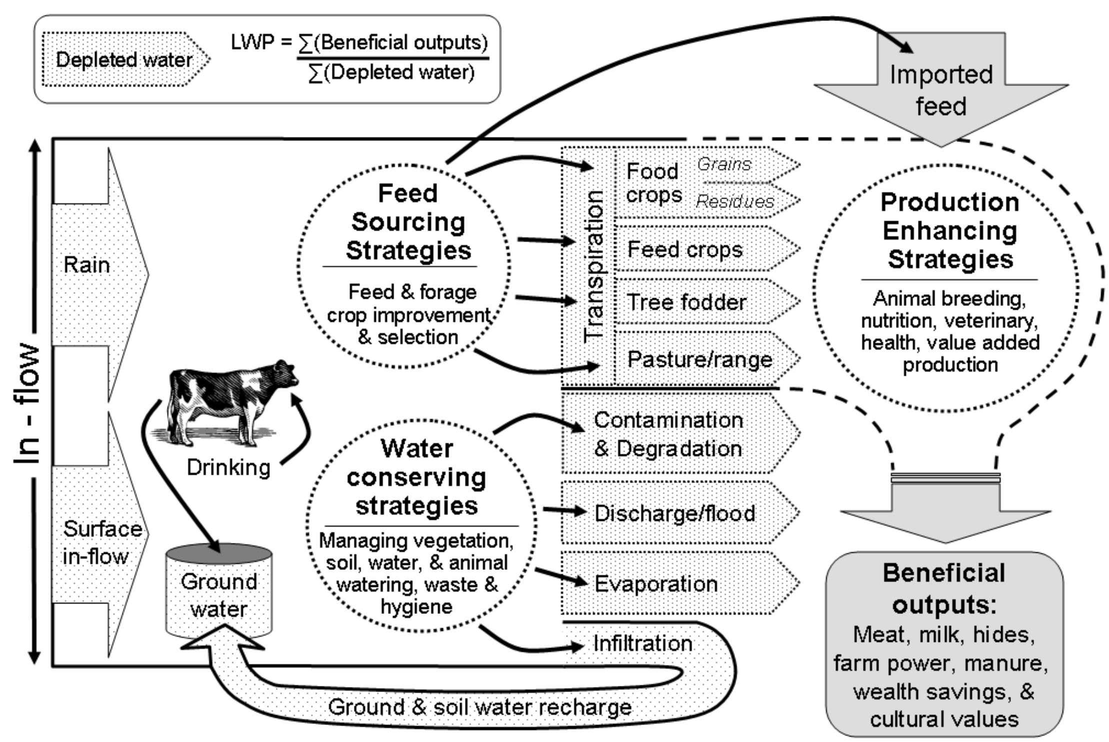


Figure 1 The framework for assessing livestock water productivity helps identify options for reducing water depletion, increasing livestock production, and enhancing ecosystems services.

Without water loss through T, plants cannot grow. In practice, disaggregating E and T is difficult and rarely done. Most published research combined T and E into one index, evapotranspiration (ET), for the purpose estimating water use in agriculture. However, shifting water depletion from evaporation and discharge to transpiration (Keller and Seckler 2005) and increasing the value of animal products and services (Peden et al. 2007) are the key means to increase LWP. Thus, the ratio of T to E is important. A high T to E ratio is indicative of probable higher agricultural WP than a lower ratio because T represents water used to enable plant growth while E represents nonproductive water depletion. For example, landscapes with little green vegetation, low leaf area index (LAI), and much bare ground will lose more water though evaporation (and even run-off on sloping terrain) and have lower levels of plant production than areas with a high LAI and little bare ground if plant species composition, environment and precipitation (inflow) remain constant. One consequence of vegetation management failure to distinguish T from E is the lost opportunity to increase WP due to excessive E and suboptimal T.

Based on the assessment framework (Figure 1), there are four basic livestock keeping strategies that can help improve LWP (Peden et al. 2007). These are optimal feed sourcing, enhancing animal productivity, conserving water resources, and providing drinking water to livestock, especially cattle. These strategies involve supply-side and demand-side management of both water resources and animal products. The four strategies along with LWP assessment framework underpin the research undertaken basin-wide plus in the country studies in Uganda, Sudan and Ethiopia.

Feed sourcing strategy

Provision of feed is a major livelihood challenge with high labor, land and farm input costs for farmers. Demands for animal feed and human food are competitive on a finite natural resource base. The major water requirement for livestock production is that needed to produce animal feed. In principle, livestock can feed on diverse plant materials including grains, grasses, fodder trees, crop residues, and crop by-products. One key strategy for increasing LWP lies in selecting the most water productive feed sources that produce enough feed to meet animals' needs.

Feed WP estimates in scientific literature vary 80 fold from the most to the least efficient (Peden et al. 2007). This huge variation is partly due to biology. Unfortunately, it also results from inconsistent methodologies. For example in Sudan, Saeed and El-Nadi (1997) assessed water use for irrigated forage sorghum and alfalfa based on ET during the growing season at the field level. In contrast, Sala et al. (1988) used annual rainfall to estimate "rain use efficiency" of Wyoming rangelands at a landscape level implying that the rainfall and evaporation during the non-growing season is also an input into plant biomass production and that all vegetative production is used as feed by livestock. Future research must include compilation of estimated WP of important forages and animal feeds using standardized definitions and methodology that distinguishes E and T. Since farmers produce crops to feed people with or without livestock present, residues and by-products generated through crop production can serve as feed for livestock with little or no additional water cost. There are also opportunities for crop breeders to enhance the quantity and nutritional value of grain crop residues for use as feed without jeopardizing grain yields and thus enhance overall WP (Blummel et al. 2003). In contrast, using high value irrigation water to produce feeds such as forage sorghum and alfalfa will have a relatively high water cost compared to use of crop residues and by-products. Within the farming or grazing system, there is need to determine what feed sourcing options will give the highest LWP. Grazing on vegetation that has little value for other human needs or for maintenance of ecosystem health may confer a low water cost source for feed. In the extreme, importing feed enables animal production without incurring any water cost for feed from within the system. In essence, virtual water supports animal production especially in urban and peri-urban dairying and fattening. One implication is that future evolution of the LWP framework may benefit by considering the price of depleted water rather than its volume.

Efforts to increase LWP through feed sourcing demands caution. First, the feeds selected must meet the nutritional requirements of the animal. One promising option under development is to estimate water productivity of feed using the ratio of metabolizable energy to water depleted. Second, high LWP does not necessarily mean high levels of production, and livestock keepers need to maintain profitable enterprises.

Water for feed is a concept that is closely linked to "water for vegetation" where vegetation may or may not be consumed by animals as feed. The section below on conserving water resources describes the non-consumptive influence of livestock on vegetation and water, but briefly, sustainable allocation of pasture, residues, and by-products for feed implies maintenance of essential ecosystem service.

In extensive production systems, animal feeds are about 50% digestible with the other half emerging from the animal as manure. Only about half of the water depleted to produce feed actually supports animal maintenance and production. Often, manure is highly valued and widely used for replenishing soil fertility, domestic fuel, and construction of housing. However, manure may be a major a cause of environmental degradation especially water contamination. Thus, manure management can have a major influence on the net beneficial benefits derived from livestock and thus on LWP.

Oxen, equines, and buffaloes provide farm power for crop production and marketing in many basins including the Blue Nile. Water used for feed to enable animal traction is an input into crop production. Where farm power is the primary use of an animal, beef may actually be a by-product of animal production and only be "produced" when an animal is no longer capable of cultivating land.

Enhancing animal productivity strategy

Historically, Animal Science research emphasized increasing livestock production often focusing on single outputs such as meat and milk. Most of this research took place in developed countries and gave little emphasis to developing country livestock production systems involving multiple animal sourced products and services. In all countries, the total water cost of animal production has been largely ignored. No matter how much or how little water plants transpire to produce animal feeds, LWP will be low if livestock do not use feed efficiently. High rates of mortality and morbidity lower LWP by reducing beneficial outputs. Just as it is important to ensure good crop health and soil fertility to achieve high levels of crop water productivity, one key to enhancing LWP requires good animal husbandry that maintains healthy animals with appropriate quantity and quality of feed intake in a stress free environment. Numerous technologies and practices can help achieve this state (Ranjhan 2001; Steinfeld et al. 2006; Peden et al. 2007).

Animals use feed energy for maintenance and for productive growth, lactation, reproduction, and farm power. Energy available over and above maintenance may become available for production and reproduction. In much of Africa, feed scarcity limits intake implying that most consumed feed supports maintenance leaving little for production. Increasing the ratio of feed energy for production to maintenance has high potential for increasing LWP. For example, providing on-site drinking water to dairy cows instead of having them trek daily for drinking water reduces stress and expenditure of energy enabling substantive increases in milk production (Muli 2000).

Constructing shelter against extreme temperature, providing veterinary services to reduce morbidity and mortality, and where practical, night grazing also reduce stress on animals enabling greater production and higher LWP. Traction power from oxen is a vital input for crop production in the Ethiopian Nile region. Farmers use oxen for only short periods each year but must maintain them and breeding adults year-round making maintenance costs relatively high. Technologies such as conservation agriculture could reduce the need for cultivation and thus oxen leading to an overall increase in WP.

Increasing the daily feed intake of domestic animals has been a primary goal of the animal sciences. Although this strategy may help increase energy flow for production, it may not increase feed conversion efficiency for that production and by implication for LWP. Opportunities exist to select and breed animals having higher feed conversion efficiency and not just higher rates of intake (Basareb 2003). Formulating feeds and feed strategies with appropriate nutrients and forage composition can help increase feed conversion efficiency (Gebreselassie et al. 2008) and thereby reduce water requirements for feed production.

Because the LWP concept measures benefits in monetary units, it follows that market conditions influence conversion of water to beneficial animal outputs. Thus, LWP may be higher when livestock keepers have good access to markets, have disease free, quality, and high value products, and can add value at the farm gate such as by converting liquid milk to butter or cheese. However, caution is needed when relying only on aggregate monetary valuation of LWP because this does not allow disaggregation of animal products into diverse nutrients required for human nutrition. There remains need to recognize that animals source foods provide essential nutrients such as Vitamin B12 and micronutrients that are often not otherwise readily available to poor farmers producing crops on nutrient depleted soils. Post PN37 research has started assessing bio-energetic implications for LWP, but this is not considered within this paper.

Conserving water resources strategy

Conserving water is a key strategy for increasing LWP if users (in this case livestock keepers) have access to it and use it effectively. Here we focus on conservation, but use is part of the other three strategies. The primary challenge to conserving agricultural water is maintaining high levels of vegetative ground cover that promote increased transpiration, infiltration, and soil water holding capacity and decreased evaporation and discharge. In grazing areas, herds may need to limit animal stocking rates to levels that allow moderate production and avoid overgrazing that removes excessive ground cover or shifts plant species composition from palatable to unpalatable types. Well-managed grassland is often the best land-use in terms of capturing rainfall, encouraging its storage in soil and promoting transpiration and thus plant production. This is especially true in drylands and on steep slopes.

Where livestock depend partly or entirely on crop residues and by-products, maintaining vegetative ground cover is also vital, but different management options exist. For much of the year traditionally cultivated land is devoid of vegetative cover, vulnerable to water loss through runoff and evaporation and may suffer from declining soil organic matter and water holding capacity. In Ethiopia, soil erosion and by implication run-off is eight times higher on annual croplands than on grazing lands (Hurni 1990). As on grazing land, increasing WP in croplands requires concerted effort to maximize water depletion by transpiration and to reduce evaporation and runoff. Conservation agriculture (CA) potentially traps moisture in soil as a consequence of reducing excessive run-off and infiltration below root layers. Accompanied by sufficient vegetative (crop) cover, CA can help increase WP especially on cultivated steep slopes and rainfed areas subject to high risk of drought. In some cases, water harvesting and ground water recharge techniques can capture surplus water enabling storage for dry seasons and higher WP on a year-round basis. Because livestock keeping is highly integrated into rainfed agriculture in developing countries and feed scarcity is widespread, excessive use of crop residues for livestock and household energy aggravates degradation of land and water resources associated with cultivation. Interventions, aimed at producing animal feeds utilizing crop residues and by products, must accommodate the need to maintain vegetative cover and soil moisture.

Providing drinking water strategy

Livestock, especially cattle, are highly dependent on water resources particularly in arid and semiarid lands. Without drinking water, they die, and when drinking is restricted in amounts and frequency, stress reduces animal production. The agroecosystem process of animal drinking takes place within the system. Water drunk within it is not depleted because it remains within and supports ecosystem functioning. After animals consume water, it can be lost as fecal moisture or urine and deposited on the soil-vegetation complex from which it may infiltrate or evaporate. A very small amount may be lost as evaporation from the pulmonary tissues of the animal. Nevertheless, drinking water must be of high quality and available in small but adequate quantities. Although the cost of providing a unit of drinking water may also be high, the amount of water drunk is less than 2% of that needed to produce feed (Peden et al. 2007).

Livestock drink about 25-50 l/TLU/day, with variation dependent on many factors such as species, breed, ambient temperature, water quality, feed intake, water content of feed, animal activity, pregnancy, and lactation (King 1983). Water loss through urine and faeces also must be replaced through drinking or with the water content of feed. Water consumed is correlated with feed intake and ranges from about 3.6 to 8.5 l/kg of feed at ambient temperature below about 15^0C to 27^0C respectively. Lactating cows drink more, as much as 85 l/day for high producers. Water deprivation reduces feed intake and hence constrains weight gains, milk production, and LWP. In mixed crop-livestock systems of SSA, piped water, although expensive, delivered to the farm combined with zero grazing will increase production (Muli 2000) and LWP.

Poor management of livestock and water in pastoral areas means that watering sites are often contaminated or filled with sediments, adjacent pastures overgrazed, domestic use of the water jeopardized, and both animal and human health put at risk. Yet, perhaps the most important contribution of providing drinking water in grazing lands is the opportunity to more optimally distribute livestock, especially cattle, to make more effective use of forages without overgrazing the land. For example, one case study in Wyoming demonstrated that 77% of grazing occurred within 366 m of water and 65% of available pasture was more than 730 m from water (Gerrish and Davis 1999). In Africa, livestock watering points are often inadequate in number and sub optimally distributed and managed. In dry seasons of some areas, livestock travel for hours to reach watering points resulting significant loss of energy. In Sudan, Faki et al. (2008) indicate that achieving an optimal spatial distribution of livestock and drinking water sites can greatly increase LWP and reduce land and water degradation in large parts of the Nile basin.

5 METHODS

Objective 1: Hot spots and issues at the Nile Basin level

Spatial analyses

A multi-stage data collection and analysis process was undertaken to obtain a broad brush understanding of the spatially and temporally variable:

- Availability of water resources in the Nile Basin,
- Livestock demand for water resources for both feed production and drinking water,
- Benefits from meat and milk production as a proxy for all animal products and services because data for these other benefits were not available, and
- Livestock induced potential for land degradation through run-off driven soil erosion.

This information was used to estimate livestock water productivity (LWP). Full documentation of the methods can be found in van Breugel et al. (2010 b, 2010c). In brief, spatial analyses integrated available information on livestock diets and feed requirements, livestock densities, herd composition, livestock energy requirements, feed conversion efficiency, water requirements to produce feed from grazing land and from crop residues, livestock drinking water requirements, and spatial distribution of available water and livestock production systems.

Since the objective was to identify "hotspots" for livestock-water interactions through lens of water productivity analyses, we defined hotspots to include "development domains" where intervention options could improve LWP through better management of livestock, water and pasture resources and through improved marketing of livestock products. The development domains were defined on the basis of livestock distributions and densities, access to markets, and human population densities.

Unlike conventional approaches to assessing crop water productivity, we attempted to consider the concept of water depletion through discharge or runoff. The need for this arises when upslope catchments or watersheds lose water to downstream areas. From a basin perspective, LWP does not include internal runoff processes, but upstream loss may result in a downstream gain. For example, rainwater discharged from the Ethiopian highlands leads to lower upstream LWP, but it contributes to basin scale LWP if used downstream in Sudan or Egypt. Publication of detailed methods for this analysis are anticipated in a future publication by van Breugel et al. (2010a). In brief, spatial analyses of the Nile basin livestock induced soil erosion potential were carried using the Universal Soil Loss equation (USLE) that depends on rainfall erosivity, soil erodibility, slope, accumulation areas, and vegetative cover. The GIS tool used came from the Grass Development Team (2007). The results for the Nile basin were mapped and compared to the Global Assessment of Human Induced Soil Degradation (GLASOD) data base. Hotspots for livestock-induced erosion (and runoff) were identified and after overlaying the erosion potential map on the livestock density data and relating this to animal demand for feed. In essence, we need to know where overgrazing would lead to excessive runoff and would likely cause sedimentation of downstream or downs-slope water bodies.

Hydrology

Because livestock production systems cover most of the Nile Basin, these systems inevitably play a key role in river basin hydrology. PN 37 considered basin-wide hydrology by linking livestock-water interactions to precipitation and evapotranspiration in the livestock production systems.

Gender, policy, institutions

PN37 set out to mainstream gender analyses within all aspects of the project. The first step was the development of a gendered sustainable livelihood framework relevant to integrated livestock and water management and the methodology and its application in Ethiopia are described in van Hoeve and van Koppen (2005). Gender was also actively considered in PN37 in Uganda's Cattle Corridor (Oyesegire 2009) and in the Central Belt of Sudan through collection of gender disaggregated data or observation and expert opinion. At the basin, level a simple questionnaire was distributed to researchers in Uganda, Ethiopia, and Sudan describe gendered access to, control of, and benefits from livestock and related use of natural resources including water. This simple analyses documents researchers' perception but does not constitute a formal or long term field based survey based on quantitative data.

Policy and institution analyses were based on available literature, knowledge from key informants and insights emerging from researchers involved in CPWF research in the Nile Basin. The output for this component of the basin-wide analysis is presented as a review based on a larger document being developed by Tilahun Amede and scheduled for publication in 2010.

Objective 2: Technologies, practices and policy: National and sub-national levels

Ethiopia, Sudan and Uganda are very different countries. However, livestock production within their parts of the Nile basin is common to all all-be-it in diverse production systems. Each of these three country teams employed somewhat different approaches to assessing LWP due to differences in data availability, landscapes, farming systems, and country priorities, and the composition their groups. Nevertheless, all organized their research around the integrative livestock water productivity assessment framework (Figure 1). Each approach is described separately, but the reader is referred to source documents for more details of the methodology (Alemayehu et al., 2008b; Faki and Peden, 2010; Haileslassie et al., 2008, 2009 a, 2009b; Mugerwa, 2009; Owoyesigire 2009; Zziwa, 2008).

Ethiopia

Several tributaries of the Nile flow out of Ethiopia. This research focused on the Blue Nile sub-basin or Abbay as it is known in Ethiopia. The Ethiopian Agricultural Research Institute (EIAR) took responsibility for conducting field based research in the Gumera watershed while ILRI undertook complementary studies in the same area and integrated these field based studies with others to give an overview of the important role of the Ethiopian Highlands in terms of livestock-water interactions. Please refer to the source documents for details of the methodology.

Alemayehu et al. (2008b) undertook a yearlong survey of farming households in the Gumera watershed located on upslope from the Eastern shore of Lake Tana at the source of the Blue Nile River. This study area is a hotspot for livestock-water interaction and ranges from 1700 MSL to about 3800 MSL. Production in the lower areas is based on rice farming. In the mid elevations, crops are dominated by teff, finger millet, wheat and maize. The higher elevations are characterized by barley, triticale, potatoes and highland pulses. Livestock are important in all three areas. Twenty smallholder farmers were surveyed in each of these farming systems on a year-round basis to estimate animal production, income from sale of animal products, and land use patterns, crop yields (grain and residues). LWP at household scale was estimated for each farming system, but water depletion excludes run-off. Alemayehu et al. (2008b) also assessed runoff (discharge) and soil erosion from the farmers' fields in each of the three farming systems. In the grazing areas, estimates were made on pastures that were communally owned with unrestricted grazing, communally owned with enforced by laws restricting grazing, and privately tenured pastures. Runoff and erosion were compared to runoff from cultivated land.

Haileslassie et al. (2009a, 2009b) assessed LWP in the Gumera Watershed mentioned in the previous paragraph but worked at a watershed scale. Detailed methods are given therein. In brief, these researchers developed the methodology for assessing LWP based on surveys of farming households and use of secondary watershed level data. They estimated the value of crops (grains and residues) and livestock products and services (meat, milk, traction, and manure). They based estimates of water depletion on evapotranspiration (ET) from croplands. They categorized participating farmers through participatory wealth ranking and then described spatial variability of

LWP in terms of differences associated with production systems and wealth or level of poverty. In a third study, Gebreselassie et al. (2009l) used existing feeding trial data from ILRI's Debre Zeit research station in Ethiopia to determine how dietary composition and animal breed and weight affect LWP. Methodological details are given Gebreselassie et al. (2009).

Sudan

Sudan's Central belt includes pastoral, agro-pastoral, mechanized, and non-mechanized rainfed mixed crop-livestock systems and irrigated mixed crop-livestock farming as well as periurban animal production especially around Khartoum. As part of PN37, research in Sudan focused on the country's Central Belt. There were two components, one led by the Agricultural Economics and Policy Research Center (AEPRC) with the Agricultural Research Corporation, and the other by the Animal Resources Research Corporation (ARRC). Both ARC and ARRC operate within the jurisdiction of the Ministry of Science and Technology. Research undertaken by ARRC focused on human health risks associated with water while the AEPRC undertook a broad range of research on livestock-water interactions within the Belt. This included household surveys in North Kordofan, Butana/Gederef, Gezira and Managil using a structured questionnaire with samples ranging from 75 to 105 households in different areas for a total of 361. Household heads were interviewed on aspects related to livestock production including those on feed, water, gender and resource competition. Details of the methods and study areas are contained within several publications (Faki and Peden 2010, Fathelbari and Musa 2008, Goreish and Musa 2008). The results presented in this paper constitute a brief summary of their work, but readers are encouraged to refer to source documents. In brief, AEPRC addressed the following topics:

- Overview of livestock-water issues and interactions in the Sudan.
- Characterization of Sudan's Central Belt based on spatial analyses by ILRI; a large areas that includes pastoral, agropastoral, and rainfed mixed crop-livestock, irrigated mixed crop-livestock and periurban livestock systems.
- Linkages between livestock and poverty with gender disaggregated consideration of gendered access to water resources.
- Community and higher level institutional arrangements governing water use by and allocation for livestock and other demands for water.
- Characterization of livestock-water productivity including water requirements for livestock.
- Analysis of production opportunities and constraints related to water use by livestock in selected locations within the Central Belt:
    - Kordofan pastoral rain-fed systems
    - Gezira-Managil Irrigation scheme.
    - Butana/Gederef rainfed mixed crop-livestock systems.
    - Characterization of the magnitude and factors affecting competition for water and consequent conflict linked to water use by crop and livestock producers.
    - Characterization of allocative water efficiency related to livestock-water interactions.
    - Intervention options to improve water resource use efficiency and allocation.

In addition, ARRC undertook studies in health risks associated with shared human and animal use of water resources in two case studies in Sudan. Fathelbari and Musa (2008) assessed the effect of chemical and microbiological contamination of open dug wells, water harvesting systems (hafirs), boreholes, springs and pools in Al State, and the detailed methods are available in this paper. Goreish and Musa (2008) examined the prevalence of snail-borne diseases in irrigated areas of the Sudan, and the detailed methods are available in this paper.

Uganda

The White Nile River flows northward out of Lake Victoria through one of Uganda's most impoverished regions where limited access to water keeps many poor trapped in poverty and efforts to sustain livelihoods leads to widespread land degradation. This is the Cattle Corridor that stretches from the north-eastern region bordering on south-eastern Sudan to the Southern District of Mbarara. Makerere University's Department of Animal Science led PN37 research in Uganda.

The results reported herein emanate from three Master's theses and the detailed methodology is reported therein (Mugerwa 2009, Zziwa 2009, Owoyesigire 2009). These individuals addressed key issues of land and pasture management, water management, and socio-economic studies in a systems concept at the scale of small watersheds that included human-made water harvesting systems known as valley tanks, upslope pastures and other vegetation including some crops, livestock production and local inhabitants and water users. Detailed methodology for each is found in their respective theses. The three students combined efforts to assess LWP based on concepts captured in (Figure 1).

Mugerwa (2009) conducted field experiments to assess the potential for reseeding and fencing of degraded upslope pastures for the purpose of increasing livestock production and protecting downslope valley tanks. After the first season of data collection, Mugerwa found the termites completely destroyed reseeded pastures. Consequently and following suggestions from supervisors and colleagues he included a third treatment that involved manuring the plots before reseeding was done. His trials ran for two wet seasons and two dry seasons in 2007 and 2008. This study involve estimates of baseline soil chemical composition and changes therein, botanical composition, dry matter production and growth rates, species richness and vegetative ground cover.

Zziwa (2009) conducted field studies of soil erosion, run-off, sedimentation and water availability (quantity and quality) in eight valley tanks. Upslope areas compared were un-vegetated catchments, vegetated catchment, vegetated gullies and open gullies. Aquatic vegetative cover of the valley tanks consisted of *Azolla*, *Lemna*, *Pistia* and *Nymphaea sp*. The studies were conducted from November 2006 to October 2007. All micro dams were used for watering livestock with attached watering troughs, noting that may nearby valley tanks where animals physically entered the water to drink all had higher levels of contamination than those studied in this project. The amount of drinking water consumed by the livestock was measured along with evaporation and precipitation. Water quality estimates of NO^-_2, NO^-_3, NH^+_4, TN, TP, TDS (mg/L) and Turbidity (FAU) were made.

Owoyesigire (2009) conducted surveys of 183 household in Nakasongola and Kiruhura Districts, Uganda, backed up by key-informant information gathering to obtain information on general household characteristics, herd size & ownership, benefits from livestock, crops grown, amount of water consumed, issues of overgrazing,water sources and challenges faced in managing them. Comparisons of the LWP based on differences in resource ownership, gender, and livestock type with in pastoral communities were made.

