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The Impact of Commercial Horticulture on River Water Resources in the Upper Ewaso Ng'iro River Basin, Kenya

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Mount Kenya serves as a natural water tower in the savanna-dominated Upper Ewaso Ng'iro River Basin in the Kenyan highlands. Major water users in the upper reaches of the river include medium- and large-scale commercial horticulture farms that produce flowers and vegetables for export using perennial irrigation schemes. These farms first appeared in the region in 1991 and gradually became powerful stakeholders that compete with small-scale farmers and urban centers over seasonally scarce water, increasing the potential for conflict. A comprehensive survey of commercial horticulture farms in the study area, including expert interviews with managers, enabled detailed analysis of the sector's development and its impact on local river water resources. Calculation of the horticulture sector's dry season water use revealed an increase from zero liters per second (L/s) in 1991 to 357 L/s in 2003 and 663 L/s in 2013, far exceeding minimum river flows. Despite this absolute increase in total water use, reliance on river water has decreased by roughly 30% since 2003, with a dramatic absolute increase in the use of alternative sources such as water stored in dams and groundwater. At the same time, the share of river water used varies greatly between specific rivers (2.2–32.5%), depending on the local availability of alternative water sources. Overall, to mitigate water conflicts, long-term monitoring and local stakeholder engagement must accompany practices and policies of efficiency.

Keywords: *Horticulture; water; labor; sustainability; Laikipia; Kenya; East Africa.*

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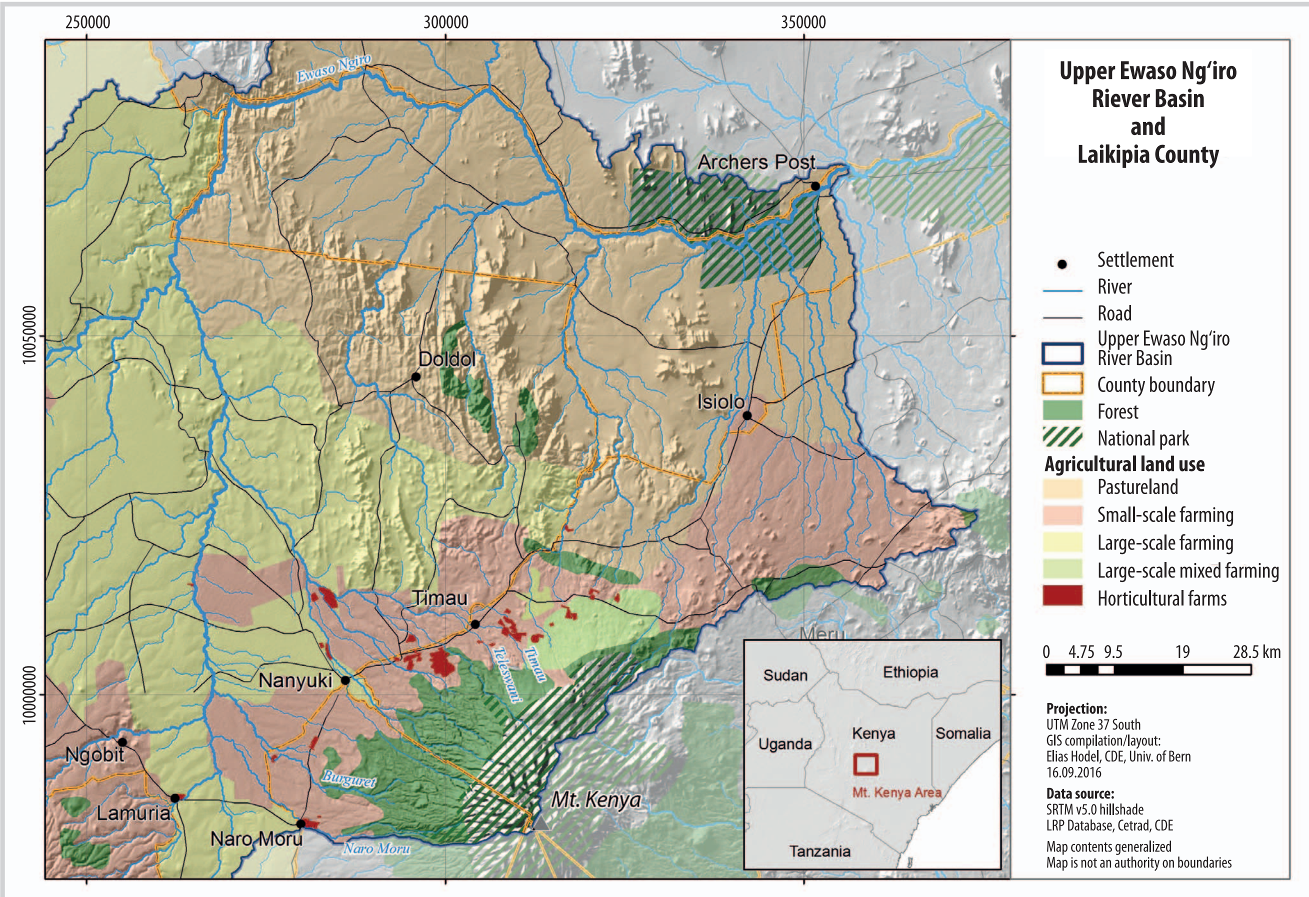
Introduction

