Developing cost-effective investment portfolios for the Upper Tana-Nairobi Water Fund, Kenya

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Introduction: The RIOS Model

The Resource Investment Optimization System (RIOS) model — developed by the Natural Capital Project and The Nature Conservancy (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 for undertaking those activities, and economic data on their costs. The output of the RIOS model is a map of the locations of selected interventions, chosen based on ranked cost-effectiveness scores to achieve one or more ecosystem services objectives.

An example of applying RIOS for managing sediment retention in two watersheds in the Cauca Valley near Cali, Colombia shows that the RIOS optimized investment portfolio provided an average of 5-times improved return on investment—as measured by % sediment retention per cost— compared with a (simulated) ad-hoc non-optimized approach to investment planning (Tallis *et al*., 2011).

RIOS can develop investment portfolios that target a range of different water resource objectives, including:

- Groundwater recharge enhancement
- Maintenance of base flows
- Sediment retention
- Reduce nutrient loading (nitrogen and phosphorus)
- Flood mitigation
- Biodiversity

The underlying premise of the RIOS diagnostic screening approach is that a small set of biophysical and ecological factors determine the effectiveness of different conservation strategies in accomplishing different objectives. RIOS incorporates a set of critical factors that impact the effectiveness of activities to achieve each objective. In the development of RIOS, a review of experimental studies, review papers, and hydrologic model documentation was used to identify the subset of factors most frequently cited as important for determining the magnitude of the source and effectiveness of activities that impact erosion control, nutrient retention, groundwater recharge, etc. Because budget allocation and fund investments are annual or multi-year processes, the RIOS tool focuses on impacts of transitions on an annual or longer-term time scales. Therefore, factors identified from the literature review as influencing impacts on a daily or seasonal basis are not included in the model framework (such as antecedent soil moisture or daily rainfall intensity).

In the long term, much of the impact of activities will be determined by conditions on the surrounding landscape. Therefore, RIOS relies on a set of four major components across its framework that captures the processes influencing these impacts and the effectiveness of activities: (1) upslope source magnitude (2) on-pixel source (3) on-pixel retention (4) downslope retention (Figure 1). Each of the aforementioned components is represented by one or more factors (data inputs) within each objective. For example, the downslope retention component for erosion control is calculated as a function of each pixel's distance to the nearest stream as well as the slope and sediment retention capacity of all the downslope pixels.

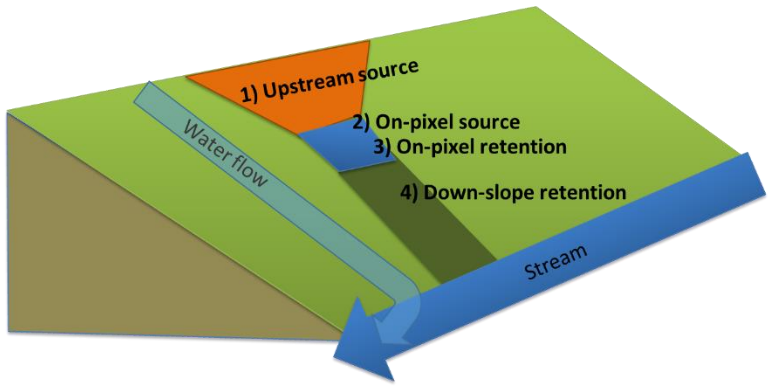

Figure 1. Four key processes used in the RIOS framework to account for the impact of a landscape change on objectives.

Figure 1 shows these four key processes on the landscape that impact the effectiveness of different conservation strategies in achieving the objectives. All land management changes (transitions) will be more effective in places downstream of a large upstream source (whether it be sediment, nutrient, runoff, etc.). This is because vegetation can trap more sediment or infiltrate more water if the amount of sediment and flow coming down from upstream is greater. The opposite is true for the downslope condition. Transitions will be more effective when they are placed upstream of an area with low retention or infiltration. Local conditions also determine the impacts of activities, such that protecting native vegetation will have the biggest impact in places with low on-pixel sources of sediment and high on-pixel retention, while revegetation and improved management practices will have the biggest impacts in places with large sediment sources and low retention.

RIOS calculates a score for each pixel on the landscape, indicating how effective an activity is expected to be for improving the desired objective, relative to other places. RIOS then combines scores across objectives via weighted summation. This results in every pixel being assigned one score per activity that reflects its ability to influence all of the desired objectives. Activity scores are divided by the activity cost to produce an ROI raster for each activity. Once the landscape and feasibility constraints are met, selection of priority areas is entirely driven by return on investment (ROI), where investments are represented by activity costs and returns are determined by relative rankings. RIOS selects priority areas by choosing the highest ROI parcels in order, until the defined budget is spent. Therefore the number and extent of priority areas is determined by the size of the budget and the specified costs per activity. The output of this prioritization process is the recommended investment portfolio. More information on how RIOS calculates scores and uses budget and feasibility information to produce portfolios may be found in the RIOS User's Guide (Vogl *et al.*, 2015).

The RIOS approach requires typically readily available data and takes a rather simplified approach to diagnostic screening. However, it provides several important features. A ranking approach allows for rapid optimization across multiple objectives, in this case base flow and sediment retention, combining the questions of 'in what?' and 'where?' to invest. The approach also factors in the landscape context, providing a simple method to include some relatively complex and very important components of hydrological processes. It develops ranks based on the change the water fund is trying to make; not only on the current condition of the watershed. Finally, the diagnostic screening approach in RIOS, though simple, provides considerably more transparency and is more easily replicated with local capacity than applying more sophisticated, process-based models in a complex dynamic optimization approach would do. For more detailed information on the theory and potential applications of RIOS, see the RIOS User Guide (Vogl *et al.*, 2015).

RIOS Modeling for the Business Case

In this study, the RIOS model was applied in each of the three priority watersheds of the Upper Tana-Nairobi Water Fund: The Thika-Chania, the Maragua, and the Sagana-Gura. The objective of the study is to produce scenarios of future landscapes, representing different management interventions across a range of budgets. The priority investment portfolios were produced as the first step in a return on investment (ROI) analysis that links activities with biophysical impacts and, ultimately, economic impacts to various beneficiaries in the water fund area.

The analysis used to assess ROI for the Upper Tana-Nairobi Water Fund combined several widely used tools: (i) Resource Investment Optimization System (RIOS) to spatially target the investment portfolios; (ii) Soil & Water Assessment Tool (SWAT) to assess the biophysical impacts and benefits of the investments; and (iii) a range of economic valuation tools to estimate the economic benefits for upstream and downstream users. The result was an assessment of the fund's potential ROI, considering the benefits to several different locations and beneficiaries if the RIOS-designed portfolios were implemented (Apse *et al*., 2015). In this report we detail the methods and results for step (i) – using spatially-explicit ecosystem service modeling to target investments in specific activities for the water fund, focusing on the most cost-effective investment locations.

To date, the focus of many soil and water conservation activities undertaken in the Upper Tana basin has been primarily to improve conditions at the site scale, to reduce erosion and sedimentation into streams and improve agricultural practices. Thus far, attention has not been given explicitly to ecosystem services to connect the improvements at activity sites with watershed-scale goals for soil and water conservation. Our analysis adds to ongoing conservation efforts by employing biophysical models to target activities that will promote more cost-effective ecosystem service returns, improving the potential for site-level activity impacts to scale up to changes in services delivered to downstream beneficiaries.

The Business Case study (Apse *et* al., 2015) was intended to initiate an adaptive cycle for the establishment and management of the Upper Tana-Nairobi Water Fund (Figure 2). The combination of the two models (RIOS and SWAT) allows for the most comprehensive assessment to date of 1) cost-effective places for the water fund to prioritize investments given target budget level(s) and 2) the quantitative and monetary benefits that could result from full implementation of each investment portfolio (Figure 2, Phase I). A key factor in linking the RIOS and SWAT models is to ensure that the same data and inputs are used to drive both models, ensuring consistency across the analysis. The results of this ROI assessment can then be used in future phases to set quantitative targets for the water fund, in terms of the physical changes that they would like to affect the landscape, and the financing goals necessary to achieve these targets (Figure 2, Phase II).

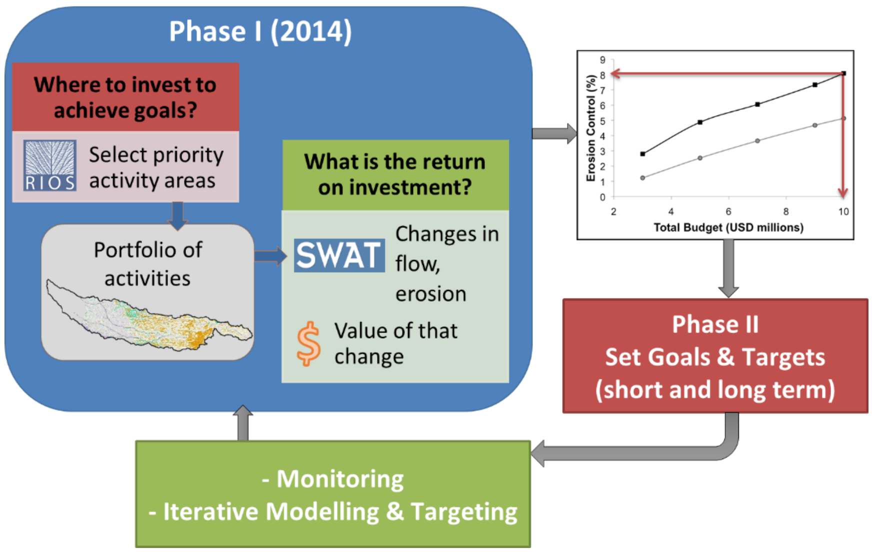

Figure 2. Schematic of the modeling process (Phase I) and suggested future work to iteratively set goals and targets for the water fund, design activity implementation, and monitor impacts (Phase II).