6 RESULTS

Objective 1: Hot spots and issues at the Nile Basin level

Nile Livestock production systems

Livestock production systems, modified from Seré and Steinfeld (1996), vary greatly across the Nile Basin (Table 1, Figure 2). They are categorized on the basis of aridity, length of growing season and land use. In addition, some land has been designated as "other" signifying land that was not used for. This includes wetlands that may in fact seasonally include animals. Throughout this report, unique letter codes designate each system (Table 1).

One prime characteristic of the Nile Basin is that livestock grazing is the dominant land use occupying about 60% of the total land areas. However, the extremely dry hyper arid systems that cover about 31% of the northern third of the basin have few animals. The extensive less arid grazing systems are mostly in the central and western areas. Mixed crop-livestock systems cover about one third of the basin, mostly found in the Southern half. Irrigated systems cover only a small area, probably less than 2% of the basin, but the methods used in this study cannot give precise estimates. These irrigated areas generally are associated with high livestock numbers and are thus classified as mixed-crop livestock systems, a unique concept not normally characteristic of irrigation management. This study suggests that as much as 99% of the land has rainfed livestock production. However, livestock densities are so low in hyper-arid and other areas (Table 2) that many observers would not classify this land as being agricultural in nature. Taking into account only arid, temperate and humid production systems, rainfed agriculture covers about 60% of the basin's land area.

Table 1. Unique letter codes and major characteristics of livestock production systems (Figure 2) in the Nile River basin.

Unique code	Area (km^2)	% of basin land area	Aridity	Length of growing season (days/year)	Land use
LGHYP	935,132	31.2	Hyper arid	0<1	Rainfed Livestock grazing
LGA	758,593	25.3	Arid-semiarid	1-180	Rainfed Livestock grazing
MRA	608,547	20.3	Arid-semiarid	1-180	Rainfed Mixed crop-livestock
MRT	228,005	7.6	Temperate	>180	Rainfed Mixed crop-livestock
MRH	155,575	5.2	Humid	>180	Rainfed Mixed crop-livestock
LGH	123,618	4.1	Humid	>180	Rainfed Livestock grazing
MIHYP	35,322	1.2	Hyper arid	0<1	Irrigated Mixed crop-livestock
LGT	13,749	0.5	Temperate	>180	Rainfed Livestock grazing
MRHYP	6,381	0.2	Hyper arid	0<1	Rainfed Mixed crop-livestock
MIA	2,842	0.1	Arid-semiarid	1-180	Irrigated Mixed crop-livestock
MIT	0	0.0	Temperate	>180	Irrigated Mixed crop
MIH	0	0.0	Humid	>180	Irrigated Mixed crop
OTHER	110,512	3.7	Various	Variable	Wetlands, forest, park, etc.
Urban	20,170	0.7	Various	Not relevant	>450 people km^2
Total land area	**2,998,446**	**100.0**			**Basin mosaic of land uses**

Table 2. Estimated populations and densities of sheep, goats, cattle and people within production systems defined in Table 1.

LPS	Land area (km^2)	Number (millions)				Mean density (no/km^2 ± s.e.)			
		Sheep	Goats	Cattle	People	Sheep	Goats	Cattle	Human
LGHYP	935,132	2.7	1.9	2.1	5.5	3	2	2	6
LGA	758,593	15.2	12.6	17.1	9.4	20	17	22	1
MRA	608,547	16.1	14.2	22.3	18.3	26	23	37	30
MRT	228,005	5.0	4.1	13.0	35.0	22	18	57	15
MRH	155,575	1.1	3.3	6.1	20.8	7	21	39	134
LGH	123,618	1.7	1.7	1.2	.8	14	14	10	7
OTHER	110,512	0.8	1.0	1.8	6.4	7	9	16	58
MIHYP	35,322	1.8	1.3	2.3	32.7	51	34	64	926
URBAN1	20,170	0.7	0.8	0.8	43.5	34	41	38	2,156
LGT	13,749	0.2	0.3	0.3	.2	15	20	23	15
MRHYP	6,381	0.1	0.1	0.1	.4	17	21	11	57
MIA	2,842	0.1	0.1	0.2	.2	31	32	63	86
TOTAL	**2,998,446**	**45.4**	**41.5**	**67.2**	**173.2**	**15**	**13**	**22**	**58**

- Average human population densities are considerable higher when only the core urban areas, i.e., the urban areas as defined by GLC2000, are taken into consideration (6250 no/km2). Average sheep and especially cattle densities on the other hand are considerable lower in these core urban areas (respectively 20 and 13 no/km^2).
- Livestock densities are from the FAO modelled livestock densities (FAO 2005), human population densities from CIESIN (2004).
- These figures are estimates based on models for **only** the Nile basin part of riparian countries. Some differences exist between these figures based on FAO data and estimates provided by riparian governments. There is need for a basin-wide livestock census based on standardized methodology.
- “s.e.” is the standard error of the estimated mean density

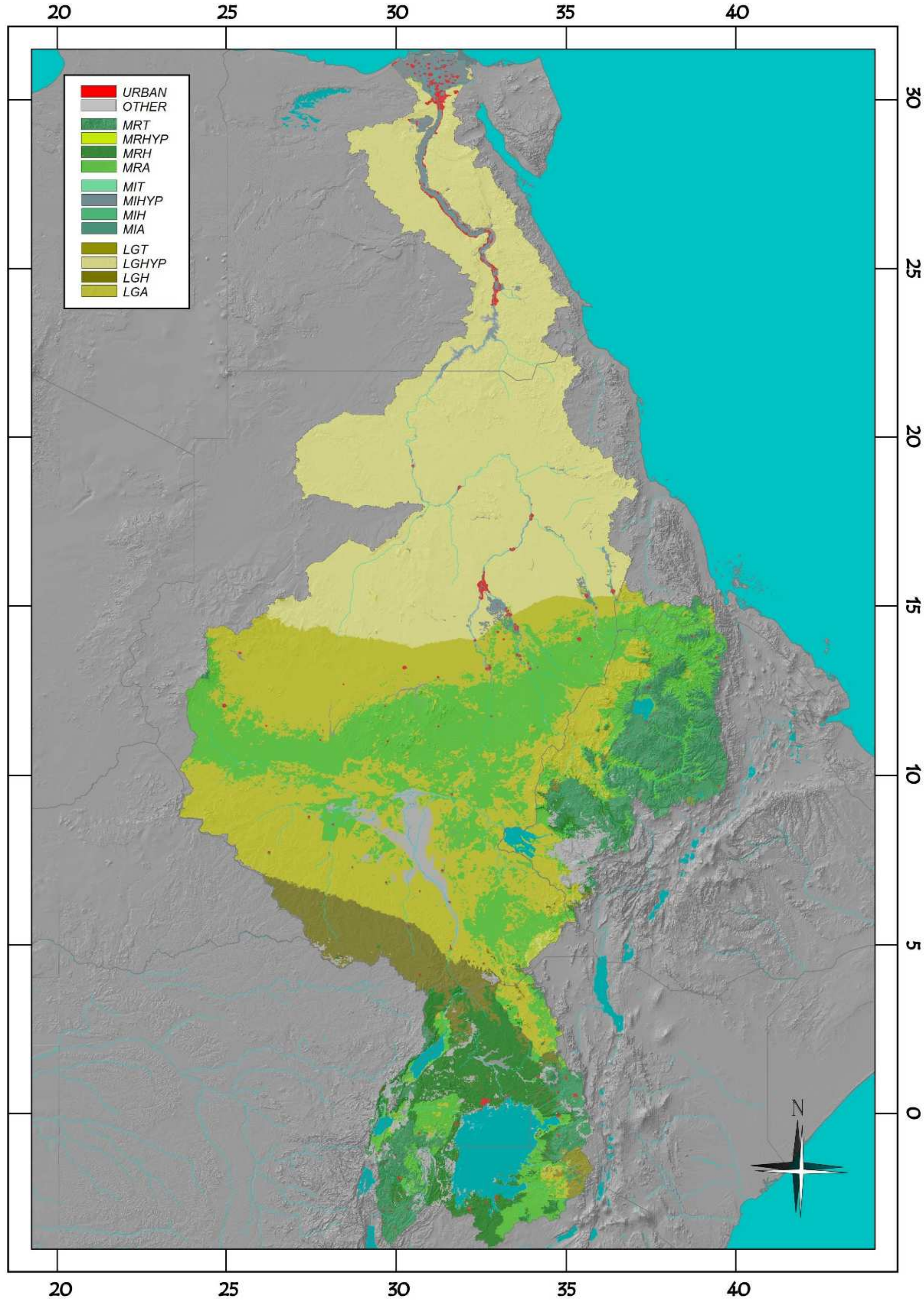


Figure 2. Livestock production systems in the Nile basin, overlaid on a shaded relief map to give an idea of the distribution of the livestock production systems relative to the major topographic features in the region.

Nile Basin Livestock populations

The Nile Basin is home to millions of livestock including cattle, sheep, goats, equines, swine, poultry and buffalo Table 2, Table 3 and Table 4). In total, domestic animals outnumber the 173 million people residing in the basin. Numerically, cattle, sheep and goats are most common. In terms of production systems, the lowest densities of livestock occur in extensive and dry rangelands or grazing areas while the highest animal densities are associated with the large scale irrigation and high concentrations of people. Livestock and human numbers and densities vary greatly among riparian countries. Sudan has more livestock within the Nile Basin than any other riparian country, but it also has the lowest density of both people and animals. Some of the less common animal species are concentrated in small parts of the basin. For example, buffalo are only found in Egypt, camels are mostly widespread only in Sudan while Uganda has the most swine. Because livestock vary greatly in size, we show the distribution of livestock densities in terms for tropical livestock units (TLU) where one TLU represents 250 kg animal live weight (**Error! Reference source not found.**). In brief, the highest overall TLU densities are found in the Nile Delta and in the southern half of the basin, especially in the Central Belt of Sudan, the Ethiopian highlands and in the areas surrounding Lake Victoria.

Table 3. Estimated populations and densities of sheep, goats, cattle and people within the basin part of Nile riparian countries that have been ranked according to human density.

Country	Land area (km^2)	Number (millions)				Density (no/km^2)			
		Cattle	Sheep	Goats	People	Cattle	Sheep	Goats	People
Rwanda	20,681	0.74	0.24	0.83	6.25	36	12	40	302
Burundi	12,716	0.19	0.11	0.46	3.61	15	9	36	284
Kenya	47,216	4.19	1.41	1.58	12.14	89	30	34	257
Egypt	285,606	2.78	3.06	1.97	64.85	10	11	7	227
Uganda	204,231	4.97	1.25	2.97	23.35	24	6	15	114
DR Congo	17,384	0.06	0.03	0.10	1.96	3	2	6	113
Tanzania	85,575	5.51	0.76	2.89	7.38	64	9	34	86
Ethiopia	361,541	13.96	5.39	3.72	25.38	39	15	10	70
Eritrea	25,032	0.85	0.73	0.83	01.14	34	29	33	46
Sudan	1,932,939	33.89	32.21	26.07	27.18	17	17	13	14
Total	2,992,921	67.13	45.17	41.41	173.23	22	15	14	58
Numbers are based on the FAO modelled livestock densities (FAO 2005 a, b, and c). There are differences in estimated livestock populations for some areas. These figures are estimates based on models for **only** the Nile basin parts of riparian countries. There is need for a basin-wide livestock census based on standardized methodology.									

Table 4. Estimated densities of pigs, poultry, equines, camels, and buffalo within the basin part of Nile riparian countries that have been ranked according to human density.

Country	**Number (X1000)**				
	Swine[1]	Poultry[2]	Equine[3]	Camel[4]	Buffalo[s]
Rwanda	335	74	-	-	-
Burundi	42	199	-	-	-
Kenya	47	270	-	8	-
Egypt	8	272	1,127	35	2,113
Uganda	1,939	86	13	-	-
DR Congo	23	4	-	-	-
Tanzania	21	120	13	-	-
Ethiopia	12	50	850	73	-
Eritrea	2	11		14	-
Sudan	617	18	420	2,029	-
Total	**3,046**	**1,104**	**2,423**	**2,137**	**8,710**
	Density (no/km^2)				
Rwanda	16.2	1,532	-	-	-
Burundi	3.3	2,532	-	-	-
Kenya	1.0	12,733	-	1.6	-
Egypt	<1	77,743	4.0	<1	65.7
Uganda	9.5	17,618	<1	-	-
DR Congo	1.3	68	-	-	-
Tanzania	0.2	10,269	<1	-	-
Ethiopia	<1	18,124	2.4	<1	-
Eritrea	0.1	276		<1	-
Sudan	<1	34,371	<1	<1	-
Total	**1.0**	**0.4**	**0.8**	**0.7**	**0.7**

Notes: Numbers are based on the FAO modelled livestock densities (FAO 2005 a and b). National estimates from GLIPHA (2008). There are differences in estimated livestock populations for some areas. These figures are estimates based on models for **only** the Nile basin parts of riparian countries. There is need for a basin-wide livestock census based on standardized methodology. . Camels are predominantly found in the arid and semi-arid zones where cropping is rare or intermittent (de Leeuw and Rey 1995, Ahmed et al. 2003, Le Houérou 1980). For each country we assumed the proportion of camels occurring within the Nile basin boundaries to be equal to the proportion of the arid and hyper-arid lands in a country to fall within the basin' boundaries. Buffaloes were assumed to live in the irrigated areas only. The proportion of the number of buffaloes in Egypt was assumed to be equal to fraction of the irrigated areas falling within the boundaries of the Nile basin. “No data” is indicated by “-“ and assumed to be zero.

provides estimates the volume of water required to produce feed for maintenance for cattle, sheep and goats combined in ten main production systems and the ten riparian countries and for the whole basin. Figure 3 shows the spatial distribution of this water use. In total livestock need about 68 billion m^3 for feed production in the Nile Basin. About 63.5% (43 billion m^3) of the water used for feed lies in Sudan, the largest country with the largest livestock population (Table 5). Ethiopia follows a distant second with about 12 billion m^3 being used. Kenya, Uganda and Tanzania follow with about 3 billion m^3 each being used within the Nile Basin. These figures are based on evapotranspiration but exclude runoff or downstream discharge from the production systems, an issue dealt with later in this report. About 40 billion m^3 (60%) are used in the arid-semiarid grazing and mixed crop-livestock systems (LGA & MRA) areas of the basin.

Table 5. Total water for livestock (cattle, goats and sheep) feed production by country and livestock production system (million m^3/yr) within the Nile Basin and based on maintenance plus additional energy requirements.

	LGA	LGH	LGHYP	LGT	MIA	MIHYP	MRA	MRH	MRHYP	MRT	Total
Sudan	20,459	14,167	6112	6	161	277	14,481	8	55	21	42,994
Ethiopia	857	26	-	48	-	-	2,203	204	-	8,464	11,800
Kenya	4	1	-	140	-	-	163	786	-	2,218	3,312
Uganda	183	136	-	13	-	-	490	1,708	-	576	3,105
Tanzania	103	9	-	71	-	-	777	1,835	-	121	2,915
Egypt	-	-	327	-	-	1359	-	-	4	-	1,690
Eritrea	253	-	2	4	-	-	579	-	-	121	958
Rwanda	-	-	-	-	-	-	127	80	-	466	673
DR Congo	-	3	-	-	-	-	4	14	-	20	418
Burundi	-	-	-	-	-	-	1	26	-	191	219
Total	21,859	1591	6,441	280	161	1,636	188,238	4,660	59	12,198	67,706
Note: Estimations are based on the premises that water depletion for crop residues is already accounted for and therefore is not included in the livestock water requirement calculations. Note: Peri-urban livestock are not included in this table.											

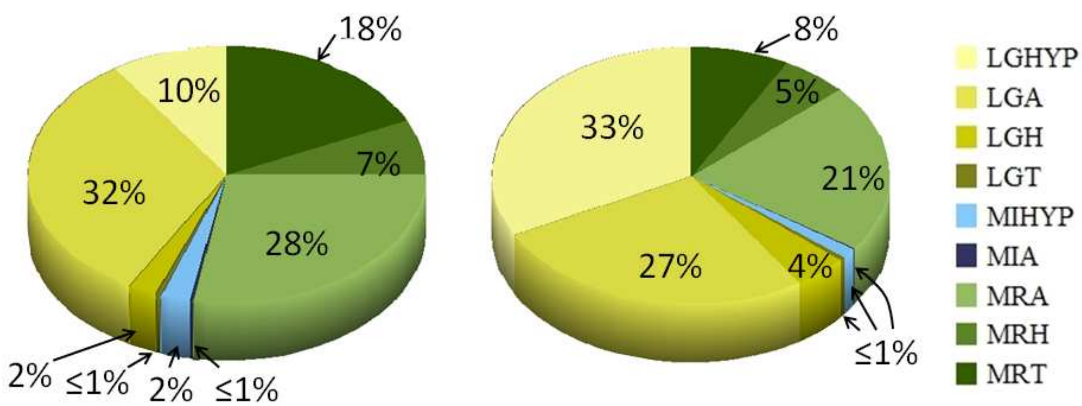
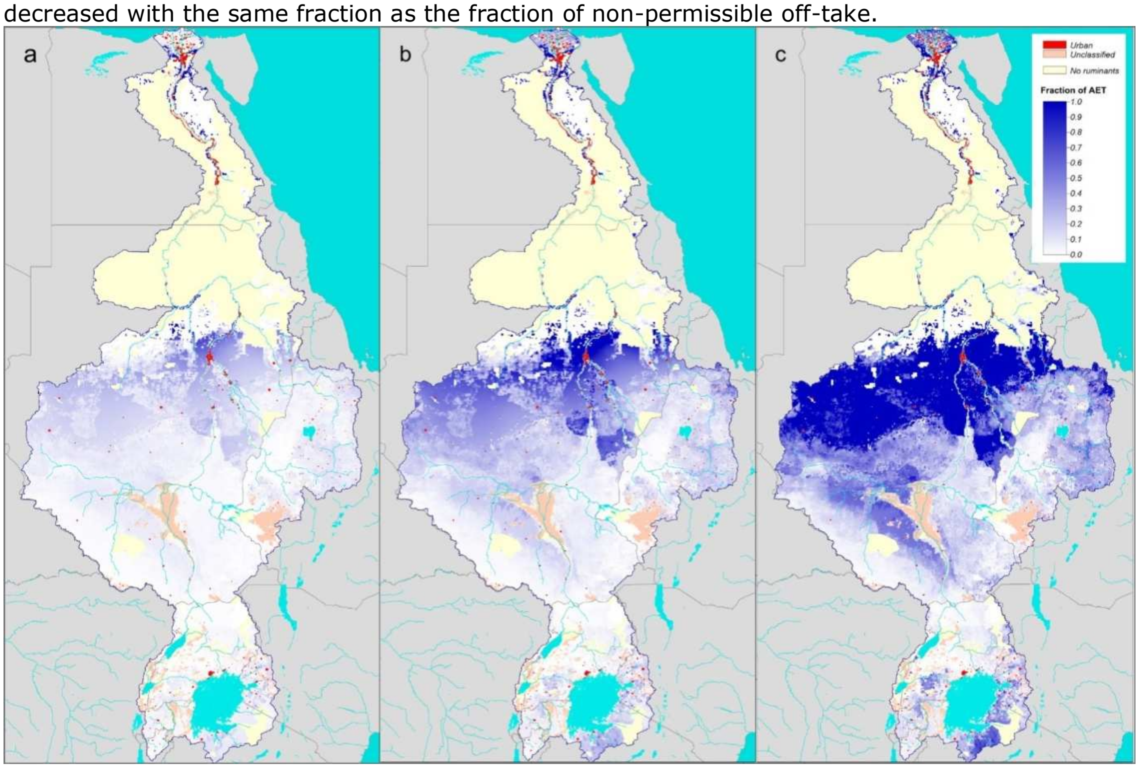


Figure 3. Comparison of percent of water within major production system used for feed production (left) with percent of basin land covered (right) by these systems in the Nile Basin.

Figure 4. (a) Total annual livestock water use (cattle, goats and sheep) expressed as fraction of the total annual evapotranspiration. This excludes water for residues and crop by-products; (b) The same but accounting for water for non-consumable biomass and including water for residues;

(c) Like b, but assuming a maximum permissible off-take (see text), whereby total available AET is decreased with the same fraction as the fraction of non-permissible off-take.



Source: Rainfall data came from CRU climate data base (New et al. 2002).

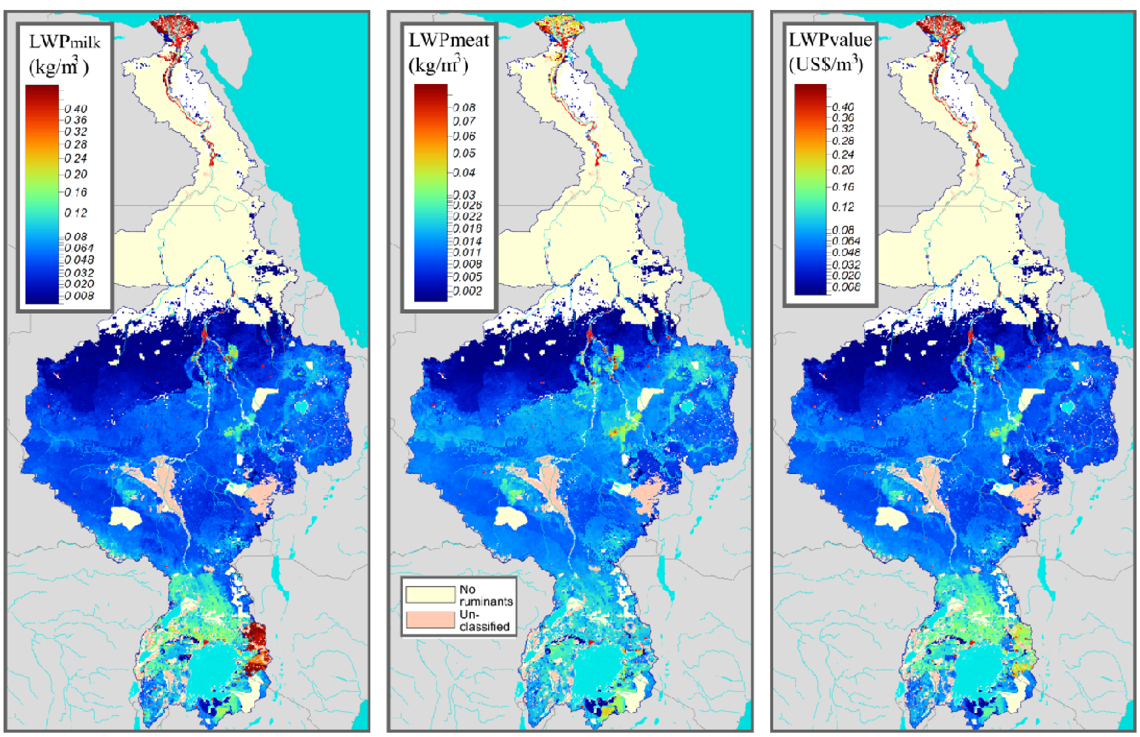


Figure 5. Similar to Figure 4 but assuming a decrease in AET proportional to the difference between rainfall in an average and low-rainfall year.

The relative distribution of basin water used for providing animal feed differs from the distribution of basin land area among production systems (Figure 3). The hyper arid grazing areas (LGHYP) cover about one third of the basin but account for only 10% of the water used for feed. In contrast, the temperate mixed crop-livestock systems (MRT) occupy about 8% of the land area but account for about 18% of the water used for animal feed. In the semi-arid grazing and rainfed mixed crop-livestock systems (LGA and MRA), relative water use is about the same as the relative land area covered by these systems. Although small in absolute area, the relative water use for feed is higher than the relative land area covered in the irrigated mixed systems. These results suggest livestock production will likely place greater demand on agricultural water where production systems are undergoing intensification.

Livestock water productivity (LWP)

Van Breugel et al. (2010b, 2010c) describe the data gaps in the Nile Basin. As a proxy for total livestock water productivity (LWP), they report the estimates for meat and milk, but ignore other animal products and services such as traction, cultural values and hides. Based on this proxy, economic LWP (USD/m^3) varies greatly among production systems (Table 6). The highest LWP values are found in the irrigated mixed crop-livestock systems in hyper arid areas MIHYP. In terms of income, all other production systems showed LWP being 16% or less of the MIHYP estimate. Overall, LWP for milk was much higher than for meat. In considering LWP for milk, the results demonstrate the importance of the scale of analyses. LWP_{lact} for individual lactating animals was much higher than that of the herd to which they belong although this difference appears to be less in the irrigated areas in the northern half of the basin (MIHYP).

The spatial distribution of LWP for meat, milk and income is shown in Figure 6. The highest LWP is found in the Nile Delta region, in scattered small areas around Khartoum and Lake Victoria. The lowest values occur over vast regions of most of the Southern Nile. There is a 40-50 fold difference between the lowest and highest observed estimates of LWP.

Table 6. Estimated livestock water productivity[1] for goats, sheep and cattle combined per livestock production system and ranked left to right by LWPincome.

LWP Parameter[2]	MIHYP	LGT	MRT	LGH	MRA	MRH	LGA	MIA	LGHYP	Basin
LWPmilk (kg/m^3)	0.526	0.082	0.079	0.064	0.050	0.057	0.026	0.041	< 0.001	0.037
LWPlact (kg/m^3)	0.626	0.752	0.784	0.413	0.336	0.480	0.085	0.342	0.002	0.213
LWPmeat (kg/m^3)	0.068	0.011	0.010	0.012	0.014	0.011	0.008	0.013	0.001	0.008
LWPincome (USD/m^3)	0.488	0.077	0.073	0.067	0.062	0.061	0.034	0.006	0.004	0.042
Estimates are based on the premises that water depletion for crop residues is already accounted for within crop production and therefore does not enter the LWP calculation. See text for explanation of the differences between the LWP parameters. Basin estimates derived after weighting production systems estimates by their respective areas within the basin.										