Since the global food and financial crises of 2007–2008, the world has seen a substantial upsurge in agricultural investments and large-scale commercial agriculture schemes by private companies and institutions (Deininger and Byerlee 2012). Africa remains the most-targeted continent (Anseeuw et al 2012). These large-scale land acquisitions (LSLAs) often result in major shifts in the governance of land and related natural resources such as water (Woodhouse 2012; Breu et al 2016).

The debate on LSLAs is effectively split along contrasting visions of development (Dell'Angelo, D'Odorico, and Rulli 2017). Supporters of LSLAs argue that acquisitions help to develop neglected agricultural sectors by countering the failure to maximize the potential and productivity of small-scale farming (FAO, IFAD, UNCTAD, WB 2010; Deininger and Byerlee 2011; Collier and Dercon 2014). Critics, in contrast, argue that the shifts frequently harm the environment, local livelihoods, food security, and human rights of local populations and refer to the acquisitions as "land grabs" and challenge narratives of investors targeting land that is "idle" or "unused" with legitimate concerns about speculative activities (De Schutter 2011; Borras et al 2012; Messerli et al 2014; Dell'Angelo, D'Odorico, Rulli, et al 2017). It is this more critical research that has investigated how access to water may be a key driver of LSLAs (Woodhouse 2012; D'Odorico et al 2017; Dell'Angelo et al 2018). Land and water acquisition are inseparably linked, especially in the case of agricultural activities. Thus, this hydrological dimension of LSLAs is crucial in fueling debates about the respective merits of large-scale versus small-scale farms in achieving development goals.

FIGURE 1 Land use including commercial horticulture in the Upper Ewaso North River Basin, 2013. (Data source: this survey, Shuttle Radar Topography Mission v5.0 Hillshade, Laikipai Research Project Database, Centre for Training and Research in Arid and Semi-arid Lands Development (CETRAD) and Centre for Development and Environment (CDE). (Map by Elias Hodel)

