Journal of Environmental Management xxx (2016) 1–14

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Valuing investments in sustainable land management in the Upper Tana River basin, Kenya

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ARTICLE INFO

Article history:
Received 15 April 2016
Received in revised form
28 September 2016
Accepted 7 October 2016
Available online xxx

Keywords:
Water fund
Integrated modelling
Valuation
SWAT
RIOS
Sustainable land management

ABSTRACT

We analyze the impacts of investments in sustainable land use practices on ecosystem services in the Upper Tana basin, Kenya. This work supports implementation of the Upper Tana-Nairobi Water Fund, a public-private partnership to safeguard ecosystem service provision and food security. We apply an integrated modelling framework, building on local knowledge and previous field- and model-based studies, to link biophysical landscape changes at high temporal and spatial resolution to economic benefits for key actors in the basin. The primary contribution of this study is that it a) presents a comprehensive analysis for targeting interventions that takes into account stakeholder preferences, local environmental and socio-economic conditions, b) relies on detailed, process-based, biophysical models to demonstrate the biophysical return on those investments for a practical, decision-driven case, and c) in close collaboration with downstream water users, links those biophysical outputs to monetary metrics, including: reduced water treatment costs, increased hydropower production, and crop yield benefits for agricultural producers in the conservation area. This study highlights the benefits and trade-offs that come with conducting participatory research as part of a stakeholder engagement process: while results are more likely to be decision-relevant within the local context, navigating stakeholder expectations and data limitations present ongoing challenges.

1. Introduction

In recent decades, a number of programs have emerged globally based on the recognition that investing in watershed services – linking downstream users who benefit from clean, flowing water with upstream landholders whose actions enhance or degrade those services – can be a proactive and flexible strategy for securing clean water while addressing other development and conservation goals (Bennett et al., 2016; Bremer et al., 2016; Talberth et al., 2013). Furthermore, private sector investment is increasingly seen as key to closing the growing funding shortage for water infrastructure globally (Rodriguez et al., 2012; Sadoff et al., 2015).

Such programs have succeeded in garnering significant public, private and philanthropic support, often based on the premise that they will result in a net positive social return-on-investment (ROI; Bennett and Carroll, 2014). That programs demonstrate such potential is a critical step to leverage multiple funding sources and to satisfy the increasing interest from investors in having credible estimates of financial or risk-related ROI for their investments (Bennett and Carroll, 2014).

A common issue cited by practitioners, although less visible in the policy rhetoric around investing in watershed management, is the critical importance of using best-available science to target investments in soil and water conservation activities in order to maximize the positive impacts downstream (Naeem et al., 2015; Rocha et al., 2012).

Further, a program's efficiency goals must also be balanced with issues of equity, local values, and feasibility in order to ensure the ongoing grassroots support necessary to long-term program success (Kolinjivadi et al., 2015; Pascual et al., 2014).

In this study, we focus on the recently developed Upper Tana-

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http://dx.doi.org/10.1016/j.jenvman.2016.10.013

Please cite this article in press as: Vogl, A.L., et al., Valuing investments in sustainable land management in the Upper Tana River basin, Kenya, Journal of Environmental Management (2016), http://dx.doi.org/10.1016/j.jenvman.2016.10.013

Nairobi Water Fund (referred to as “the Nairobi Water Fund”) as an example of such a program. In 2012, local NGOs and stakeholders – including the Nairobi City Water and Sewerage Company (NCWSC) and Kenya Electricity Generating Company (KenGen, the State-owned energy company) – partnered with The Nature Conservancy (TNC) to design a watershed investment scheme to improve Nairobi's water security. The Nairobi Water Fund, launched in 2015, is now a Charitable Trust governed by an independent Board of Trustees (providing leadership, financial and communications support) and a Management Board, with broad institutional representation drawn from the private sector, public sector (including water, environment, and agricultural ministries), and nongovernmental organizations.

In the Upper Tana watershed, various soil and water conservation activities have previously been implemented through public and private funds raised by TNC and local NGOs. The primary focus of many of these programs has been to improve conditions locally, to reduce erosion and sedimentation into streams and to improve agricultural practices at the scale of individual farms or stream reaches.

Efforts to introduce watershed-scale management began with several analyses completed by a previous program, called “Green Water Credits,” which was focused on connecting improvements from upstream activities with downstream services in a payments for ecosystem services (PES) scheme (Hunink et al., 2012). That project was not implemented, however, principally due to a lack of stakeholder participation which led to poor financial and political backing (Kauffman et al., 2014). These and other similar efforts have demonstrated that connecting quantifiable improvements in watershed performance with specific downstream beneficiaries, and clearly communicating their potential financial benefits, are essential to engage funders and stakeholders and to ensure the long-term sustainability of such schemes (Bremer et al., 2016; Kauffman et al., 2014).

In the context of payments for watershed services, several studies have used watershed modelling approaches to identify priority locations for soil and water conservation activities, and to quantify impacts that could result from program implementation (Hunink et al., 2013; Rocha et al., 2012). However, many studies use pre-defined scenarios (e.g., Quintero et al., 2009) or else estimates of current service delivery and/or threats to determine the locations of priority intervention areas (e.g., Rocha et al., 2012).

While some monetize the value of watershed interventions to specific beneficiaries, such as downstream hydropower (Guo et al., 2007; Sáenz et al., 2014), we are not aware of any studies that use spatially explicit models of ecosystem change that incorporate beneficiaries to target the nature and location of investments and subsequently assess their impact on multiple services. Furthermore, most studies consider only one or two benefit streams and usually focus on a single beneficiary, not considering many of the multiple alternative values that can accrue from conservation and restoration programs.

Finally, identifying priority locations and conservation activities is not simply a biophysical optimization problem. The particular socio-political context, values and power dynamics between stakeholders should all be included in the project design. Biophysically-optimal plans for watershed interventions are not as relevant or feasible when it comes to guiding implementation if sufficient attention has not been given to an engagement process that builds trust and incorporates relevant concerns (Kauffman et al., 2014; Kumar et al., 2014).

To address these issues, we describe a new methodology for evaluating potential soil and water conservation activities in the Upper Tana based on their contribution to specific ecosystem services (see, for example, Brauman et al., 2007; de Groot, 2006). Our approach links an ecosystem services targeting tool (Resource Investment Optimization System – RIOS) with a hydrologic model (Soil and Water Assessment Tool – SWAT) and a set of economic models to

1) Target watershed interventions based on both their benefits to the environment and their potential to influence ecosystem service flows;
2) Quantify the potential improvement in hydrologic services that would result from implementation of prioritized activities; and
3) Estimate the financial return-on-investment considering multiple stakeholders and benefit streams.

The project took place in an iterative stakeholder process to define the project scope, benefit streams, activities, feasibility constraints, costs, and budgets. Stakeholder engagement helped to ensure that the results are decision-relevant and tailored to the local context. The results of this study have been used for stakeholder outreach and to determine priority areas for the Fund to implement its activities.

2. Methods

2.1. Study area

The Upper Tana River basin covers approximately 17,000 km^2 with a population of about 5.3 million. Average annual rainfall in the basin ranges from approximately 2000 mm yr^{-1} at higher altitudes to only 500 mm yr^{-1} at lower altitudes, with an average annual potential evapotranspiration around 1000 mm (Jaetzold et al., 2006). It encompasses some of the most critical areas for water supply to the city of Nairobi and surrounding communities (the Aberdare Mountains and Mount Kenya), supports one of Kenya's most important agricultural areas, and supplies half of the country's hydropower output as well as 95% of the water supply for the city of Nairobi (Droogers et al., 2011).

Forests and wetlands in the Upper Tana play an important role in maintaining water quality and quantity. However, population is increasing in the middle and upper mountain regions, with rain-fed agriculture expanding into previously uncultivated areas and now representing about 60% of the overall land use (Hunink et al., 2013). Soil erosion contributes to loss of soil fertility and declining crop yields for the millions of smallholder farmers throughout the basin (Kauffman et al., 2014). Increasing sediment in the Tana River is affecting the quality of water and significantly impacting water treatment and infrastructure costs for NCWSC and other municipal water suppliers. KenGen, the leading electric power generation company in Kenya, produces about 80% of electricity consumed in the country, and is increasingly impacted by declining water yields, particularly during the dry season. For example, during the 2009 drought, KenGen's electricity sales dropped 12% compared to the previous year, a decline of USD 19.8 M (KenGen, 2010).

Based on a previous PES feasibility study that modeled water and sediment flows (Hunink et al., 2013), we identified three subwatersheds in the Upper Tana as key focus areas: Maragua, Sagana and Thika/Chania (Fig. 1). The Thika/Chania watershed was selected because of its critical contribution to Nairobi's water supply. NCWSC is one of the principal stakeholders in the Water Fund and a member of its original Steering Committee. A socioeconomic baseline survey (Leisher, 2014) suggests that the Maragua watershed has similar land and water-use issues as the Thika/Chania, is of key interest as a significant source of sediment, and is also relevant for water supply, as NCWSC has plans for a new water diversion from that watershed. The Sagana watershed was selected as an important water source for the town of Nyeri, and for its

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relatively high contribution to water yield from the Aberdare Mountains.

2.2. Stakeholder engagement

We solicited feedback from a wide range of stakeholder interests to define the study objectives, activities, benefit streams, feasibility and budget constraints. Stakeholder engagement consisted of a series of four workshops in Nairobi from February 2013 to December 2014. During these workshops, members of the public-private Steering Committee at the time,[1] as well as local stakeholders from Kenya National Federation of Agricultural Producers (farmer association), various water-user associations (WRUAs), Jomo Kenyatta University, East Africa Breweries, Frigoken Horticulture (agri-business), Water Services Trust Fund (public-private water infrastructure financing corporation), Sustainable Agriculture Community Development Programme (agricultural extension NGO), and Green Belt Movement (conservation and community development NGO) contributed to the study design and provided input on feasible watershed interventions, assumptions, and preliminary results.