Methods: Data Collection

The RIOS model requires data on physical and landscape factors such as land use and management, soils, climate, topography, etc., as well as socio-economic information such as budgets, activity costs and preferences, and the distribution of populations who would benefit from activities within the project areas. Data were gathered from previous work in the basin (e.g., Green Water Credits), local agencies and experts (e.g. WRMA, KenGen), national census data, etc. Where local or national data sources were not available, either to be used as model inputs or to guide model parameterization, global datasets and a review of relevant literature were used. See Tables 1 and 2 for a listing of data requirements for the RIOS model, sources, and final values applied. Below is a detailed description of the data used in RIOS and the sources by data type.

Objectives

In the current study, we apply the sediment retention and base flow model objectives. Other water-related objectives are available in RIOS, as detailed above, and can be used by the water fund if they decide to expand their priorities to include additional objectives. Running other objectives may require collection of additional data.

In RIOS, users have the option to weight objectives relative to each other. Default values assume that all objectives are considered equally in determining the activity scores. For all sub-watersheds and budget levels, we assigned the sediment retention objective twice the priority of the base flow objective, meaning that the objective weight for sediment retention = 2 while the objective weight for base flow = 1.

Spatial Data

Land Cover

TNC carried out a detailed update of the Africover land use maps, using satellite imagery, detailed maps from stakeholders and ground truth points. The final pixel resolution of these maps is 15 m. These high resolution maps were used as input for the RIOS model (Figure 3).

Soils

Soils data used in the RIOS model were the same used for the SWAT modeling (Hunink and Droogers, 2015). These data originated from the Green Water Credits project (Batjes, 2010). The data set was derived from the 1:250,000 scale Soil and Terrain Database for the Upper Tana (SOTER_UT, ver. 1.0) and the ISRIC-WISE soil profile database, using standardized taxonomy-based pedotransfer procedures. RIOS requires soil erodibility, soil depth and soil texture as spatial inputs.

Soil erodibility, sometimes noted as K, is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. This factor represents the soil component of erosion; the relative impact that different soil types may have on the sediment produced from a given area.

Soil depth is the maximum depth of the soil to an impervious layer. Below this depth, root penetration is inhibited because of physical or chemical characteristics of the soil.

The soil texture index is used as a proxy for the probability of runoff generation given the general properties of the soil. Each soil type is assigned a rank, based on the texture (Sandy = 0.2; Light = 0.4; Medium = 0.6; Heavy = 0.8; Heavy to Rock = 1.0).

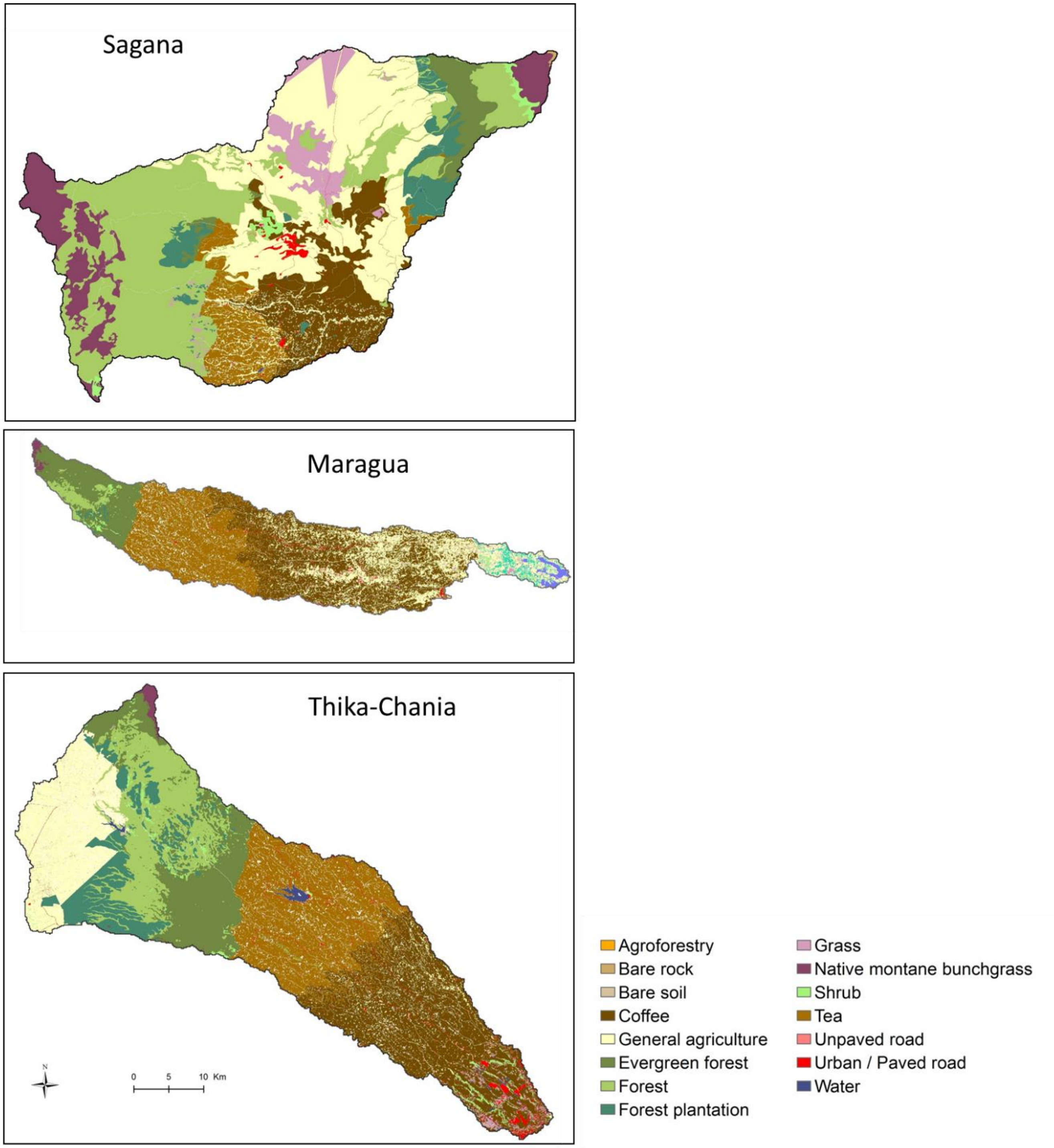

Figure 3. Land uses in the three study watersheds.

Climate

The baseflow maintenance objective in RIOS requires spatial data on mean annual rainfall and actual evapotranspiration. Mean annual rainfall was derived from the daily rainfall data collected from local weather stations used in the SWAT modeling for this project (Hunink and Droogers, 2015), and interpolated to cover the area of interest. Actual evapotranspiration was estimated using the InVEST Water Yield model, using interpolated rainfall data provided by FutureWater (Hunink and Droogers, 2015) and the same biophysical input layers listed here for RIOS.

The sediment retention objective in RIOS requires spatial data on the erosivity of rainfall. Rainfall erosivity depends on the intensity and duration of rainfall in the area of interest. The greater the intensity and duration of a rain storm, the higher the erosion potential. This factor represents the relative impact that rainfall intensity will have on the amount of sediment produced from a given area. Rainfall erosivity was derived from the interpolated rainfall data used in the SWAT modeling for this project (Hunink and Droogers, 2015).

Land Cover-Based Parameters

The RIOS model uses several land cover-based parameters that represent critical factors influencing infiltration and runoff, erosion, sediment export, and sediment retention. Descriptions of these parameters and sources are provided in Table 1, and the parameter values used in this study are given in Table 2. Sometimes multiple land use classes are assigned identical values for RIOS parameters, due to a lack of information that would allow us to assign distinct parameters to these different classes. In these cases, the distinct classes were retained in the input data in order to 1) preserve land management differences in subsequent modeling and valuation steps and 2) report results in a way that is meaningful to stakeholders.

Table 1. Land use and land cover-based parameters used in the RIOS model, and a description of sources for the Tana watersheds used in this study.

Parameter	Description	Source(s)
sed_exp	Cover-management factor for the USLE (decimal between 0 and 1). Represents how susceptible each LULC type is to erosion.	SWAT parameter database (Arnold et al., 2012): http://swat.tamu.edu/media/69419/Appendix-A.pdf InVEST database (NatCap 2013): http://naturalcapitalproject.org/database.html
sed_ret	Sediment retention efficiency (percent). Represents the ability of each LULC class to retain sediment in water flowing overland.	InVEST database (NatCap 2013): http://naturalcapitalproject.org/database.html
root_depth	The maximum root depth for vegetated land use classes (mm), given as the depth at which 95% of a vegetation type's root biomass occurs.	SWAT parameter database (Arnold et al., 2012): http://swat.tamu.edu/media/69419/Appendix-A.pdf
K_c	Vegetation evapotranspiration coefficient associated with each LULC. K_c reflects local climatic conditions, based on the evapotranspiration of a reference vegetation such as grass of alfalfa grown at that location.	FAO 1998, Table 12 (Allen et al., 1998): http://fao.org/docrep/x0490e/x0490e0c.htm InVEST Kc calculator: http://ncp-dev.stanford.edu/~dataportal/invest-data/Kc_calculator.xlsx Texas A&M University Crop Coefficients: http://texaset.tamu.edu/coefs.php
rough_rank	Vegetation roughness, representing the ability of each LULC type to retard surface flow across the landscape. Derived from Manning's n parameter for overland flow, ranked among all vegetation types present in the study area.	Engman 1986 Morgan et al. 1998 NRCS 1986 USDA AGWA documentation (Burns et al., 2007): http://www.tucson.ars.ag.gov/agwa
cover_rank	Vegetation cover (percent), representing the ability of each LULC type to retard surface flow across the landscape and promote infiltration.	Calculated percent cover by LULC type based on global 1km resolution 8-day Leaf Area Index derived from MODIS satellite data.