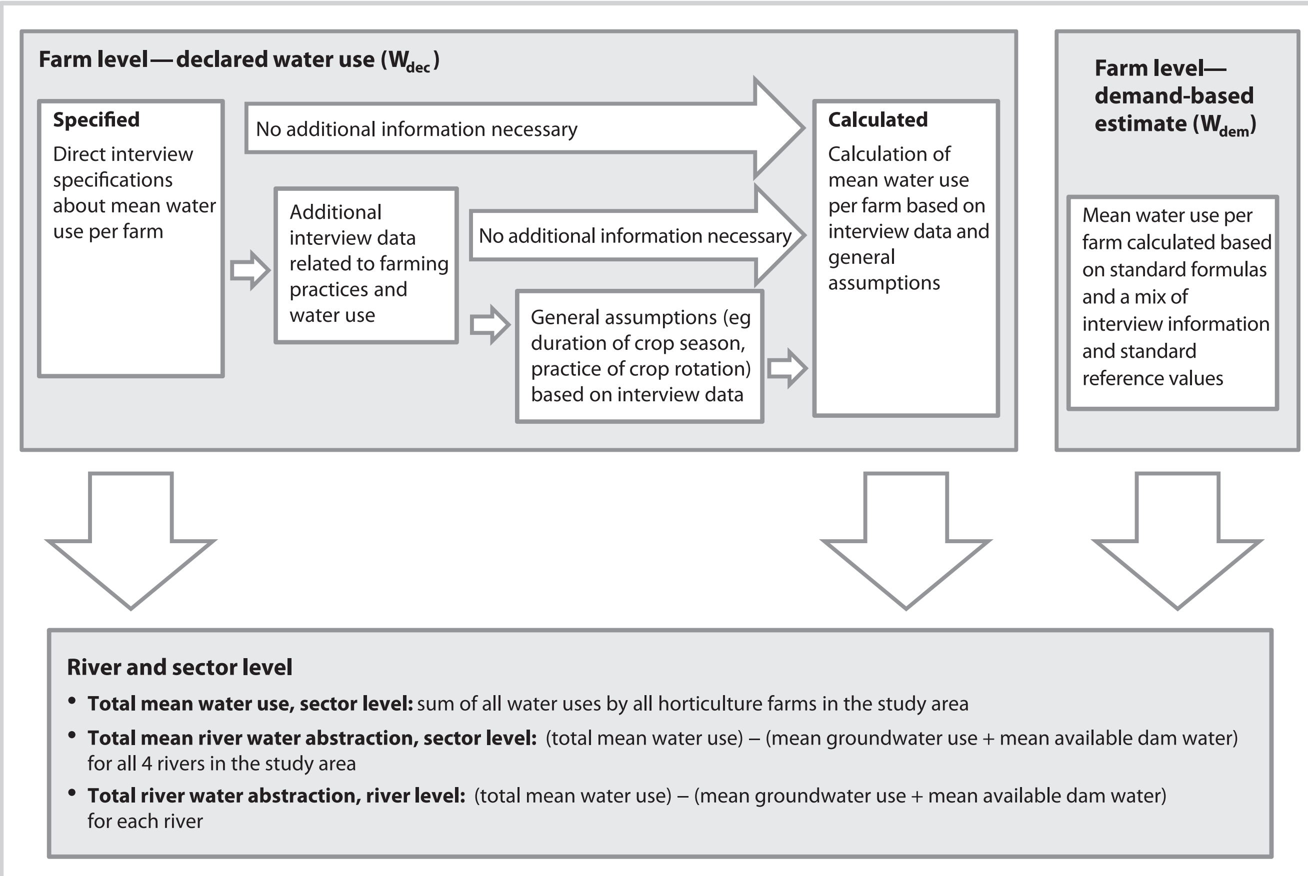


In Kenya, large-scale agricultural investments are widespread; in particular, the horticulture sector has rapidly emerged as the second-largest foreign-exchange earner after tea (Lanari et al 2016). The Upper Ewaso Ng'iro River Basin, situated on the Laikipia Plateau and the northwestern slopes of Mt. Kenya, offers ideal growing conditions for horticulture. We argue that commercial horticulture farms in this area are important and powerful actors with vested interests in negotiations over use of river water. Their role in Kenya's water governance regime has been under-researched, with most work focusing on either small-scale farmers or households (see, for example, Dell'Angelo et al 2016; Gower et al 2016; McCord, Dell'Angelo, Gower, et al 2017). The Upper Ewaso Ng'iro River Basin is a fruitful area for study because it exemplifies the types of socioenvironmental competition and conflict that may arise between small- and large-scale rural systems when resources, such as water, become scarce.

The study area (Figure 1) is characterized by an upland–lowland gradient with distinct environmental and socioecological features. The northwestern slopes of Mt. Kenya in the Upper Ewaso Ng'iro River Basin have a humid climate that progresses to semiarid on the Laikipia Plateau and arid in the northern lowlands (McCord et al 2015). During colonial times, the lower slopes of the mountain were dominated by large ranches; but since independence in 1963, the area has experienced a rapid influx of agropastoral smallholders (Kiteme et al 2008). This has led to considerable agricultural intensification, massive land use change (from extensive ranching to small-scale mixed farming), and population growth. Population in Laikipia County tripled in 30 years, from 134,524 in 1979 to 399,227 in 2009 (KNBS 1981, 2010). Some of the larger farms from the colonial era have remained in operation; beginning in the 1990s, many were transformed into highly mechanized, export-oriented commercial horticulture enterprises. This further intensified use of local land and water, mainly for exports (Wiesmann et al 2000).