Several field visits to regional Water Resource Management Authority (WRMA) and NGO offices within the study area were also conducted, to discuss prevailing agricultural practices and challenges for implementing sustainable agriculture. We also considered information on current practices from a baseline socio-economic survey conducted with 730 inhabitants in the Maragua and Thika/Chania watersheds (Leisher, 2014).

At the conclusion of the study, we presented final results of the economic analysis during a fifth stakeholder workshop (in February 2015) and trained local participants on the methods and tools used to complete the analysis, building capacity for adaptively managing the Water Fund's investments.

2.3. Overview of modelling approach

Our approach integrates a prioritization model based on biophysical landscape characteristics, service flows to beneficiaries, and feasibility constraints with a physically-based watershed simulation model to 1) identify potential benefit streams and watershed interventions; 2) select and target activities; 3) estimate the impacts of implementation; and 4) quantify the value to beneficiaries where possible (Fig. 2).

Step one resulted from the initial stakeholder engagement process. Step two involved the use of a high-resolution spatial prioritization tool to allocate the type and location of conservation investments in the different sub-basins, subject to budget constraints and stakeholder concerns (Resource Investment Optimization System – RIOS; Vogl et al., 2015). We then evaluated the results using the Soil and Water Assessment Tool (SWAT; Arnold et al., 1998) to simulate spatially explicit changes in water yield, erosion, and suspended sediment. Finally, we link those biophysical outputs to monetary metrics, including: reduced water treatment costs, increased hydropower production, and crop yield benefits for farmers in the conservation area. The analysis focused on the benefits that would arise over a 30-year time horizon from a USD 10 M investment in these sub-watersheds disbursed over a period of 10 years.

2.4. Model descriptions

2.4.1. Resource Investment Optimization System (RIOS)

The Resource Investment Optimization System (RIOS) model — developed by the Natural Capital Project and TNC — is a free and open-source software tool for targeting investments in soil and water conservation activities with the goal of achieving the greatest ecosystem service returns towards multiple objectives (Vogl et al., 2015). RIOS accomplishes this by combining information on biophysical conditions and landscape context that can impact the effectiveness of activities (e.g., climate, soils, land use, and topography), social information describing feasible interventions and land use changes, stakeholder preferences, and cost data.

The underlying premise of RIOS is that a small set of biophysical and ecological factors determine the effectiveness of different soil and water conservation activities, based on a review of experimental studies, review papers, and hydrologic model documentation to identify the subset of factors most frequently cited as important for determining the magnitude of impact on erosion control, nutrient retention, groundwater recharge, and other hydrologic processes. Because budget allocation and fund investments are annual or multi-year processes, the RIOS tool focuses on impacts of landscape changes on multi-annual time scales. Our analysis used the sediment retention and baseflow objectives built into RIOS, which provide a relative ranking of the potential impact of activities implemented in different areas of the landscape.

The baseflow enhancement objective is based on the assumption that activities that improve infiltration will tend to increase retention of water in the soil profile and facilitate its slow release into streams. It incorporates factors that influence the volume of runoff generated on or above each pixel (for example, rainfall, evapotranspiration, soil texture, slope, and land cover) along with factors influencing infiltration locally and downstream (for example, soil depth, land cover, distance to streams). The sediment retention objective incorporates factors that determine the effectiveness of activities to reduce erosion from each pixel area, as well as their ability to retain sediment from upslope and the likelihood of eroded sediment reaching waterways (for example, rainfall erosivity, soil erodibility, soil depth, land cover and management, slope, and distance to streams). More details on model structure may be found in Vogl et al. (2015). The output of the RIOS model is a map of the locations of selected interventions, chosen based on ranked cost-effectiveness scores for achieving one or more ecosystem services objectives within specified constraints of budget and feasibility.

2.4.2. Soil and Water Assessment Tool (SWAT)

SWAT was developed primarily by the United States Department of Agriculture (USDA) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Arnold et al., 1998). The SWAT model has been extensively used, is in the public domain and can be considered as the de-facto standard in ecosystem and watershed service assessments (Francesconi et al., 2016).

SWAT represents all the components of the hydrologic cycle including: precipitation, interception storage, surface runoff, soil storage, infiltration, evaporation, evapotranspiration, lateral flow, percolation, pond and reservoir water balances, shallow and deep aquifers, and channel routing. It includes sediment production based on a modified version of the Universal Soil Loss Equation applied at a daily time step, and routing of sediments in river channels.

SWAT has been successfully applied to catchments of different sizes, often in relatively data poor regions (Betrie et al., 2011; Dile

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[1] Members of the Steering Committee included The Nature Conservancy (TNC), NCWSC, KenGen, International Centre for Tropical Agriculture (CIAT), Tana and Athi Rivers Development Authority (TARDA), and Water Resources Management Authority (WRMA).

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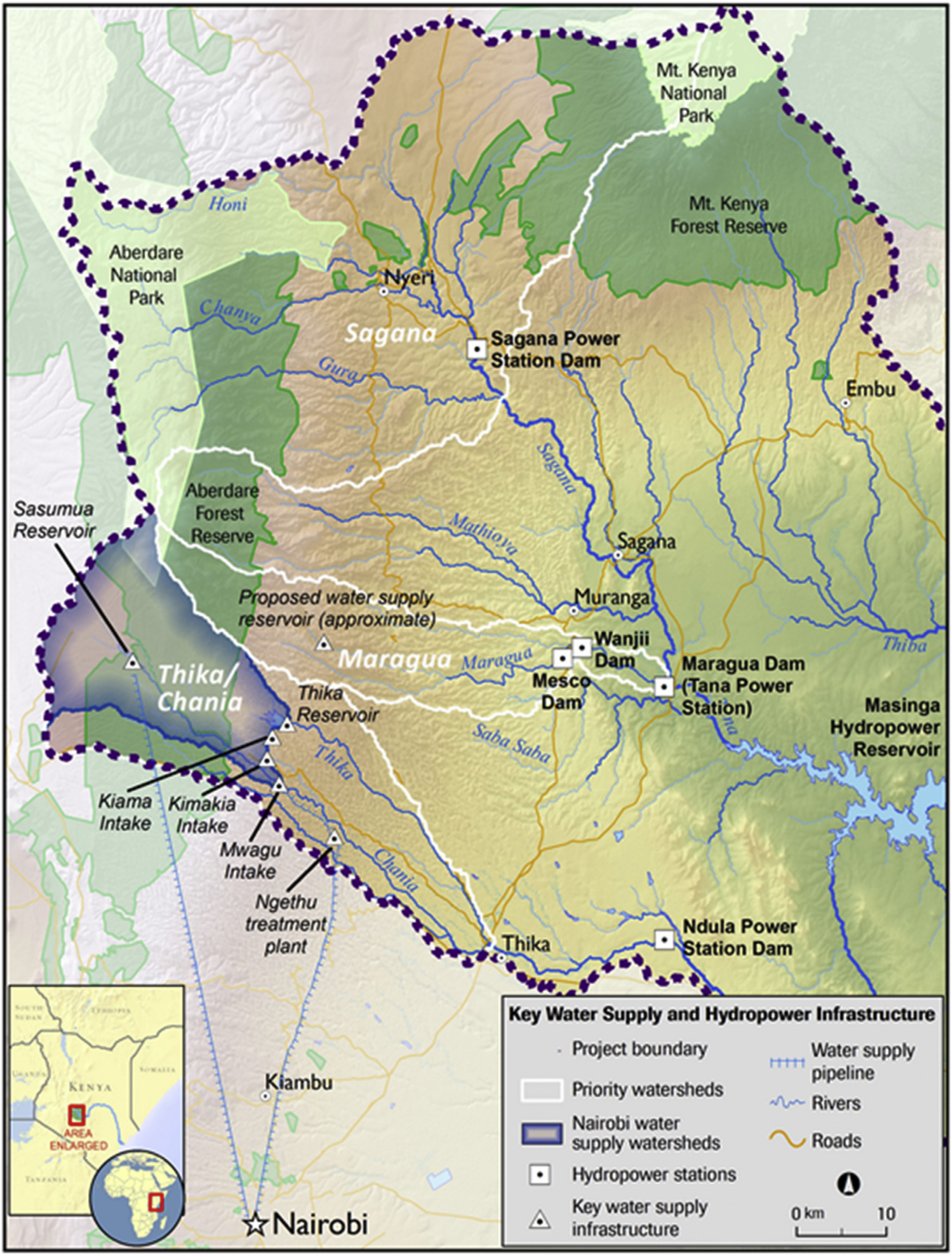

Fig. 1. Map showing location of the Upper Tana basin and the three sub-watersheds used in this study. This map also shows critical points for water service benefits in the Upper Tana: major water extraction points for the municipalities of Nairobi and Nyeri, as well as the location of the Masinga Reservoir. Reprinted with permission from Apse et al. (2015).

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et al., 2016; Immerzeel and Droogers, 2008). After calibration, the model can be applied at different spatial resolutions and levels of detail, and provides spatially distributed output of sources and sinks of sediment. This model has been used extensively in scenario studies of changing land-use and management conditions (Baker and Miller, 2013; Bossa et al., 2012; Hunink et al., 2012).

2.5. Data & analyses

2.5.1. RIOS application

In this study, the RIOS model was applied to the three study watersheds to produce scenarios of future landscapes, representing different management interventions for a given budget. Total budgets and allocation were pre-set; therefore, this study does not seek to determine the optimal budget to maximize ROI. Rather, we attempt to demonstrate whether the Nairobi Water Fund can show a satisfactory ROI given a realistic funding goal as determined by the Steering Committee members. Budgets were pre-allocated to each sub-watershed based on consultation with the Nairobi Water Fund Steering Committee, reflecting relative priorities for activity intervention areas within each sub-watershed, rather than across sub-watersheds.