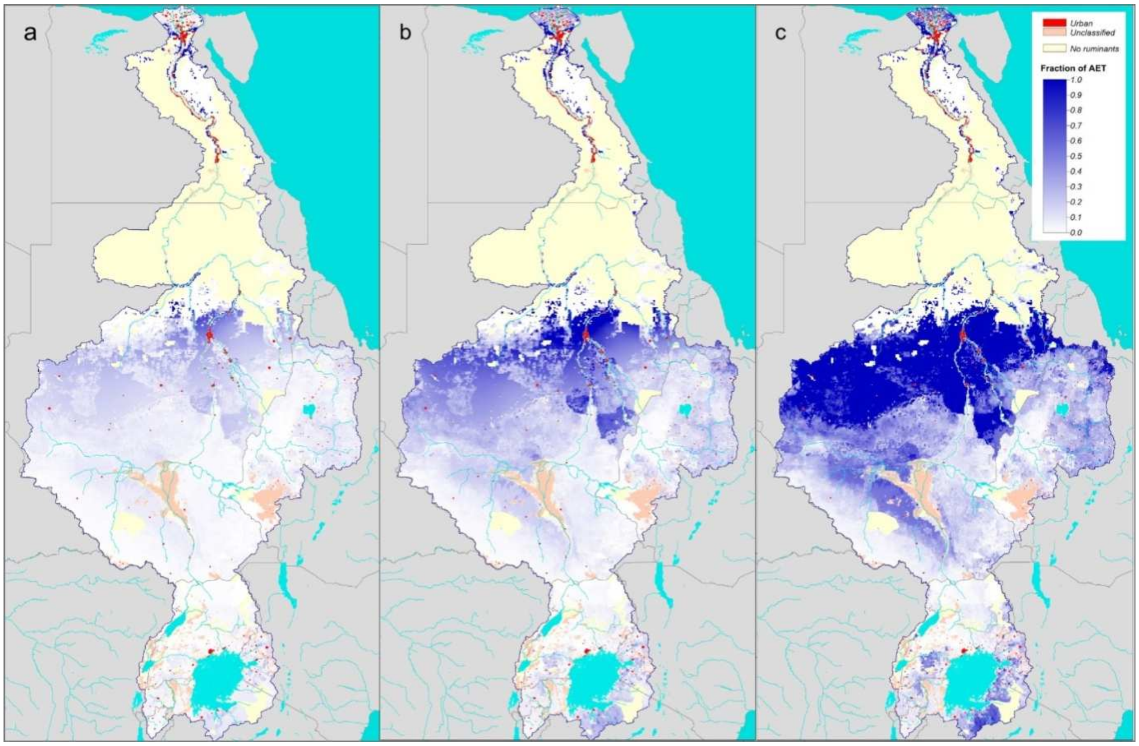


Figure 6. Livestock water productivity expressed as (a) the ratio of summed value of produced meat and milk and the water depleted to produce the required livestock feed, (b) ratio of meat production and depleted water, and (c) ratio of milk production and depleted water.

Livestock- induced soil erosion

The foregoing estimates of livestock water productivity do not take into account the water depleted from areas within the basin due to agriculturally related land degradation that enhances local runoff and soil erosion and consequently downstream sedimentation and flooding. At basin level, this will not affect LWP (or overall agricultural water productivity) as long as the excessive local discharge does not reach the Mediterranean Sea or not contribute to lower production at its source. However, soil erosion and discharge cause locally important loss of water productivity and may do so downstream unless the soil and water can be captured and re-used.

In general, the greatest risk of erosion and associated runoff in the Nile basin occurs in the Ethiopian and Southwest Ugandan highlands (
Figure 7). This risk is common on overgrazed land and along trekking routes that are often hotspots for vegetative loss and associated erosion and run-off. One major consequence is reduced infiltration and soil moisture that constrain pasture production and thus water productivity. Taking into account both absolute livestock densities and feed-water balances tends to confirm generally high erosion risk in Ethiopia. We hypothesize that in the absence of effective downstream water storage structures, this run-off will not contribute to downstream agricultural production.

In mixed crop-livestock systems, inappropriate cultivation may be equally or more important as a determinant of erosion and run-off. The observed feed supply and demand balance suggest that the potential for livestock induced erosion is quite widespread and uniform across much of the southern half of the basin in relative terms.
Figure 8 shows the distribution of areas with flood risk that imposes constraints on downstream users. The hotspots for livestock induced flood risk are found in heavily populated and irrigated areas around Khartoum, adjacent to some of shoreline of Lake Victoria and the Nile Delta. This study has not measured the degree to which this risk has led to loss by downstream users from upstream livestock keeping practices. Furthermore, locally important areas of livestock induced soil erosion (particularly around drinking water sites) are not shown on maps at the scale used in Figure 8.

Policies and Institutions

In the Nile basin, the majority of the rural population is engaged in mixed crop-livestock farming. In the rangelands, where the potential for rainfed or irrigated agriculture is limited, livestock form the basic means of subsistence and livelihood. However, the overall awareness of policy makers and planners as well as donors as to the role of livestock and their keepers appears to be modest.

A review on the nature, functions and gaps of organizations, policies and institutions in the three riparian countries (Ethiopia, Sudan and Uganda) indicated that the organizational setup affecting livestock and water stretches from national level policy and strategy making, to ministerial offices, to local micro-planning and implementing offices. The concept of national versus local is the major difference among the three countries. In Ethiopia and Sudan, local organizations are responsible to sub-national (regional) organizations that, except for few strategic national issues, are relatively autonomous to plan and execute their own priorities. The local organizations in these two countries serve as implementing partners to their respective regional superiors. In Uganda, there is only a single step from national to district/local government. Due to this shortcut, districts have relatively broader planning and policy influencing capacity to affect the livestock-water agenda. However, in the case of livestock, the policies initiated in all the three countries are national in nature and lack local input in their build up. Perhaps with varied intensity, the three countries have non-governmental organizations (NGOs) and community based organizations (CBOs) directly and indirectly working in livestock and water related issues. Traditional institutions are particularly active in resolving livestock and water related conflicts arising from competing land and water uses by different clans and ethnic groups within a boundary.

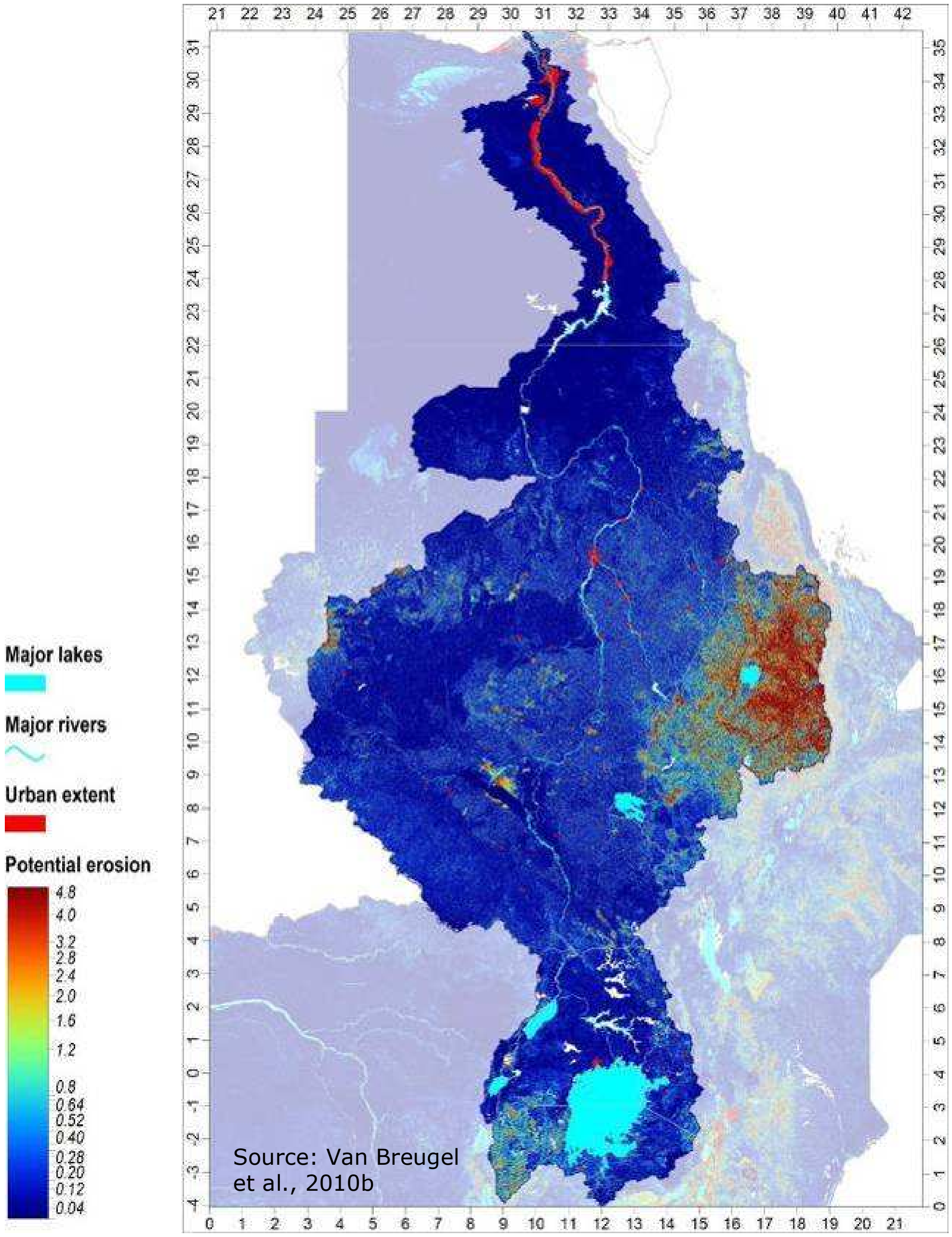
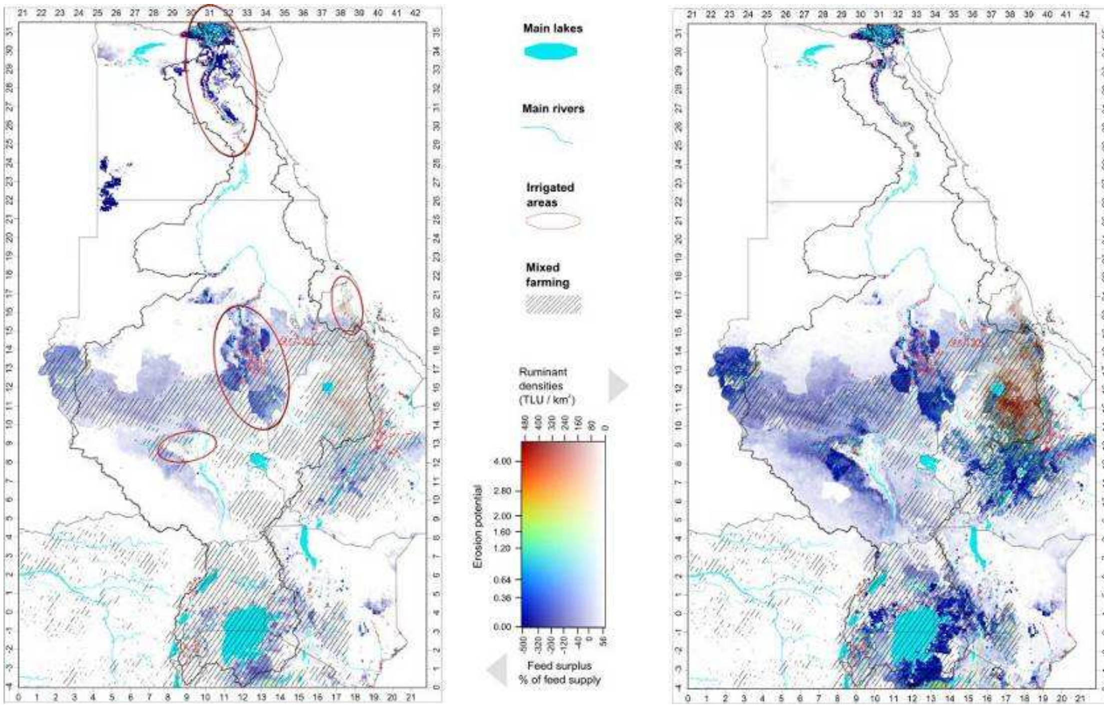


Figure 7. Relative potential surface water erosion risk from all causes in the Nile Basin.



Source: Van Breugel et al. 2010b

Figure 8. Potential surface erosion and flooding risk taking into account livestock densities (right) and feed surpluses (left) in the Nile Basin.

Policy and institutional gaps in livestock and water management are identified both at basin and case-country level. At basin level, the major obstacle facing livestock use and management is weak institutional capacity to enforce them. The escalating emergence of transboundary issues also calls for coordinated monitoring and evaluation of the impact of current livestock policies and institutional arrangement at basin level. The establishment and maturation of the Nile Basin Initiative (NBI) is an encouraging development. Given the importance of livestock, there is need to link the NBI to organizations and policy involving animal production. In particular, opportunities exist to strengthen several NBI projects such as the Socio-economic Development and Benefit Sharing (SDBS) Project, the Efficient Water Use for Agricultural Production (EWUAP) Project, and the Nile Transboundary Environmental Action Project (NTEAP). There are three key entry points. First livestock and animal products migrate and are traded widely in the basin, often without government regulation related to sharing economic benefits and controlling disease. Second, CPWF research demonstrates that integration of livestock into large scale irrigation development increases sustainability and investment returns. Third, overgrazing often aggravates inappropriate cropping practices and thereby generates negative transboundary environmental impacts.

Similarly, in October 2009, the Association for Strengthening Agricultural Research in Eastern and Central Africa called for proposals (http://www.asareca.org/resources/reports/NRMFCN1.pdf) for research on *Enhancing Water Productivity for Improved Smallscale Farming and Agro-Pastoralism in Eastern and Central Africa*. Such initiatives suggest potential benefits could accrue from greater collaboration in future.

At the case-country level, a range of policy and institutional gaps are reviewed. Livestock policies lack a comprehensive approach for development of the sector. Despite its contribution in enhancing economic and social well-being in the basin, livestock remain a subsidiary sector and all possible interventions, policies and plans are subordinated to other sectors such as water and crop production. In addition, policies for livestock development are poorly provided, biased towards commercialization and have very little to do with alleviating poverty. Livestock research in general and livestock-water interaction in particular remain rudimentary in national policy. Improving livestock water productivity is barely mentioned in national livestock policies of all. The existing livestock and animal feed policies lack in-depth analysis of the steps that have to be taken to improve efficiency of livestock water use. However, the policies aimed at providing livestock services (e.g. veterinary care in Sudan) are progressive and can be viewed as a potential basis for improvement. In Sudan, the Animal Health and Disease Control General Directorate runs three departments consisting of Animal Health, Epizootic Disease Control and Veterinary Public Health. The gaps in this directorate are the inability to creating accessible and affordable service to poor and distant pastoralist communities which constitute majority of livestock owners.

Generally, in spite of the fact that the livestock sector has not received enough attention, there are encouraging signs where positive developments are emerging, mainly in relation to formulating policies. For instance in Uganda, major policy actions that come into view in different times were: a) National policy for the Delivery of Veterinary Services; b) The National Veterinary Drug Policy; c) The National Meat Policy; d) Animal Feed policy; and e) Local government and district level livestock strategy. However, the main bottleneck is the absence of adequate institutions and organizations to properly enforce policies. In the case-countries, organizations related to livestock are either inadequately funded and/or politically weak compared to other sectors such as land and water. As a result, policies/provisions made at national level are poorly implemented and weekly monitored at local levels. Institutions/organizations related with livestock but dealing with broader issue such as irrigation, food security and resources management are well formulated with clear mandate and detailed terms of reference but mostly each institution pursues its own mandate with minimum coordination. There exists weak institutional arrangements and lack of requisite human, financial and material resources, and viable and clear administrative rules and regulations. This gap is more vivid at the grass roots levels where policy is not informed by clear understanding of local needs and where inadequate, fragmented and thinly distributed resources impedes policy implementation.

Although variation exists, institutions involved in livestock production such as provision of feed, water and insurance receive low attention. Secured access to these inputs is one of the key incentives that enables poor and vulnerable livestock holders to positively respond to market needs. Lack of enabling conditions for sustainable use of livestock and water is common in the three countries. There is an enormous need to shift focus from relief to development, from short-lived and quick-impact objectives to long-term, all encompassing, environmentally sustainable and consciously monitored interventions. In recent years, recurring operational needs seem to have made NGOs and CBOs lose sight of long-term development objectives. Limited coordination guiding local organizations towards integrated and sustainable water efficient livestock development prevails. Key improvement areas pertaining to livestock-water policies and institutions in the three countries include:

i. Participatory policy development (one that allows consultation with livestock keepers), with an intent to forge sound policies for guiding and leading livestock water improvement, has to be in place. There requires raising awareness of policy makers so that the livestock sector receives the attention it deserves.

ii. In Ethiopia, Sudan and Uganda, policies related to livestock are not adequate and where they exist, they are not enforced with efficient and well-authorized institutions. Adequate financial resources, legislated mandate, and effort to establish sound and efficient institutions that can facilitate the implementation is required because existing 'organizational hierarchies' characterized by vertical and horizontal linkages (particularly in Ethiopia) have mixed mandates and inadequate communications. Building an appropriate legal and regulatory framework of the livestock sector with measures to encourage the emergence of CBOs and civil society including actions to better equip them in implementing policies on the ground also remains one of the priorities.

iii. The tendency observed in the three countries is that the issue of the livestock sector is 'kick-starting' and is being mentioned in policy arenas. To promote the livestock sector in a sustainable manner, national policies and strategies need to be wary of not giving "the wrong incentives" that may relieve current shortage but end up putting pressure on land and water. Policies promoting cost-sharing arrangements are commonly effective. Responding to recurrent and more appealing needs such as strategic distribution of watering points for pastoralists need to be reviewed in light of their long term impact on land degradation, climate change and managing vulnerability.

iv. Concentration of too many herds of livestock around small watering points such in Karamoja and Nakasongola, Uganda, and in many places in Sudan could escalate into conflict, land degradation and ultimately reduce resources use efficiency. This phenomenon also affects environmentally threatened natural wetlands.

v. Proven research and development intervention options related to improved management of livestock and water need to be disseminated to end users in a timely manner. This implies a need for effective sharing of information among regional, national, and international partners.

vi. Evidence shows that good access to markets and reasonable as well as efficient taxation systems are not in place in the three countries. Transportation of livestock and their products to market outlets is time consuming compromising the quality and prices of animals and animal products. In addition, multiple and excessive taxes are levied at different points in the market chain (e.g. Sudan). Measures to encourage livestock productivity such as by avoiding prohibitive tax system and improving local and international marketing outlet must be carefully crafted.

vii. Generally, the existing sectoral policies within the countries studied (e.g. food security, irrigation development, watershed management, etc.) rarely integrate livestock and water issues. Comprehensive and integrated policies that consider livestock-water interactions are desirable to improve productivity and production. Such integration implies need for greater understanding livestock-water interactions and trade-offs.

In the Nile basin, the majority of the rural population is engaged in mixed crop-livestock farming. In the rangelands, where the potential for rainfed or irrigated agriculture is limited, livestock form the basic means of subsistence and livelihood for the people. However, the overall awareness of policy makers and planners as well as donors as to the role of livestock and their keepers appear to be modest. Participatory policy development (one that allows consultation with livestock keepers), with an intent to forge sound policies for guiding/leading the livestock water improvement, has therefore to be in place. There is therefore a need to raise the awareness of policy makers so that the livestock sector should get the attention it deserves.

Gender

Across a broad range of asset and resource classes including financial, social, human, and natural capital, men tended to dominate in terms of access, control and benefits compared to women. This was true in all three countries (Table 7). However, there were considerable differences among countries, but these are a confounded mix of cultural, climatic, ecological and production systems. Because these results are based on site specific perceptions, they do not necessarily represent the countries from where they came. Focusing on women's access to resources in Uganda's Cattle Corridor, they appear at least equal to men with respect to crops, credit, goats, and poultry in Uganda, but of all the assets, they only have equal or greater control of poultry. Ugandan men dominate with respect to all other resources. In Ethiopia highland mixed crop-livestock systems, women's access to river water, wells, cattle including oxen, goats, equines and poultry and their control over cattle and poultry compares well with men. In Sudan's central belt that comprises several production systems, women have at least equal access to river water, land, goats, equines, and poultry and control over river water, goats, and poultry. While more detailed research is needed, these results suggest that targeting investments on specific types of water and livestock resources may yield greater positive impact on women, an important consideration for poverty reduction if they make up the majority of the poor in these countries. However, the fact that men have greater access to and control over other resources such as extension and veterinary services also suggests that such investments may be need there with a focus on women to help improve the benefits they get from both water and livestock resources. In this project (PN37), poultry were largely ignored, but may require greater attention in Phase 2.

Table 7. Researchers' perception (% share of resource pie) of gendered access to, control of, and benefits from farm related resources including water and livestock.

Resource	Location	Access		Control		Benefits
		Male	Female	Male	Female	
Grazing land	Ethiopia	80	20	80	20	Animal feed
	Sudan	75	25	75	25	
	Uganda	100	0	100	0	
Horticulture	Ethiopia	60	40	60	40	Food production and cash income
	Sudan	80	20	100	0	
	Uganda	55	45	55	45	
Extension	Ethiopia	70	30	70	30	New cropping system, irrigation and feed and milk production
	Sudan	90	10	90	10	
	Uganda	95	5	95	5	
Crops	Ethiopia	60	40	60	40	Food, feed and cash income
	Sudan	75	25	75	25	
	Uganda	10	90	85	15	
Trees	Ethiopia	60	40	70	30	Construction, fuel wood, shade and cash income
	Sudan	60	40	95	5	
	Uganda	90	10	95	5	
Credit	Ethiopia	70	30	70	30	Purchase of inputs like fertilizer and pesticide, oxen, sheep, goats and farm implements
	Sudan	90	10	90	10	
	Uganda	50	50	100	0	
Labour	Ethiopia	70	30	70	30	Timely finish agricultural activities, house construction and social activities
	Sudan	80	20	80	20	
	Uganda	85	15	85	15	
Team work	Ethiopia	60	40	80	20	Timely finish agricultural activities, house construction and social activities
	Sudan	75	25	75	25	
	Uganda	75	25	65	35	
Farm inputs	Ethiopia	80	20	80	20	To increase livestock as well as crop production
	Sudan	90	10	90	10	
	Uganda	85	15	95	5	
Veterinary services	Ethiopia	60	40	60	40	To increase livestock production
	Sudan	90	10	90	10	
	Uganda	75	25	95	5	
Cash	Ethiopia	75	25	75	25	To buy cloth, farm tools, food, health, schooling, animals
	Sudan	75	25	75	25	
	Uganda	65	35	95	5	
WATER						
River	Ethiopia	50	50	70	30	Drinking, food preparation, animal watering, irrigation and washing clothes
	Sudan	50	50	50	50	
	Uganda	100	0	100	0	
Land	Ethiopia	80	20	80	20	Crop production, tree plantation and house construction
	Sudan	50	50	80	20	
	Uganda	85	15	100	0	
Wells	Ethiopia	30	70	70	30	Drinking, food preparation, animal watering and washing clothes
	Sudan	75	25	75	25	
	Uganda	85	15	85	15	
Water harvesting systems	Ethiopia	60	40	60	40	Vegetable and fruit production, domestic use, animal watering
	Sudan	100	0	100	0	
	Uganda	85	15	100	0	

Table 7 **cont'd.**

Resource	**Location**	**Access**		**Control**		**Benefits**
		Male	Female	Male	Female	
LIVESTOCK						
Cattle	Ethiopia	50	50	50	50	Meat, cash income, milk, butter, hides, manure
	Sudan	90	10	90	10	
	Uganda	75	25	77	23	
Oxen	Ethiopia	50	50	80	20	Traction, meat and cash income
	Sudan	100	0	100	0	
	Uganda	100	0	100	0	
Sheep	Ethiopia	50	50	70	30	Meat, cash income, skin, manure
	Sudan	75	25	90	10	
	Uganda	75	25	80	20	
Goats	Ethiopia	50	50	70	30	Meat, cash income, skin, manure
	Sudan	50	50	47	53	
	Uganda	45	55	50	50	
Equines	Ethiopia	60	40	80	20	Traction, meat and cash income
	Sudan	50	50	0	100	
	Uganda	-	-	-	-	
Camels	Ethiopia	60	40	80	20	Transport, traction
	Sudan	100	0	100	0	
	Uganda	-	-	-	-	
Poultry	Ethiopia	50	50	10	90	Meat, eggs and cash income
	Sudan	0	100	0	100	
	Uganda	20	80	20	80	

Objective 2: Technologies, practices and policy: National and sub-national levels

Ethiopia

Livestock keeping is an integral part of Ethiopian farming that depends mostly on rainfed grain productions. Traditionally, crops and livestock have been operationally separated by functionally linked. Diverse farming systems vary in the relative importance of varous animals species and crop types. The regional states of Amhara, Benishangul, Gambella and Tigray along with parts of Oromia and SNNP fall within the nile basin. The terrain covered is a mosaic of complex farming systems where cereal based mixed farming systems predominate. Throughout, livestock are an important and integral component of agriculture. The nationally reported land area, extent of cultivation along with animal and human populations are shown in (Table 8).

Table 8. Total and cultivated land area and human and livestock populations in the Nile Basin part of Ethiopia disaggregated by regional states.

Regional States	Area in Basin (1000 km^2)	Culti-vated portion (%)	Populations (millions)				
			People	Cattle	Sheep	Goats	Equines
Amhara	143	40	14.9	10.3	5.2	3.7	1.8
Oromia	95	55	10.7	9.6	2.5	1.1	1.2
Benishangul	41	7	0.6	0.3	0.1	0.2	<0.1
Tigray	40	35	3.5	2.6	0.7	1.7	0.4
Gambella	27	1	0.2	0.2	<0.1	0.1	0.0
SNNP	19	39	1.8	2.0	1.0	1.0	0.1
Total	365	37	31.7	25.0	9.5	7.8	3.5

Source: Drived from CSA (2002)
Note: There is some disagreement in the populations sizes of livestock herds partly because of differences in census methodology, year of census, and the fact that some of states shown in this table include areas lying outside of the Nile Basin. There is need for a basin wide livestocks census based on standardized methods.