As a result of these developments, there has been an increase in the aggregate demand for freshwater from both large- and small-scale agriculture, which has led to the gradual depletion of the Ewaso Ng'iro River and its tributaries within the Upper Ewaso Ng'iro River Basin (Gichuki 2002; Wiesmann et al 2000; Notter et al 2007). With upstream users abstracting 60–95% of available

FIGURE 2 Procedure for estimating mean dry season water use at the farm, sector, and river levels.



water depending on season and year (Wiesmann et al 2000), this is particularly problematic for the lower semiarid and arid reaches of the system, where the river and its tributaries increasingly run dry (UNEP 2014: 258–259). Coupled with a decrease in rainfall frequency, these developments have exacerbated issues of equity in water resources distribution. Kenya adopted a participatory and polycentric river basin governance system with its 2002 Water Act that has shown success in mitigating and reducing conflicts between different water users (Baldwin et al 2016; McCord, Dell'Angelo, Baldwin, et al 2017). However, perceived inequality continues to pose a considerable threat to effective water governance (Dell'Angelo et al 2016). Within that context, commercial agriculture is a large, highly visible water user that is often blamed first by smaller water users when water becomes scarce during the dry season.

Material and methods

Data collection

The data described here were collected in 2 surveys, between February and April 2003 and between September and October 2013, via expert interviews with owners and managers of commercial horticulture farms. In 2003, the survey comprised 23 interviews with commercial horticulturists representing 24 medium or large companies (and operating on 28 farms); in 2013, 28 interviews were conducted with representatives of 30 companies operating on 35 farms. Only commercial horticulture farms of at least 5 hectares (ha) were interviewed to exclude small-scale farmers. Horticulture refers to the cultivation of fruit, flowers, and vegetables.

To assess the impact of the commercial horticulture sector in the study area on the various tributaries in the Upper Ewaso Ng'iro River Basin, it was necessary to calculate the mean dry season water use of each horticulture farm. Calculations were done only for the dry season—in particular for the driest month, February—because this is when heavy water use is most likely to trigger conflicts between stakeholders. Water use was calculated in 2 ways: as demand-based estimates and based on declared water use. These methods are described below and summarized in Figure 2.

Calculation of demand-based estimates

Demand-based estimates use standard estimates of water demand based on climatic conditions, cropping area, crop type, and the cropping calendar. This procedure was adapted from the Kenyan Ministry of Water Development (MoWD 1986) and the Food and Agriculture Organization (FAO 1977). While the original equation combined on-farm water demand for different water uses, including livestock and human consumption, we adapted it as follows to focus on irrigation water:

$$W_{dem}\left[m^3/s\right] = DW_I/(1-x) \tag{1a}$$

in which W_{dem} stands for the total water demand for irrigation during the dry season, x is the percentage of nonirrigation water use on farm, and DW_I stands for daily water demand for irrigation. DW_I is in turn calculated as follows:

$$DW_I\left[\mathrm{m}^3/\mathrm{s}\right] = (A \times 10{,}000 \times ET_O \times Kc \times [1/\mathfrak{y}])/(24 \times 60 \times 60) \tag{1b}$$

in which A = dry season area under cultivation (ha), ET_O = reference potential evapotranspiration = 0.005 m/d, Kc = crop factor (refers to influence of crop type on crop water needs) = 0.8, and $\mathfrak{y}$ = irrigation efficiency = 70%. The original equation assumed a crop factor of 0.8 and an irrigation efficiency of 70%, which were adopted for this study because these values were not indicated by interviewees. Percentage of nonirrigation water use on farm was specified by some interviewees; when it was not specified, the sector's median of 5% was used for the calculation.

Calculation of declared water use

Declared water use (W_{dec}) was calculated based on information provided in the surveys with horticulture companies. Four commercial farms specified their total dry season water use as well as the share of water taken from different water sources (river, dam water, or groundwater) in such a way that the indicated values could be used directly in our calculations. For farms for which precise estimates were not provided (possibly because this is seen as sensitive information), values were estimated based on other information obtained in the interviews. For example, some farms indicated daily dry season water use per hectare but also let us know the total area under cultivation, which made it possible to calculate a farm-level total. The results of calculations made in this way must be considered approximations.