In addition to biophysical and socio-economic data, RIOS also uses information on feasibility, preferences, and the distribution of populations who would benefit from activities within the project areas (“beneficiaries”). Data were compiled from previous work in the basin (e.g., Droogers et al., 2011; Hunink et al., 2013; Onduru and Muchena, 2011), local agencies and experts (e.g. WRMA, KenGen), and national census data (Table 1). Where local or national data sources were not available, global datasets and relevant literature were used (Table 1; Section S1).

In the current study, we apply the sediment retention and base flow model objectives. We assigned the sediment retention objective twice the priority of the base flow objective, to reflect the primary (sediment retention) and secondary (dry season flow) objectives of the Nairobi Water Fund.

2.5.1.1. Activities and costs. RIOS requires data on feasible activities and budget allocations to create realistic plans for watershed interventions. Soil and water conservation activities were chosen through stakeholder consultation workshops and a review of literature (e.g., WOCAT, 2014). Out of an initial list of feasible interventions gathered from the first two stakeholder consultation workshops, six activities were selected by the modeling team to represent a variety of soil and water conservation strategies: 1) riparian management to restore or maintain native vegetation along stream channels (1163 USD ha^{-1}); 2) agroforestry to increase and diversify vegetation and tree cover in croplands (1163 USD ha^{-1}); 3) terracing in croplands (353 USD ha^{-1}); 4) grass strips to slow runoff and trap sediments in croplands (141 USD ha^{-1}); 5) reforestation of native vegetation along margins of National Forests (1163 USD ha^{-1}); and 6) road mitigation activities, such as sediment traps, to reduce sediment export from unpaved roads (4945 USD ha^{-1}). The feasibility of applying activities in different areas and restrictions to their implementation due to physical factors, logistical or legal constraints were determined in consultation with local stakeholders (Table S3).

Activity costs were based on consultation with stakeholders from WRMA and other NGOs that have decades of experience implementing similar activities in the Tana watershed (e.g., Green Belt Movement). Per-hectare costs reflect the cost to implement each activity in its recommended best practice form and spacing on a hectare of land – including labor and material – but did not consider ongoing maintenance costs or potential payments to landholders that the Water Fund might choose to implement. Maintenance costs were considered, however, in calculating the net present value and ROI (see Section 2.5.3). Costs were estimated in Ksh and converted to USD at the exchange rate of 85.918 Ksh USD^{-1} (as of February 2014).

2.5.1.2. Beneficiaries. Beneficiaries are input as a spatial data layer with a weight assigned to each cell based on the potential for activities to contribute positive benefits to people for a given objective. For this study, the beneficiaries input was based on district-level population density from Kenya's 2009 Population and Housing Census. Population density was used directly to represent benefit to local landholders of soil conservation on their lands. For baseflow enhancement, we performed a flow length calculation for each pixel, weighted by downslope population density, to represent the potential for improved water retention to benefit people in the downstream flow path. See Section S2.3 for more information on the per-pixel calculation of beneficiaries.

2.5.1.3. Budget allocation. For this analysis, a total of USD 10 M was taken as a reference budget, to be spent over a period of 10 years. We also explored budgets ranging from USD 2.5 M up to 15 M, but here we focus on a USD 10 M budget (the initial fundraising target of the Fund). The total budget was distributed as follows: Thika-Chania USD 4.5 M (45%); Sagana-Gura USD 3 M (30%); and Maragua USD 2.5 M (25%). This proportional budget allocation was negotiated and agreed among the major stakeholders to reflect the strategic importance and relative priority of the Water Fund acting in each of the three watersheds. The total amount was equally divided among the six activities, which reflected stakeholder preferences to consider all activities that have a perceived positive benefit to landholders, beyond those benefits directly modeled in the RIOS tool. In the Thika/Chania only, half of the budget was pre-allocated to the area contributing flow to the system of intakes from which NCWSC draws their supply (“Nairobi water supply watersheds” in Fig. 1), while the remaining funds were allocated throughout the entire Thika-Chania watershed.

2.5.2. SWAT application

The three watersheds were divided into sub-basins and calculation units, based on the digital elevation model, the location of monitoring points, and existing infrastructure. The high detail in input data, especially on land use, results in a high number of calculation units (6098), and thus output with a high level of spatial detail. The SWAT model was calibrated to observed flow obtained from local sources, sedimentation data from a reservoir bathymetric survey conducted in 2011 (Hunink and Droogers, 2011), and daily data on turbidity (2004–2014) obtained from NCWSC (Table 1; Section S3.2).

The RIOS portfolios (spatial distributions of recommended soil and water conservation activities) were evaluated for their impacts on erosion, sediment concentrations, sediment loads, and flows using SWAT. We altered the land use and land management parameters for calculation units where activities were recommended, based on assumptions about how parameters respond to pixel-level intervention within each unit (Section S3.4).

We used the calibrated SWAT model to simulate for each spatial unit the absolute and relative changes in the hydrologic response due to activity implementation, including runoff, erosion, and sediment yield. Changes in agricultural yields were then estimated using modeled soil loss reduction and soil water balance from SWAT, as described in Section 2.5.3.2, below.

2.5.3. Economic return-on-investment

Our ROI analysis focused on the two primary objectives identified by the Water Fund's Steering Committee: controlling erosion

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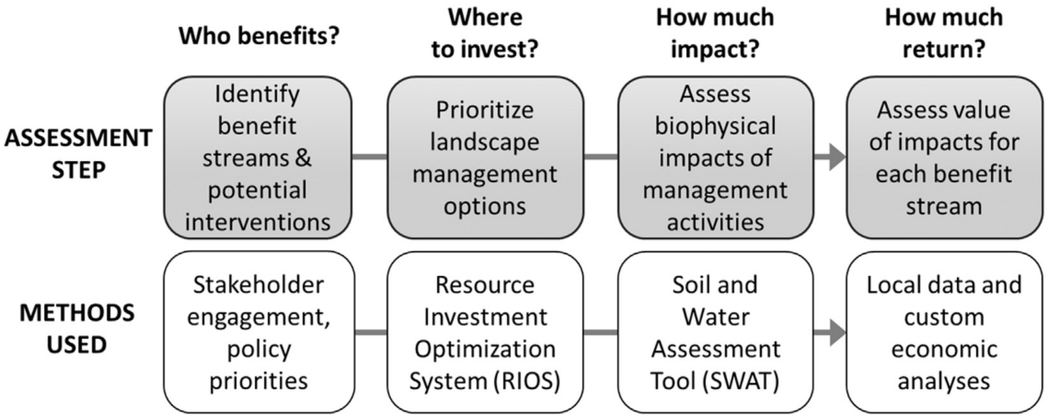

Fig. 2. Overall modelling approach linking the spatial prioritization tool RIOS, impact assessment model SWAT, and return on investment (ROI) analysis.

Table 1
Biophysical data used in the RIOS and SWAT models.

Dataset	Spatial/temporal resolution	Source	RIOS	SWAT
Digital elevation model	90 m	Shuttle Radar Topography Mission	X	X
Soils	1 km	SOTER_UT (Batjes, 2010)	X	X
Land use/land cover	15 m	By TNC based on ASTER and Landsat imagery	X	X
Climate observations	Daily	WRMA and Kenya Meteorological Dept.		X
Climate	Statistics	id.	X	
Streamflow observations	Daily	WRMA		X
Sediment observations	Long-term and daily	NCWSC and Hunink and Droogers (2011)		X
Types of conservation interventions	N/A	Stakeholder consultation	X	X
Activity costs per-hectare	N/A	Stakeholder consultation	X	
Feasibility constraints	N/A	Stakeholder consultation	X	
Beneficiaries	Administrative Units (resampled to 15 m pixels)	2009 Population and Housing Census	X	

(for soil health and reducing sediment in water) and improving dry season water flows. We estimated monetized benefits for three different sets of stakeholders, each of which has at least one benefit stream and sometimes more than one:

1. Agricultural producers and others in this sector's value chain
2. Municipal water supply – NCWSC
3. Hydropower operations – KenGen

Our sensitivity analysis and discussion also explores plausible monetization for households who extract raw water for drinking, and a broader array of potential but non-monetized benefits.

2.5.3.1. Timing of interventions and benefits. Our analysis of hydrologic and soil outcomes assumed a landscape where interventions have been fully implemented. We compared them using the same historical climate data used on the pre-intervention landscape. Because we are interested in economic viability, the timing of costs and benefits matters, so we specified trajectories for the manifestation of costs and benefits over time, and then discounted both into present values, to account for the fact that benefits and costs have different values depending on when they are realized.

We assumed that the USD 10 M investment will be disbursed at a rate of USD 1 M per year for ten years. Ten years was selected as the timeframe for implementation as it reflects the realities of time required to mobilize local engagement across a large region.

Net benefits were calculated over a default time horizon of 30 years, by summing the costs and benefits estimated for individual benefit streams as described below. We assumed a 5% discount rate, corresponding to the average real interest rate in Kenya from 2004 to 2013 (World Development Indicators). The effect of alternate discount rates on net present value is explored in the sensitivity analysis section (S5) of the Supplemental Material.

Benefits materialize accounting for the timing of implementation, and also allowing for lags related to biophysical processes. Agricultural benefits (related to soil depth) manifest over a 15-year period from implementation (as described in Section S4.1.2), while sediment-related benefit streams are assumed to be delayed by three years from implementation (as described in Section S4.2). The interaction of these ramping-up periods with the implementation schedule means that the full annual benefits are only realized starting in year 25.