The Gumera watershed study area for PN37 drains into the eastern shore of Lake Tana. There are three major farming systems (Table 9). The barley-potato based cropping complex includes sheep as the most widespread domestic animal, but cattle and equines are also present. Horses are the main source of draught power in this area. Cattle dominate the downstream plain area where the rice-noug based cropping complex is practiced. Livestock productivity in Gumera watershed area was noticed to be sub-optimal with milk yield ranging from 0.6 to 1.8 l/day and the average live-weight of mature cattle reaching about 210 kg/head.

Table 9. Livestock holding of a household in different cropping systems of the mixed crop-livestock farming practices in Gumera watershed areas.

Cropping system	Household number	Livestock holding at a household level			
		TLU*	Cattle heads	Shoats	Equine
Barley-potato based complex	20	3.6±0.3	4.2±1.6	14.4±4.5	2.37±2.1
Teff-finger millet–wheat based complex	20	3.7±0.2	7.7±1.8	5.5±2.4	1.9±1.7
Rice-noug based complex	15	3.0±0.3	9.1±1.6	4.0±2.2	1.2±2.1

SE = standard error

LWP

Two studies within PN37 independently assessed livestock water productivity in the Gumera Watershed. There were similarities and differences that have yet to be explained.

Alemayehu et al. (2008b) accounted for water in feed with reference to its relative value compared to that of grain, based on local market prices and also water required for growing pasture. In this case, some of the water utilized by crops was attributed to livestock feed and assigned as a water cost of subsequent animal production. This implies that if animals eat crop residues, the water cost of growing grain would decrease leading to higher crop water productivity. Crop water productivity exceeded that of Livestock water productivity. Economic Livestock water productivity (LWP) tended to increase with an increase in the proportion of crop residues used to meet annual livestock feed requirements (Table 10). Overall LWP appeared to be 0.07 USD/m^3 of water input under traditional mixed crop/livestock farming in Gumera watershed area. The higher LWP under rice-noug based cropping complex (Table 6) can probably be explained by the double cropping practice which exploits the residual moisture after the end of the main rainy season. This practice favors the availability of more crop-residues as supplemental feed resources during dry season at times when feed supply becomes critical. The present estimate of LWP is derived empirically and appears a little bit lower than that estimated by Peden et al. (2007). This lower estimate might be associated with subsistence based livestock production in this area, unlike the situation described by Peden *et al*. (2007), in Awash Valley where marketing opportunities, through encouraging farmers to fatten beef and small ruminants around areas of sugar industries, might be related to better livestock productivity.

Haileslassie et al. (2009a; 2009b) also assessed LWP in the Gumera watershed (Table 11). These estimates of LWP were lower than that reported by Alemayehu et al. (2008b). Further investigation is required to explain these differences. One possibility may arise from differences according to whether or not water is attributed to production of crop residues. Nevertheless, results in Table 11 are consistent with other estimates and suggest that in monetary terms, LWP compares favourably with crop water productivity.

Table 10. Crop and livestock water productivity in different cropping systems of the mixed crop-livestock farming in the Blue Nile Basin.

Cropping system	**Crop**	**Proportion of crop-residues produced/annual feed requirement (%)**	**CWP (Kg/m^3)**	**CWP (USD*/m^3)**	**LWP (USD/m^3)**
Barley-potato based	Barley	28.7	0.54	0.36	0.06
Teff-finger millet –wheat based	Teff	31.6	0.56	0.57	0.06
Rice-noug based	Rice	56.8	0.35	0.26	0.08
Mean		39.0	0.48	0.04	0.07

Source: Alemayehu et al. (2008b).
*1 USD = 9.76 Ethiopian Birr.
Note: These results differ from all other in PN37 because they suggest that CWP is much higher than LWP that was observed in other project sites and studies within PN37. Further investigation is needed to confirm whether these differences are attributable to different methods or represent different socio-economic and biophysical conditions.

Table 11. Livestock and water productivity by farming household health class in three farming systems of the Gumera watershed, Blue Nile highlands, Ethiopia.

	Production system	Wealth group			Weighted mean
		Rich	Medium	Poor	
Crop water productivity (kg/m^3)	Potato-barley	0.5	0.3	0.4	0.5
	Barley-wheat	0.5	0.3	0.4	0.4
	Teff-millet	0.4	0.3	0.3	0.3
	Rice	0.5	0.5	0.5	0.5
Crop water productivity (USD/ m^3)	Potato-barley	0.5	0.2	0.3	0.3
	Barley-wheat	0.5	0.3	0.3	0.3
	Teff-millet	0.2	0.3	0.2	0.2
	Rice	0.4	0.3	0.2	0.3
Livestock water productivity (USD/m^3)	Potato-barley	0.5	0.5	0.4	0.5
	Barley-wheat	0.5	0.5	0.6	0.5
	Teff-millet	0.6	0.3	0.2	0.3
	Rice	0.4	0.3	0.1	0.3

Source: Haileslassie et al. (2009b)

Influence of livestock management on natural resources

The impact of traditional livestock keeping on runoff and soil erosion levels vary with scale, cropping patterns, land use and tenure arrangements of the pasturelands. Communally owned and open unrestricted grazing management was found to be the most susceptible to erosive runoff next to cropland, with the resultant sedimentation amounting to more than 40 t/ha at slopes of 15-25% (Table 12), but only during the main rainy season. However, there is considerable opportunity to improve this situation including through altering the way communal grazing lands are managed and utilized. This particular study shows that soil erosion, measured as sediment load, was reduced by more than 60% as a result of changes in managing communal pasturelands. These measures taken for improving productivity of the natural pasture includes collective action in managing the resource supported by local bye-laws. The finding on soil losses from the flat grazing pastures is in agreement with Taddesse *et al*. (2002, 2003) while the figures from 15-25% slopes are higher than those reported by Taddesse *et al*. The differences arise due to differences in terrain, stocking density and rainfall intensity. Moreover, Hellden (1987) reported that the soil loss from cultivated cropland reaches up to 117.7 t/ha over a year period at a land slope of 15-60%.

Table 12. Runoff volume and sediment load of the main rainy season from pastures having different ownership patterns and slopes.

Pastureland ownership pattern	**Slope (%)**	**Runoff volume (m^3/ha)**	**Sediment load (t/ha)**
Communally owned and open unrestricted grazing	<10	10,125.0	26.3
	15-25	12,825.0	45.27
Communally owned pasture supported with local by-laws	<10	3,307.5	7.84
	15-25	4,927.5	14.24
Privately owned enclosed pasture	<10	1,147.5	1.65
	15-25	1,687.5	3.39
Cropland (Hellden, 1987)	<10		29.4
	10-15		69.6
SE±		607.5	1.47
Source: Alemayehu et al. (2008b).			

LWP intervention options in Ethiopia

PN37 research in Ethiopia focused on temperate highland rainfed mixed crop-livestock systems. The studies confirmed the LWP is generally low and can be improved. Effective use of crop residues for animal feed and maintaining vegetative cover to control run-off and soil erosion emerged as two priority interventions for increasing LWP. Under current management practices, there appears to be a need to improve community management of common property grazing lands or to consider encouraging private tenure of the rangeland.

Sudan

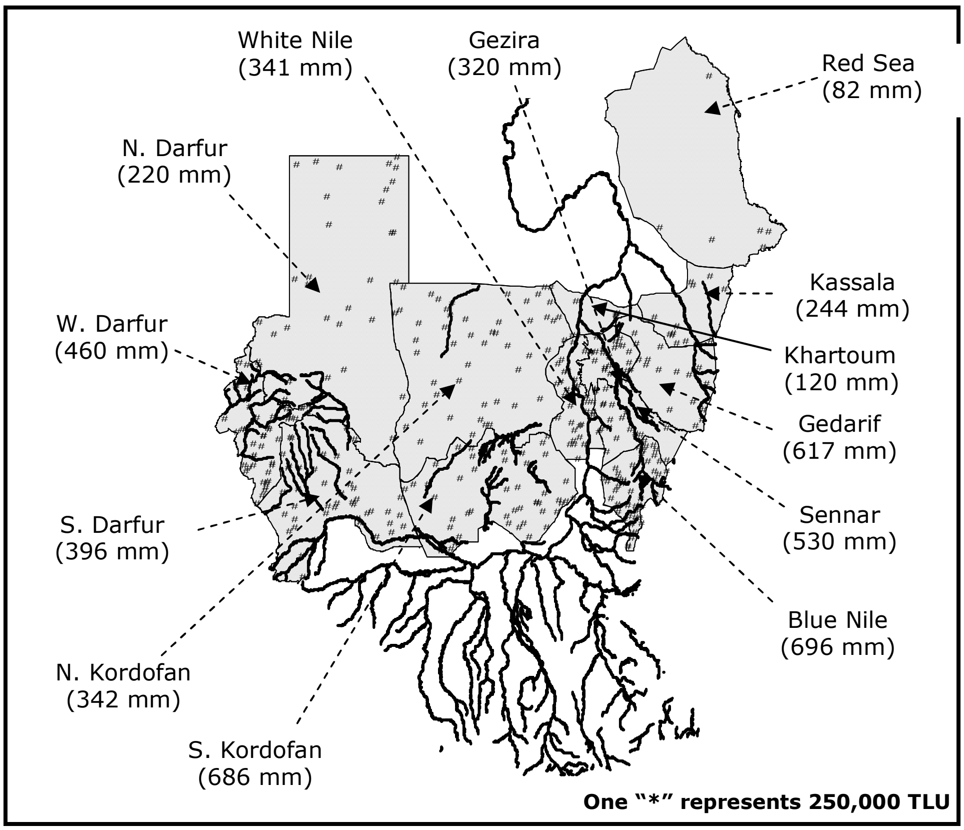
General overview of the belt

The belt, identified as the focus for this study, spans area expansions across the central part of Sudan and extends from the western parts of the country bordering Chad, Libya and the Central African Republic up to Sudan's eastern borders with Ethiopia and Eritrea. The gross expanse of the belt is embraced between a little south of latitudes 10^{o} and latitude 20^{o} N in the west, but extends northwards up to about latitude 23^{o} N in the eastern fringes to accommodates the Red Seas area. It encompasses 13 States, namely the three States of Greater Darfur (North Darfur, West Darfur and South Darfur), the two States of Greater Kordofan (North Kordofan and South Kordofan), White Nile, Sennar, Blue Nile, Gezira, Khartoum, Gedarif, Kassala and the Red Sea States

The belt covers 75% of the country and accommodates some 80% of the population as of 2007. It also hosts about 73% of Sudan's total livestock wealth. The belt's link to the Nile Basin is strong in terms of irrigated livestock activities from the Nile and its tributaries, livestock mobility between rainfed and irrigated systems, and livestock trade with other Nile-Basin countries such as Ethiopia (Faki et al. 2008; Faki and Peden 2010). Animal movement occasionally involves crossing borders with States in the Southern part of the country such as the northern parts of Upper Nile and Bahr Elgazal as well as with bordering countries, especially Chad and Central African Republic. Livestock access to the Nile system in dry periods allows better utilization of the vast grazing lands that are accessible during more favorable periods during the rainy season.

Rainfall ranges from less than 100 mm/year in the far north of the belt to about 800 mm/year in its far south. Surface water is available from the Nile and its tributaries and other seasonal rivers, mainly Gash and Baraka in eastern Sudan. These water resources predominate within the central and eastern parts of the belt while the western part is primarily dependent on rainfall and ground waters, although there are seasonal streams that dry out shortly after the rainy season. The belt's central and eastern zone accommodates Sudan's big irrigation schemes, namely Gezira, New Halfa, Rahad and Suki. The former two schemes are irrigated by gravity from dams on the Blue Nile and Atbara rivers, respectively while the latter two largely depend on pumping from the Blue Nile. Also along the White and Blue Niles, pup irrigation is prevalent within schemes that vary in size and, as the case with all irrigation schemes except for sugar plantations, cropping is undertaken by small farmers. This region also boasts of all of the irrigated sugar cane plantations of Sudan. On the other hand, basin irrigation is mostly confined to the Gash and Baraka deltas. Livelihoods within the belt are primarily rural and agriculture dependent. Both cropping and livestock keeping are major activities and the belt forms the hub of Sudan's agriculture. It produces most of Sudan's grains, almost all of its oil seeds and cotton, and all of its sugar, in addition to many other crops. Livestock rearing is a major source of livelihood, almost equal in importance to that of crops. Transhumance and nomadic modes of livestock production thrive on natural pastures, but there are modern sedentary dairy farming activities within and in the vicinity of towns and big settlement areas. Historical developments of the pattern of use of natural resources have resulted in the present situation of their degradation as will come later with more elaboration. In consequence, and in spite of basically rich natural resources of the belt, most of the identified acute poverty in the country are situated there. Although some of these spots, such as Southern Kordofan and Blue Nile are war-driven, others such as North Kordofan and North Darfur in the west and Kassala and Red Sea in the east are primarily the outcome of unchecked and irrational use of natural resources. For a full account of the characteristics of the Central belt refer to Faki and Peden (2010).

Basin-wide analyses reported earlier (Figure 4, **Error! Reference source not found.**, and Figure 6) demonstrate that the Central Belt of Sudan is a major livestock-water hot spot of in the Nile Basin. Detailed analyses undertaken in the country shed further light on this important region. The Central Belt contains the majority of Sudan's livestock and is undergoing rapid human and agricultural expansion (Figure 10). Livestock populations are growing faster than the human population but croplands are expanding less quickly.



Data Source: Meteorological Authority, Sudan, except for West Darfur and Sennar states where informal rainfall data were obtained for a lesser period.

Figure 9. Spatial distribution of livestock TLU, rivers and streams, and long-term (thirty-year) average rainfall in states' capitals across the belt.

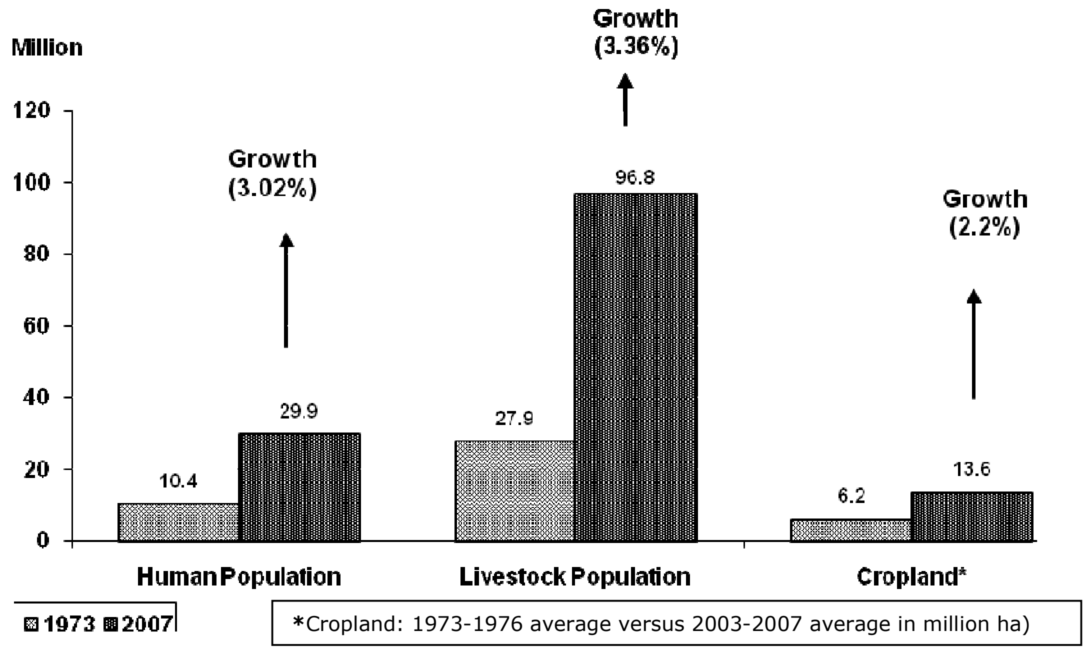


Figure 10. Population, livestock and cropland growth within the belt, 1973-2007.

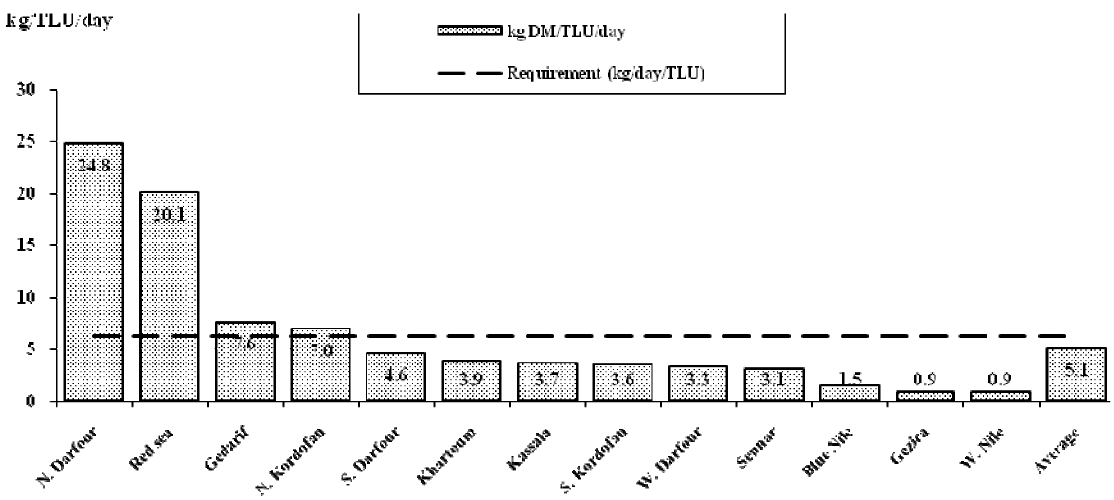
In Sudan, availability of and access of livestock to drinking water are the overriding determinants for animal production. Livestock tend to concentrate near rivers and water points especially in the dry season leaving large areas of the Central Belt relatively unpopulated (Figure 10). Within the belt, animal demand for drinking water exceeds availability in all areas except for Khartoum and Red Sea State (Table 13). During peak periods, unsatisfied demand in the belt exceeds one million m^3/day.

In addition to the critical situation of drinking water, feed availability is jeopardized by low and variable rainfall in pastoral areas, which provide about 74% of animal intake. Estimates of daily feed balances in states across the belt are shown by Figure 12. Four states, namely North Darfur, Red Sea, Gederef and North Kordofan reveal positive average daily balances while feed deficits are evident of all other states. However, the positive balance in the former two states is largely a result of low livestock population. Rainfall there is scanty and pastures cover is expected to be variable and dispersed engendering risks for drinking water and feed availability. The most affected states are those in the Central Region (Blue Nile, Gezira and White Nile), but these are endowed with surface water and irrigation facilities that could mitigate feed shortages. The highest pressures are therefore in West Darfur, South Kordofan, and Kassala states. On average, a dry matter (DM) deficit of 1.15 kg/day/TLU exists representing 18% of the requirements. Pastures do not remain in good condition for the whole year, and animal movement within the country, a traditional practice, forms the most important strategy to alleviate feed and water shortages. This is further supported by utilization of crop residues that provide about 21% of the feed needs. Because of feed and water constraints coupled with suboptimal management of land resources, livestock production is low and variable.

Table 13. Average daily rural drinking water availability, demand, and balance (m^3/day) in different states within Sudan's central belt, 2007.

State/Region	Available Water	Average drinking demand	Peak drinking demand	Balance at average demand	Balance at peak demand
Red Sea	126,410	20,075	31,677	106,335	94,733
Khartoum	83,210	24,979	28,083	58,231	55,127
Gedarif	55,096	66,417	85,896	-11,321	-30,800
Kassala	43,972	61,441	86,709	-17,469	-42,737
Sennar	32,839	71,622	92,136	-38,783	-59,297
North Darfur	52,448	87,478	115,947	-35,030	-63,499
White Nile	48,184	118,823	156,805	-70,639	-108,621
Gezira	61,507	140,928	170,469	-79,421	-108,963
Blue Nile	19,133	151,871	203,441	-132,738	-184,309
South Darfur	51,088	187,184	235,637	-136,096	-184,549
West Darfur	29,495	172,336	229,290	-142,842	-199,795
Greater Kordofan	244,488	335,245	464,446	-90,757	-219,959
Total	**847,870**	**1,438,399**	**1,900,536**	**-590,530**	**-1,052,669**

* Requirements are calculated according to Payne (1990): average demand 25, 30, 4, 4 l/day for cattle, camels, sheep, and goats; at peak summer months, respective values: 35, 65, 4.5, and 4.5 l/day. Human rural requirements are 20 l/day/person according to the Ministry of Irrigation.
Source: Available water computed from data of the Ministry of Irrigation; Livestock in 2007 estimated from data of MoARF (2007).



Notes: Feed balances are calculated according to daily feed dry matter (DM) requirements (dotted line: 6.25 kg/TLU/day assuming 2.5% DM of animal weight per day based on Ahmed El-Wakil, personal contacts). Data on pasture availability are from the Range department of the Ministry of Agriculture, provided by Mr. Mohamed Shulkawi).

Figure 11. Feed balances by state across Sudan's Central Belt.

A key feature of the Central Belt is very low livestock water productivity (Table 13). One of the major factors causing this is the spatial imbalance of feed and drinking water resources. In brief, LWP is low where animals have access to drinking water because competition among them for feed results in inadequate feed intakes and consequent low rates of production. Ironically, LWP is also low in areas with underutilized feed because animals cannot access this feed due to lack of drinking water nearby.

Pastoral and agro-pastoral (North Kordofan)

North Kordofan lying approximately midway between Khartoum and Darfur in the West is predominantly agro-pastoral. Livestock production is the dominant livelihood strategy. Rainfall at the urban center of Elobeid has an average range of 200-600 mm/year. Livestock depend mostly on natural pastures for feed and only about 14% of feed comes from crop residues. Access to drinking water is a major constraint year round and is especially critical in the dry season. Underlying causes of conflict are cropping around water points, summer water shortages, and narrow and often blocked migratory corridors between pastures and watering sites. The summer time deficit for domestic and livestock water in Kordofan state is about 60 thousand m^3/day or about 36% of total demand. Migration is the primary coping strategy. The harsh climate imposes severe constraints on animal production especially in the dry seasons (Table 14). Keys to improving livelihoods are improving access to water for livestock especially in areas where there is surplus feed and through improved veterinary service to help mitigate losses from morbidity and mortality.

Table 14. Cattle and sheep productivity indicators according to rainy season precipitation in North Kordofan (%/year).

Item	**Cattle**			**Sheep**		
	Season Conditions			Season Conditions		
	Good	Normal	Poor	Good	Normal	Poor
Pregnancy	69.6	39.3	21.9	79.3	47.2	27.4
Twining				42.9	22.2	11.7
Mortality	10.5	16.2	35.3	17.9	18.1	35.4
Abortion	19.7	11.6	19.0	18.0	12.0	17.4
Change in weight	74.4	43.2	-20.6	72.2	40.5	-22.0
Av Rainfall (mm)	509	349	227	509	349	227
Source: Authors' survey.						

Rainfed crop-livestock systems (Butana/Gedarif):

The Butana region lying partly in Gedarif State about half way between Khartoum and the Eritrean border is a mix of pastoral, agro-pastoral and mechanized rainfed farming livelihoods. Eighty-six percent of livestock feed comes from pasture, but there are millions of tons of unutilized crop residue from mechanized farming in Gedarif State primarily because of lack of nearby drinking water (Table 15). As in North Kordofan, during low rainfall years, livestock suffer from low reproductive rates, weight loss, and higher mortality and morbidity.

Table 15. Camel, cattle and sheep productivity indicators according to rainy season precipitation in Butana/Gederef (%).

Item	**Camels**			**Cattle**			**Sheep**		
	Season Conditions			Season Conditions			Season Conditions		
	Good	Normal	Poor	Good	Normal	Poor	Good	Normal	Poor
Pregnancy	71.8	62.6	35.7	83.1	61.4	34.4	102.1	74.1	47.9
Twining							42.8	22.6	16.2
Mortality	10.1	6.2	20.5	4.7	6.9	26.4	9.2	9.6	17.9
Abortion	16.0	9.2	25.9	5.7	8.4	21.7	4.7	10.5	21.8
Change in weight	84.8	24.6	-37.7	85.9	19.4	-43.8	94.9	23.0	-42.5
Av Rainfall (mm)	360	263	185	360	263	185	360	263	185

Irrigated crop-livestock systems (Gezira-Managil):

The Gezira-Managil irrigation scheme covers about 882,000 ha and was home to about 2 million livestock excluding camels and horses in 2001 with variable numbers across years (
Table 16).
About 40% of Gezira's tenants own livestock, and the average households owns about 12 domestic animals excluding poultry. While the actual number of animals present in Gezira is not precisely known, livestock keeping contributes about 30 % to 40% of farmers' income, and there is potential for further increases. Dairy production is the most lucrative livestock based livelihood practice giving about 60% return on investments. The main constraint to livestock production is shortages of feed. The major sources of feed are grass from canal banks (74,000 tonnes), fallow land (321,000 tonnes), and crop residues (2,996,000 tonnes), but animal numbers are declining due to feed shortages. High taxation, poor milk marketing systems, and diseases aggravate efforts to increase animal production. The research suggests that there is considerable scope for increasing livestock water productivity within the irrigations systems through better management of the water, improved use of crop residues and by products, improved veterinary services, and better marketing of livestock products especially milk.

Table 16. Livestock populations (thousand) in the Gezira Irrigation Scheme 1965-2001.

Type	**1965**	**1975**	**1980**	**1985**	**1998**	**1999**	**2001**
Cattle	145	204	441	218	247	410	247
Sheep	231	326	659	347	590	580	590
Goats	161	226	410	426	1,126	640	1126
Donkeys	55	78	90	235	171*	107	139*
Total	593	834	1,600	1,226	2,135	1,737	2,103
TLU	212	298	594	407	483	578	467
Density (TLU/km^2)	21.0	29.6	58.96	40.4	47.9	57.93	46.9

* indicates estimates only; Source: Sudan Gezira Board, annual reports, 1999, 2002.