In addition to river water, most commercial horticulture farms have access to other water sources—such as groundwater or water stored in on-farm dams (dam water)—that enable them to bridge the dry months. Thus, to calculate a farm's dry season river water use, it was necessary to subtract the water used from other sources from the farm's total water use. Ideally, respondents broke down their total water use by source, as shown here:

$$\begin{aligned}&\text{Declared Dry Season River Water Use}\\&\quad + \text{Declared Dry Season Groundwater Use}\\&\quad + \text{Declared Dry Season Dam Water Use}\\&\quad = \text{Declared Total Dry Season Water Use}\end{aligned} \tag{2}$$

The total declared dry season water use seldom matched the declared use of different water sources taken together. For those discrepancies, we used the larger of the 2 values in our calculations. In other words, if the declared total use was less than the sum of the declared uses from different sources, the declared total was increased accordingly; and if the declared total use was larger than the sum of the declared uses from different sources, the latter values were increased accordingly.

Equation 2 was then modified to reflect the assumption that available storage water would cover the gap in total water used, since at least 10 out of the 35 farms had large dams to store abundant water:

$$\begin{aligned}&\text{Declared Dry Season River Water Use}\\&\quad + \text{Declared Dry Season Groundwater Use}\\&\quad + \text{Declared Dry Season Dam Water Use}\\&\quad + \text{Further Dam Water Availability}\\&\quad = \text{Declared Total Dry Season Water Use}\end{aligned} \tag{3}$$

For farms where dam water was unavailable or insufficient to cover the gap in the declared total water use, river water was assumed to cover the missing amount. Groundwater was excluded as a possible source of additional water because the total amount pumped is fixed by the pumping hours and the borehole pumping capacity per hour, which interviewees indicated separately in the survey. There was some uncertainty regarding the indicated pumping hours, which could have been under- or overestimated by interviewees; there was no way to verify their statements. For these farms, the following equation was used:

$$\begin{aligned}&\text{Declared Dry Season River Water Use}\\&\quad + \text{Declared Dry Season Groundwater Use}\\&\quad + \text{Declared Dry Season Dam Water Use}\\&\quad + \text{Further Dam Water Availability}\\&\quad + \text{Undeclared Dry Season River Water Use}\\&\quad = \text{Declared Total Dry Season Water Use}\end{aligned} \tag{4}$$

Reformulation of Equation (4), in turn, enabled calculation of the total water abstracted by horticulture farms from rivers during the dry season, whether declared or undeclared:

$$\begin{aligned}&\text{Declared Dry Season River Water Use}\\&\quad + \text{Undeclared Dry Season River Water Use}\\&\quad = \text{Total Dry Season Water Use}\\&\qquad - \text{Declared Dry Season Groundwater Use}\\&\qquad - \text{Declared Dry Season Dam Water Use}\\&\qquad - \text{Further Dam Water Availability}\end{aligned} \tag{5}$$

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TABLE 1 Inventory of commercial horticulture farms located in the study area, 2003 and 2013.[a]

	2003	2013
Number of vegetable[b] farms	21	18
Number of flower farms	3	16
Number of mixed farms (vegetables[b] and flowers)	4	1
Total area under cultivation (ha)	1085	1385
Area under flower cultivation (ha)	54	434
Area under vegetables[b] (ha)	1031	951
Mean annual number of employees	5934	11,631

[a] Source: survey data.
[b] This category also includes herbs and fruit.

As W_{dem} indicates only the total amount of water used for irrigation, the same procedure as for W_{dec} (above) was used to calculate the shares of the different water sources. As for W_{dec}, this relied heavily on the information obtained from the interviewees and must thus be considered an approximation.

W_{dec} and W_{dem} were calculated individually for each commercial horticulture farm. In general, the W_{dec} procedure resulted in lower values of river water use than the W_{dem} procedure. There are 2 possible explanations for this difference: (1) the dry season water use per farm and hectare could be higher than indicated by interviewees, and the effective capacity or duration of available storage water could be smaller; or (2) the W_{dem} procedure may generally overestimate water quantities, as suggested by Aeschbacher et al (2005). Overall, we can assume that the W_{dem} values represent the upper range of dry season water use and the W_{dec} values the lower range.

Aggregation of farm-level data

Once calculated, the farm-level data were aggregated at 2 levels:

1. *Sector level:* all commercial horticulture farms in the study area
2. *River level:* all commercial horticulture farms abstracting water from a specific river.