2.5.3.2. Benefits to agricultural producers. The benefits of reduced erosion on agricultural productivity manifest as a change in yields resulting from avoided soil losses, which lead to higher soil productivity than would occur without the project. The SWAT model provides predictions of soil loss reduction and soil water balance, but does not dynamically model the complex processes and interactions that determine soil fertility changes over time. Therefore, we applied a productivity index function developed by Pierce et al. (1983) and slightly modified by Mulengera and Payton (1999) and Duan et al. (2011). This approach relates relative yields to soil depth, soil pH, organic matter, and clay content. We applied the modified equation using data on available water content and organic matter in soils from the Upper Tana, along with SWAT outputs on soil erosion and evapotranspiration. Assuming equivalent relative changes in evapotranspiration following changes in yield, we used crop-specific water productivity values from Kenya (Leisher, 2014; Mekonnen and Hoekstra, 2014) to estimate changes in revenue (See Section S4.1.1).

Because the economic water productivity statistics rely on revenue data at the end of the Kenya supply chain, it is not certain what fraction of the change in revenue is captured as profit by the farmer, captured as profit elsewhere in the export and domestic value chains, or is used to cover costs associated with the increase in production. As a default, we assumed 50% of the change in revenue is a true benefit, but this is a key uncertain parameter explored in the sensitivity analysis (explained in greater detail in Section S5).

2.5.3.3. Benefits to NCWSC. Following consultation with NCWSC staff, we determined that the primary benefits to NCWSC and other municipal water systems come from lowered sediment concentrations that reduce treatment and maintenance costs. For NCWSC, the analysis focused on the Mwagu intake that serves the Ngethu treatment plant, as this is the single largest water withdrawal point for Nairobi's water supply (approximately 400,000 m^3 per day). We quantified three main cost savings: avoided flocculant use, avoided energy costs, and greater water revenue from reducing use of processed water to backwash filtration systems.

For flocculant and energy costs, we developed simple regressions relating turbidity to electricity costs and to flocculant use. We then made the assumption of a direct linear relationship between monthly turbidity and monthly sediment concentration. Modelling results predicted sediment concentration would be reduced by 55–58%. For simplicity and conservativism, we chose to estimate savings based on an average 50% reduction in peak turbidity, and calculated the long-run savings by multiplying this by the maximum average monthly spending attributable to variation in electricity or flocculant expenses (Bryant, 2015).

Another major benefit to NCWSC is based on the assumption (vetted by NCWSC staff) that reduction of sediment concentration by over 50% will allow NCWSC to meet its target of reducing the use of processed water in plant operations by 30%. Processed water is used to backflush clogged sand filters, and represents lost revenue from treated water that could otherwise be delivered to NCWSC customers. These benefits were calculated by multiplying the saved process water volume by an adjustment to the volumetric tariff to account for efficiency considerations (62%, provided by NCWSC staff). The value of process water saved was taken to be 0.163 USD m^{-3}, equal to 75% of the volumetric tariff. Because of the long time horizon, we assumed that these benefits will also accrue when NCWSC has expanded its capacity to meet estimated demand (650,000 m^3 day^{-1}).

2.5.3.4. Benefits to hydropower production. We quantified two major benefits for KenGen: increased power generation from increased water yield flowing into Masinga reservoir, and avoided interruptions in electricity generation due to sedimentation. To estimate the change in generation at the Masinga facility, we utilized data provided by KenGen on power generation per unit volume as a function of surface height. For downstream facilities in the Seven Forks Cascade, we estimated change in potential energy based on effective head and multiplied by the conversion efficiency of energy fed to the grid (Bryant, 2015).

Additionally, the smaller power plants upstream of Masinga are likely to experience fewer operational interruptions linked to high sediment. For example, at the 20 MW Tana power station just above Masinga, operations must be interrupted periodically to remove excess sediment accumulated near the intake, which also has the potential to damage turbine seals. We made the assumption that the frequency of interruptions is approximately proportional to the sediment concentration, and consider the change in foregone generation due to reduced shutdown times (Bryant, 2015). Changes in generation were valued at 0.0356 USD kwh^{-1} based on the average generation cost (KenGen, 2014).

3. Results

3.1. Priority activity implementation

The results of the RIOS analysis were activity "portfolios" for each of the three priority watersheds, highlighting areas where soil and water conservation activities are likely to have the greatest impact (Fig. 3). Activities were recommended on areas representing 16% of the Maragua and Thika-Chania watersheds (7554 and 14005 ha, respectively), and 4% of the Sagana (6361 ha).

3.2. Hydrologic impacts

Modelled benefits derive from either changes in flows or changes in soil erosion, calculated as a change from the baseline SWAT outputs to those with the activity scenarios implemented. These benefits include 1) reduced soil loss due to decreased erosion and soil retention in the watershed; 2) reduced suspended sediment in streams; and 3) changes in seasonal water flow due to improved infiltration and water regulation.

Model results show significant reductions in erosion across the study area, ranging from 0.1 to >3.0 tons ha^{-1} yr^{-1} (Table 2; Fig. 4). These changes are primarily seen in agricultural areas, degraded lands, and unpaved roads, the three classes on which the majority of activities occurred.

Because more sediment is retained in upland areas, this translates into significant reductions of in-stream sediment concentrations for all months at the Mwagu water intake point (Fig. 5).

The change in total sediment export from the study area has important implications for reservoir storage volume. Mean annual sediment exported by the three study watersheds is reduced by over 35% for the simulation period, from 5.0 to 3.2 megatons yr^{-1}. This reduction in cumulative sediment export translates to approximately 1.2 M m^3 of avoided volume loss in the Masinga reservoir annually – a 15% reduction compared to the estimated current reservoir sedimentation rate (Hunink and Droogers, 2011).

The relative impact of interventions on stream flows is smaller than reductions in sedimentation, but has potentially significant implications for power generation and water supply. For example, at the Mwagu water intake, average monthly flows are predicted to diminish slightly in the wet season and increase slightly in the dry season (Fig. 6). Averaged over the simulation period, July, August and September show increases of over 15%, during a time when water availability for Nairobi is often stressed. The dry season increase is smallest in years with the lowest total rainfall, due to the fundamental issue that watershed interventions can only do so much when there is very little water available, such as during periods of drought.

3.3. Ecosystem services benefits by stakeholder group

3.3.1. Agricultural producers

Reduced erosion can improve soil fertility and water retention, benefiting farmers through higher production and increased revenues (Table 3). Results show that the changes in revenue per hectare on intervened area are substantial, ranging from a mean of 68 USD ha^{-1} for the general agriculture land use class, 264 USD ha^{-1} in coffee, to 479 USD ha^{-1} in tea. These improvements are in the same order of magnitude as the estimated baseline income per hectare for coffee and general agriculture. It is important to note that these changes in revenue represent the difference between yields without intervention and yields with the intervention. Both are modeled as decreasing over time, because some soil is still lost

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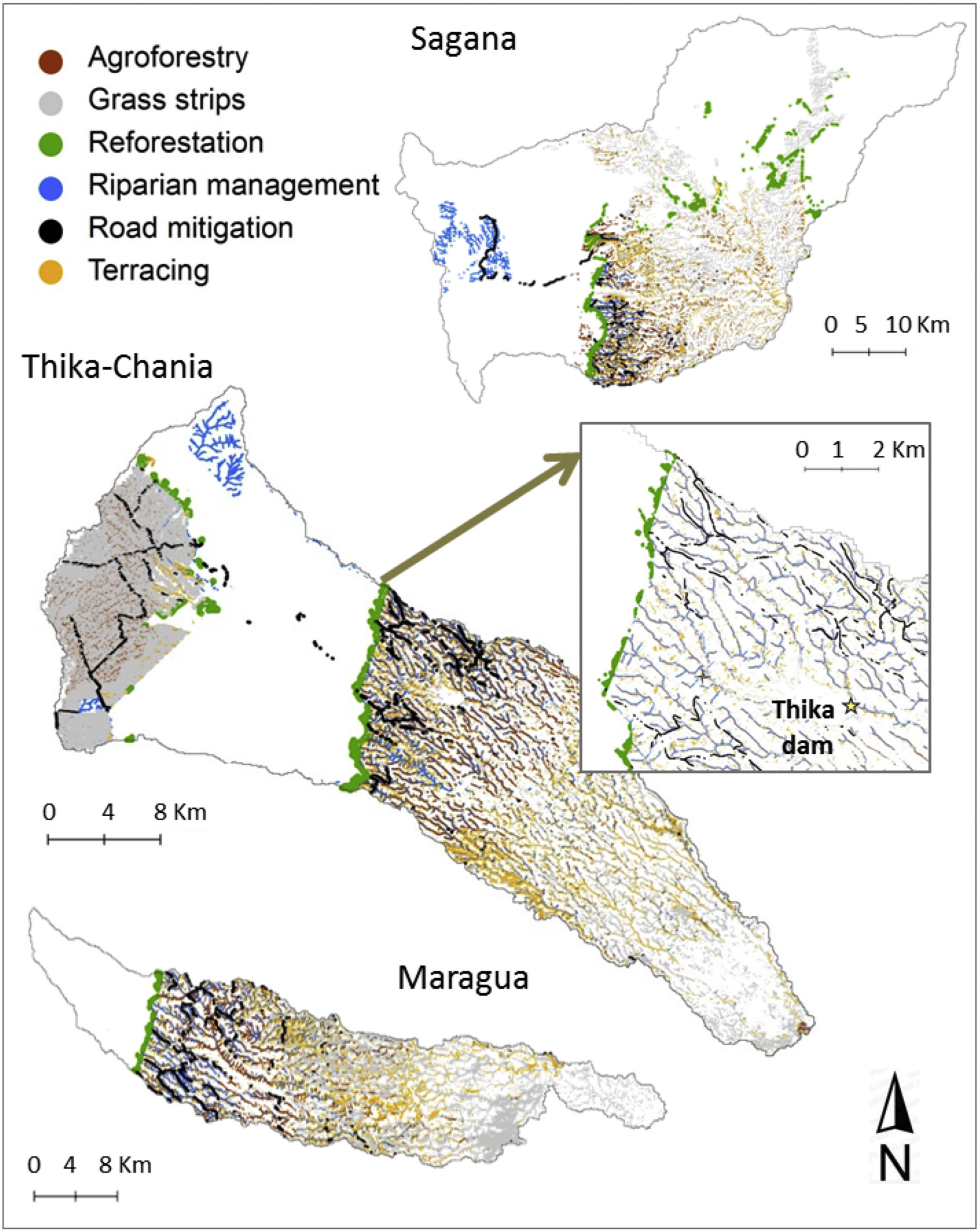

Fig. 3. Investment portfolio for USD 10 M budget target across the three priority watersheds for the Upper Tana-Nairobi Water Fund.