Table 2. Land use parameter values used in the RIOS model for the Upper Tana watersheds.

DESCRIPTION	sed_exp	sed_ret	root_ depth	Kc	rough_ rank	cover_ rank
Urban and paved roads	0.99	0.2	0	0.2	0.011	0.1
Bare soil/unpaved roads	1	0.26	500	0.15	0.02	0.16
Grass	0.034	0.845	2000	0.865	0.13	0.3
Shrub	0.128	0.505	2000	0.3	0.4	0.5
General agriculture	0.412	0.84	1000	1.1	0.09	0.39
Tea	0.08135	0.84	1850	1.015	0.3535	0.883
Coffee	0.4393	0.84	1600	1.055	0.276	0.45
Mixed forest	0.025	0.7375	3500	1.008	0.6	0.91
Water	0	0.2	10	1.05	0.0001	0
Evergreen forest	0.025	0.7375	3500	1.008	0.6	0.92
Forest plantation	0.121	0.7375	3500	1.008	0.6	0.79
Pineapple	0.055	0.84	3500	0.4	0.12	0.26
Wetland	0.003	0.94	2200	1.2	0.6	0.31
Orchard	0.412	0.84	1000	1.1	0.09	0.39
Corn	0.412	0.84	1000	1.1	0.09	0.39
Native montane bunchgrass	0.03	0.845	2000	0.925	0.15	0.28
Bare rock	1	0.26	500	0.15	0.02	0.16
Unpaved road	1	0.26	500	0.15	0.02	0.16
Agroforestry	0.121	0.7375	3500	1.008	0.6	0.79

Budgets, Activities and Allocation

In addition to geographic and land-use information, RIOS also requires socio-economic data about feasible activities and budget allocations in order to create realistic plans for watershed management interventions. Soil and water conservation interventions for input to the RIOS model were chosen in consultation with the Steering Committee and TNC project staff, and a review of literature on conservation interventions (e.g., WOCAT, 2014).

For the Business Case analysis, a total of $10M (US dollars) budget was taken as a reference budget amount, to be spent over a period of 10 years. This total budget was distributed as follows among the three priority watersheds: Thika-Chania 45%; Sagana-Gura 30%; and Maragua 25%, as was decided by stakeholders during a workshop held in Nairobi in February 2014. It was also decided to distribute the total amount equally among the 6 activities, which means that to each activity corresponds 16.7% of the total budget. Then, RIOS was run with different investment levels: $2.5 million; $5 million; $10 million; and $15 million (representing 25%; 50%; 100% and 150% of the $10 million target investment, respectively). Because costs are expressed in Kenya shillings (Ksh), the budgets for all watersheds were converted to Ksh using the current exchange rate as of Feb 2014.

In the Thika/Chania catchment, two investment priority areas were defined because of the watershed's special relevance for the fund and for the supply of water to the city of Nairobi. Assuming that the initial investment priority will be where activities will benefit Nairobi's water supply, we defined this as the area contributing flow to the system of intakes from which Nairobi Water and Sewer Company draws their supply (including the Mwagu wier). For each portfolio, half of the budget was designated to be spent in this area, and the remaining funds were allocated throughout the Thika-Chania watershed. For the other two watersheds, all of the budget for each scenario is allocated across the whole area based on cost-effectiveness.

After several meetings with the Steering Committee, other stakeholders and experts, and based on previous efforts and projects in the basin (as for example Green Water Credits), the following six activities were selected to be input into the RIOS investment portfolio analysis, to prioritize spatially in the watersheds:

1. Riparian management

2. Agroforestry

3. Terracing

4. Reforestation

5. Grass strips

6. Road mitigation

These activities are not meant to limit the activities that the fund might decide to engage in based on the results of this prioritization; in fact some of them are intentionally vague (e.g. "road mitigation"). The activities modeled here are meant to be representative of a range of activity types that impact different parts of the landscape in different ways – riparian corridors, crop lands, reducing encroachment in forested lands, addressing erosion from dirt roads, etc. The impact and effectiveness of these activities was assumed to reflect an average change that such activities would cause in the landscape. For example, while there are many different types of terracing possible (e.g. terracing with grass strips, bench terraces, cut-and-fill, fanya juu), and because the site-specific impacts of activities will vary depending on site-specific conditions, our modeling assumed that impact of the "terracing" activity would reflect implementation of the activity in a way best suited to specific site conditions.

Per-hectare costs for the activities were initially estimated from a review of the WOCAT (2014) database, and refined based on consultation with stakeholders during a meeting in February 2014. The per-hectare cost reflects the cost to implement each activity in its recommended best practice form and spacing on a hectare of cropland or other land use (such as roads). Costs include implementation (labor + material), and do not consider long-term maintenance costs or potential payments to landowners. Costs are assumed to be the same regardless of the land use type or starting condition of the place where they will be implemented (i.e. the cost of reforestation is the same whether on tea or mixed cropland). In reality the cost of activity implementation is likely to vary across the fund area depending on specific site conditions, changes in material costs, etc., but it was not feasible for this study to develop cost estimates that take into account all these combinations of factors.

RIOS also requires information on the feasibility of applying the activities on different land use types, and any restrictions to their implementation due to physical factors, logistical or legal constraints, etc. Table 3 gives the final activities and feasibility restrictions that were applied, based on consultations with local stakeholders and the TNC project team. Area-based restrictions were input as GIS shapefiles defining places where each activity should be prevented, for example, riparian management was prevented on all areas greater than 15m away from the stream network.

Table 3. Information on activities, costs, and where they are allowed within the RIOS modeling framework.

Activity	**Cost (KSh/ha)**	**Allowed on**
Riparian management	98,800	All land types within 15m buffer alongside streams, except urban, open water, bare rock, native montane bunchgrass, agroforestry, and roads. Not allowed within the border of Kenya Forest Service lands.
Agroforestry	98,800	Bare soil, grassland, and croplands (except pineapple)
Terracing	30,000	Bare soil, croplands (except tea), and agroforestry lands with >12% slope and >15m from stream channel.
Reforestation	98,800	Grassland, shrub, and croplands (except pineapple) located within 500m inside the border of Kenya Forest Service lands (anti-encroachment strategy)
Grass strips	12,000	Bare soil, croplands (except tea), and agroforestry lands with <12% slope
Road mitigation	424,863	Unpaved roads

Beneficiaries

In the RIOS model, the selection of priority areas is driven by the biophysical characteristics of the landscape as well as the number of people who may potentially benefit from improvements in water services due to implementing activities in these areas (beneficiaries). The beneficiaries input is a spatial data layer with a weight assigned to each cell based on the potential of activities to contribute positive benefits to people for a given objective. For this study, the potential for people to benefit was based on the 2009 Kenya national census data. These data provide population density (population/km^2) by administrative units, which was then used in two different ways for the two objectives.

For the sediment retention objective, the population density was used directly for the beneficiaries input. The assumption here is that administrative units with a higher population density will experience greater benefits (i.e. benefit more individuals) than units with a lower population density. Because much of the land is farmed, local populations will benefit directly from reduction in erosion on their lands, making units with high population density a higher priority for project activities.

For the baseflow enhancement objective, we assume that the benefits of enhanced flow resulting from conservation activities in any given area will be a function of the number of people downstream. If many people live and draw their water from downstream of a proposed riparian enhancement program, for example, while fewer people live and draw their water downstream from another potential area, then the area with more downstream beneficiaries should be preferred for project implementation. We addressed this by creating a beneficiaries input layer calculated as a weighted flow length in ArcGIS, using the population density by administrative unit as the weighting factor.

An exception to the above approach to beneficiaries was the case of the Sagana-Gura watershed. Here the population density of Nyeri town is very high: 927 to 4,092 persons/km^2, compared to less than 700 persons/km^2 in surrounding areas. However the water supply intake point that supplies water to this large population center is located approximately 10 km upstream of the urban area of Nyeri, and therefore the dependence of the urban area population on areas upstream of the intake is not well-represented by the census data on population density. To create the beneficiaries layer for the Sagana-Gura watershed, therefore, we re-distributed the population of the high-density administrative units surrounding the Nyeri urban area equally throughout the area upstream of the water supply intake point. Using this modified population density map, we then calculated the beneficiaries using the same process described above.

Figures 4 through 6 show the beneficiaries for the three priority watersheds, averaged for the two objectives. From these maps, you can see that there are prominent areas within each watershed where the fund’s activities have the potential to benefit more people, whether through direct benefits of erosion control on their lands, or by helping to augment the river flows that they depend upon for water supplies.