Periurban livestock production (Khartoum State):

Khartoum state is an arid area located at the junction of the Blue and While Nile rivers where rainfall ranges between 60 mm and 100 mm annually. According to the 2008 population census Khartoum is home to about 5.3 million people and, and its dense population (230 persons/km^2) is growing rapidly. Khartoum is bestowed with high market availability of agricultural products, a large part of which is produced in the State. The State produces a high portion of its needs from fodder, milk and eggs, but most importantly represents a site where different types of livestock coming from distant states such as Kordofan and Darfur are fattened and finished for slaughter, domestic sales, exports and some processing. Khartoum is also the center for milk processing into yoghurt and other similar milk products that are traded to other states. From a livestock perspective, Khartoum constitutes a major urban environment where policy and practice are conducive to animal production. Estimated cattle, sheep, goat and camel herd sizes in 2006 Khartoum were 234, 428, 633, and 5.7 thousand head respectively (MOARF, 2007). Both milk and meat production is important. Khartoum is unique within the Nile Basin because it has in place comprehensive policies and institutional support for encouraging livestock production and trade in livestock and feed supplies.

Results of a formal survey conducted in Khartoum State in season 2007-2008 (Faki and Peden 2010) showed that dairy farming was run by farmers with advanced education levels adopting many reasonable management practices. Such practices included a favorable herd composition of about 51% milking cows, breeds of cattle crossed with foreign blood in 82% of the farms, fenced and equipped farms and abundant water and feed supply. Deep wells formed the major water source but direct use of Nile water in 27% of the farms was considerable. Yet, a sizeable portion of farms depended on carts (18%) and a few on tankers for their water supply. Nevertheless, water supply was largely secured, enabling good animals' access to drinking water almost at lib. In 82% of the cases cows were watered more than twice a day and in 18% watering commenced twice a day.

Feed consisted of a mixture of concentrates and roughage material, while natural pasture grazing was quite limited. The feeding regime seemed to be favorable for milk production and indicates awareness about good feed management but the amount of concentrates fed to cattle is generally not geared to the level of productivity. Own fodder production was prevalent with about two thirds of the farms producing irrigated fodder, mostly sorghum grass although alfalfa production was tangible. Yet in all, cultivation of feed legumes was quite limited. Canals from the River Nile and dug wells were the main water sources for fodder cultivation in 92% of the farms that grew irrigated fodder. In spite of the relatively widespread irrigated fodder production, about one third of the farms still depended on the market for sourcing part of their green fodder needs.

Many deficient management practices related to water use were evident, including congested fence areas, insufficient and inflexible shading cover according to season that affected water intake, use of immobile cement troughs in many farms inducing water losses and inflexible use, and lack of testing of water quality. On the feeding side, feed legume production was limited, most probably affecting feed quality as well as rotational aspects of farm production. Moreover, the fed quantities of both concentrates and green fodder were not associated with milk productivity indicating irrational feeding behavior.

Using variable costs and benefits from milk sales, financial losses were incurred in dairy farms. The general belief among owners was that dairying was a losing undertaking where many farms went out of business while others chose to continue in order to remain in operation hoping for better future situations. The main reason for losses was obviously the low milk yield that compares unfavorably with the costly amounts of feed, which is in turn a function of many of the mal-management practices mentioned earlier, including extravagant use of water with little consideration of the economies of scale.

Estimates of water productivity (Table 17) were anchored on water for fodder production and that for cattle drinking and other farm uses. The total average use of water per animal of 18,236 l/day includes a high amount utilized for fodder production (18,073 l) forming 112 folds that of drinking water. On average each liter of milk required 3,620 litres of water, but a much larger amount of water (3,588 l) was associated with fodder production as compared with a requirement for drinking water (and other farm uses) of 32 liters.

In conclusion, the basis for high productivity is available where better management practices are essential, particularly those of relevance to the water issue.

LWP intervention options in Sudan

The Central Belt of Sudan is vast and diverse and many opportunities exist to improve water use by livestock. Among numerous options, PN37 research suggests identified several that could help increase LWP in the country. Foremost among these are:

- Provision of veterinary care to reduce animal mortality and morbidity.

- Provision of drinking water throughout the country.
- Enhancement of market opportunities for livestock and animal products.
- Effective use of crop residues.
- Integration of livestock into large scale irrigation development.
- Limiting herd sizes and increasing productivity per animal implying the need for alternative forms of wealth savings for herders.
- Strategically establishing drinking watering supplies in areas with surplus feed but reducing animal numbers around established watering points.
- Restricting animal access to open water and riparian habitat through use of drinking troughs.

Table 17. Water use and productivity in dairy farms in Khartoum State 2007/2008.

Item	**Level**
Water for fodder irrigation:	
Total water (cu m/ha/season/animal)*	6,597
Water for drinking & other farm uses (cu m per farm)**	2,240
Grand total water for fodder and drinking (cu m/farm/day)	8,837
Av no of animals per farm	38
Av total water per animal per day (l)	18,236
Av water for fodder production (l/animal/day)	18,075
Av drinking water/animal/day (l)	161
Av total water/l of milk	3,620
Av water/l of milk for irrigated fodder	3,588
Av drinking water/l of milk	32
* Based on 1.2 ha of irrigated fodder per animal, 5.5 irrigations and 1,000 m^3 per irrigation. ** Calculated according to an average number per farm of trough of 2.13, an average size of trough of 4.27 m^3, a trough fill-level of 0.9, and evaporation and break losses ratio of 0.25.	

Uganda

Mugerwa (2009) shows that dry matter yields, percentage ground cover, growth rates, and species richness for different rehabilitation treatments in the different seasons (

Table 18). In both seasons, the dry matter yield varied significantly ($p \leq 0.05$) with treatments. Mean dry matter production (3303 kg/Ha) from manured plots was 125% higher than that (1602 kg/Ha) from non-manured plots. Season significantly ($p \leq .0001$) affected dry matter production. Mean dry matter production (2895 kg/Ha) in the wet season was 23% higher than that (2349 kg/Ha) in the dry season with highest and lowest mean dry matter yields recorded for MR (see notes in Table 18) and control treatments, respectively.

Regardless of the season, the control plots remained bare (100% bare ground) throughout the two years. Manuring significantly ($p<0.0001$) increased the percentage vegetation cover in the study area. Generally, the percentage of bare ground for non-manured plots was 5 and 2 times more than that for manured plots in the wet and dry seasons respectively. Furthermore, the percentage bare ground for all treatments shows an average increase of 21% in the dry season. A similar trend was observed for forbs and grass cover.

Pasture growth rates were not affected ($p > 0.05$) by both season and the rehabilitation intervention treatments (

Table 18). However, there were significant season and treatment interaction for species richness (

Table 18). The highest species richness (10 species per m^2) was shown by MR treatment in the wet season and lowest, 1 and 0 species per m^2, by FO (see notes in Table 18) and control treatments respectively in the dry season. Detailed results related to botanical diversity and soil chemistry are reported in Mugerwa (2009).

Zziwa (2009) assessed the impact of upslope pasture management on downslope valley tanks. Average annual rainfall during the study was 1275 mm/year while evaporation was only 702 mm/year. Although water scarcity was felt by local people, water was plentiful compared to other parts of the Nile Basin. Nevertheless, without water harvesting, water was neither available nor accessible for much of the year. Valley tanks with up-slope vegetation showed a 0.4%/year decrease in water storage capacity, but tanks with little or now up-slope vegetation lost 18.0 % of their water storage capacity in the same period. In addition, the presence of up-slope vegetation in the catchment appeared to be related to higher quality water in the valley tank in terms of NH_4^+, NO_2^-, NO_3^-, TN, and Turbidity. The aquatic vegetation cover (*Nymphaea spp., Azolla sp., and Lemna spp.)* also appeared to be related to water quality, but the study could not determine if the water quality influenced the presence of these plant species or if the plants affected water quality. In any case, there were differences in behavior among the three species.

Table 18. Dry matter yield, percentage ground cover, growth rate and species richness for different rehabilitation treatments under different seasons.

Season	Treatment *	Ground cover (%)				DM (kg/Ha)	Growth rate (cm)	Species (No./m^2)
		Bare ground	Forbs	Grass	Weeds			
Wet	Control	100	0	0	0	0	0	1
	MR	2.4	37.5	56	3.2	4,506	5.2	9
	MRI	22.8	31.5	43	2.2	2,710	8.7	10
	MO	11.5	11.3	74	3.2	3,706	10.7	9
	RO	50.4	17.6	31	0.4	1,949	2.7	9
	FO	70.8	0	29.2	0	1,606	10.1	5
Dry	Control	100	0	0	0	0	0	0
	MR	29.1	15.3	54.5	1	3,138	-3.4	4
	MRI	49.1	8.6	42.7	2.3	2,502	-5.6	3
	MO	28.7	2.7	68.2	0.7	3,253	-4.5	2
	RO	72	7.9	20.1	0.5	1,688	7.2	2
	FO	86.1	0	13.6	0	1,164	9.8	1
	SE	5.3	3	5	0.9	396.4	6.5	0.83
Significance (p-values)								
Treatment		<0.001	<0.001	<0.001	<0.001	0.024	0.09	<0.001
Season		<0.001	<0.001	0.02	0.10	<0.001	0.49	<0.001
Season*Treat		0.05	<0.001	0.41	0.33	0.423	0.42	<0.001

* Treatments: "MR" = Manure left on the soil surface plus reseeding; "MRI" = Manure incorporated into soils plus reseeding; "MO" = Manuring only; "RO" = Reseeding only; "FO" = Fencing only.

Owoyesigire (2009) surveyed households in Nakasongola where his colleagues Mugerwa (2009) and Zziwa (2009) undertook their field studies plus additional households in Kiruhura District of Uganda. Full details of this research can be found in Owoyesigire (2009). In brief, there were large and gender-distinct differences between settled and non-settled livestock keepers in terms of ownership of and access to land, water, and livestock resources as well as their roles in managing these resources and benefiting from them. A key finding is that settled communities had more secure access to water resources year-round. In terms of livestock water productivity, the settle and non-settled communities realized about 0.07 USD/m^3 and 0.04 USD/m^3 of water respectively while the former also benefited from production of crops and had more access to domestic water.

LWP intervention options in Uganda

PN37's Ugandan experience confirms the importance of integrating pasture and water management as part of the LWP enhancing strategy of conserving water. Rehabilitation of degraded pasture is a key intervention not only for enhancing feed production but also for preventing siltation of downslope water bodies including valley tanks. The tipping point enabling pasture restoration was the discovery that night corralling of livestock provided sufficient manure that diverted termites from consuming young pasture seedlings to a manure-based diet. Future control of stocking rates will be necessary.

Establishment of valley tanks also enhanced the value of pastures. By providing drinking water during the dry season, they reduce livestock mortality and morbidity associated with trekking long distances from the pasture to distant watering points in riparian areas along the Nile River. Establishment and maintenance of riparian vegetation and aquatic plants helps ensure water quality, but requires that animals drink from nearby watering troughs rather than having direct access to the reservoir.

The Uganda experience also demonstrated that successful establishment of pasture and water harvesting systems depends on appropriate community based participation and management, enabling government policy, and access to financial assets.

7 DISCUSSION

PN37 is the first study of its kind in attempting to understand how livestock-water interactions vary across a major river basin (the Nile), to assess livestock water productivity (LWP) over such a large area, and to suggest options for sustainably increasing LWP with the intent of improving food security and livelihoods in an environmentally sustainable manner while reducing competition and conflict driven by water scarcity. Much of previous literature on livestock use of and impact on water resources focused on intensified livestock production in developing countries. In many cases the focus is on single commodity production such as meat or milk. In contrast, this study emphasizes that livestock have multiple and often simultaneous uses (e.g., meat, milk, hides, traction power, and a means for wealth accumulation) in a wide range of production systems (rainfed and irrigated; intensive and extensive; livestock dominated and mixed crop-livestock systems. Additionally, relatively little literature on and investments in water resources management has given due attention to animal production.

The primary actors in the Nile are poor livestock keepers affected by climate change, encroachment of crop production into traditional grazing land thereby limiting access to feed, imposition of political boundaries across migration routes, and reduced access to water and land resources. Increasingly, they require greater access to markets that enable income generation. In many parts of the Nile basin, agricultural intensification often leads to economically more powerful stakeholders gaining control the natural resource endowments on which livestock keepers depend, trapping the latter in a cycle of poverty and desertification. In other areas, livestock keepers are making a transition from pastoral to agro-pastoral to mixed crop-livestock production, a process that requires new technology, policy, practices and institutional arrangements to be successful. PN37 research shed light on many of these issues and points to pathways by which better integration of livestock and water management will help achieve more equitable, productive and sustainable use of the Nile's water.

When PN37 commenced, recognition of livestock keeping as an important water user was largely absent. When acknowledged, prevailing views considered livestock to be wasteful users of water resources in terms of excessive use of water for feed and overgrazing leading to widespread water and related land degradation. Our research suggests that livestock use of water is less than 25% of the 100,000 l/kg of beef reported by Goodland and Pimental (2000). Equally important in the Nile, livestock use of water generates multiple benefits rather than meat alone. In the some areas, particularly the Ethiopian highlands, oxen are vital to crop production. Without them, lower crop production would aggravate chronic hunger.

LWP assessment methodology

A key preparatory element in this project was the development of the livestock-water productivity assessment framework (Figure 1) that underpins much of the analyses and thinking of the rest of the project. When tested in diverse production systems, the generic framework seems to be robust in handling conditions ranging from extensive grazing systems to intensive mixed crop-livestock systems at local, watershed and basin scales. Four major strategies emerged through which increases in livestock water productivity (LWP) and consequent human development environmental development goals can be achieved and that appear to be applicable in a wide range of production systems and at various geographic scales:

- Selection of feed sources that have high plant water productivity. This includes effective use of crop residues in areas where crop production is the most appropriate livelihood strategy.
- Adoption of appropriate livestock production enhancing technologies and management practices that increase feed conversion efficiency and reduce, mortality, morbidity, and energy demanding stress on animals, and promote marketing opportunities for livestock and livestock products.
- Conservation of water resources through better vegetation and soil management that encourages infiltration and transpiration and discourages excessive run-off and evaporation.
- Strategic allocation of watering sites to ensure that there is a spatially optimal balance of feed and water resources across Nile landscapes.

Assessing LWP is challenging and leads to debatable results. Essential data required to assess LWP at the basin level are lacking in both quality and quantity, and thus recommendations based on them need to be used with caution. For example, there are huge differences among estimates of animal population sizes and densities used by national and international organization. Aggravating this problem is variability in the size of animals within one species. For example, local cattle are often much smaller than hybrid or exotic animals. One big gap in this study is that poultry have been ignored but these are important especially for the rural poor. Standardized censuses for the entire basin are needed.

Whether to include the water cost of crop residue production as component of crop water productivity or livestock water productivity has been debated vigorously. A standardized approach within general efforts to assess total agricultural water productivity is needed. An extension of this question is whether to assign the water cost of manure production to animals or to maintenance of ecosystem services based on the premise that manure replenishes soil fertility.

PN37 research adopted monetary units to integrate diverse estimates of benefits arising from LWP. However, this measure does not take into account many benefits that could be worth assessing such as the water productivity of generating cultural values and producing protein. Additionally, many animals are kept in excessively large herds (*hoarding* being the term described in Sudan). Two reasons are common for this. They are wealth accumulation and cultural prestige. Anticipated losses from future drought motivate the former. Because PN37 and other research demonstrated that many grazing areas overstocked, some measure is needed to reduce animal densities. How do to this is a priority research question. Research in PN37 assessed water costs of livestock in terms of volume (m^3). We hypothesize that many of our conclusions would be quite different if we use the price or value of water instead. We suggest future investigation in this area. Future research will benefit from clearly defining and standardizing the definitions and units for both livestock benefits and water depletion.

PN37 focused on understanding and increasing LWP. However farmers' do not segregate their well being into classes based on academic disciplines. The simplistic approach to hydrology taken by the project did not separate evaporation and transpiration. Need exists to integrate LWP and crop-water productivity concepts with other approaches to encourage environmentally sustainable intensification of agriculture that improves livelihoods and food security and reduces poverty.

PN37 took a small step towards integrating the LWP and sustainable livelihoods framework. Given the importance of addressing gender and poverty issues, more methodological development is warranted.

LWP at the basin scale

Overall LWP in the Nile Basin is much lower than what is desirable and possible. The basin receives about 2 trillion m3/year of rain. Six livestock production systems occupy about 60% of the basin's land area and support about 50% and 90% of the Nile's people and livestock biomass (TLUs of cattle, sheep and goats respectively. These six systems also receive about 1.68 trillion m^3/year which amounts to about 85% of the total Nile rainfall resource. Furthermore, these six systems lose 75% (1.27 trillion m^3/year) of this precipitation in the form of evapotranspiration (ET). PN37 was not able to partition this ET into component evaporation (E) and transpiration (T). The project also did not attempt to assess fate and distribution or track the flow of rain water that reaches and passes through the Nile's lakes, rivers and reservoirs. It also did not consider important hydrological phenomena such as the basin's recycling ratio. Although various authors report slightly different levels of rainfall for the basin, we conclude that at least half the Nile's rainfall is depleted through ET within the six major livestock-production systems comprised of both mixed crop-livestock and livestock dominated production. We hypothesize that one of the greatest opportunities to increase availability and access to agricultural water in the Nile Basin will come from focus on rainfed livestock and crop production with a concerted effort to convert E to T. Such a process implies greatly increasing vegetative cover at landscape and basin scales. Anticipated impact includes control of desertification, sequestration of carbon, and greatly increase primary production to enhance food security and natural biodiversity.

With the Nile Basin, LWP varies spatially. Application of the LWP framework at PN37's study sites indicates LWP is highest (0.40 USD/m^3) in Ethiopia, followed by Sudan's large scale Gezira irrigation scheme (0.20 USD/m^3) with the lowest estimates observed in Uganda's Cattle Corridor (0.5-0.8 USD/m^3) (Figure 12). Many factors contribute to these differences among sites and countries but their relative importance varies spatially in the basin. All of these factors can be classified based on their relevance to one of the four LWP enhancing strategies (Figure 1), namely: Strategic sourcing of feed, enhancing animal production, conserving water resources, and strategically allocating watering points in landscapes.

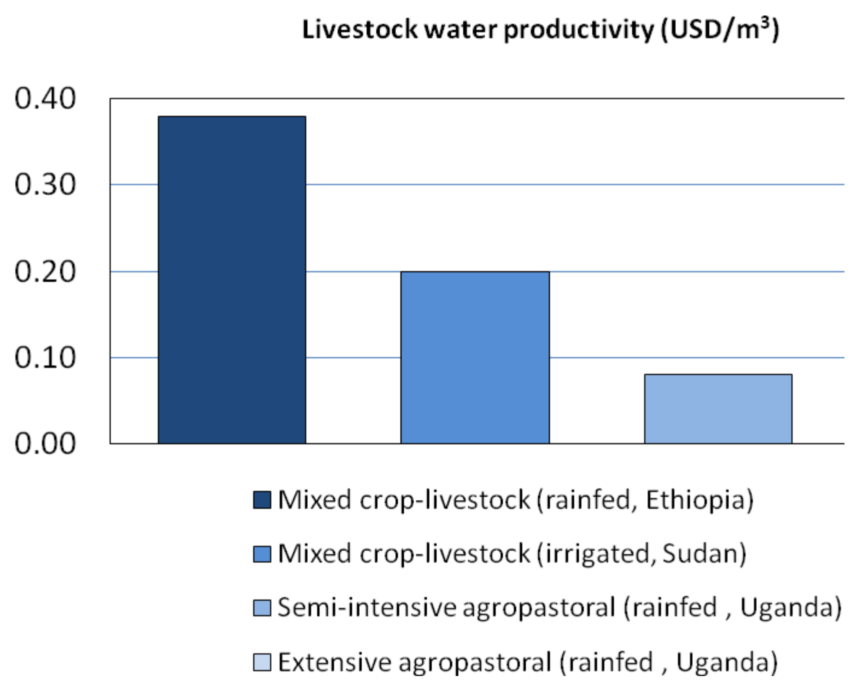


Figure 12. Livestock water productivity estimates for four production systems in Ethiopia, Sudan and Uganda.

LWP lessons from the Nile

Livestock are significant users of land and water resources in the Nile Basin, and when mismanaged they contribute to degradation of these key natural resources. Contrary to published and often popular literature relevant to industrialized livestock production is not applicable to the Nile Basin and this probably holds true for most of sub-Saharan Africa. In brief, livestock water productivity in SSA is much higher than reported in developing countries. Due the fact the African livestock usually provide multiple products and services, developed country focus on meat or milk production would lead to estimates of low water productivity when the cultural benefits and the value of traction power, hides, skin and manure are ignored. Also, cattle in Africa eat almost no grain unlike the large amounts consumed in industrialized animal production.

Because African livestock consume either grass (often on land unsuitable for cultivation) or crop residues (where agricultural water simultaneously produces both feed for animals and food for people), LWP in Africa can be expected to be lower than in many developing countries where grain is widely consumed. Using an integrative index of water productivity such monetary units can help factor in all benefits arising from livestock keeping. Based on monetary LWP, livestock production compares favourably with horticultural crop water productivity and exceeds frequently reported levels of crop water productivity, largely because animal products attract higher market prices than crops.

Livestock production occupies a much larger area of the Nile Basin than crop production does. In the livestock dominated areas, livestock keeping is often the best and only agricultural option for using agricultural water. By implication, policy needs to recognize the potential need for optimal allocation of agricultural land use to the most suitable areas for each and this would likely include restrictions on encroachment of irrigated and rainfed farming into pastoral areas.

From a river basin perspective, the research suggests that livestock access to much of the blue water in the Nile's lake and river systems is restricted because using it in traditional ways to water animals leads to severe morbidity and mortality associated with water related disease, the stress of trekking long distances to water, and shortage of feed resources near the watering points. The partners' research in Ethiopia, Sudan and Uganda suggest that this is a widespread problem in virtually all Nile production systems. Shifts towards stationary production will reduce health risks and energy requirement and accordingly the drinking water requirements, and improve levels of production and meat quality. However, long trekking routes from pasture to market centers such as Khartoum will require provision of feed and water along the way.

PN37's research in both Uganda and Sudan demonstrated the need to integrate pasture and water management in ways that keep animal numbers in balance simultaneously with feed and drinking water resources. This will involve provision of drinking water supplies (e.g. haffirs and valley tanks) where feed surpluses exist and protection of riparian and nearby pasture from overgrazing where drinking water supplies exist.

The benefits and costs associated with livestock use of water and pasture resources is highly gendered implying that intervention options designed to improve livestock water productivity need to take into account their impacts on women, men, children and also diverse ethnic groups. In Ethiopia, Sudan and Uganda, men tend to benefit more from livestock keeping the women and efforts to bring about more equitable gains will need effort. Enabling institutional, policy and investment environments are necessary for effective action to increase LWP.

Livestock development domains

Given high spatial variety in livelihoods and land and water resources across the Nile basin, knowledge accumulated in PN37 was captured within a "development domain" model to provide a guide to areas that should be the focus of future investment in the integrated development of livestock and water resources. Informed by local or regional knowledge from some parts of the Nile and building on spatial analyses undertaken by PN37, Figure 13 suggests where various combinations of LWP, length of growing season, access to markets and livestock populations create different opportunities for improving overall basin water management through livestock related interventions. The information in Figure 13 is not a "silver bullet". Rather it can guide consultation in selecting these options. For example, LWP may be low due to inherent biophysical constraints or inappropriate livestock keeping or land and water management practices. In vast areas of the Nile, the former conditions imply that overriding water scarcity is so severe that feed production is low and few options exist for any form agriculture including animal production. However, in other areas, LWP may be low due to land degradation where restoration of vegetation is possible, to high animal morbidity and mortality where veterinary interventions are needed, or to herders simply keeping large numbers of animals for wealth preservation with little or no interest in increasing production. In areas with good access to markets, monetary LWP might be improved through investments in animal production and processing of animal products. In large scale irrigation systems, this is clearly the case, but such investments in livestock need to be integrated with efforts to improve irrigation management. Some parts of the Nile Basin have relatively short growing season, especially in the northern half of the Sudan's Central Belt. Spatial analyses suggest that these areas are particularly vulnerable to climate change. They may benefit from mitigative investments in water harvesting and storage. Also some of these extensive grazing areas can only be used effectively if herders have access to dry season watering sites and pasture and if the migration routes to them are safeguarded and supplied with water and feed for trekking animals. In some areas, livestock densities are high, and water related interventions there might have the greatest positive impact because of economies of scale in terms of the number of livestock reached.

The foregoing are merely examples of how understanding the spatial distribution of livestock, water, and land resources and the interactions among them can help in planning livestock related interventions that can increase the effectiveness of water development and water related interventions that are necessary for effective livestock development. Furthermore, where Figure 13 shows "high" LWP, recall that this is relative term, and that compared to potential LWP is very low throughout the entire basin. In most places, reducing water depletion related to livestock production by at least 50% is feasible almost everywhere.

The Ethiopian, Sudanese and Ugandan production systems chosen for this study turn out to be hotspots of great importance for both river basin and more local development planning. The Ethiopian highlands remain under great pressure in terms food security, and the current agri-cultural practices in the mixed rainfed crop-livestock systems must undergo major transformation in terms of crop and animal husbandry of human needs are to be met in an environmentally sustainable way. At sub-basin scale, this implies massive uptake of appropriate technologies that can influence the hydrology of the basin to ensure that local and downstream peoples benefit. The Central Belt of Sudan is likely to be a hotspot for future impact of climate change as the project length of growing season shortens. The Ugandan Cattle Corridor covers about one third of the country and a trend toward settlement of pastoralists is underway and water harvesting integrated with pasture improvement and improved rainfed cropping will become increasingly important. In all three countries, irrigation development can be expected. PN37 results suggest that investments in irrigation can have much greater positive returns if livestock production is included as one of the income generating options to be supported by irrigation water use.