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even with the Water Fund interventions; however, the decrease in productivity is much lower with interventions than without them.

The greatest economic benefits to farmers accrue on the coffee areas, especially in the Maragua sub-watershed, followed by general agriculture (Table 3). The benefits are smaller for tea, but still notable, in particular in the Sagana-Gura sub-watershed. More details on the spatial distribution of yield benefits can be found in Hunink and Droogers (2015). The long-term change in annual revenues that can be expected from soil preservation is approximately USD 3 M per year after 10 years.

3.3.2. *Municipal water supply—NCWSC and others*

High turbidity leads to higher flocculant and energy use in the water treatment process, and increases backwashing frequency for the filters. Results show that after all interventions are implemented and have reached full potential to retain sediment, the resulting reduction in sediment concentration at the Ngethu treatment facility would translate to approximately USD 40,000 annually in avoided flocculants and USD 3900 annually in avoided energy costs. Most significantly, a 30% reduction in the processed water currently diverted for backwashing could increase profits by around USD 220,000 per year, even under our conservative assumptions.

The Sasumua treatment works, also run by NCWSC, would see sediment concentrations reduce on the order of 70%. Beyond Ngethu and Sasumua, NCWSC currently has plans for more offtakes from the Maragua sub-watershed and potentially a new reservoir and treatment plant. All of these areas are expected to see significant sediment reduction, on the order of 50%. This will benefit operation and maintenance costs in a manner similar to Ngethu, and may allow some capital cost savings for sediment removal infrastructure.

Overall, the present value of avoided costs to NCWSC is estimated to be over USD 3 M after scaling up for impacts on other existing and planned water supply sources (by assuming new infrastructure will increase the water being supplied).

3.3.3. *Hydropower production—KenGen*

KenGen is expected to benefit from both increased water yields and from avoided losses in electricity production due to reduced sediment loads. Results show that on average (and assuming no significant change in consumptive water withdrawals) the Masinga reservoir should see annual inflows rise by an average of 41 M m^3 per year. If all of this increase were to be captured as increased power production, this would lead to at least 17 M additional kWh of electricity in an average year (depending on reservoir level and the efficiency with which the additional yield is captured in downstream generation). Assuming this were valued at the low average generating tariff of 0.0356 USD kWh^{-1}, this corresponds to about USD 600,000 per year in revenues. This is likely a conservative estimate, as KenGen's value and efficiency of generation may often be higher, particularly during the dry season.

There are unfortunately very limited data to estimate the relationship between high sediment accumulation and shutdowns that reduce power generation. As an example, however, assuming that an average 50% reduction in sediment will result in a doubling of time between interruptions from two years to four years, this would translate to an average of 800,000 additional kWh yr^{-1}, or USD 30,000. This benefit may also be relevant to other smaller upstream power stations such as Wanjii and Ndula.

3.4. *Net benefits of the Nairobi Water Fund*

Fig. 7 shows how benefits, costs and annual benefits are anticipated to be realized over time.

Since benefits and costs have different values depending on when they are realized, we use discounting to convert benefits and costs into present values. Net present value (NPV) captures the discounted costs and benefits as they accumulate, and predicts at what point the Fund will become financially viable, under certain assumptions. Based on our analysis, the Nairobi Water Fund can reach viability near its 20th year after implementation. The relatively long time-period reflects the fact that investments are not implemented immediately in year 1, but are spread out in annual increments over 10 years.

For the Fund overall, if NPV is positive at a time horizon deemed reasonable by the stakeholders, it is considered an economically viable investment. Note that NPV continues to rise as the time horizon is extended, and that in reality benefits will likely continue to accrue after 30 years.

4. Discussion

4.1. *Aggregate benefits and costs*

A conservative estimate of the cumulative results across benefit streams shows that the NPV of the proposed investment plan for soil and water conservation activities is USD 5.9 M over 30 years (Table 4). These results demonstrate that a well-designed and well-implemented Water Fund will produce benefits that outweigh its costs under a variety of assumptions. We attempted to apply conservative assumptions in our analysis of all benefit streams, so our results represent a lower bound of the full potential social benefits that the Fund could provide to communities in the Upper Tana watershed and to the residents of Nairobi.

Note that the total present value of the cost is not equal to USD 10 M because of the discounting that occurs over the 10-year implementation period. If all USD 10 M were spent the first year, the present value of costs would be higher, but benefits would be higher as well.

To test the sensitivity of NPV, we varied parameters associated with specific benefit streams, including timing of benefits relative to implementation, inclusion of processed water savings, true agriculture benefits as a fraction of revenue change, among others. We also varied the discount rate and time horizon. In general, most values would need to deviate from their assumed values by well over 10% to negate the NPV, though the model is highly sensitive to assumptions about ongoing maintenance requirements. See Section S5 for additional details.

4.2. *Non-monetized benefits*

It addition to the benefit streams listed in Table 4, there are a number of non-monetized benefits that have not been explicitly

Table 2
Reduction in erosion in thousand tons (percent) within each priority watershed, for major land uses.

	Degraded land	Coffee	General agriculture	Tea	Unpaved roads	Total
Sagana-Gura	−3 (90%)	−55 (14%)	−131 (25%)	−3 (14%)	−20 (24%)	−212 (29%)
Maragua	−142 (93%)	−100 (57%)	−54 (36%)	−1 (9%)	−100 (78%)	−399 (85%)
Thika-Chania	−54 (80%)	−81 (24%)	−179 (75%)	−1 (8%)	−127 (58%)	−442 (69%)

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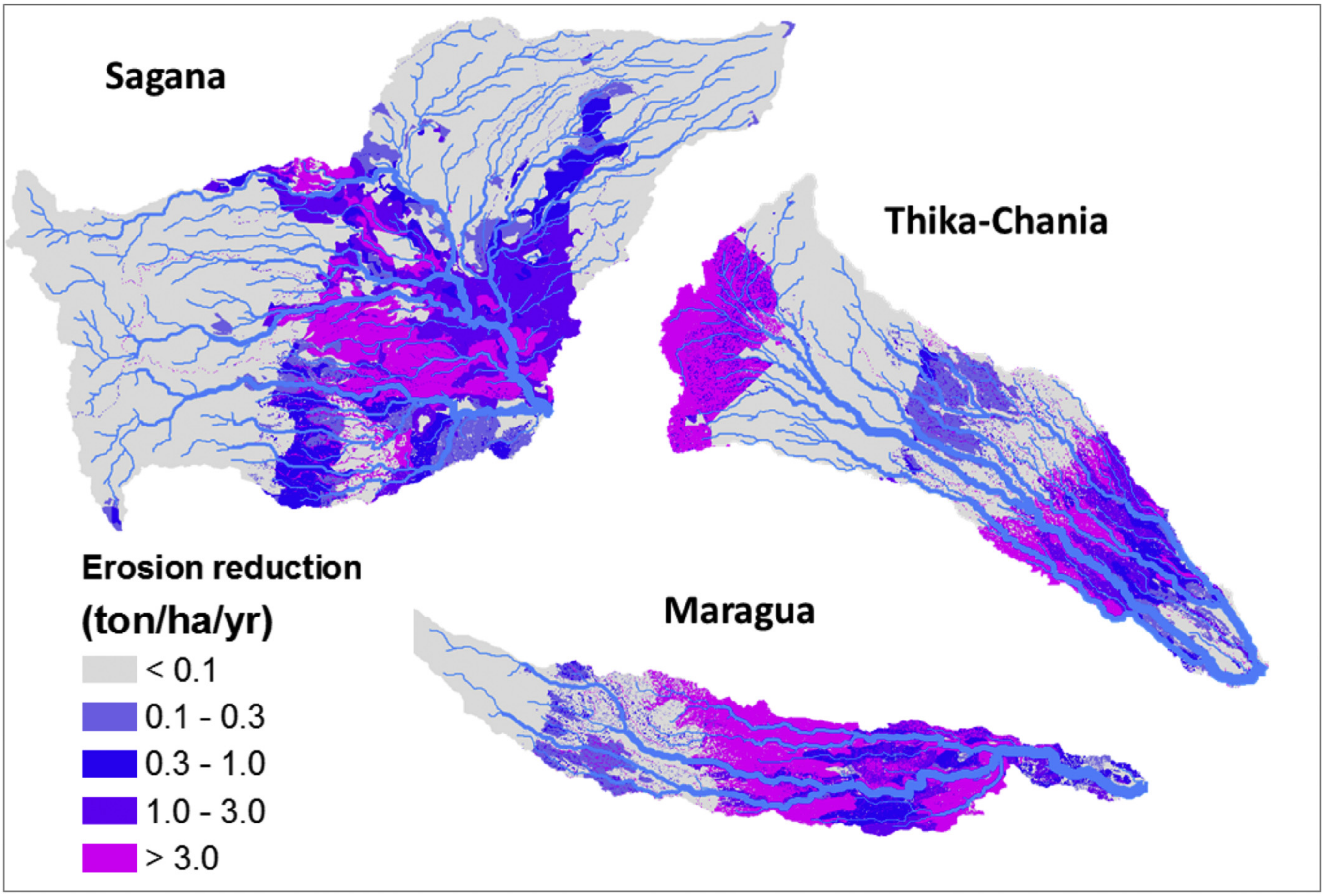

Fig. 4. Erosion reduction for the USD 10 M investment scenario (ton ha^{-1} yr^{-1}) for the three study watersheds.