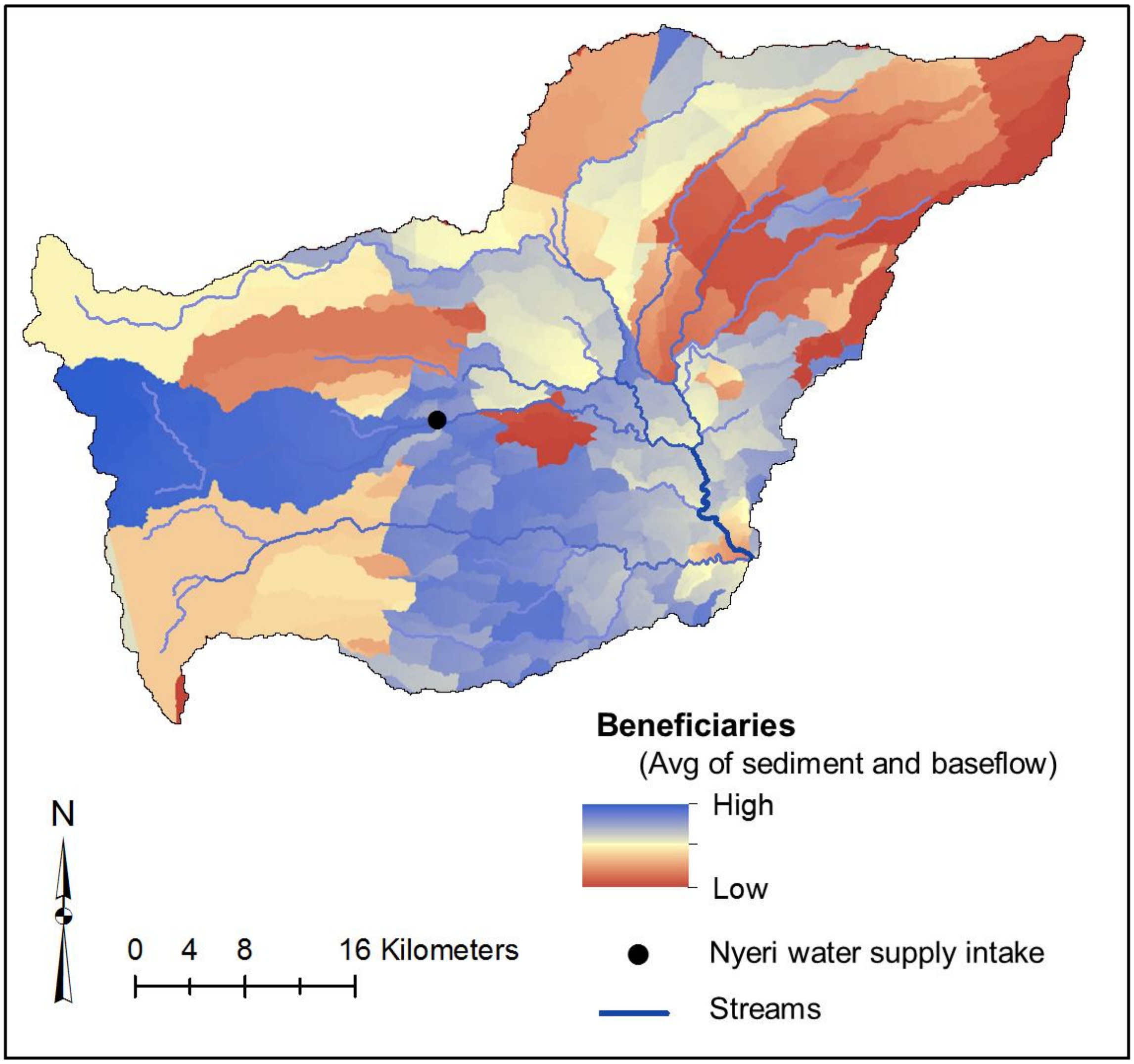

Figure 4. Beneficiaries for the Sagana-Gura watershed. This map shows the average of beneficiaries considered for the sediment and for the baseflow objectives.

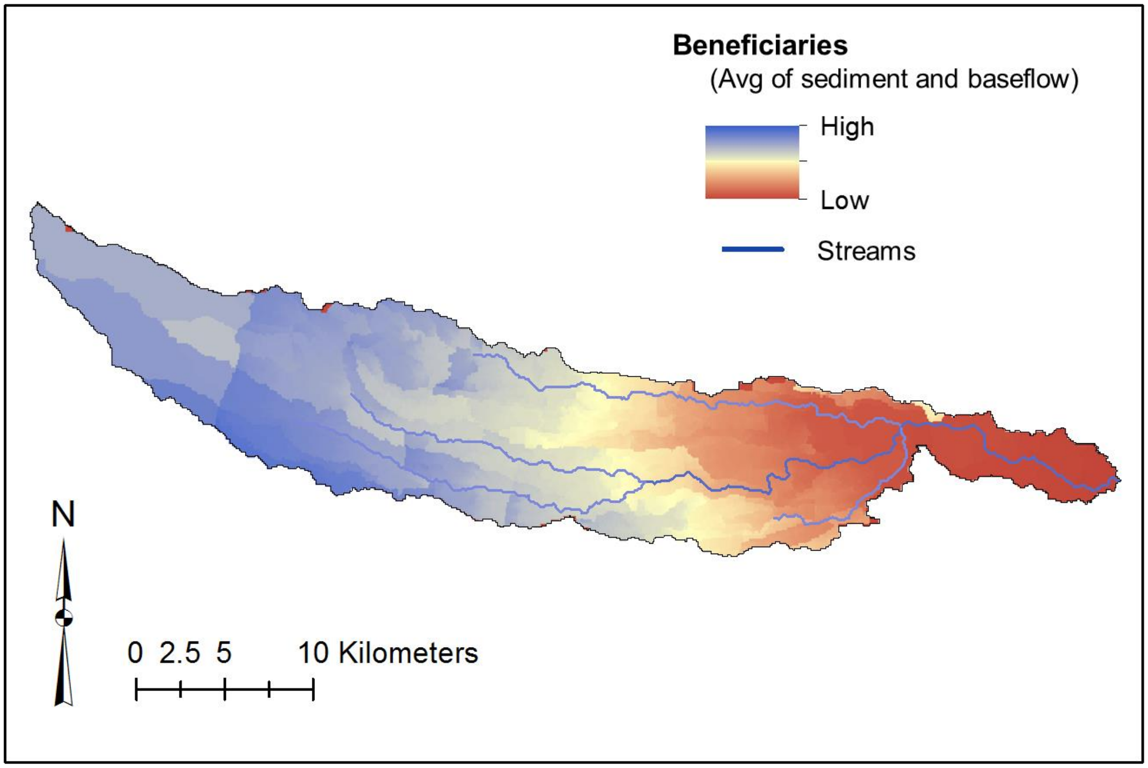

Figure 5. Beneficiaries for the Maragua watershed. This map shows the average of beneficiaries considered for the sediment and for the baseflow objectives.

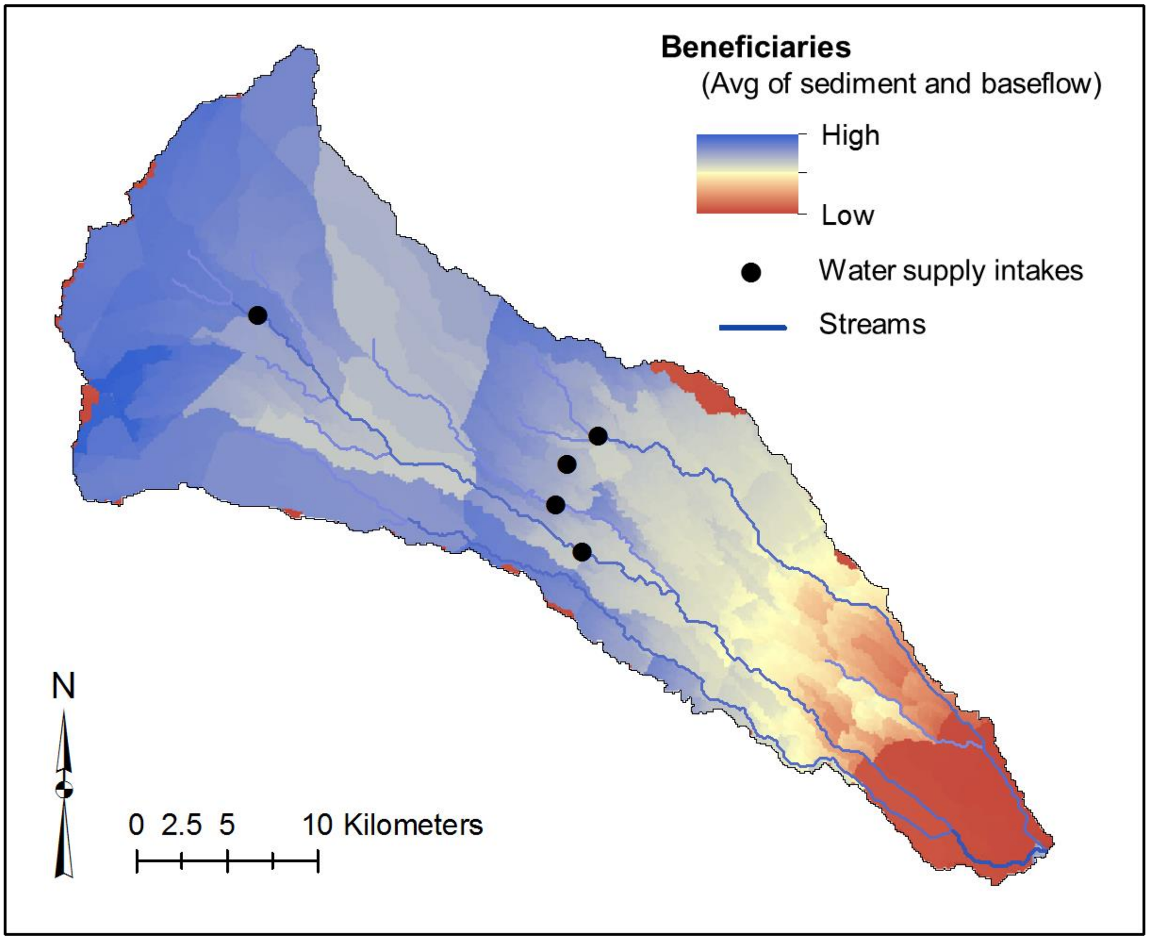

Figure 6. Beneficiaries for the Thika-Chania watershed. This map shows the average of beneficiaries considered for the sediment and for the baseflow objectives.