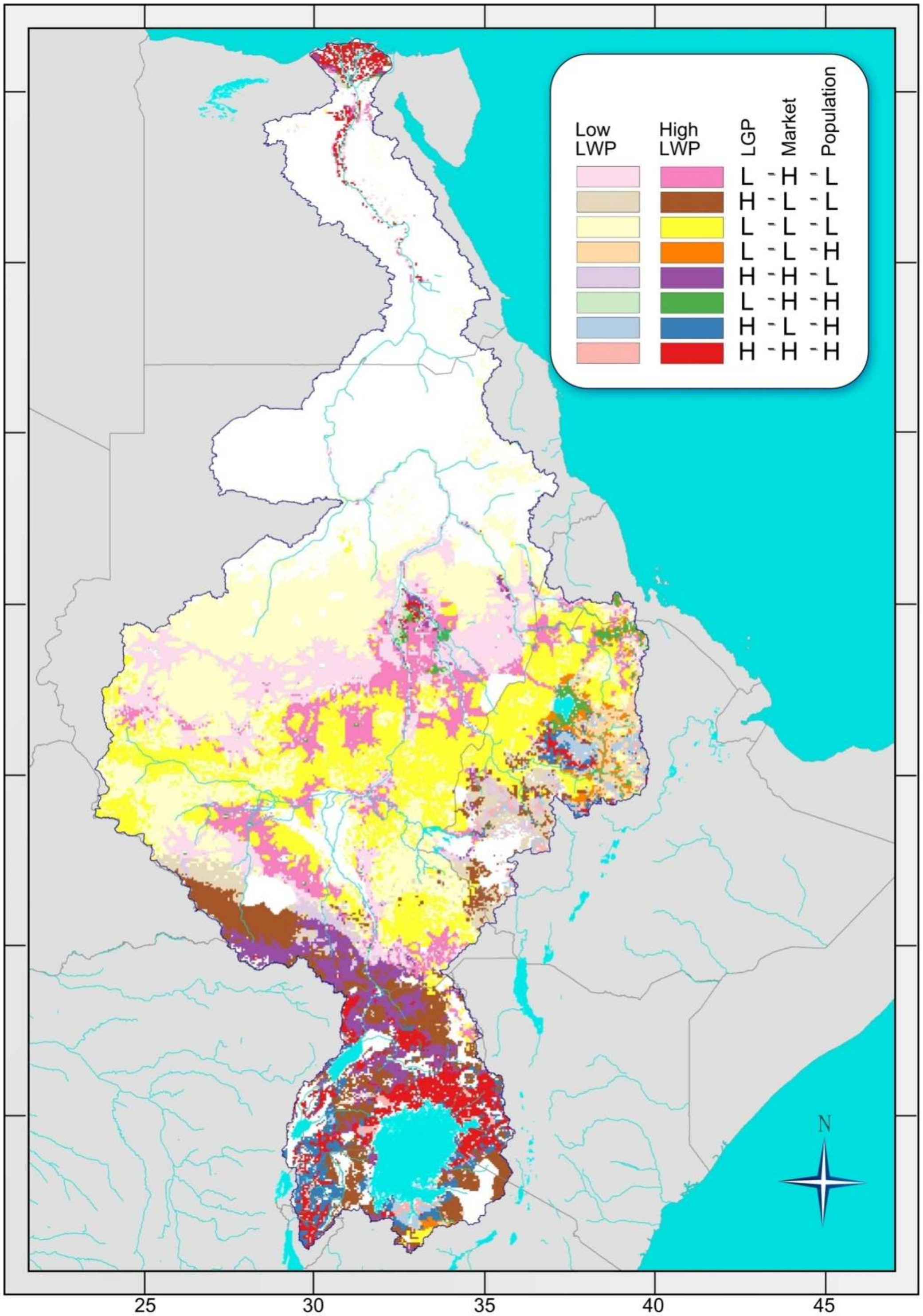


Figure 13. Indicative livestock-water development domains in Nile Basin suggest locations where well-chosen intervention options might help make better use of water for sustainable land management and improved livelihoods.

8 CONCLUSIONS

With support under the umbrella of the CGIAR Challenge Program on Water and Food (CPWF), this research project (Nile Basin Livestock-water productivity, PN37) embarked on an investigative query to understand how much water livestock use and degrade in the Nile River Basin. During the five year journey from inception to project end, PN37 developed a livestock water productivity framework (LWP) and tested the concept at the levels of the whole basin and case studies in Ethiopia, Sudan and Uganda. The LWP framework builds on previously developed water accounting models used to assess crop water productivity. Contrary to scant published literature available before the CPWF, PN37's research suggests that LWP is much higher than commonly believed. In general, LWP compares favorably with horticultural crop water productivity (CWP) and is higher than grain CWP at least when assessed in terms of monetary units such as US dollars per cubic meter. Perhaps more important, there are huge opportunities to increase LWP through improved feed sourcing, adoptions of off-the-shelf animal production practices, conservation of water associate with water use by livestock, and optimally distributing domestic animals across large land areas to avoid overgrazing near watering points and underutilization of feed far from them. Limiting stocking levels may be necessary.

This general conclusion appears to be valid over a range of geographic scales from households to the river basin and over diverse agro-ecosystems and socio-cultural contexts. For the whole Nile River Basin, the greatest opportunity for increasing poor farmers' and herder's access to water will be through focused and integrated development of rainfed agriculture (i.e. livestock dominated and mixed crop-livestock production systems). This area receives about 1.68 trillion m3 of rain of which about 75% is depleted as evapotranspiration and never contributes to the blue water system comprised of the Nile's lakes and rivers. The key challenge is to rehabilitate vegetative cover by shifting water lost through evaporation to transpiration.

Although there are many livestock production systems in the Nile Basin, six occupy about 60% of the land area. Each system is unique. Case studies from Ethiopia's mixed crop-livestock systems (temperate highlands), Sudan's Central Belt (Large scale irrigation, rainfed grain production and grazing systems), and Uganda's Cattle Corridor, confirm the relevance of the LWP approach to local and national development programs. In all cases, well-known technical interventions such as improved range management, cultivation, animal production, marketing, and water management are needed. However, these are not sufficient. PN37 research suggests that livestock keepers and farmers require enabling conditions to improve water productivity. Among these, access to land tenure, water rights, farm inputs, extension services, credit, health care, education and veterinary services are important. Additionally, agencies charged with the mandate for water development have tended to ignore the importance of livestock as a legitimate user of the Nile's water resources while those responsible for livestock have given little thought to water management issues. Investment strategies have rarely taken an integrated approach to livestock, crop and water development but doing so can lead to higher investment returns and greater environmental sustainability. When investing in water and agriculture, research suggests that development will have gender differentiated impacts by which men women and children may not share equitably share in the benefits and costs associated with such development.

The key recommendation emerging from PN37 research is that Nile Basin Initiative the inter-governmental body that will follow it plus the ten riparian country governments need to take an integrate approach to livestock, crop and water planning, investment, development, and management that starts with the premise that rainwater rather that water contained in lakes and rivers is the primary water resource. Fallowing out of this suggestion is the potential for massive increases in people's access to water resources, livelihood options and poverty reduction.

9 OUTCOMES AND IMPACTS

This portion of the PN37 focuses on main outcomes and impacts achieved. A summary follows in the table below. Like many research for development projects, impacts during a project lifespan are often few or non-existence. However, in this project, impact has been achieved in terms of having a documentable impact on the research agenda of the CGIAR and its component centers and inter-center programs. Outcomes are more evident as in terms of verifiable behavioral changes in actors' behavior. A key an unexpected outcome was discovery that since PN37 created the term, *livestock water productivity*, its use on the Web as grown with many web sites, not associated directly with PN37, promoting LWP concepts.

Summary Description of the Project's Main Impact Pathways

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
World Wide Web	Awareness & uptake of the LWP concept.	During the project period, greatly increased awareness developed regarding the potential for increasing LWP worldwide.	The following apply to all three sets of actors: 1) PN37 emphasized communication of project results rather than focusing on scientific publications. The key output driving this change was the LWP framework supported by case studies. 2) Key researchers and managers within ILRI, IWMI, host NARES (Ethiopia, Sudan and Uganda), CPWF management team and PN37 were visionary, thought outside the box and supported pursuit of this new research area.	Prior to CPWF Phase1, the term, *Livestock water productivity*, was not in use. At present (November 2009), this term received about 37,500 "hits" from a Google search.
CGIAR (Including the Science Council, CPWF, and some CG centers (ILRI, IWMI, ICRISTAT, CIAT, and System Wide Livestock Program)	Integration of livestock-water interactions within their respective research programs.	Prior to CPWF Phase 1, little thought had been given to research on the livestock-water nexus. During Phase 1, re-searchers and research managers in both sectors realized that this knowledge gap presented a major opportunity to improved water and livestock productivity in developing countries.		All institutions mentioned are either involved in livestock-water research or have acknowledged this as priority in at least one publically available document.
Ugandan set of stakeholders involving Makerere University, Local government, media and livestock keepers	Makerere's Animal Science Department took the unusual step of integrating hydrology into MSc training.	One enabling pre-condition to project success was the willingness of faculty and students to embark on an uncharted journey and to adapt to the unexpected when necessary.		Evidence of the change includes three novel and interlinked MSc theses, the authors of which now all have PhD scholarship to purse this line of research. In Nakasongola, the University invested in community development by enabling construction or rehabilitation of two water harvesting systems to which the community also contributed.
Sudanese stakeholders integrating LWP concepts into other projects	Increased awareness among researchers about importance of LWP	Many individuals working in both livestock and water resources management in Sudan are acutely aware of the importance of livestock-water issues. PN37 played a catalytic role in articulating issues in projects such as one on "Improving livestock production and marketing"	PN37 researchers in Sudan tend to work on multiple projects. While this was not explicitly a PN37 strategy, the effect was real.	The Sudan component of PN37 was late in starting. However PN37 team members in the country expect that project outputs will contribute to policy development in future.

The Web uptake of the LWP concept is likely to have the greatest impact and likelihood of success because the process has already started and is no dependent on the project or our institutions. The "genie is out of the bottle". However, we do expect several more project publications will fertilize continued dissemination. One reason why this impact may be important is the concepts are being shared widely to strategically influential stakeholders (e.g. see page 40 at http://www.odi.org.uk/events/2009/03/30/431-presentation-margaret-catley-carlson.pdf). The PN37 team is hopeful that high level decision-makers and investors will come to understand that integrating livestock and water development has great potential to increase returns on development investments while enhancing environmental sustainability.

At the local level, the Makerere led set of stakeholder have the stage for meaningful impact in Nakasongola District, Uganda. One outcome of the project has been the awarding of three PhD scholarships to the CPWF supported MSc students. To succeed, the Ugandan PN37 team will likely need to procure modest funding to support that adoption and scaling up process. Anticipated benefits will likely include improved livelihoods, greater crop and livestock production, reduced vulnerability during drought years and rehabilitation of degraded lands.

The research on LWP raises more questions than it answers. For example, LWP to date has focused volume of depleted water. There is good reason to believe that our understanding will change significantly if consider the price rather than volume of water. There is also need to better integrate LWP concepts with hydrological sciences. Globally, there is still much evidence that the majority of institutions with both livestock and water management mandates are not aware of the potential benefits that can come from integrating livestock and water development. The same holds true for many investor organizations and Ministries of Finance. Within the CPWF Phase 2, livestock-water issues feature as integral aspects of rainfed water management and multiple uses of water systems. There is less evidence to suggest that basin priorities have considered livestock-water issues. Within ILRI, livestock-water issues have been mainstreamed into its INRM research within its *People, Livestock and Environment* Research Theme. There is still need identify the "tipping point" beyond which many key stakeholders in developing countries will spontaneously encourage integrated livestock and water development.

The foregoing also applies in Uganda, but in the case of Uganda, the research team and ILRI are actively seeking funds for follow up.

In Sudan, there will be a need for small one-day country workshop or seminar in 2010 to share findings with stakeholders in the country.

All three about of the above "actors'" changes, especially the first two were unexpected. The outcomes in Nakasongola were partially expected, but at the project planning stage we could never have predicted the details in term of outputs and outcomes. At the global level, the project team never thought about the possibility that the LWP concept would spread so far and so fast. At the local level in Nakasongola, we did anticipate the likely biophysical impact of better managing small reservoirs (valley tanks) and upslope pasture. However, we had no idea that termites would intervene and devour one student's research project. Thanks to highly effective supervision by Makerere faculty, what the student considered to be a catastrophic failure was transformed in a novel technical innovation in the project.

The project took advantage of the unexpected by embracing these developments and learning from them. In addition to handling the initial "termite crisis", many of the communications opportunities arose serendipitously. Team members' willingness to respond to external and CPWF queries led to much wider than anticipated dissemination of concepts and research outputs

In future, we feel that the project would have avoided many inefficiencies the project been more closely integrated with other CPWF projects.

10 INTERNATIONAL PUBLIC GOODS

PN37 generated several International public goods (IPG). Foremost has been the *livestock water productivity* (LWP) framework captured schematically in Figure 1. The concept is well documented and available in several forms (e.g. Peden et al. 2007; 2009). The concept is now being used beyond the project especially within the CPWF. Following up on the development of this framework has been several tools that enable researchers to model or assess LWP. One key activity of PN37 was development of spread sheet model to enable field level assessment of LWP. PN37 publications such as Gebreselassie et al. (2009) and Haileslassie et al. (2009a, 2009b) have used this model. Newly funded projects are now also employing the methods. At the basin, scale different GIS tools were used to assess LWP (van Breugel et al. 2010b, 2010c). As a post PN37 activity and subject to available resources, the PN37 team plans to publish the methodologies in a form that integrates experience from several projects.

Beyond the LWP tools, the project generated numerous research outputs including maps, tables and reports. This report includes a selected set of these. All are available from ILRI, the CPWF, or publications cited herein. For some cartographic information and spatial data bases used in this project, future use depends on agreements and conditions set by those who have ownership rights.

11 PARTNERSHIP ACHIEVEMENTS

PN37 involved a unique partnership operating across the Nile Basin with key node being in Addis Ababa, Cairo, Kampala, Khartoum and Nairobi. During the project period there was some transition and change among active organizations and personnel. During the project, greatly increased travel costs and communication constraints limited meaningful interaction among members the project team and among the team, CPWF management and other stakeholders.

In spite of these and other constraints, the PN 37 team brought together a unique blend of researchers and stakeholders committed to the vision that that integrated livestock and water management and development could lead to improved food security, poverty reduction, better livelihoods, reduced conflict and rehabilitation of land and water resources. The result has been added value to science and PN37 outcomes as reported for example in Section 13 of this report.

From the science perspective, PN37 (in association with other CPWF projects and management) contributed to widespread acceptance of the water-livestock nexus as an important research area for the future. Research results reveal new and novel ways for making better use of agricultural water throughout the Nile River Basin and also more globally. Evidence also suggests that uptake of these ideas has spread far beyond the immediate network of PN37 researchers and stakeholders. This dissemination of project outputs via the World Wide Web was pivotal.

From a project leader`s perspective, it is doubtful that project could have achieved most of the science outputs and outcomes in the absence of the CPWF. CPWF funding was needed but not sufficient. Perhaps more important was the “space” created under the CPWF in which there was freedom to pursue new ideas in collaboration with a novel mix of supportive colleagues. The two international fora on water and food, the training programs for project MSc students, the inclusion of the Ugandan team in the CPWF video on the Nile are examples where CPWF management provided an enabling environment for the project to succeed and for project personnel to realize “buy-in” to the CPWF goals.

12 RECOMMENDATIONS

The overall recommendation from PN37 is that concerted effort is needed by diverse stakeholders to integrate livestock, crop and water development. This holds true at basin, national, sub-basin, watershed, community and household levels. It includes research, development, extension and investment organizations and personnel. Such integration also often will benefit from inclusion of other sectors of the economy such as public health. Past failure to integrate livestock and water management has contributed to sub-optimal returns on investments and aggravated human suffering and land and water degradation.

Having established the need to integrated livestock and water research and development, numerous research, extension, policy, and institutional recommendations are possible. However, developing a long list of detailed intervention options may not be helpful because all will be site and context specific. Thus, a few selected and illustrative suggestions follow:

Research:

Although the livestock water productivity (LWP) framework has proved useful, the concept remains a "work in progress".   There is need to improve and standardize the quality, availability and access to livestock, crop, and water data for all Nile countries.

In future, several methodological aspects of LWP are needed. They include:

- Consideration of the most appropriate measures or units for benefits derived from livestock. Although PN37 used kg/m^3 and USD/ m^3, other appropriate units may be preferable. In any case, the challenge remains about how include benefits such as cultural values of animals and nutritional values of animal sourced food.
- Consideration of the most appropriate measure of water depletion. Most research including PN37 has focused on volume of water (m^3), but different understanding would come from utilizing the price of water instead. Furthermore, most research has defined depletion as being evapotranspiration (ET). However separating E and T is essential converting E to T is to become an important avenue for increasing water productivity.
- One value of the current LWP approach is that it has provided an opportunity to better understand livestock-water interactions. However, isolating livestock-water interactions in the context of landscape and basin management or human development may not be helpful. Future research is needed to integrate livestock and crop water productivity into more holistic agro-ecosystem concepts that include people.
- The project achieved progress in understanding the gendered implications of improving LWP especially in terms of four main LWP enhancing strategies. Further effort is needed in this area and we further suggest that gender concepts be extended to include ethnicity and age and to implement gender analysis within the sustainable livelihoods approach.

PN37's country studies revealed example interventions to increase LWP, but these are not exhaustive. Future research needs to expand the range of potential technologies, policies, financial instruments and institutions that can help increase water productivity and to provide extrapolation domains to indicate where and when they could be helpful.

Policy, Institutions, Investment and Development:

In all countries throughout the Nile, at local to basin scales, there are major gaps in terms organizations' and policies' relevance to fostering integrated livestock and water development. Because among country differences are so great, one recommendation cannot fit all national contexts or needs. Nevertheless, key issues require attention.

Basin level:

- Because the total amount of rainfall far exceeds the blue water resources of the Nile River Basin, using rainwater more productively and equitably in rainfed agriculture holds great promise of poor peoples' access to water and reducing demand on relatively scarce and increasingly degraded rivers, lakes and wetlands. A key recommendation is the need for river basin management to include both green and blue water resources.
- PN37 research confirmed that integrating investments in water and livestock development increases investment returns and environmental sustainability. This should be accepted as a fundamental principle in future agricultural water development.

- The mandates of the Nile Basin Initiative, national agricultural research systems and the CGIAR include improving the lives of millions of poor cultivators and livestock keepers. Building on the existing agreement for collaboration between the CGIAR and the NBI, PN37 research recommends collaborative projects that integrate sustainable livestock, crop and water development for poverty alleviation.

- Through better management of vegetation (including cropland and rangeland), conversion of evaporation to transpiration can drive plant growth enabling greater water allocation to agricultural production and provision of ecosystem services. Basin, wide innovation in this area can make available billions of cubic meters of water that would otherwise not be available for human use. PN37 experience from Ethiopia, Sudan and Uganda provide evidence that such gains are possible.
- Throughout the basin, PN37 research confirmed that access to land, water, markets, and assets (e.g. credit to construct water harvesting ponds and to buy farm inputs, education, and health care) enable livestock keepers and farmers to increase water productivity and realized enhanced agricultural production. The research also demonstrated that common property communal grazing and watering areas are hotspots for natural resources degradation and animal disease transmission. There is need for regulatory mechanisms to enable rural poor people to either better manage the commons or to secure their access to privately tenured land and water resources. Notwithstanding the unique cultural and ecological contexts that vary throughout the basin, we recommend that relevant authorities collaborate to empower local people to undertake development activities that involve increasing agricultural water productivity.

National and local levels:

- In the Ethiopian Highlands, rainfed agriculture on steep slopes leads to high rates of soil degradation, runoff and low levels of crop and animal production. There is need for massive investments in land management practices that focus on soil and water conservation. This is true in both grazing and annual cropland areas.
- In the Central Belt of Sudan, a vast area of diverse livestock production systems, PN37 numerous opportunities for increasing livestock water productivity exist. In North Kordofan area, improved range management coupled with effective community based natural resource management and appropriate land tenure is a priority. In Butana, water harvesting coupled with improved road access to markets is necessary. In Gezira, effective integration of livestock into irrigation management is needed.
- In Uganda's Cattle Corridor, much land is locked into a state of severe degradation and low productivity in spite of relatively plentiful precipitation. PN37 research suggests that controlling termites through innovative reseeding of pasture coupled with development and maintenance of community based water harvesting systems can potentially and greatly increase agricultural water productivity enabling improved livelihoods and food security. Modest investments are needed in Nakasongola and neighboring districts to scale out PN37 research results.

13 PUBLICATIONS

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APPENDIX A

The following is a compilation of key publications and their respective Abstracts:

Alemayehu, M., Peden, D., Taddesse, G., Haileselassie A. and Ayalneh, W. 2008. **Livestock water productivity in relation to natural resource management in mixed crop-livestock production systems of the Blue Nile River Basin, Ethiopia.** In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008. Mixed crop-livestock farming is the most important production system in the Ethiopian highlands. Traditional livestock management practices often jeopardize water quality, human and animal health, and aggravate water mediated land degradation. The objectives of this study focused on determining livestock water productivity and investigating the effect of traditional livestock management patterns on sustainability of natural resource use in the Blue Nile Sub-basin. Overall, livestock water productivity (LWP) was about 0.65 Birr/m^3 of water under the traditional farming practices. LWP tended to increase proportionally with the volume share of crop residue in livestock feed. Communally owned and open unrestricted grazing land suffered most from erosive runoff events, with the concomitant sedimentation amounting to more than 40 t/ha at a slope of 15-25% by washing away pasture top soil. Traditional farming practices have evolved toward maximizing water use efficiency by exercising a double cropping pattern which takes advantage of residual moisture left after first cropping. This practice favors availability of more feed resources in the dry season, and thus contributes to increased livestock productivity. There is great opportunity to further increase LWP by implementing practical and relevant interventions that improve existing low levels of animal productivity.
Amede, T., Descheemaeker, K., Peden, D. and van Rooyen, A. 2009. **Harnessing benefits from improved livestock water productivity in crop–livestock systems of sub-Saharan Africa: synthesis.** *The Rangeland Journal* 31(2): 169–178. The threat of water scarcity in sub-Saharan Africa is real, due to the expanding agricultural needs, climate variability and inappropriate land use. Livestock keeping is the fastest growing agricultural sector, partly because of increasing and changing demands for adequate, quality and diverse food for people, driven by growing incomes and demographic transitions. Besides the economic benefits, rising livestock production could also deplete water and aggravate water scarcity at local and global scales. The insufficient understanding of livestock–water interactions also led to low livestock productivity, impeded sound decision on resources management and undermined achieving positive returns on investments in agricultural water across sub-Saharan Africa. Innovative and integrated measures are required to improve water productivity and reverse the growing trends of water scarcity. Livestock water productivity (LWP), which is defined as the ratio of livestock outputs to the amount of water depleted, could be improved through: (i) raising the efficiency of the water inputs by integrating livestock with crop, water and landscape management policies and practices. Improving feed water productivity by maximizing transpiration and minimizing evaporation and other losses is critical; (ii) increasing livestock outputs through improved feed management, veterinary services and introducing system-compatible breeds; and (iii) because livestock innovation is a social process, it is not possible to gain LWP improvements unless close attention is paid to policies, institutions and their associated processes. Policies targeting infrastructure development would help livestock keepers secure access to markets, veterinary services and knowledge. This paper extracts highlights from various papers presented in the special issue of *The Rangeland Journal* on technologies and practices that would enable improving water productivity at various scales and the premises required to reverse the negative trends of water depletion and land degradation.
Bekele, Mekete. 2008. **Integrating Livestock Production in to Water Resources Development: Assessment on Livelihood Resilience and Livestock Water Productivity at Alewuha and Golina Rivers. MSc Thesis, Awassa University, Awassa, Ethiopia.** A survey was conducted from December to June 2006 with emphasis to estimate the livestock water productivity (LWP) at farm household level under rainfed and irrigated mixed crop livestock farming system and assesses the implications on the livelihood resilience of farm households at Alewuha and Golina schemes. Data collected using household survey involving a total of 160 randomly selected respondents and discussion with key informants. Beneficial outputs of livestock

and crop production and depleted water for producing them were estimated and then water productivity as the ratio of the beneficial outputs and depleted water were determined. Variability of water productivity between farm households of the different farming systems under the two schemes had prevailed. Livestock water productivity showed significant difference ($p<0.001$) between households under different farming system at Alewuha and Golina schemes. The value of LWP in ETB ranged from 0.60±0.02 at Golina rainfed to 0.76±0.01 at Alewuha irrigated farm households. Livestock feed water productivity showed significance difference ($p<0.001$) between farm households under farming systems of the two schemes. The highest livestock feed physical water productivity (DM m^{-3} of water depleted) was estimated for Alewuha irrigated farming system at 0.7±0.03kg m^{-3} yr^{-1}, while the lowest was for Golina rainfed farming system at 0.54±0.02kg m^{-3} yr^{-1}. Much of the water depleted for livestock feed were accounted for feed from grazing lands, whereas crop residues were the prominent contributors for the livestock feed resource base, which were found at a negative feed balance to the prevailed livestock holding at farm household level. LWP showed significant and positive correlation with area of cultivated crop land ($r = 0.26$), livestock feed physical water productivity ($r = 0.50$) and farm water productivity (crop livestock) ($r = 0.49$) at household level. Livestock, besides their remarkable contribution for traction service which was found as the highest beneficial output valued at the present LWP study and ranked as the primary purpose of keeping cattle, were important assets to absorb shocks during times of disaster and mitigated food shortage were revealed. High beneficial outputs obtained from livestock in particular and agriculture in general and more utilization of animal power and family labour force under irrigated farming systems are indications that irrigation can bring more livelihood resiliencies of farm households, thereby facilitating asset building and further investment for increased productivity. Integrated holistic approaches of food-feed sourcing, water saving and conservation and livestock productivity enhancing strategies are important to lift up the prevailed low livestock water productivity and their contribution to the livelihood resiliencies of the farming community.
Curtis, Lori. 2007. **An economic valuation of water in a mixed crop-livestock farming system in the Gumera watershed of the Blue Nile basin, Ethiopia.** MSc Thesis, University of Edinburgh. As water is not only a requirement of agricultural production, but a key limiting input, this increase in the food requirements of the country will create an intensification of pressure on Ethiopia's water resources. Water conservation tools will become paramount for ensuring that there is sufficient water to fulfill the needs required of it, and economic tools will be valuable for determining that water is allocated to the uses in which it has the highest values. This study investigates the value of water in a mixed crop-livestock farming system in the Gumera Watershed of Ethiopia. Using information obtained from farmers about flows of revenues and expenses, the value of water is determined using the net-back analysis. The relationship between crops and livestock is analyzed on farms using a sample which consists of both rainfed and irrigated farms. The parameters of the model are examined to determine which directly influence the value of water, and where on the farm the value of water is greatest. The value of water was determined to be highest in livestock keeping, however this was also the area where there was greatest variability from farm to farm. The farming system as a whole had the lowest magnitude of variability in the value of water from farm to farm. The results showed that despite the fact that the value of water was lower on a mixed crop-livestock farm as opposed to either crops or livestock on their own, water resources management tools should be applied to the entire farm, as the interdependence of each factor on the other was too important to truly be able to separate them from one another.
Faki, H., El-Dukheri, I., Mekki, M., and Peden, D. 2008. **Opportunities for increasing livestock water productivity in Sudan**. In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008. Livestock and irrigated and rainfed crop production make up most of Sudan's agricultural GDP. Sudan is highly dependent on Nile waters flowing from upstream countries and on rainfed cropping and grazing within the country. This region has experienced high human and livestock population growth rates, increased cropping and widespread deforestation. This study addresses livestock water productivity (LWP) in the central belt of Sudan. In most of the belt there is a severe drinking water shortage for both animals and people. Livestock also suffer from feed shortages. The research suggests that LWP is low near watering points, because high animal concentration has degraded the nearby pastures. LWP is also low far from watering points because lack of water prevents animals from accessing otherwise available feed. The study concludes that improved natural resources legislation, institutional arrangements, marketing of livestock products, and veterinary care,

combined with efforts to optimally expand watering sites while limiting animal densities near them, can help increase LWP in an environmentally sustainable manner.