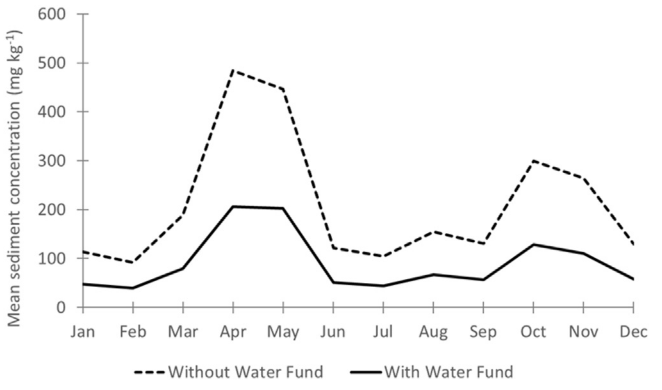

Fig. 5. Mean monthly sediment concentration at the Mwagu intake, the primary water intake for Nairobi's Ngethu water treatment plant. Results predict that sediment concentrations are reduced by 50–60%, depending on the month.

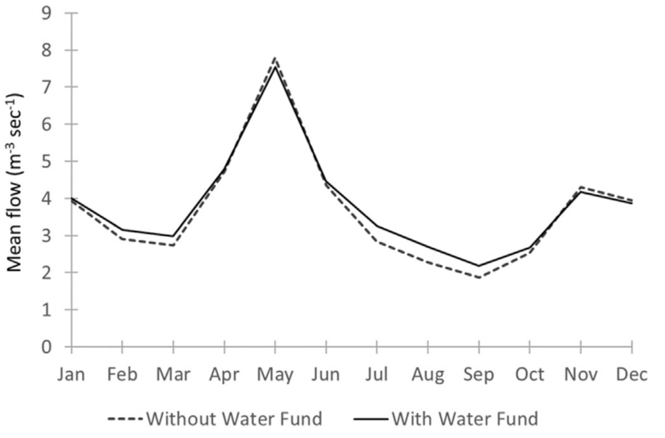

Fig. 6. At the Mwagu water supply intake, mean monthly flows (m^3 sec^{-1}) are increased in the dry months and slightly decreased in the peak wet months.

valued here. These include benefits to local livestock and dairy production from increased fodder grown in buffer strips, secondary benefits of increased disposable income from improved yields and employment opportunities through the Water Fund's activity implementation. Furthermore, for the roughly half a million residents in the study area who do not have access to treated water, improved water quality can reduce costs for those who engage in home treatment, and provide health benefits for those who do not.

In particular, several additional benefits to municipal water treatment were assessed, both for NCWSC and other towns in the area such as Nyeri, Thika, and Murang'a. The largest financial benefit to NCWSC might well be the avoided disposal of wet sludge, which is currently disposed of without cost. The annual mass of sediment intake into the Ngethu treatment plant is expected to decrease by about 15,000 tons in the intervention scenario. If NCWSC can be sure of lower sediment loads in the future due to Water Fund investments, they could significantly reduce the size

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Table 3
Annual increases in farmer revenues per watershed and crop type (USD million).

Watershed	Baseline Revenue	Revenue Change (percent)	Revenue Change by Crop Type		
			General agriculture	Coffee	Tea
Sagana-Gura	64.0	0.8 (1.3%)	0.3	0.3	0.3
Maragua	50.4	0.8 (1.7%)	0.4	0.6	0.1
Thika-Chania	76.4	1.0 (1.3%)	0.6	0.5	0.1
Total	**190.7**	**2.7 (1.4%)**	**0.9**	**1.6**	**0.4**

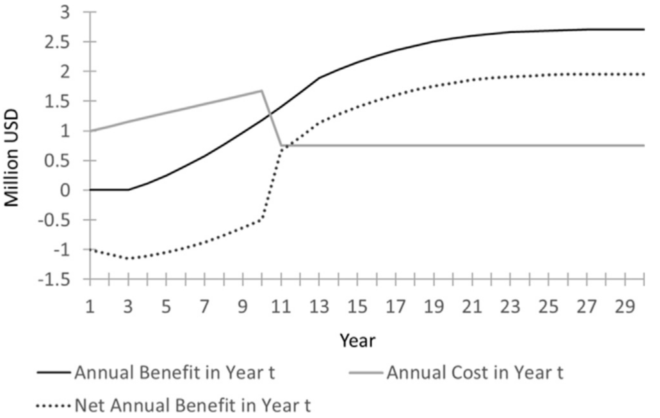

Fig. 7. Annual benefits and costs by year including ongoing maintenance after 10 years (in USD million).

and capital investment associated with a planned sludge treatment and disposal system, although the exact savings would require data on the proper sizing and cost of such a system under the business-as-usual scenario. Avoided interruptions to service during high-sediment days and increased dry-season base flows could potentially translate to improved service delivery. Clean and reliable water supply to urban-based private sector processers – such as bottling plants – is crucial for a growing economy and a sustained source of foreign exchange for the country.

KenGen is likely to benefit also from avoided loss of storage capacity in Masinga reservoir (due to avoided sedimentation). However, monetizing this benefit would require detailed engineering-economic modelling incorporating data on reservoir storage, capital costs for new infrastructure development, and management rules for the Masinga Dam and the Seven Forks Cascade. Additional benefits to KenGen from reduced reservoir sedimentation are expected, including a greater ability to optimally manage flows and water balance within the Seven Forks Cascade to maximize power generation. Our results also do not capture the avoided maintenance cost required to keep turbine intakes open (likely using dredging), as sediment accumulation advances toward the downstream end of the reservoir over time. We also anticipate there would be avoided dredging costs for small upstream dams where sedimentation occurs near turbine intakes.

Many residents of the Upper Tana do not have access to treated water. According to Kenya's 2009 census, there were approximately 606,000 people within our study area whose primary water source was raw water from streams, who could also represent additional beneficiaries of water quality improvements. Even a very small willingness-to-pay for improved water quality by these populations quickly translates to very significant benefits. For example, valuing improved water quality at 0.005 USD per person per day would lead to approximately USD 10 M in benefits over the 30-year time horizon.

Further, turbidity and suspended solids have been correlated with bacterial pathogen content in a number of studies (Irvine et al., 2003; Lawrence, 2012; LeChevallier and Norton, 1992). The relationship between sediment concentration, pathogen content, pathogen exposure and health is complex and beyond the scope of this study. However, it is likely that a reduction in sediment being carried into streams will have some positive effect on health outcomes, most likely through reduced incidence of diarrhea, which can be both costly and deadly when adequate treatment is unavailable.

4.3. Limitations

Our analysis assumes an average value for changes in power generation of 0.0356 USD kwh^{-1}. In reality, the financial value to KenGen and the social value to Kenyans as a whole will depend on the time and conditions of generation, as well as the details of the power-purchase agreements to which KenGen is party. Especially

Table 4
Cumulative benefits across benefit streams. Note: figures are rounded to three significant digits within each row, while sums are based on exact values. Bolded text indicates subtotals of costs/benefits for each stakeholder group and grand totals. Further details on the underlying assumptions and parameters for the Net Present Value calculations can be found in Bryant (2015).

Stakeholder	Benefit or (Cost)	Present Value (USD)
Water Fund	**Investment cost**	**(7,110,000)**
Ag producers	**Net additional cost, e.g. maintenance**	**(8,520,000)**
Ag producers	**Farmers**	**12,000,000**
NCWSC	Avoided flocculant costs	394,000
NCWSC	Avoided electricity costs	36,700
NCWSC	Net revenue from saved process water	2,090,000
NCWSC	Benefits of above, applied to demand met in future	870,000
NCWSC	**Total NCWSC benefits with scale-up**	**3,390,000**
KenGen	Avoided interruptions	281,000
KenGen	Increased generation from increased water yield	5,870,000
KenGen	**Total KenGen benefits**	**6,150,000**
Present Value of Benefits		**21,500,000**
Present Value of Costs		**(15,600,000)**
Net Present Value (NPV)		**5,900,000**

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during the dry season, it is quite likely that the value of increased generation is higher, when KenGen currently relies on expensive fossil generation to cover low hydropower production. Reducing gains is that fact that the efficiency of hydropower generation will presumably be lower in the dry season due to the lower heads.

There is also some risk of double counting across certain benefits, for example, avoided energy use by NCWSC may reduce revenues for KenGen. However, in that particular case, avoided payments by NCWSC are negligible compared to KenGen's gains, and even then double counting would only occur if KenGen could not sell the saved electricity. We have not given detailed consideration to potential tradeoffs such as this, but neither do we have compelling reasons to think there are major tradeoffs between beneficiaries that would reduce the overall cost-effectiveness.

There are three primary sources of uncertainty related to the agricultural benefits. Firstly, because benefits to the agricultural sector are based on the crop export value, not all of this increase in revenue accrues to farmers. Some of that value is captured elsewhere in the value chain, there are additional costs associated with moving the increased yields through the value chain, and export prices tend to be highly volatile. This means that direct benefits to farmers from the increased production will likely be lower than is suggested by the gross revenue change; therefore, benefits are scaled down by 50% relative to revenue, to account for this issue.[2] However, even with this adjustment, these agricultural yield benefits comprise a major portion of benefits produced by the Water Fund.

A second source of uncertainty is the fact that cropping patterns are influenced to some level by market prices of farm inputs and outputs. Thus land management practices can sometimes change rapidly over time, with implications for erosion and sediment loss both during and after conversion.

Thirdly, the relationship between erosion, agricultural practices, and crop productivity is highly dependent on a wide range of biophysical conditions. This means that the modeled relationships between erosion and agricultural productivity are purely empirical and based on few ground-truth data. In addition, a survey by Leisher (2014) indicates that 54% of farmers practice soil conservation on <25% of their land and only 11% on >50%. While we did consider existing soil conservation practices on average, we did not have spatial data on their locations which would influence the estimates of activity benefits for particular locations.