Results

The results of the RIOS analysis are four portfolios for each of the three priority watersheds, representing different levels of investment. Figures 7 through 10 show the portfolios designed for the three watersheds for each of the four budget levels: $2.5 million, $5 million, $10 million, and $15 million USD. The figures also show how the budget for each scenario was allocated among the Sagana-Gura, Maragua, and Thika-Chania areas.

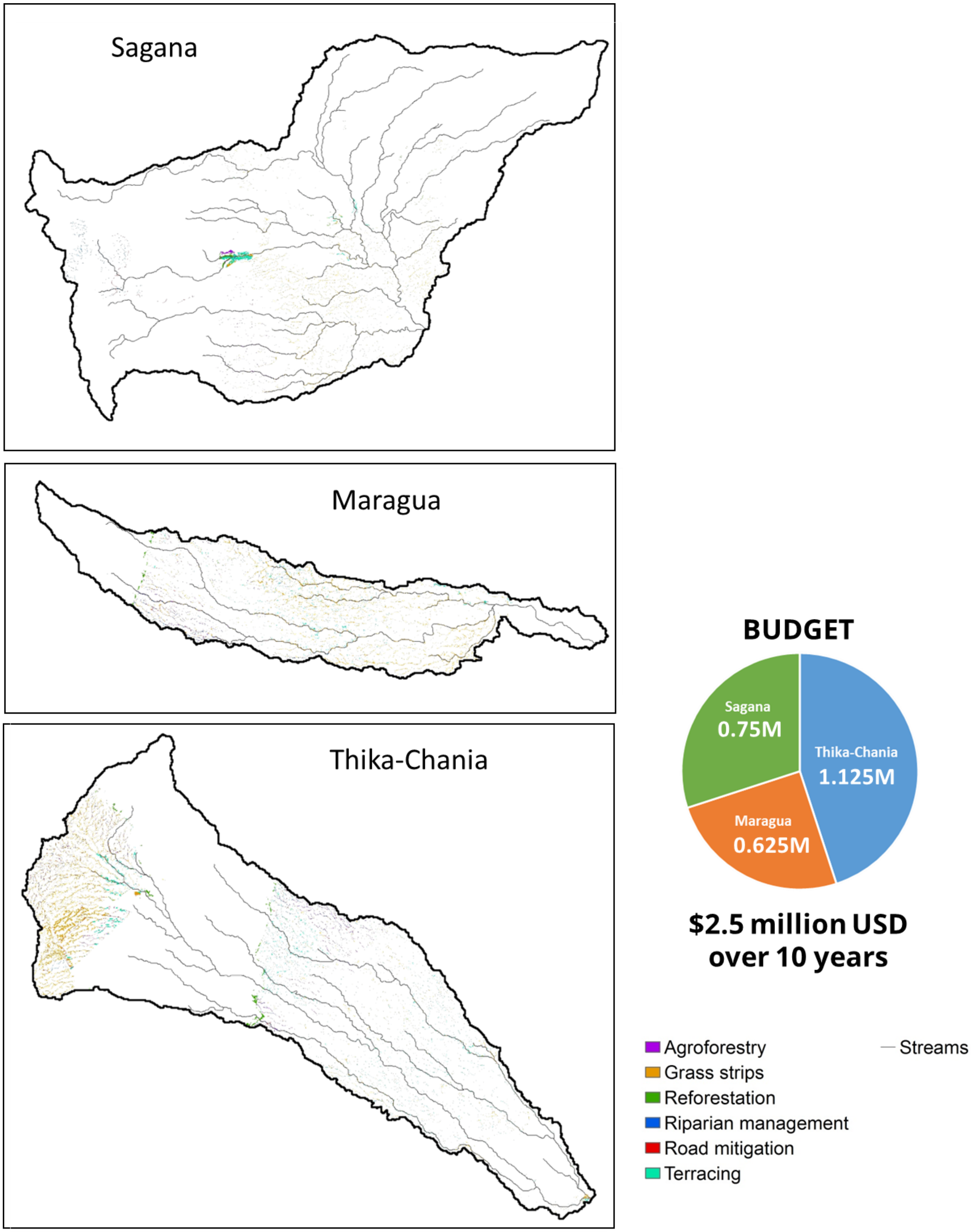

Figure 7. Investment portfolio for $2.5 million budget target across the three priority watersheds for the Upper Tana-Nairobi Water Fund.

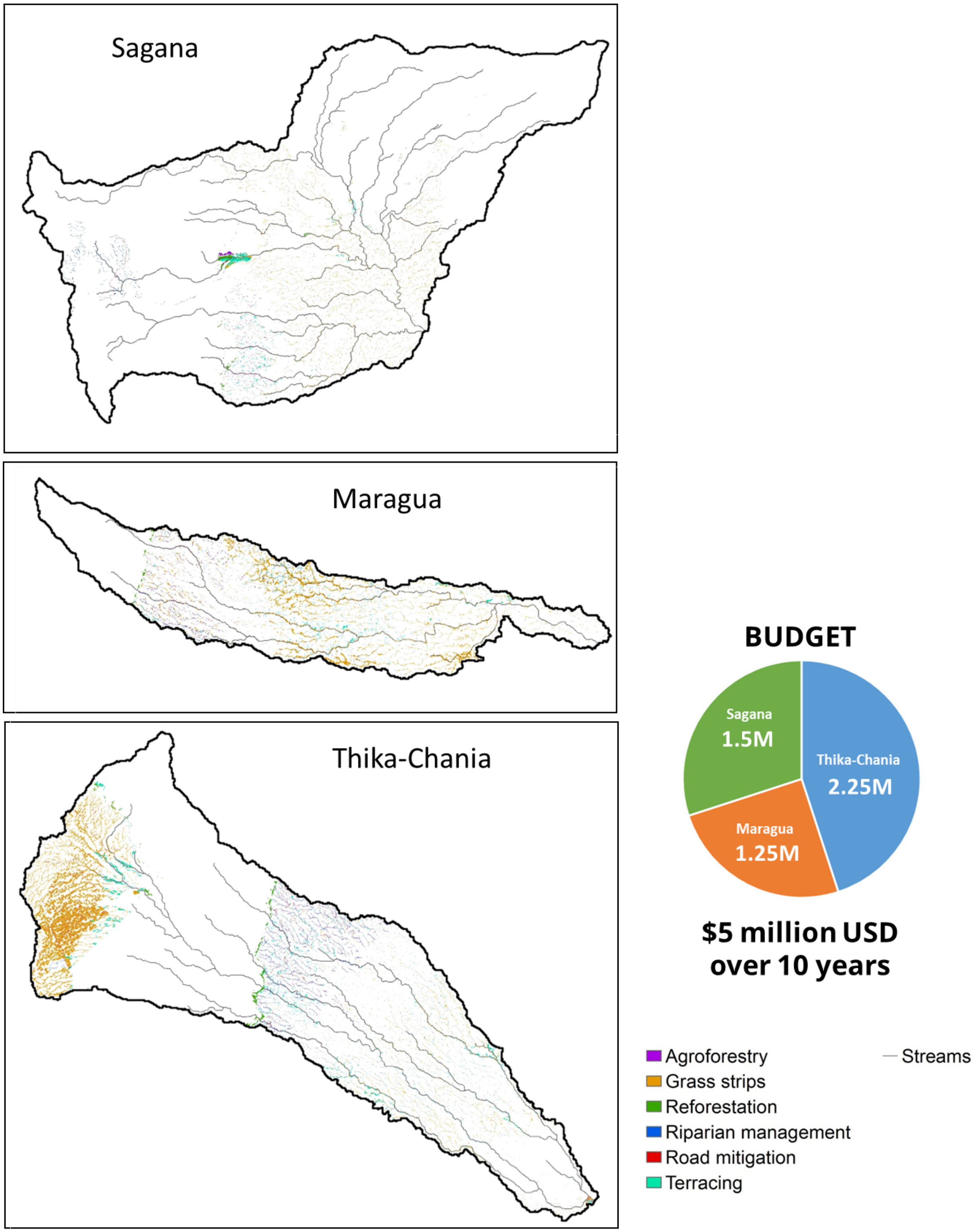

Figure 8. Investment portfolio for $5 million budget target across the three priority watersheds for the Upper Tana-Nairobi Water Fund.