Fathelbari, M.O. 2009. **Water production systems and methods of their improvement in Al Gadarif State, Eastern Sudan.** MSc thesis, Sudan Academy of Science, Khartoum.

Near final draft of abstract: The aim of this work was to study the effect of livestock on water depletion by chemical and microbial contamination, and evaluate the water resources for defects in designs and other relevant parameters in AL Gadarif State, eastern Sudan. Samples were collected from 95 different water sources including open dug-wells, hafeers, microdams, deep and shallow wells, pools and springs and examined for physical parameters(turbidity, total dissolved solids and PH), chemical parameters (nitrate , nitrite, ammonia and lead), and coliform, faecal coliform and *E. coli*. Two standard methods were applied to detect for microbiological contamination, multiple-tube method and membrane filter technique. The results showed that water from hafeers and pools had a very high turbidity, but nitrite, ammonia, pH, and total dissolved solids were within the safe limits for drinking water. About 54% of all the 85 water sources had nitrate concentrations above acceptable levels. Shallow and dug wells samples revealed high levels of nitrate compared with WHO guideline (96% and 52.2% respectively). Defects in design of open dug wells affected water quality by elevated lead content from 7 out of 10 locations. 88.75% of the sources were at high or very high risk of pollution with *E.coli*, 80% with faecal coliform. Forty samples were checked for *Vibrio cholerae, Salmonella, Klebsiela* and *Citrobacter* using H_2S Hiselective test kit medium and 42.5% were positive for *Vibrio* spp, 22.5% for *Salmonella*, 22% *klebsiela*, 10% *citobacter* and 2.5% *E.coli* spp. A number of measures were suggested to minimize contamination caused by livestock. It is obvious that most of the water sources were vulnerable to risk of pollution and this was manifested in the outbreaks of acute watery diarrhoea in Gadarif State in 2006 , 2007and 2008.

Fathelbari, M.O. and Musa, M.T. 2008. **Water production systems and methods for their improvement in Al Gadarif State, Eastern Sudan**. In Fighting Poverty Through Sustainable Water Use: Volumes I, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008.

The aim of this research was to study the effects of livestock on water depletion by chemical and microbial contaminants, and to evaluate watering structures for defects in design, and to evaluate water from different sources for pH values, turbidity, and electrical conductivity in Al Gadarif State, Eastern Sudan. Ninety-five water samples from different water sources (open dug wells, microdams, hafeers, boreholes, springs, and pools) were analyzed for microbiological and chemical contaminations. Two standard methods were applied to detect fecal coliforms including *E. coli* and 12.5% of samples were below the WHO recommended limits, while 1.5, 7.5, 38.8, and 40% had low, medium, high, and very high pollution with fecal coliforms. Samples were checked for specific coliforms, and 42.5 % were positive for *Vibrio* sp., 22.5% for *Salmonella*, 10% for *Citrobacter*, 20% for *Klibsiella* spp., and 2.5 % for *E.coli*. Chemical analysis indicated water pollution by nitrate, nitrite, and ammonia content. Shallow and dug wells had high levels of nitrate (compared with the WHO guidelines) in 54.1% of samples, and some had high levels of lead because of faulty installation of water pumps and contamination from lead in gasoline. pH, electric conductivity, and total disolved solids were normal, but turbidity was high in hafeers and pools. Most of the water sources were at risk of pollution because of human and animal wastes. This was manifested in the outbreaks of acute watery diarrhea in Al Gadarif State in 2006 and 2007. Possible measures to minimize contamination caused by humans and livestock include separation of water for human use from that of animals, better harvesting of water, and construction of water sources.

Gebreselassie, G., Peden, D., Haileslassie, A. and Mpairwe, D. 2009. **Factors affecting livestock water productivity: animal scale analysis using previous cattle feeding trials in Ethiopia.** *The Rangeland Journal* 31(2) 251–258.

Availability and access to fresh water will likely constrain future food production in many countries. Thus, it is frequently suggested that the limited amount of water should be used more productively. In this study we report the results of our investigation on effects of feed, age and weight on livestock water productivity (LWP). The main objective is to identify technologies that will help enhance LWP. We combined empirical knowledge and literature values to estimate the amount of water depleted to produce beef, milk, traction power and manure. We estimated the LWP as the ratio of livestock products and services to the depleted water. In the feeding trials, various combinations of maize and oat stover, vetch, lablab and wheat bran were combined in different proportions to make 16 unique rations that were fed to the experimental animals of different age and weight groups. We observed differences of LWP across feed type, age and weight of dairy cows. The value of LWP tended to increase with increasing age and weight: the lowest LWP (0.34 US$/$m^3$) for cows less than five years whereas the highest LWP value was 0.41 US$/$m^3$ for those cows in the age category of 8 years and above. Similarly, there was an increase in LWP as weight of the animal increased, i.e. LWP was lowest (0.32 US$/$m^3$) for lower weight groups (300–350 kg) and increased for larger animals.

There were apparent impacts of feed composition on LWP values. For example, the highest LWP value was observed for oat, vetch and wheat bran mixes. Taking livestock services and products into account, the overall livestock water productivity ranged from 0.25 to 0.39 US$/$m^3$ and the value obtained from a cow appeared to be higher than for an ox. In conclusion, some strategies and technological options such as improved feeds, better herd management, appropriate heard structure can be adapted to enhance LWP.

Goreish, I.A. and Musa, M.T. 2008. **Prevalence of snail-borne diseases in irrigated areas of the Sudan.** 2008. In Fighting Poverty Through Sustainable Water Use: Volumes I, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008.

The Government of the Sudan integrated animal production within crop rotation in the country's major irrigation schemes, subjecting animals to water-borne diseases. This work was conducted in irrigated areas of the Nile Basin and its tributaries in Sudan to study the prevalence of water-borne diseases in natural and constructed habitats. We examined 1152 cattle, 889 camels, and 11,122 humans from 2000 to 2005. Overall, infections of *Schistosoma bovis* and *Fasciola gigantica* were high, but varied greatly among sampling sites. Average *S. bovis* prevalence was highest in The White Nile State where in some localities it exceeded 90%. *Fasciola gigantica* prevalence reached 28% in cattle in River Nile State. The prevalence of Schistosomiasis in camels was 60% in Kordofan State and 17% in Eastern State. In Tambol, El Gzera State, the average of *S. bovis* infection was 45%, with highest prevalence of 64%. The highest prevalence for *S. mansoni* in humans (82.5%) was found in New Halfa irrigated scheme, while the highest prevalence for *S. haematobium* was found in people in El Rahad area, North Kordofan State, where it reached 93%. The impact of these parasites on animal health and productivity and policy options to reduce disease risk are discussed. The research indicates that livestock water productivity in irrigation systems could be increased, if irrigation and livestock development and management collaborated to mitigate the threat of water-borne disease to domestic animals.

Haileslassie A., Peden, D., Gebreselassie, S., Amede, T., Wagnew, A., and Taddesse, G. 2009. **Livestock water productivity in the Blue Nile Basin: assessment of farm scale heterogeneity**. *The Rangeland Journal* 31(2): 213–222.

A recent study of the livestock water productivity (LWP), at higher spatial scales in the Blue Nile Basin, indicated strong variability across regions. To get an insight into the causes of this variability, we examined the effect of farm households' access to productive resources (e.g. land, livestock) on LWP in potato–barley, barley–wheat, teff–millet and rice farming systems of the Gumera watershed (in the Blue Nile Basin, Ethiopia). We randomly selected 180 farm households. The sizes of the samples, in each system, were proportional to the respective system's area. Then we grouped the samples, using a participatory wealth ranking method, into three wealth groups (rich, medium and poor) and used structured and pre-tested questionnaires to collect data on crops and livestock management and applied reference evapotranspiration (ET_0) and crop coefficient (K_c) approaches to estimate depleted (evapotranspiration) water in producing animal feed and food crops. Then, we estimated LWP as a ratio of livestock's beneficial outputs to water depleted. Our results suggest strong variability of LWP across the different systems: ranging between 0.3 and 0.6 US$ m^{-3} $year^{-1}$. The tendency across different farming systems was comparable with results from previous studies at higher spatial scales. The range among different wealth groups was wider (0.1 to 0.6 US$ m^{-3} $year^{-1}$) than among the farming systems. This implies that aggregating water productivity (to a system scale) masks hotspots and bright spots. Our result also revealed a positive trend between water productivity (LWP and crop water productivity, CWP) and farm households' access to resources. Thus, we discuss our findings in relation to poverty alleviation and integrated land and water management to combat unsustainable water management practices in the Blue Nile Basin.

Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T., and Descheemaeker, D. 2009. **Livestock water productivity in mixed crop–livestock farming systems of the Blue Nile basin: Assessing variability and prospects for improvement.** *Agricultural System*s 102(1-3):33-40. Water scarcity is a major factor limiting food production. Improving Livestock Water Productivity (LWP) is one of the approaches to address those problems. LWP is defined as the ratio of livestock's beneficial outputs and services to water depleted in their production. Increasing LWP can help achieve more production per unit of water depleted. In this study we assess the spatial variability of LWP in three farming systems (rice-based, millet-based and barley-based) of the Gumera watershed in the highlands of the Blue Nile basin, Ethiopia. We collected data on land use, livestock management and climatic variables using focused group discussions, field observation and secondary data. We estimated the water depleted by evapotranspiration (ET) and beneficial animal products and services and then calculated LWP. Our results suggest that LWP is comparable with crop water productivity at watershed scales. Variability of LWP across farming systems of the Gumera watershed was apparent and this can be explained by farmers' livelihood strategies and prevailing biophysical conditions. In view of the results there are opportunities to improve LWP: improved feed sourcing, enhancing livestock productivity and multiple livestock use strategies can help make animal production more water productive. Attempts to improve agricultural water productivity, at system scale, must recognize differences among systems and optimize resources use by system components.
Haileslassie, A., Gebreselassie, S., Peden, D., Amede, T. and Descheemaeker, K. 2008. **Impacts of access to resources on water productivity: the case of the Blue Nile**. In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008. Producing more product per unit of agricultural water used is a key for future food and environmental security. We report how access to productive resources (here referred as level of wealth and poverty), such as land and livestock, affects farmers' management decisions and resultant water productivity (WP); and how in mixed crop-livestock systems, WP of crops and livestock complement each other. The mixed farming systems in the highlands of Blue Nile Basin (Gumera, Ethiopia) were selected. Farm data were collected from 180 randomly selected households, using a structured questionnaire. The sample farm households were stratified into three wealth categories (rich, medium, and poor) using a participatory wealth ranking method. New LocClim (version 1.06) was used to estimate evapotranspired water in producing animal feed and food-crops, and beneficial outputs of livestock and crop yields were calculated from primary data and empirical knowledge. Finally WP was estimated as ratio of beneficial outputs to water depleted. Our results indicated significantly lower WP values for the poor farm households. In view of the results, we concluded that poverty alleviation and fostering pro-poor intervention technologies must be part of strategies to ensure sustainable water use.
Mpairwe, D., Mutetikka, D., Kiwuwa, G., Mugerwa, S., Owoyesigire, B., Zziwa, E. and Peden, D. 2008. **Options to improve livestock-water productivity (LWP) in the cattle corridor within the White Nile sub-basin in Uganda.** In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008. The 'cattle corridor' is generally too dry for crop production and suffers from land degradation caused by overgrazing and indiscriminate harvesting of trees for charcoal burning. Drinking water is seasonally scarce forcing farmers to migrate with their animals to the Nile. Makerere University established a study site in Kiruhura and Nakasongola districts within the cattle corridor, as part of the CPWF Nile Livestock Water Productivity (LWP) project, to identify options for enhancing LWP and increasing animal production. The sustainability of water harvesting systems, options for reseeding highly degraded pastures, and gender and social-science dimensions of livestock keepers were studied. This paper is a synthesis of the work and suggests options for improving LWP, livelihoods, and environmental sustainability. Rehabilitation trials suggested use of cattle manure as the key to reseeding highly degraded areas. Total dry matter (DM) production, ground cover, and species richness were greatly increased by manure application. Water resource utilization and livestock productivity in the pastoral communities were seriously affected by inadequate water, gender, land ownership and utilization, access to and ownership of water sources, and distance to a water source. Sedimentation, evaporation, and degradation of water are critical factors that reduce the availability and quality of water.

Mugerwa, S., Mpairwe, D., Sabiiti, E.N., Mutetikka, D., Kiwuwa, G., Zziwa, E., and Peden, D. 2008. **Cattle manure and reseeding effects on pasture productivity.** In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008. Uganda's rangelands are seriously degraded due to overgrazing, which causes loss of vegetation cover and soil erosion. Consequently, soils have low levels of nitrogen, phosphorus, potassium, and soil organic matter (SOM). Low SOM eventually increases the destructive effects of termites on pasture. Under such conditions, water is used inefficiently regardless of the quantity received, leading to low livestock water productivity. This work was aimed at rehabilitation of degraded pastures through reseeding, fencing, and use of manure for improved livestock water productivity. The effects of these treatments on pasture productivity in wet and dry seasons are presented. In both seasons, dry matter yields varied significantly with treatments. Highest dry matter yields (3820 kg/ha) occurred in the manured reseeded treatment. Vegetative ground cover was significantly affected by the interaction between season and treatment. Control plots had no vegetative cover in either season, whereas only 2% and 29% of the manured reseeded plots had bare ground in the wet and dry seasons, respectively. Generally, manured plots showed high dry matter production, species richness, percentage cover, and drastic changes in botanical composition compared to nonmanured plots. Reseeding and manure application is an effective and practical intervention to rehabilitate degraded rangelands and increase livestock water productivity.
Mugerwa, Swidiq. 2007. **Effect of reseeding and cattle manure on pasture and livestock water productivity in rangelands of Nakasongola District, Uganda.** MSc thesis, Makerere University. Rangeland degradation attributed to overgrazing, termite activity and deforestation has resulted in the development of large bare surfaces locally known as "*Biharamata"* in Nakasongola District. Devoid of adequate vegetation cover, the rangelands are associated with reduced water infiltration, accelerated runoff causing soil erosion, silting of downstream water reservoirs and hence reduced livestock water productivity. This research was therefore aimed at improving livestock water productivity in rain-fed pastoral production systems through restoring vegetation on degraded bare surfaces. The effect of reseeding and cattle manure application on pasture productivity and the resultant impact of these interventions on livestock water productivity were investigated. Six treatments were studied- Fencing plus manuring (FM), Fencing only (FO), Fencing plus reseeding (FR), Fencing + manure left on soil surface + reseeding (FMR), Fencing + Manure incorporated in to the soil + reseeding (FMR^1) and control (C) (no manuring, fencing and reseeding). Data on soil nutrient status and pasture productivity was collected over a period of one year covering two dry seasons and two wet seasons. In both seasons, the dry matter yield varied significantly ($p < 0.05$) with treatments. Highest mean dry matter yield (3820kg/ha) was recorded in fenced, manured and reseeded plots and lowest in the control and fenced only plots. Mean dry matter production (3300kg/ha) recorded for the manured plots was 125% higher than that (1470kg/ha) from non-manured plots. Treatment and season interaction led to significant ($p < 0.05$) changes in percentage bare ground and species richness. The lowest percentage bare ground (2.4%) was recorded in the wet season for fenced, manured and reseeded treatment. Generally, the percentage bare ground for non-manured plots was 5 and 2 times more than that for manured plots in the wet and dry seasons, respectively. Highest species richness (10 species per m^2) was recorded in fenced, manured and reseeded plots. Regardless of the season, treatments caused significant differences in crude protein (CP) content and neutral detergent fibre (NDF). Highest pasture CP (9.7%) value was recorded in fenced, manured and reseeded plots and lowest (4%) in fenced only plots. The CP (9.4%) content for manured plots was 73% higher than that (5.5%) recorded for non-manured plots. Highest percentage of NDF (85%) was recorded in fenced only plots and lowest in fenced, manured and reseeded plots. Treatment and season interaction led to significant ($p < 0.001$) differences in organic matter digestibility (OMD). Highest OMD (65%) was recorded in fenced, manured and reseeded plots and lowest (37%) in fenced only plots. Increase in dry matter production led to improvement in livestock water productivity. Highest increment (31% increases) in livestock water productivity was recorded in fenced, manured and reseeded plots with dry matter yield of 7644kg/ha/yr. Inclusion of cattle manure during reseeding operations improves pasture and livestock water productivity in degraded rangelands. The intervention is particularly important in termite infested degraded rangelands where pasture establishment is usually limited by termite damage. The success of this intervention however, lies in the ability of pastoralists to work out mechanisms that will enable them combine their herds so as to quicken the process of manure deposition and to

ensure that a large area is covered in a short time.

Ndikumana, J. and Kamide, R. 2005. **Challenges and Opportunities for the Livestock Industry in East and Central Africa: Strategic priorities for Research.** Proceedings from *Challenge Program on Water and Food Workshop on Nile Basin Water Productivity: Developing a Shared Vision for Livestock Production*, Kampala, 5–8 September. http://www.ilri.org/data/livelihood/UgandaWorkshop2005/Jean%20Ndikumana.pdf.

The review of the research domain indicated that the Nile basin member countries are net importers of livestock products and the trend is expected to worsen if appropriate science based technologies, markets, policies and institutional innovations are not generated and/or utilised to ensure that future production is sufficient to meet the increasing demand. The evaluation of existing results indicated that a number of technologies that might increase the productivity per animal have been generated by national and international research institutions in the region but for various reasons, such as poor packaging of the technologies, poor market opportunities, inadequate policies and institutional set up, their adoption and effective utilisation by the smallholder farmers have generally been low.

The constraints and opportunities analysis shows that the major constraints to significant contribution of the livestock sub-sector to sustainable livelihoods are the poor returns from the sector and its low contribution to the sustainability of the environment and ecoservices. Poor returns from the sector were further attributed to the low farm level profitability and to poor market opportunities. Further analysis using the constraints tree techniques led to the identification of a wide range of constraints at various levels from which potential research activities to address the constraints were identified. The constraints analysis and opportunities also showed that a wealth of opportunities exists to increase the adoption rate of technologies and increase the productivity and economic returns from the livestock sector while enhancing the quality of the environment.

Owoyesigire B., Mpairwe, D., Mutetika, D., Bashasa, B., Kiwuwa, G. and Peden, D. 2008. **Socioeconomic factors affecting livestock water productivity in rainfed pastoral production systems.** In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008.

A study was conducted in Nakasongola and Kiruhura pastoral communities of Uganda to estimate livestock water productivity (LWP), and establish socioeconomic factors that affect LWP in rainfed pastoral production systems of the Nile Basin watershed. A semistructured questionnaire was administered to 185 households. Crop water requirements and livestock benefits were estimated and data used to compute LWP. The main factors affecting LWP included gender within the household, level of education, land ownership and utilization, access and ownership of water sources, and tree harvesting for use in charcoal burning. Livestock water sources included: boreholes, wells, ponds, valley dams, swamps, rivers, and lakes. Livestock water sources varied with seasons with an average distance of 7 km in the dry season and 3 km in the wet season. Important livestock beneficial outputs included milk, meat, and sales from live animals. Average annual milk production was 3260 l/household in Nakasongola and 15,070 l/household in Kiruhura. In all the surveyed pastoral communities, LWP was < US$/1 m^3. It was concluded that to improve LWP, pastoral communities should improve overall allocation and use of water and land resources for all users.

Owoyesigire, Brian. 2009. **Assessment of factors affecting livestock water productivity of rainfed pastoral production systems in the Nile River Basin of Uganda.** MSc Thesis, Makerere University.

The study was conducted in Nakasongola and Kiruhura districts of Uganda to establish Livestock water productivity (LWP) and the socio-economic factors that affect LWP in rainfed pastoral production systems in rainfed pastoral communities of the Nile river basin. Socio-economic factors affecting LWP were established through a semi-structured questionnaire administered to 185 households. Depending on the degree of mobility of people and livestock in search for water and pastures, data collected were separated into three pastoral subsystems namely settled, non-settled and semi-settled. Data for estimation of LWP parameters was collected using the same questionnaires and in addition physical measurements of the crop fields and yields were conducted. LWP was computed as the ratio of beneficial outputs to the amount of water depleted in producing them. Socio-economic data was analysed using a multiple linear regression (MLR) model. The

results revealed that the socio-economic factors affecting LWP in the three pastoral systems included gender, education level of the household head, livestock herd size, land ownership and utilisation, access to and ownership of water sources. Land degradation was severe in the non-settled pastoral community while overgrazing was common in all the pastoral systems. Gender specific roles existed in perfoming livestock water related activities in all three sub systems. Sources of water for livestock included; boreholes, wells, ponds, valley tanks, swamps, rivers and lakes, and, distance to these sources varied with season with an average of 5.2 km (SD± 3.7 km), 7.41 km (SD± 7.01 km), and 3.8 km (SD ± 2.8 km) for the settled, non-settled and semi-settled systems respectively. In the wet season the distance covered to access water was shorter i.e 1.39 km (SD± 1.3 km), 3.0 km (SD± 2.3 km), and 1.3 km (SD± 0.74 km) for the settled, non-settled, and semi-settled systems respectively. The most important livestock beneficial outputs included milk, meat and sale of live animals. The most important benefit in the settled pastoral community was milk while in the non-settled pastoral community sales from live cattle formed the highest proportion of household income. Average annual milk production was 15,070, 3,260 and 2,652 litres per household in the settled, non-settled and semi-settled pastoral communities respectively. Pasture production was the most important form of water depletion in all pastoral communities. The amount of water depleted (crop water requirement) in the settled pastoral community was significantly higher (6,248,580 m^3) than in both semi-settled (2,008,361 m^3) and non-settled community (5,831,548 m^3). The settled pastoral community had a higher LWP (0.075 US$/m^3$) compared to the non-settled and semi-settled communities (0.034 and 0.051 US$/m3, respectively). It was concluded that settlement of pastoralists improved availability and management of pastures and water which results into increased livestock beneficial outputs and hence improved LWP. Key options to improve LWP included; enactment and enforcement of bylaws that protect surface water sources from siltation, promotion of access to water and its availability, intensification of livestock-crop integration and improved pasture and livestock management.
Peden, D., Amede, T., Haileslassie, A., Taddesse, G. 2008. **Strategies for Improving Livestock Water Productivity.** In Fighting Poverty Through Sustainable Water Use: Volumes I, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008. Increasing agricultural water productivity (WP) is a global priority for sustaining future food production and ecosystem services. Previous WP studies focused on crop production especially under irrigation. Livestock keeping, however, occupies more land area worldwide than crops. It is also a major component of agricultural GDP, providing meat, milk, income, farm power, manure (for fuel, soil fertility replenishment, and house construction), insurance, and wealth savings to hundreds of millions of people worldwide, but livestock keeping requires a lot of water. Unfortunately, inappropriate livestock keeping practices often cause needless water degradation and depletion. Within the CGIAR Challenge Program on Water and Food, this project employed a water accounting approach to develop a livestock water productivity (LWP) assessment framework that was used to identify strategies for increasing LWP, assess LWP in the Blue Nile Basin, and suggest opportunities to improve LWP more widely. Four major strategies for increasing LWP are: providing feeds composed of plants having high crop water productivities; using marketing and animal sciences such as genetics, veterinary health services, and nutrition to maximize potential benefits derived from animal products and services; adopting animal management practices that encourage increased transpiration and infiltration and reduced runoff, evaporation, and contamination; and spatially allocating watering sites to balance supply and demand for animal feed and drinking water. In the Nile region, LWP currently compares favourably with crop water productivity. There is still a great opportunity to further increase LWP by integrating investments, development, and management of agricultural water and livestock in the Nile and other developing regions of the world.
Peden, D., Faki, H., Alemayehu, M., Mpairwe, D., Herrero, M., Van Breugel, P., Haileslassie, A., Taddesse, G. and Bekele, S. 2008. **Opportunities for increasing livestock water productivity in the Nile River Basin.** Proceedings of the Nile Basin Development Forum, Khartoum, Sudan, November 17-19, 2008. Livestock keeping in the Nile Basin contributes greatly to human security, income, culture and agricultural gross domestic product (GDP). However, inappropriate managed livestock use much water and cause excessive water and land degradation. Livestock-water interactions are complex, but not well understood. Investments in agricultural water development often ignore potential and actual benefits and costs associated with animal use of and impact on water. Apart from drinking