Other uncertainties relating to the modelling approach include the discrepancies between some high-resolution data (such as land use) with lower-resolution data (such as soils). For example, the RIOS model resamples all inputs to the land cover resolution, in this case 15 m, to make recommendations for activity implementation. Heterogeneity in soils, micro-topography, and farmer practices means that actual impacts of activities will depend on site-specific conditions where they are implemented.

The overall goal of this study was to assess the long-term biophysical and economic viability of investments at a watershed level. Thus as results are aggregated in space and time, some of the above-mentioned uncertainties are reduced. Further, we made every effort to produce conservative estimates of returns for all benefit streams. Still, we found that identifying and, to the extent possible, quantifying and communicating these uncertainties to be essential when presenting and engaging stakeholders in the Water Fund.

4.4. *From theory to practice*

The Water Fund is moving forward with the USD 1 M per year investment plan with a fundraising goal of USD 10 M. The initial 2-year investment plan (approved July 2016) is fully funded, and the Fund is targeting regional “hotspots” of activity based on the results of this study. Of note, however, is that the Management Board found it impracticable to target interventions at the scale that benefits were modeled in this study (15 m resolution; Fred Kihara, *pers. comm.*, July 30, 2016). This underscores the fact that whether or not the ROI estimated in this study is realized will depend greatly on the skill of local experts and their ability to translate the priority areas identified into local interventions that address the most critical problems on-site.

Currently, a major strategy of the Fund has been to engage farmers with capacity-building and technical assistance, expecting that once benefits are realized, farmers will have direct economic incentives to continue the practices on their own without relying on direct payments. This approach assumes that the current lack of adoption stems from a combination of lack of information and access to capital, as well as low risk tolerance and low resilience to shocks. They assume that these constraints can be overcome by farmer extension efforts and some assistance with materials, while requiring that farmers show good faith effort via their own in-kind contributions of labor and land.

Although a decision to pursue direct payments to landholders could significantly alter our ROI calculation, it is our hope that by demonstrating a methodology, and building capacity among technical staff in Kenya to replicate it in the future, ongoing and adaptive management of the Fund can proceed considering the full range of costs and benefits in a systematic way. Ongoing monitoring of project uptake and participation, as well as socioeconomic and hydrologic monitoring, has been implemented to allow for ongoing hypothesis testing and course correction (Fred Kihara, *pers. comm.*, July 30, 2016).

5. Conclusions

This study presents an integrated analysis framework for targeting interventions that takes into account local environmental and socio-economic conditions, and then relies on detailed, process-based, biophysical models to demonstrate the economic return on those investments considering multiple hydrologic services.

Our analysis framework allows the integration of multiple benefit streams, identified through consultation with local stakeholders and considering a wide range of monetary and non-monetary values. We incorporated stakeholder engagement and interests at all stages of study design and analysis, which presented a unique set of benefits and challenges. The major benefit streams are intended to provide a business case for actors like NCWSC and KenGen to invest money into the Fund; however, many of the greatest economic and social benefits accrue to other actors (e.g. farmers, raw water users). This implies that investment from development sources will likely continue to be an important source of funding in the near future, as has been shown in similar programs elsewhere (Bremer et al., 2016).

Engaging stakeholders in the study design and vetting results – particularly for priority activity locations and for the economic analysis – means that results are more likely to be relevant and feasible when it comes to guiding outreach and program implementation. The participatory process itself helps to build trust among stakeholders and buy-in to the goals of the program, making results more likely to influence future policy (McKenzie et al., 2014; Posner et al., 2016; Rosenthal et al., 2015).

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[2] From a theoretical standpoint, this added value could range between zero and 100%, neither of which are considered plausible. This study uses the midpoint and includes sensitivity analysis around this figure. The nuances of this issue are discussed further in Bryant (2015).

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However, managing expectations with regards to the accuracy and feasibility of monetary valuation given data limitations presented ongoing challenges. In particular, there was often a tension between evaluating the economic (i.e., social) case for watershed interventions by summing multiple benefit streams, versus conducting a financial analysis for individual actors (which often would require even more highly detailed data). Our experience showed that actors such as NCWSC and KenGen were reluctant to commit investments commensurate with their expected benefits from this study, without more detailed analyses of the firm-level ROI. However, both indicated their support of the present analysis as a positive and informative step toward that ultimate goal, helping to further refine relevant questions and data needs.

Overall, this study demonstrates the benefit of using an integrated process to 1) target, 2) quantify, and 3) explore ROI for different soil and watershed conservation scenarios. Cost-benefit analysis remains a strongly supported method for evaluating investments in water infrastructure (Sadoff et al., 2015), so developing comparable methods to evaluate the benefits of natural infrastructure strategies goes a long way towards closing the gap between grey and green infrastructure approaches to meeting water security challenges. The information produced in this study fulfils a critical need for emerging water funds to show a positive ROI, engage new stakeholders, leverage new funding sources and attract investors.

Acknowledgments

The authors would like to thank the following individuals for their contributions to this work: Fred Kihara and Craig Leisher (The Nature Conservancy) for their assistance with initial project scoping and stakeholder outreach; Dan Kelly (The Nature Conservancy) for his work on spatial data collection and quality control; Fred Kizito (International Center for Tropical Agriculture, Kenya) for assistance with stakeholder outreach and local data collection; members of the Upper Tana-Nairobi Water Fund Steering Committee, The Green Belt Movement, and the Sustainable Agriculture Community Development Programme for their participation, advice, and invaluable input on sustainable land management practices in the local area. We are grateful to the guest editor and two anonymous reviewers whose constructive feedback we believe has greatly improved the quality of this manuscript. Funding: This work was supported by the Embassy of Sweden in Kenya, the Pentair Foundation, the Sall Family Foundation, and the Gordon and Betty Moore Foundation.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2016.10.013.

References

Apse, C., Bryant, B., Droogers, P., Hunink, J., Kihara, F., Leisher, C., Vogl, A., Wolny, S., 2015. Upper Tana-Nairobi Water Fund: a Business Case (Version 2). The Nature Conservancy, Nairobi, Kenya. http://www.nature.org/ourinitiatives/regions/africa/upper-tana-nairobi-water-fund-business-case.pdf.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment part I: model development. JAWRA J. Am. Water Resour. Assoc. 34, 73–89. http://dx.doi.org/10.1111/j.1752-1688.1998.tb05961.x.

Baker, T.J., Miller, S.N., 2013. Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. J. Hydrol. 486, 100–111. http://dx.doi.org/10.1016/j.jhydrol.2013.01.041.

Batjes, N.H., 2010. Soil Property Estimates for the Upper Tana, Kenya, Derived from SOTER and WISE. Main, Wageningen, Netherlands.

Bennett, G., Carroll, N., 2014. Gaining Depth: State of Watershed Investment 2014. Forest Trends' Ecosystem Marketplace.

Bennett, G., Cassin, J., Carroll, N., 2016. Natural infrastructure investment and implications for the nexus: a global overview. Ecosyst. Serv. 17, 293–297. http://dx.doi.org/10.1016/j.ecoser.2015.05.006.

Betrie, G.D., Mohamed, Y.A., van Griensven, A., Srinivasan, R., 2011. Sediment management modelling in the Blue Nile Basin using SWAT model. Hydrol. Earth Syst. Sci. 15, 807–818. http://dx.doi.org/10.5194/hess-15-807-2011.

Bossa, A.Y., Diekkrüger, B., Giertz, S., Steup, G., Sintondji, L.O., Agbossou, E.K., Hiepe, C., 2012. Modeling the effects of crop patterns and management scenarios on N and P loads to surface water and groundwater in a semi-humid catchment (West Africa). Agric. Water Manag. 115, 20–37. http://dx.doi.org/10.1016/j.agwat.2012.08.011.

Brauman, K.A., Daily, G.C., Duarte, T.K., Mooney, H.A., 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. Annu. Rev. Environ. Resour. 32, 67–98. http://dx.doi.org/10.1146/annurev.energy.32.031306.102758.

Bremer, L., Auerbach, D.A., Goldstein, J.H., Vogl, A.L., Shemie, D., Nelson, J.L., Kroeger, T., Benítez, S.P., Calvache, A., Guimarães, J., Higgins, J., Klemz, C., León, J., Lozano, J.S., Moreno, P.H., Veiga, F., 2016. One size does not fit all: diverse approaches to natural infrastructure investments within the Latin American Water Funds Partnership. Ecosyst. Serv. http://dx.doi.org/10.1016/j.ecoser.2015.12.006.

Bryant, B.P., 2015. Ecosystem Services Assessment and Valuation of Proposed Investments for the Upper Tana-Nairobi Water Fund. Stanford, CA, http://www.nature.org/ourinitiatives/regions/africa/ecosystem-service-assessment-technical-appendix.pdf.

de Groot, R.S., 2006. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. Landsc. Urban Plan. 75, 175–186. http://dx.doi.org/10.1016/j.landurbplan.2005.02.016.

Dile, Y.T., Karlberg, L., Daggupati, P., Srinivasan, R., Wiberg, D., Rockström, J., 2016. Assessing the implications of water harvesting intensification on upstream-downstream ecosystem services: a case study in the Lake Tana basin. Sci. Total Environ. 542, 22–35. http://dx.doi.org/10.1016/j.scitotenv.2015.10.065.

Droogers, P., Hunink, J.E., Kauffman, J.H., van Lynden, G.W.J., 2011. Water Use and Demand in the Upper Tana Catchment, Kenya—a Cost-benefit Analysis Using the Water and Evaluation and Planning Tool (WEAP). Wageningen, The Netherlands.