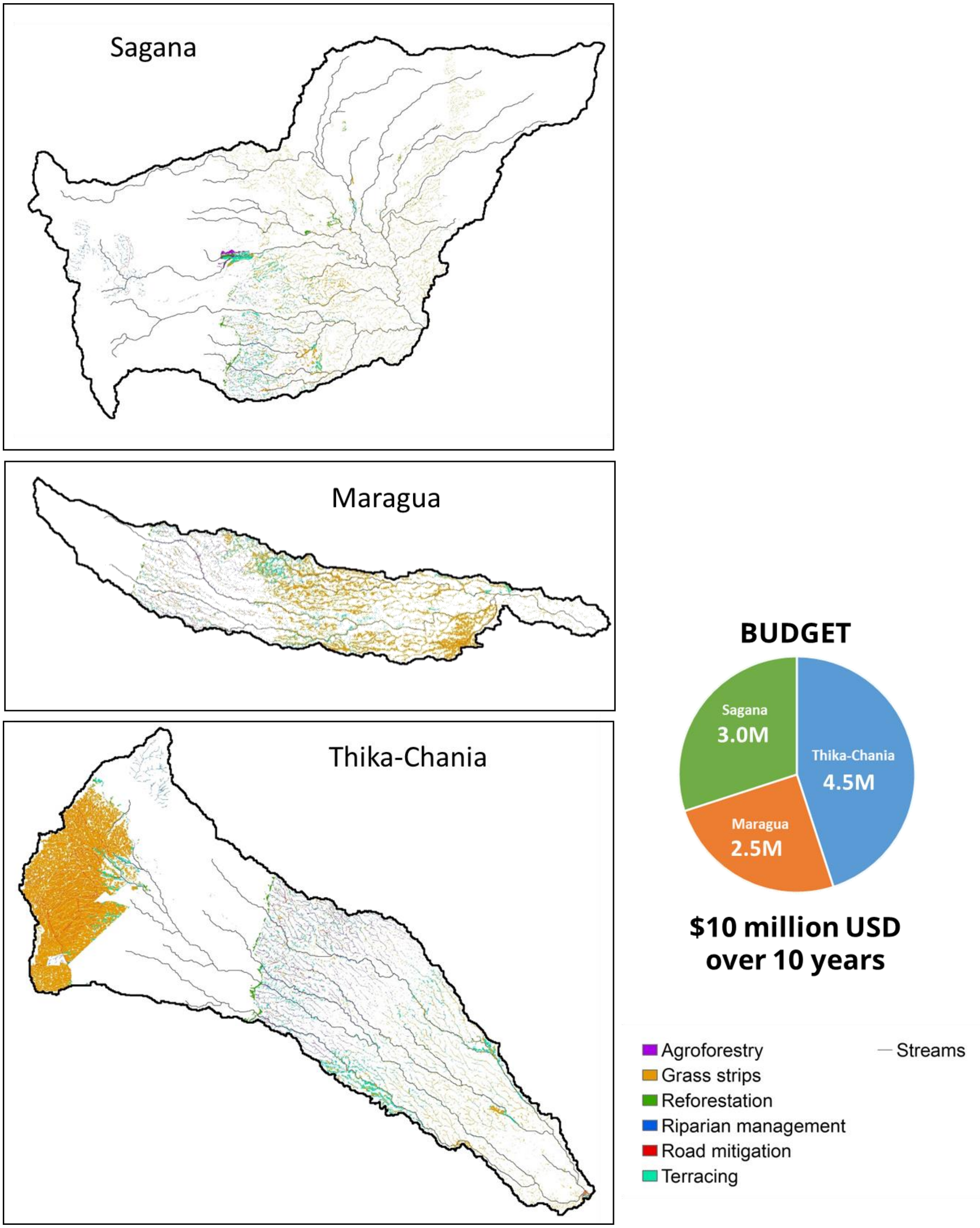

Figure 9. Investment portfolio for $10 million budget target across the three priority watersheds for the Upper Tana-Nairobi Water Fund.

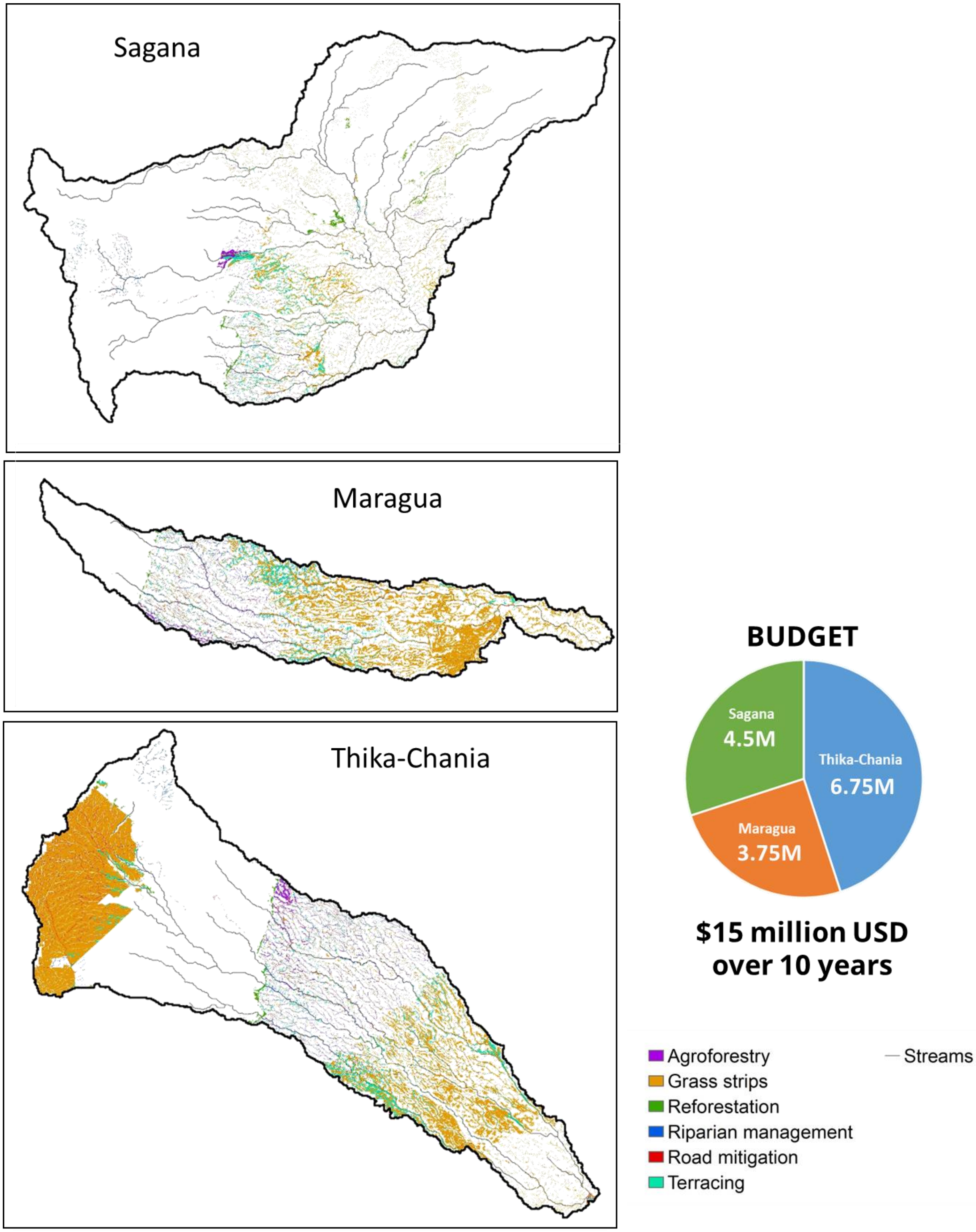

Figure 10. Investment portfolio for $15 million budget target across the three priority watersheds for the Upper Tana-Nairobi Water Fund.

RIOS combines information on physical characteristics of the landscape (land management, topography, soils, climate) with information about the places where benefits are needed (such as water extraction points) as well as where people are likely to benefit (census data). The resulting portfolios therefore highlight areas where there is the potential for the fund to have the greatest impact with their activities, integrating across various considerations like the current condition of each site, its slope, location relative to important water supply points, and the population density. For example, in the $10 million USD portfolio for Thika-Chania (Figure 11), a large portion of the area upstream of Sasuma Dam, currently under General Agriculture, is chosen for grass strips. This area is one that shows significantly high erosion potential in the baseline scenario, based on the SWAT model analysis (Hunink and Droogers, 2015). For this reason, and because of its location above a major water supply for NWSC's system, it is an area of high priority for the water fund to work. The slopes in this area are not particularly steep (<12%), which is why the model selected grass strips for much of the area, with terracing on a smaller portion of the land where slopes are >12%.