requirements, livestock management frequently overlooks water-related issues. This knowledge gap leads to inefficient and inequitable use of water resources in particular. Within the CGIAR *Challenge Program on Water and Food*, we developed a livestock-water productivity (LWP) assessment framework to identify key animal-water interactions and opportunities for increasing LWP in diverse Nile production systems. We applied this framework to mixed crop-livestock systems in the Ethiopian highlands, the Cattle Corridor of Uganda, and rangeland and rainfed and irrigated crop-livestock production in the central belt of Sudan. We used these analyses to suggest technology and policy options and institutional arrangements that could enable more productive and sustainable use of water. This paper summarizes our research and draws on Ethiopian, Sudanese and Ugandan case studies. This study suggests that LWP often compares favorably with crop-water productivity and exceeds that of grains. Yet, huge opportunities remain to further increase LWP potentially enabling water reallocation to satisfy competing human demands and ecosystem services. Integrating livestock and agricultural water development potentially increases both investment returns and sustainability. Four key strategies to increase LWP are suggested: 1) Wise and optimal selection of animal feeds based on high crop and feed water productivity and low price of water; 2) Improved water conservation through better management of watering sites, vegetation and soil on grazing, crop and riparian lands; 3) Adoption of proven animal production interventions such as veterinary services, good nutrition, and husbandry and using appropriate animal species and breeds; and 4) Strategic allocation of watering sites balanced with stocking limits to re-allocate grazing pressure from overgrazed to underutilized pasture. Implications and opportunities for benefit sharing, IWRM, and poverty reduction in the Nile Basin are discussed.
Peden, D., Girma Tadesse, G. and A.K. Misra, A.K. 2007. **Water and livestock for human development.** In Molden, D. (ed.): *Water for food, Water for life. A comprehensive assessment of water management in agriculture*. 2007. Earthscan, and Colombo: International Water Management Institute, pp 485-514. A book chapter without an abstract. Overview available at: http://www.iwmi.cgiar.org/assessment/Water%20for%20Food%20Water%20for%20Life/Chapters/Chapter%2013%20Livestock.pdf.
Peden, D., Taddesse, G., and Haileslassie, A. 2009. **Livestock water productivity: implications for sub-Saharan Africa.** *The Rangeland Journal* 31(2): 187–193. Water is essential for agriculture including livestock. Given increasing global concern that access to agricultural water will constrain food production and that livestock production uses and degrades too much water, there is compelling need for better understanding of the nature of livestock–water interactions. Inappropriate animal management along with poor cropping practices often contributes to widespread and severe depletion, degradation and contamination of water. In developed countries, diverse environmental organizations increasingly voice concerns that animal production is a major cause of land and water degradation. Thus, they call for reduced animal production. Such views generally fail to consider their context, applicability and implications for developing countries. Two global research programs, the CGIAR 'Comprehensive Assessment of Water Management and Agriculture' and 'Challenge Program on Water and Food' have undertaken studies of the development, management and conservation of agricultural water in developing countries. Drawing on these programs, this paper describes a framework to systematically identify key livestock–water interactions and suggests strategies for improving livestock and water management especially in the mixed crop–livestock production systems of sub-Saharan Africa. In contrast to developed country experience, this research suggests that currently livestock water productivity compares favourably with crop water productivity in Africa. Yet, great opportunities remain to further reduce domestic animals' use of water in the continent. Integrating livestock and water planning, development and management has the potential to help reduce poverty, increase food production and reduce pressure on the environment including scarce water resources. Four strategies involving technology, policy and institutional interventions can help achieve this. They are choosing feeds that require relatively little water, conserving water resources through better animal and land management, applying well known tools from the animal sciences to increase animal production, and strategic temporal and spatial provisioning of drinking water. Achieving integrated livestock–water development will require new ways of thinking about, and managing, water by water- and animal-science professionals.
Pineau, M. 2008. **Response-Inducing Sustainability Evaluation (RISE) Model to Assess Sustainability of Ethiopian Farming Systems**. BSc Thesis, Swiss College of Agriculture.

The pressure on the arable land in the Ethiopian Highlands is high due to the natural resources being constantly reduced and livestock- and water productivity being insufficient to meet actual and future food demands of the growing population. This study is embedded in the projects of the ILRI (International Livestock Research Institute) who is committed to increase livestock- and water productivity and thus alleviate poverty in 12 global benchmarked watersheds. This paper presents the application of the RISE model in a holistic way to assess the sustainability of farming systems by four communities in the Gumara watershed of Lake Tana (Nile / Blue Nile sub-basin). Twenty-nine farmers were interviewed in the Farta and Fogara district, East of Lake Tana, using an adapted RISE questionnaire. Based in the upper part of the Blue Nile sub-basin, these farmers represent a sample of the typical farming systems responsible for the major problem of soil fertility depletion and erosion that create land pressure and downstream pollution. Results revealed major sustainability deficits in economic efficiency (low incomes), social securities (no social insurance and safety nets) and in the management of the nutrient cycle (imbalance due to loss of nutrients and low yields). Other bad indicators of the 29 farms assessed are biodiversity (threatened), plant protection and economic stability (no investment). Soil still is a good, available resource but is highly subjected to erosion without there being any countermeasures in place. Moreover, it is exposed to intensive cultivation and overgrazing. The farmers perceive water as a resource that is available on a yearly basis. RISE, however, has determined that it is a highly polluted resource due to animals entering the water bodies. This has a detrimental impact both on the health of humans and livestock. High water run-offs and nutrient losses considerably lower yields. As a result, there is a high potential to increase water productivity. The RISE approach could reveal a number of intervention points on how sustainability deficits can be addressed. The analysis of results and informal interviews revealed three principal entry points that are highly efficient concerning the increased effectiveness of efforts that are already being made. The first step is to support farmers in their process of land consolidation and, as a result, considerably increase labor efficiency, farm management and motivation. Secondly, society should be organized in such a way that communal free grazing areas are managed to avoid high levels of erosion and increase fodder- and thus livestock and water productivity. Thirdly, market prices should be stabilized to allow farmers to escape the vicious poverty spiral. This study discusses several alternatives for the implementation of these three strategies as well as five other secondary entry points and enhances negative findings detected by the RISE tool. These measures helping the three main entry points are: irrigation systems to reduce the variation in water availability, applied agricultural techniques to keep soil cover and increase biodiversity, fodder production, herd management and group dynamics to stimulate change. The feedback to farmers, local NGOs and centers (CARE, GTZ, ARARI) could validated both the RISE results and the three main intervention points. Water management and good farming practices are obvious means of improvement of which there is already good awareness. They are, however, not yet fully implemented. Their efficient broad and necessary realization will only be possible after implementation of the first three entry points mentioned above.
Sere, C., Peden, D., Persley, G. and Johnson, N. 2008. **'Swimming upstream' – the water and livestock nexus.** In Fighting Poverty Through Sustainable Water Use: Volumes I, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008. The purpose of this paper is to discuss the importance of livestock in relation to improving agricultural water management. This issue is addressed across the spectrum of global, regional (basin-watershed), farming system, animal and household levels of water management. The paper also discusses future research priorities, for the two fold purpose of ensuring that: (1) livestock keeping contributes to more productive and sustainable use of agricultural water in the future; and (2) livestock play an effective role as a pathway out of poverty for the 600 million people worldwide who depend on livestock for their livelihoods. The paper concludes that the Water and Food Challenge Program has in its short life succeeded in drawing researchers' and policymakers' attention to a range of livestock related issues influencing water productivity. Having successfully raised awareness, efforts now need to concentrate on: (1) understanding the main drivers shaping the nature of the trade-offs amongst water and livestock; (2) quantifying the relative importance of feasible technology, policy and institutional interventions at various levels to improve system performance, and (3) engaging social change processes that will turn the knowledge developed into action on the ground. Given the overarching scenario of rapidly increasing water scarcity globally and rapidly growing demand for animal products in the developing world, research and development

investments at the water, food and livestock intersection should have significant payoff in terms of overall benefits - for people, livestock and the environment.

Tesfahun, D. 2006. **Catchment water balance for Blue Nile River Basin.** MSc thesis, Arba Minch University, Arba Minch, Ethiopia.

The Blue Nile River is one of the major tributary for the Nile River. It provides the greater portion (about 62%) of the total flow of the main Nile. Blue Nile originates from Ethiopia high lands at about an elevation of 2000 m.s.l. Despite enormous potential to the country as well as regional countries such as Sudan and Egypt, the information availability and low level of studies make Blue Nile as one of obscure river. The proper water balance and sub basins water yield has not been properly estimated.

This study is an attempt to estimate the total annual flow at Sudan border through estimation of water yield at each sub basins using water balance modeling. A conceptual rainfall-runoff model known as MOWBAL has been used for calibration and validate of model parameters.

Application of the MOWBAL model for 43 catchments shows that more 52% of the total gauged catchments give outstanding performance with R^2 greater than 80%, and more than 45% of the total catchments also show good performance with R^2 of more than 50%. This shows that MOWBAL appears to be a suitable model for catchments of BNRB (see table 5.2).

The estimate of water yield for each of 14 sub basins have been generated using estimation of areal average model parameters and running the model under prediction model for each sub basin. Accordingly, Dabus and Didessa sub basins contribute 22% of the total flow at Blue Nile Basin. Flows from old Gojjam district contribution reaches about 33% of the total Blue Nile flows. However, for most of the sub basins the water yield per square kilometer is found within the narrow band of 0.25 and 0.44 Mm^3/km^2.

The total flow from the Blue Nile Basin at the border to Sudan is estimated to be 52.9 BCM. This figure is comparable with WAPCOS study (1960) which is estimated to be 52.6 BCM. However recent estimates by Sutcliffe and Park (1999) and BECOM (1998) gives a figure of 49.7 BCM.

In the case of seasonal variation, the buld of the runoff (89%) on average occurs between June and October which are the rainy season for most of the sub basins. In all sub basins except Tana the peak flow occurs in August where for Tana sub basin the maximum appears in September. The long term mean annual flow of 48.66 Km^3 at Sudan border from 1912 masks a variation from low annual totals of 20.89 Km^3 in 1929 (Sutcliffe et al. 1999). In this study also which uses recent input records gives the total outflow of 52.9 km^3 at the border. This shows the annual variation of flows of Blue Nile.

In general the out puts of the model are comparable with the previous works. As this study is more in depth and the accuracy of rainfall-runoff relation ship for the sub catchments are found to be higher, the overall water yield looks reasonable.

Tulu, M., Boelee, E., Taddesse, G., Peden, D. and Aredo, D. 2008. **Estimation of livestock, domestic use, and crop water productivities of SG-2000 Water Harvesting Pilot Projects in Ethiopia.** In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008.

The quantification of water productivity of each activity in agriculture is important to improve the allocation of scarce water resources and the efficiency of their use. The major objective of this paper is to estimate the water productivity of domestic use, livestock, and crops in Sasakawa Global-2000 (SG-2000) water harvesting pilot projects in Ethiopia. The research work was entirely based upon secondary data obtained from various organizations and publications. Water productivity was calculated using simple arithmetic methods and values of parameters from various sources. Water productivity of livestock, domestic use, and crop production was estimated at US$4.82, 25.06, and 0.95/$m^3$ of water, respectively (1US$ = 8.5 Ethiopian Birr (ETB) in 2008). To show the scarcity value of water or the opportunity cost of investment in water development, these productivity values were recalculated taking the value of water in rural areas as the denominator. The resulting productivity magnitudes for livestock, domestic use, and crop water were, US$1.60, 8.50, and 0.32/dollar of water respectively. The results show that water used for domestic purposes

and livestock generated positive gross returns for rural households in the study areas.
Van Breugel, P., Claessens, L., Notenbaert, A., Van de Steeg, J. and Herrero, M.. 2010a. **Livestock induced soil erosion potential in the Nile River Basin.** *CPWF research paper* under development and submitted to the CPWF. Colombo: CPWF. Soil erosion is a serious threat of increasing dimensions and tends to blunt efforts to counter global population growth with increased and sustainable agricultural production. Previous work has described and tried to quantify the global dimensions of soil erosion and the problem seems to be particularly severe in developing countries. Especially the tropics are vulnerable because of the circumstantial convergence of intense climatic regimes, frequently fragile soils, improver use of fertilizer and conservation practices and strong dependence on soil quality for livelihoods. Investments in interventions to attenuate soil erosion are hampered by a lack of adequate spatial data characterizing erosion status and risk. Tools for assessing spatially explicit erosion patterns would be a great help for planning soil conservation measures or targeting agricultural technology interventions. Because extensive measurement of soil erosion is expensive and time consuming, erosion models that make use of data available in a Geographic Information System offer a great alternative to both assess current erosion rates and processes and simulate scenarios of for example climate change, technology or policy interventions. In this report, an attempt is made to map potential soil erosion on the sub-continental scale. We use principles of the Universal Soil Loss Equation (USLE) and its reformulations to make a qualitative assessment of soil erosion in the Nile basin countries. Data on climate, soils, topography, hydrology and land cover are derived from existing secondary data sources that are spatially explicit and have an adequate resolution to be linked, at least as proxies, to important drivers of soil erosion as represented in the USLE. Obvious limitations, boundary conditions and assumptions of both methodology and data, as well as the lack of validation possibilities restrict us to only assign classes of relative erosion probability, rather than mapping soil erosion in a quantitative way. Still, the results obtained have value in reflecting patterns of current soil erosion across the Nile basin region and highlighting hotspots of soil erosion risk where agricultural research can focus efforts of developing or applying soil conservation measures and target agricultural technology and policy interventions that can mitigate the adverse effects of soil erosion on poor people's livelihoods. To further explore this, the potential erosion map was compared with the GLASOD data layer for water erosion severity as well as with factors that might influence erosion rates or might indicate areas were erosion could potentially have a higher impact, including human population density, livestock densities and feed demand and livestock production systems.
Van Breugel, P., Herrero, M. and Peden. 2010b. **Livestock water use and productivity in the Nile basin.** *CPWF working paper series* (in press). Colombo: CPWF. In the Nile basin, agriculture is facing major challenges, such as limited water access in large parts of the basin, widespread poverty, and a rapidly growing population. It is a region where the agricultural landscape is dominated by livestock and crop-livestock production systems, making livestock not only an important source of income in rural areas but also a potential contributor to water scarcity problems. To reduce poverty and to meet future demand for food, an increase in food production will be essential. The limited water resources in large parts of the basin necessitate this increase to happen without a strong increase in water demand. To identify best options to increase agricultural water productivity and the role of livestock herein, a more spatially explicit understanding of livestock water demand versus water availability across the Nile basin is imperative. The principle objective of this study was to estimate livestock water demand and productivity in the Nile basin and compare this to water availability and a number of key factors that were expected to determine or influence the LWP, thus providing basic information for the identification of areas where interventions are most needed and likely to have a significant impact. To this affect, an inventory was made of available data at regional, national and sub-national level needed to calculate feed demand and water for feed production. Next, a spatially explicit framework was developed in which dynamic models of digestion in ruminants and crop water requirements were combined to calculate water demand for feed production. This was complemented by livestock drinking water use to get the total water requirements for livestock production across the Nile basin. This was compared to water availability within the region.

Livestock water productivity (LWP), defined as the scale dependent efficiency of direct and indirect use of water for provision of livestock products and services, can be calculated as the ratio of net beneficial livestock-related products and services to the water depleted in producing them. Unfortunately, consistent estimations of livestock products and other benefits are difficult to come by at the basin scale. We therefore did not attempt to come up with a comprehensive estimate of LWP, but instead opted to illustrate differences in the LWP between systems using milk and meat production as a proxy for overall production levels. Subsequently, we compared the spatial distribution of LWP with those of a series of environmental and socio-economic factors that may potentially influencing water productivity. The results show that in most areas livestock water productivity (LWP) is less than 0.1 USD/m^3, with only few areas showing a LWP of 0.5 USD/m^3 and higher. This is largely related to very low livestock meat and milk production at one hand and very variable, but in general low feed water productivity. Total water need for feed production was estimated to be roughly 94 billion m^3, which amounts to approximately 5% of the total annual rainfall (68 billion m^3 or 3.6% of total annual rainfall when excluding water for residues). Differences in LWP between systems and regions are large, suggesting considerable scope for improvements. We discuss the main factors influencing observed patterns of LWP and livestock water use and how this information can be used for developing strategies for increasing the water productivity of agricultural systems at the basin level.
Van Breugel, P., Herrero, M., van de Steeg, J. and Peden, D. 2010c. **Livestock water use and productivity in the Nile basin.** *Ecosystems* 13(2):205-221. Livestock are the major consumers of water but also sustain millions of pastoralist and farming families. In regions where water is a scarce commodity, such as the Nile basin, there is a need for strategies to improve livestock water productivity (LWP). This study seeks to contribute to this need through a better understanding of livestock water use and productivity within the Nile basin and how this varies across the basin. We developed a spatial framework combining dynamic models of digestion in ruminants, crop water requirements (CWRs), and animal drinking water requirements to estimate spatial distribution of livestock water requirements in different livestock production systems (LPSs). We compared this with livestock production and water availability estimates within the basin. The results show that in most areas LWP is less than 0.1 USD/m^3, with only few areas showing a LWP of 0.5 USD/m^3 and higher. This is largely related to very low livestock meat and milk production on one hand and very variable, but, in general, low feed water productivity (fWP). Total water need for feed production was estimated to be roughly 94 billion m^3, which amounts to approximately 5% of the total annual rainfall (68 billion m^3 or 3.6% of total annual rainfall when excluding water for residues). Differences in LWP between systems and regions are large, suggesting considerable scope for improvements. We discuss the main factors influencing observed patterns of LWP and livestock water use and how this information can be used for developing strategies for increasing the water productivity of agricultural systems at the basin level.
Van Breugel, P., Herrero, M., van de Steeg, J.A., and Peden, D. 2008. **Spatial variation and management of livestock water productivity in the Nile Basin.** In Fighting Poverty Through Sustainable Water Use: Volumes I, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008. Livestock are major consumers of water but also sustain millions of pastoralist and farming families. In regions where water is a scarce commodity, such as the Nile Basin, there is a need for strategies to improve livestock water productivity (LWP). This study seeks to contribute to this need through a better understanding of the spatial distribution of livestock water and feed demand, and their linkage to water availability. An inventory of available data at regional and national levels needed to calculate feed demand and water for feed production was made. Next, a spatial framework was developed in which dynamic models of digestion in ruminants and crop water requirements, and estimates of animal drinking water requirements, were combined to estimate total livestock water requirements. The latter were subsequently compared to water availability within the basin. Hotspots and recommendation domains for strategies for increasing LWP were identified, including areas where livestock production might best be encouraged or discouraged within the context of increasing water productivity and reducing land degradation. Sharing such information between upstream and downstream stakeholders and among stakeholders across sub-basins can contribute to strategies for increasing water productivity basin wide.
Van Hoeve, E. and van Koppen, B. 2005. **Beyond fetching water for livestock: a gendered sustainable livelihood framework to assess livestock-water productivity**. Challenge Program on Water and Food Workshop on Nile Basin Water Productivity: Developing a Shared Vision for

Livestock Production, Kampala, 5–8 September. http://www.ilri.org/data/livelihood/UgandaWorkshop2005/Agenderedvisiononlivestock%209-9-2005.pdf.

Livestock water productivity is defined as the amount of water depleted or diverted to produce livestock and livestock products and services (Sonder *et al,* in prep). However, different livestock species and their products vary in terms of their values and contributions for men and women in reaching livelihood objectives. Similarly, various livestock production systems generate different costs for men and women, resulting from gendered control and access.

In this paper we propose a Gendered Sustainable Livelihood Framework (GSLF), focusing on poor livestock keepers. The framework gives guidance on how to better include gender perspective in holistic assessments and subsequent use of livestock water productivity information and interventions. We use the five assets of the Sustainable Livelihood Framework (SLF) to allow an asset based assessment, taking into account access and control mechanisms which are important aspects of gender studies. The GSLF is best applied using participatory discussion tools in order to ensure a common understanding of the issues.

Zziwa, E., Mpairwe, D., Kyambande, J., Iwadra, M., Mutetika, D., Kiwuwa, G., Mugerwa, S. and Peden, D. 2008. **Upper catchment management and water cover plants effects on the quality and quantity of water in surface reservoirs.** In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008.

The effects of upper catchment management and water plants on water quantity and quality in two Ugandan pastoral communities were investigated. The objective was to assess effects of land and livestock management on water resources and livestock water productivity. Water quality and quantity in valley tanks were monitored. Results indicate that upper catchment management significantly affected total coliform (TC), fecal coliform (FC), NH4 +, NO2 -, total nitrogen, total phosphorus, TSS, and turbidity. Valley tanks in catchments with unvegetated catchments and gullies were more contaminated than in vegetated catchments and gullies. Reseeding of an unvegetated upper catchment greatly decreased the concentration of NH4 +, NO2 -, NO3-, TP, and turbidity. Silt from unvegetated catchments and gullies reduced reservoir storage capacity by 248 m^3 in a year. Valley tanks covered with *Nymphaea* spp*.* had significantly higher concentrations of NH4+, NO2-, NO3-, TN, TDS, TSS, pH, and turbidity, whereas *Azolla* spp. were associated with higher TP, TC, and FC than other cover plants. Unvegetated upper catchments and gullies have detrimental impacts on water quality and reservoir capacity. Evaporation, sedimentation, and degradation of water quality were critical factors that reduced the availability and quality of water in pastoral communities. Only valley tanks with vegetated catchments and gullies and those covered with *Lemna* species had acceptable levels of FC.

Zziwa, Emmanuel. 2009. **Effect of upper catchment management and water cover plants on quantity and quality of water in reservoirs and their implications on livestock water productivity.** MSc thesis, Makerere University.

Seasonal water fluctuations both in quality and quantity negatively affect livestock production and subsequently reduce livestock-water productivity (LWP) in rainfed pastoral production systems. The major contributing factors to this phenomenon are poor upper catchment and water resource management which result in contamination, sedimentation/silting, eutrophication due to nutrient enrichment, and excessive discharge of runoff into water reserviors. This study investigated the effect of upper catchment management (un-vegetated and vegetated catchment, un-vegetated and vegetated gullies); and water cover plants on water quality and quantity in surface water reservoirs, and their impacts on livestock water productivity (LWP) in rainfed pastoral production systems of Uganda. Water quality and quantity in sixteen reserviors were monitored on a monthly basis in Nakasongola and Kiruhura districts for a period of one year covering two dry and two rain seasons.

Sedimentation studies showed that about 250 m^3 of silt from un-vegetated catchment entered a reservoir, reducing the storage capacity by 18 % in a period of one year. The silt that entered the reservoir was responsible for degradedation of about 47 m^3 of water. Un-vegetated upper catchments therefore had detrimental impacts on water reservoirs.

Total coliform (TC), feacal coliform (FC), ammonium-nitrogen (NH_4–N) and total phosphorus (TP) levels were significantly higher ($p < 0.001$) in reservoirs receiving water from open gullies while reservoirs with un-vegetated catchments had significantly higher concentrations ($p < 0.001$) of nitrite-nitrogen (NO_2–N), nitrate-nitrogen (NO_3–N), total nitrogen (TN), total dissolved solids (TDS), total suspended solids (TSS) and turbidity.

TC and FC concentrations were significantly high ($p < 0.001$ and $p < 0.05$, respectively) in the dry season, with highest concentrations recorded in reservoirs receiving water from open gullies. NO_2–N and NO_3–N were significantly high ($p < 0.001$) in the rain season. There were significant interactions between season and treatment effects on the concentration of NO_2–N, NO_3–N, TSS and turbidity ($p < 0.001$). Reservoirs receiving water from un-vegetated catchments had high NO_2–N, TSS and turbidity in the rain season while those with vegetated gullies had high NO_3–N in the rain season.

Four plant species (*Pistia, Azolla, Lemna and Nymphaea spp*.) were identified as the common plant species covering water reserviors in the study area. The results showed that reservoirs covered by *Lemna sp* had significantly lower ($p < 0.001$) TC, FC, NO_2–N, NO_3–N, TN, TSS, and turbidity than reservoirs covered by other cover plants in the study, indicating its potential application in water quality improvement for livestock production systems. *Nymphaea spp* had significantly higher ($p < 0.001$) concentrations of nitrite, total nitrogen, TDS, TSS and turbidity while *Azolla spp* had significantly high ($p < 0.001$) TC concentrations compared to other water cover plants. This indicated that *Nymphaea spp* is an undesirable water cover plants species and hence should be eliminated.

Improvement of upper catchment and water resource management greatly increased livestock water productivity (LWP) by 353%, 518% and 280% in the settled, semi-settled and non-settled pastoral communities. In addition, un-vegetated catchments and gullies were shown to have detrimental impacts on the reservoir water quality. Therefore, a great potential exists for improving livestock water productivity in the pastoral communities of Uganda through use of vegetated catchments and gullies. Although the amount of rainfall in the pastoral communities of Uganda greatly contributes to the quantity of water available in reservoirs to sustain livestock and human needs through dry seasons, other factors such as evaporation, sedimentation and degradation of water quality may critically reduce the availability of water in pastoral communities. Therefore, increasing water supply through creation of more surface water resources without proper upper catchment and water management practices would only provide a temporal solution to problems of livestock water scarcity in dry seasons within the rangeland pastoral communities of Uganda due to high evaporation and reservoir sedimentation rates experienced in these communities.