Duan, X., Xie, Y., Ou, T., Lu, H., 2011. Effects of soil erosion on long-term soil productivity in the black soil region of northeastern China. Catena 87, 268–275. http://dx.doi.org/10.1016/j.catena.2011.06.012.

Francesconi, W., Srinivasan, R., Perez-Miñana, E., Willcock, S.P., Quintero, M., 2016. Using the soil and water assessment tool (SWAT) to model ecosystem services: a systematic review. J. Hydrol. 535, 625–636. http://dx.doi.org/10.1016/j.jhydrol.2016.01.034.

Guo, Z., Li, Y., Xiao, X., Zhang, L., Gan, Y., 2007. Hydroelectricity production and forest conservation in watersheds. Ecol. Appl. 17, 1557–1562. http://dx.doi.org/10.2307/40062056.

Hunink, J.E., Droogers, P., 2015. Impact Assessment of Investment Portfolios for Business Case Development of the Nairobi Water Fund in the Upper Tana River, Kenya (No. Report FutureWater: 133). Wageningen, The Netherlands, http://www.futurewater.es/wp-content/uploads/2015/02/TanaWF_FWreport_133.pdf.

Hunink, J.E., Droogers, P., 2011. Physiographical Baseline Survey for the Upper Tana Catchment: Erosion and Sediment Yield Assessment. Report FutureWater 112. http://www.futurewater.nl/wp-content/uploads/2013/01/2011_TanaSed_FW-1121.pdf.

Hunink, J.E., Droogers, P., Kauffman, S., Mwaniki, B.M., Bouma, J., 2012. Quantitative simulation tools to analyze up- and downstream interactions of soil and water conservation measures: supporting policy making in the Green Water Credits program of Kenya. J. Environ. Manage 111, 187–194. http://dx.doi.org/10.1016/j.jenvman.2012.07.022.

Hunink, J.E., Niadas, I.A., Antonaropoulos, P., Droogers, P., de Vente, J., 2013. Targeting of intervention areas to reduce reservoir sedimentation in the Tana catchment (Kenya) using SWAT. Hydrol. Sci. J. 58, 600–614. http://dx.doi.org/10.1080/02626667.2013.774090.

Immerzeel, W.W., Droogers, P., 2008. Calibration of a distributed hydrological model based on satellite evapotranspiration. J. Hydrol. 349, 411–424. http://dx.doi.org/10.1016/j.jhydrol.2007.11.017.

Irvine, K., Somogye, E., Pettibone, G., 2003. Turbidity, suspended solids, and bacteria relationships in the Buffalo River Watershed. Middle States Geogr. 35, 42–51.

Jaetzold, R., et al., 2006. Farm Management Handbook of Kenya. Volume II. Natural Conditions and Farm Management Information, second ed. Nairobi, Kenya.

Kauffman, S., Droogers, P., Hunink, J., Mwaniki, B., Muchena, F., Gicheru, P., Bindraban, P., Onduru, D., Cleveringa, R., Bouma, J., 2014. Green Water Credits — exploring its potential to enhance ecosystem services by reducing soil erosion in the Upper Tana basin, Kenya. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 10, 133–143. http://dx.doi.org/10.1080/21513732.2014.890670.

(KenGen) Kenya Electricity Generating Company Limited, 2014. Annual Report & Financial Statements. Nairobi, Kenya.

(KenGen) Kenya Electricity Generating Company Limited, 2010. Annual Report & Financial Statements.

Kolinjivadi, V., Grant, A., Adamowski, J., Kosoy, N., 2015. Juggling multiple dimensions in a complex socio-ecosystem: the issue of targeting in payments for ecosystem services. Geoforum 58, 1–13. http://dx.doi.org/10.1016/j.geoforum.2014.10.004.

Kumar, P., Kumar, M., Garrett, L., 2014. Behavioural foundation of response policies for ecosystem management: what can we learn from Payments for Ecosystem Services (PES). Ecosyst. Serv. 10, 128–136. http://dx.doi.org/10.1016/

j.ecoser.2014.10.005.

Lawrence, S.J., 2012. Escherichia coli bacteria Density in Relation to Turbidity, Streamflow Characteristics, and Season in the Chattahoochee River Near Atlanta, Georgia, October 2000 through September 2008—Description, Statistical Analysis, and Predictive Modeling. U.S. Geological Survey Scientific Investigations Report 2012–5037.

LeChevallier, M.W., Norton, W.D., 1992. Examining relationships between particle counts and giardia, cryptosporidium, and turbidity. J./Am. Water Work. Assoc. 84, 54–60.

Leisher, C., 2014. Maragua and Thika/Chania Baseline Survey for the Upper Tana Water Fund. Central Science, The Nature Conservancy.

McKenzie, E., Posner, S., Tillmann, P., Bernhardt, J.R., Howard, K., Rosenthal, A., 2014. Understanding the use of ecosystem service knowledge in decision making: lessons from international experiences of spatial planning. Environ. Plan. C Gov. Policy 32, 320–340.

Mekonnen, M.M., Hoekstra, A.Y., 2014. Water conservation through trade: the case of Kenya. Water Int. 39, 451–468. http://dx.doi.org/10.1080/02508060.2014.922014.

Mulengera, M.K., Payton, R.W., 1999. Modification of the productivity index model. Soil Tillage Res. 52, 11–19. http://dx.doi.org/10.1016/S0167-1987(99)00022-7.

Naeem, S., Ingram, J.C., Varga, A., Agardy, T., Barten, P., Bennett, G., Bloomgarden, E., Bremer, L.L., Burkill, P., Cattau, M., Ching, C., Colby, M., Cook, D.C., Costanza, R., DeClerck, F., Freund, C., Gartner, T., Goldman-Benner, R., Gunderson, J., Jarrett, D., Kinzig, A.P., Kiss, A., Koontz, A., Kumar, P., Lasky, J.R., Masozera, M., Meyers, D., Milano, F., Naughton-Treves, L., Nichols, E., Olander, L., Olmsted, P., Perge, E., Perrings, C., Polasky, S., Potent, J., Prager, C., Quétier, F., Redford, K., Saterson, K., Thoumi, G., Vargas, M.T., Vickerman, S., Weisser, W., Wilkie, D., Wunder, S., 2015. Get the science right when paying for nature's services. Science 347, 1206–1207. http://dx.doi.org/10.1126/science.aaa1403 (80-.).

Onduru, D.D., Muchena, F.N., 2011. Cost Benefit Analysis of Land Management Options in the Upper Tana, Kenya. Wageningen, The Netherlands.

Pascual, U., Phelps, J., Garmendia, E., Brown, K., Corbera, E., Martin, A., Gomez-Baggethun, E., Muradian, R., 2014. Social equity matters in payments for ecosystem services. Bioscience. http://dx.doi.org/10.1093/biosci/biu146.

Pierce, F.J., Larson, W.E., Dowdy, R.H., Graham, W.A.P., 1983. Productivity of soils: assessing long-term changes due to erosion. J. Soil Water Conserv. 38, 39–44.

Posner, S.M., McKenzie, E., Ricketts, T.H., 2016. Policy impacts of ecosystem services knowledge. Proc. Natl. Acad. Sci. http://dx.doi.org/10.1073/pnas.1502452113.

Quintero, M., Wunder, S., Estrada, R.D., 2009. For services rendered? Modeling hydrology and livelihoods in Andean payments for environmental services schemes. For. Ecol. Manage 258, 1871–1880. http://dx.doi.org/10.1016/j.foreco.2009.04.032.

Rocha, E.O., Calijuri, M.L., Santiago, A.F., Assis, L.C., Alves, L.G.S., 2012. The contribution of conservation practices in reducing runoff, soil loss, and transport of nutrients at the watershed level. Water Resour. Manag. 26, 3831–3852. http://dx.doi.org/10.1007/s11269-012-0106-1.

Rodriguez, D.J., van den, Berg C., McMahon, A., 2012. Investing in Water Infrastructure: Capital, Operations and Maintenance, Water Papers. The World Bank, Washington DC.

Rosenthal, A., Verutes, G., McKenzie, E., Arkema, K.K., Bhagabati, N., Bremer, L.L., Olwero, N., Vogl, A.L., 2015. Process matters: a framework for conducting decision-relevant assessments of ecosystem services. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 11, 190–204. http://dx.doi.org/10.1080/21513732.2014.966149.

Sadoff, C.W., Hall, J.W., Grey, D., Aerts, J.C.J.H., Ait-Kadi, M., Brown, C., Cox, A., Dadson, S., Garrick, D., Kelman, J., McCornick, P., Ringler, C., Rosegrant, M., Whittington, D., Wiberg, D., 2015. Securing Water, Sustaining Growth: Report of the GWP/OECD Task Force on Water Security and Sustainable Growth. University of Oxford, UK.

Sáenz, L., Mulligan, M., Arjona, F., Gutierrez, T., 2014. The role of cloud forest restoration on energy security. Ecosyst. Serv. 9, 180–190. http://dx.doi.org/10.1016/j.ecoser.2014.06.012.

Talberth, J., Gray, E., Yonavjak, L., Gartner, T., 2013. Green versus gray: nature's solutions to infrastructure demands. Solutions 4.

Vogl, A.L., Tallis, H.T., Douglass, J., Sharp, R., Veiga, F., Benitez, S., León, J., Game, E., Petry, P., Guimarães, J., Lozano, J.S., 2015. Resource Investment Optimization System: Introduction & Theoretical Documentation. Natural Capital Project. Stanford University, Stanford, CA.

(WOCAT) World Overview of Conservation Approaches and Technologies, 2014. Sustainable Land Management Technologies Database [WWW Document]. URL. https://www.wocat.net/en/knowledge-base/technologiesapproaches/database.html (accessed 1.12.14).

Please cite this article in press as: Vogl, A.L., et al., Valuing investments in sustainable land management in the Upper Tana River basin, Kenya, Journal of Environmental Management (2016), http://dx.doi.org/10.1016/j.jenvman.2016.10.013