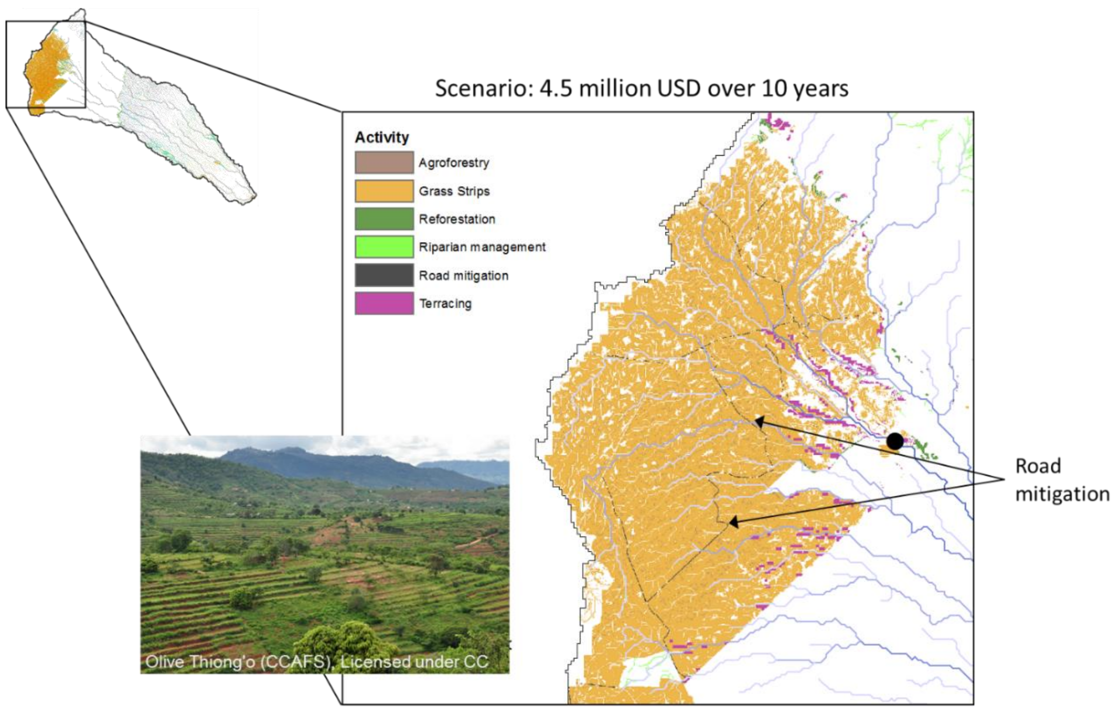

Figure 11. Detail of the western portion of the Thika-Chania watershed, for the $10 million USD total scenario ($4.5 million USD spent in Thika-Chania). This area is high priority for fund activities due to its high potential for erosion and location upstream of many of the major water supply intakes for Nairobi.

In addition, this portfolio includes a band of reforestation recommended along the inside border of the Kenya Forest Service protected area, to offset recent encroachment in that area (primarily by tea planting; see Figure 9). In the remainder of that portfolio, activities tend to be focused along riparian corridors, since buffers along streams can be a very effective way to retain sediment before it reaches waterways. Road mitigation is the most expensive activity so it is not widespread, but is focused on unpaved roads where there are high slopes and/or where there is a low potential for erosion from that segment of road to be retained before reaching the nearest waterway.

In the Maragua watershed, recommended activities are primarily terracing and grass strips in the coffee and other cropland areas downstream of the Kenya Forest Service lands. In this watershed, activities are more evenly spread throughout the area, and seem to be driven primarily by a potential for significant erosion on highly sloping agricultural lands throughout the watershed. The Maragua was previously identified as a significant source of sediment to the Tana River, so activities in the most critical erosion areas throughout this watershed will have benefits for reservoir operation downstream.

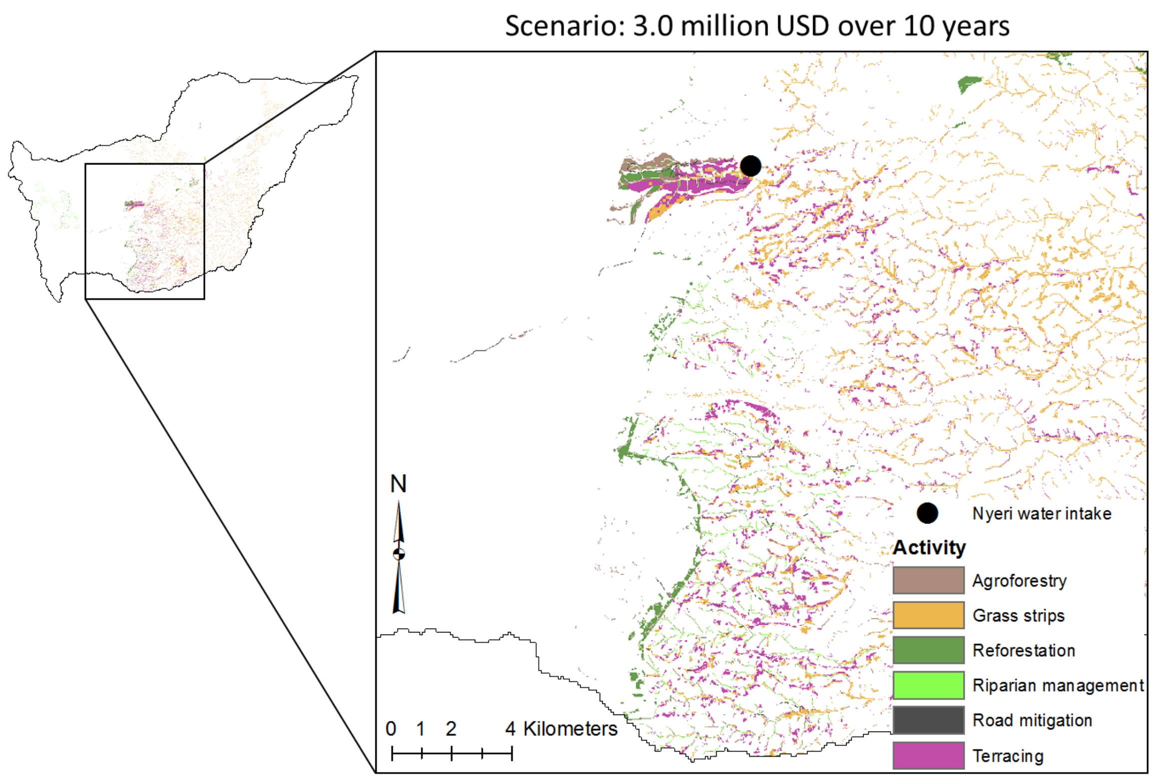

Figure 12. Detail of the central portion of the Sagana-Gura watershed, for the $10 million USD total scenario ($3 million USD spent in Sagana-Gura), showing the area with the highest concentration of activities.

In the Sagana-Gura watershed, there is a similar concentration of activities (mostly terracing, grass strips, and reforestation) above the water intake point for the town of Nyeri (Figure 12). This concentration of activities is due to the fact that by focusing their efforts on cleaning up sources of erosion upstream of this critical point, the water fund can benefit the populations of both Nyeri and Nairobi. Because of the high potential for benefits to both urban centers, the model chose this area for increased investment by the water fund. Other priority investment areas in the Sagana-Gura are due to a combination of high slopes, high potential to benefit populations in Nyeri and Nairobi, and other land management factors.

Table 4. Summary activity portfolios for the Sagana-Gura watershed at four different budget levels. Recommendations are summed by activity in terms of the total area in the portfolio (ha)* and the total cost for implementation of that activity (Ksh).

	RIPARIAN MANAGEMENT		AGROFORESTRY		TERRACING		REFORESTATION		GRASS STRIPS		ROAD MITIGATION	
Total budget (Ksh)	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**
63,863,898 ($750,000 USD)	108	10,643,724	108	10,643,724	355	10,643,400	108	10,643,724	887	10,649,610	25	10,639,632
127,727,796 ($1,500,000 USD)	215	21,287,448	215	21,287,448	710	21,287,475	215	21,287,448	1,775	21,298,680	50	21,279,263
255,455,591 ($3,000,000 USD)	431	42,574,896	431	42,574,896	1,419	42,575,625	431	42,574,896	3,549	42,587,100	100	42,568,086
383,183,387 ($4,500,000 USD)	646	63,862,344	646	63,862,344	2,129	63,863,775	646	63,862,344	5,323	63,875,520	150	63,856,909

* Represents the total area on which each activity is prioritized, in its recommended best practice form and spacing. For example, the total area of land on which grass strips are applied, not the total area of the grass strips themselves.

Table 5. Summary activity portfolios for the Maragua watershed at four different budget levels. Recommendations are summed by activity in terms of the total area in the portfolio (ha)* and the total cost for implementation of that activity (Ksh).

	RIPARIAN MANAGEMENT		AGROFORESTRY		TERRACING		REFORESTATION		GRASS STRIPS		ROAD MITIGATION	
Total budget (Ksh)	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**
53,219,915 ($625,000 USD)	90	8,869,770	90	8,869,770	296	8,869,500	48	4,783,896	1,080	12,965,130	21	8,861,580
106,439,830 ($1,250,000 USD)	180	17,739,540	180	17,739,540	591	17,739,675	48	4,759,443	2,561	30,728,700	42	17,732,719
212,879,660 ($2,500,000 USD)	359	35,479,080	359	35,479,080	1,183	35,479,350	48	4,706,091	5,522	66,260,970	84	35,474,998
319,319,489 ($3,750,000 USD)	539	53,218,620	539	53,218,620	1,774	53,219,700	47	4,597,164	8,487	101,848,050	125	53,217,277

* Represents the total area on which each activity is prioritized, in its recommended best practice form and spacing. For example, the total area of land on which grass strips are applied, not the total area of the grass strips themselves.

Table 6. Summary activity portfolios for the Thika-Chania watersheds at four different budget levels. Recommendations are summed by activity in terms of the total area in the portfolio (ha)* and the total cost for implementation of that activity (Ksh).

	RIPARIAN MANAGEMENT		AGROFORESTRY		TERRACING		REFORESTATION		GRASS STRIPS		ROAD MITIGATION	
Total budget (Ksh)	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**	**Area (ha)**	**Total Cost (Ksh)**
95,795,847 ($1,125,000 USD)	162	15,965,586	162	15,965,586	532	15,965,100	134	13,249,080	1,557	18,685,890	38	15,964,227
207,557,668 ($2,250,000 USD)	323	31,931,172	323	31,931,172	1,012	30,353,400	192	18,984,420	3,872	46,464,570	113	47,892,682
383,183,387 ($4,500,000 USD)	610	60,276,645	646	63,862,344	1,544	46,319,175	187	18,462,015	10,867	130,405,950	150	63,856,909
574,775,081 ($6,750,000 USD)	769	76,006,593	1,197	118,285,830	2,076	62,284,950	183	18,104,112	17,026	204,307,650	225	95,785,363

* Represents the total area on which each activity is prioritized, in its recommended best practice form and spacing. For example, the total area of land on which grass strips are applied, not the total area of the grass strips themselves.

As mentioned above, a high priority for early implementation in the Water Fund is to invest in activities that will benefit the water supply for the city of Nairobi. Therefore half of the budget for the Thika-Chania watershed at each budget level was allocated to be spent in the sub-watersheds upstream of the major water supply intake points, as shown in Figure 13. The remainder of the budget was allocated throughout the entire Thika-Chania watershed based on the cost-effectiveness of activities in different locations.

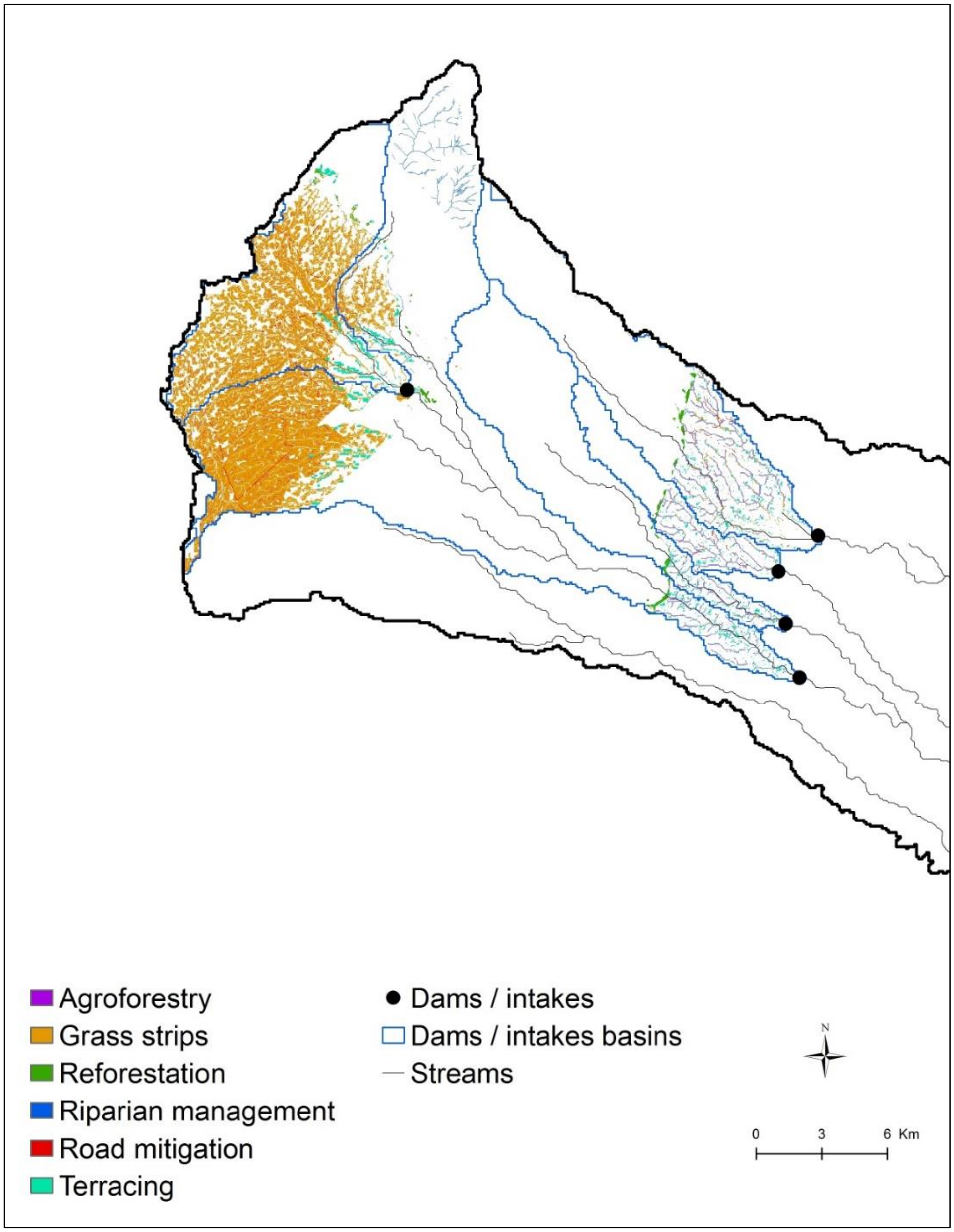

Figure 13. Map showing the upper part of the Thika-Chania watershed, highlighting the priority areas for initial activity implementation in the $10 million USD scenario. Implementation of the activities shown in this area are expected to have the greatest direct impact on the baseflow and water quality to the intake points that provide water to NWSC.

Tables 7 through 9 below summarize the recommended activities by land use type for the $10 million USD scenario. In all three watersheds, the majority of water fund activities are on coffee and general agriculture areas, followed by other kinds of croplands (tea, agroforestry) and bare soil. Implementing water fund activities (primarily terracing and grass strips) in agricultural areas can have significant improvements in erosion and sedimentation in streams, but can also lead to additional long-term benefits for landowners in terms of improved soil fertility and greater average yields (as discussed in the Business Case report; Apse *et al.*, 2015).

Table 7. Summary of total area (ha) recommended for activities by land cover type in the Sagana-Gura watershed. These values are from the $10 million USD scenario, in which $3 million USD are allocated to the Sagana-Gura.

SAGANA-GURA	Riparian management	Agro-forestry	Terracing	Re-forestation	Grass strips	Road mitigation	TOTAL (ha)
Bare soil	1	0.8	62	-	52	-	**116**
Grass	0.1	17	-	91	-	-	**108**
Shrub	0.1	-	-	23	-	-	**24**
General agriculture	19	50	675	99	2,043	-	**2,886**
Tea	165	291	-	169	-	-	**626**
Coffee	9	55	266	20	1,008	-	**1,358**
Forest	227	-	-	-	-	-	**227**
Forest plantation	0.1	-	-	-	-	-	**0.1**
Corn	10	16	229	28	332	-	**616**
Unpaved road	-	-	-	-	-	100	**100**
Agroforestry	-	-	187	-	114	-	**301**
TOTAL (ha)	**431**	**431**	**1,419**	**431**	**3,549**	**100**	

Table 8. Summary of total area (ha) recommended for activities by land cover type in the Maragua watershed. These values are from the $10 million USD scenario, in which $2.5 million USD are allocated to the Maragua.

MARAGUA	Riparian management	Agro-forestry	Terracing	Re-forestation	Grass strips	Road mitigation	TOTAL (ha)
Bare soil	5	0.5	405	-	210	-	**620**
Grass	0.4	0.7	-	-	-	-	**1**
Shrub	-	-	-	8	-	-	**8**
General agriculture	31	16	181	0.3	1,846	-	**2,075**
Tea	247	300	-	40	-	-	**586**
Coffee	75	42	410	-	2,980	-	**3,507**
Forest	0.4	-	-	-	-	-	**0.4**
Evergreen forest	0.7	-	-	-	-	-	**0.7**
Orchard	-	-	2	-	49	-	**51**
Unpaved road	-	-	-	-	-	83	**83**
Agroforestry	-	-	184	-	437	-	**621**
TOTAL (ha)	**359**	**359**	**1,183**	**48**	**5,522**	**83**	

Table 9. Summary of total area (ha) recommended for activities by land cover type in the Thika-Chania watersheds. These values are from the $10 million USD scenario, in which $4.5 million USD are allocated to the Thika-Chania.

THIKA-CHANIA	Riparian management	Agro-forestry	Terracing	Re-forestation	Grass strips	Road mitigation	TOTAL (ha)
Bare soil	3	0.1	123	-	478	-	**603**
Grass	0.6	8	-	1	-	-	**9**
Shrub	2	-	-	38	-	-	**40**
General agriculture	23	203	338	31	8,360	-	**8,955**
Tea	404	414	-	117	-	-	**934**
Coffee	68	22	657	-	849	-	**1,597**
Forest	59	-	-	-	-	-	**59**
Evergreen forest	38	-	-	-	-	-	**38**
Forest plantation	12	-	-	-	-	-	**12**
Pineapple	-	-	0.1	-	0.4	-	**0.5**
Unpaved road	-	-	-	-	-	150	**150**
Agroforestry	-	-	426	-	1,180	-	**1,606**
TOTAL (ha)	**610**	**646**	**1,544**	**187**	**10,867**	**150**	

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