Comparison with river flow

Finally, the river-level data were compared with data on each river's median flows for the month of February in 4 different decades: 1961–1970, 1981–1990, 1993–2002, and 2003–2008 or 2012. (For 2 out of the 4 analyzed rivers, Timau and Teleswani, river flow data were available only until 2008 because of theft and vandalism affecting the gauging stations.) Comparison of the decadal data enabled the assessment of commercial horticulture's possible role in declining dry season flows of the Upper Ewaso Ng'iro River over the last 50 years. The data from 1961 to 1970 are considered to represent natural river flows with little human impact; data from 1981 to 1990 represent conditions in which small-scale farmers moved in and began abstracting river water but commercial horticulture was still absent (Decurtins 1992); data from 1993 to 2002 represent the conditions analyzed in the first (2003) survey used for this study, when commercial horticulture began and rapidly grew; and data from 2003 to 2008/2012 represent the most recent conditions, in which horticulture and related irrigation activities continued to develop, but at a slower pace than in the previous decade.

Results and discussion

Agricultural and socioeconomic trends

The commercial horticulture sector in the study area has grown substantially since the first farm was opened in 1991. By 2003, the total area under horticulture had grown to 1085 ha, with most farms cultivating vegetable crops, mainly beans and peas, for export. Growth continued but slowed in the next decade, adding 300 ha (27%) to bring the total area under horticulture to 1385 ha in 2013. The number of farms increased by 25% in the same decade, from 28 farms (operated by 24 companies) to 35 farms (operated by 30 companies). This growth was accompanied by structural changes, most significantly a shift away from vegetable production in favor of floriculture, with a particular emphasis on roses beginning in the early 2000s (Table 1).

The shift to floriculture has had many consequences for the whole sector, including the following:

- Flower production is much less subject to seasonal (European) demand than vegetable production.
- Flowers are exclusively irrigated by means of drip irrigation, which is a highly efficient water use (at least 80% efficiency).
- Farm sizes are smaller. Flowers generate higher returns than vegetables, enabling farmers to operate on fewer hectares while earning more. Though the number of farms in the study area has increased, the average area under cultivation per farm has remained the same—roughly 39 ha—suggesting intensification of production.
- The role of outgrowers has decreased since flower farms do not contract them. Outgrowers are contract farming schemes; they were crucial in the establishing phase of commercial vegetable farming. Exporting businesses and farms would contract local farmers to ensure their supply of agricultural products. Their number decreased from 13 to 7 between 2003 and 2013.
- Production has reoriented toward new consumer markets. In 2003, most goods were exported to the UK (still the top export market for vegetables as of 2013). More recently, the Netherlands has become a crucial export market, because flowers are mainly sold through

auctions, facilitated by international players such as Royal FloraHolland, a cooperative agent and auctioneer.

- With vegetable horticulture in decline, the only way to remain profitable in producing vegetables has been to go large and add value. The average size of the remaining vegetable farms in the study area has increased from 42 ha in 2003 to 54 ha in 2013.
- Another new development has been the emergence of commercial herb production for export. In 2013, there were 3 farms that exclusively produced herbs.

In terms of labor, the shift toward floriculture has led to a doubling of the mean annual number of employees from 2003 to 2013. On average, flower farms employ 15–19 people per hectare, while vegetable and herb farms employ 4–5 people per hectare. Employees on both types of farms are overwhelmingly local. Floriculture also features a steady production rate throughout the year, resulting in higher rates of permanent employment. Vegetable exporters often contract existing small-scale farmers as outgrowers, mainly for beans and peas. In the past, this enabled more local small-scale farmers to earn added cash income and to obtain better access to markets. By paying wages, the horticulture sector has significantly contributed to economic development in the area and helped to secure livelihoods, especially among small-scale farmers (Ulrich 2014).

Overall, the horticulture sector makes a major economic contribution to the study area, as recent employment and salary figures show. In 2013 the horticulture sector employed 11,631 people in the study area (up from 5934 in 2003) and paid approximately 3,582,348 Kenyan shillings (roughly US$ 41,447; XE 2016) per day in salaries. It is by far the most important employer in the rural areas in terms of number of employees and total salary disbursement. This regional cash influx generates economic multiplier effects, such as the appearance of new retail businesses close to farm gates, as well as new transportation services, especially *matatus*, local taxis, and minibuses (Bonner 2006). At the same time, while the growing availability of off-farm work increases rural households' cash income, it can also increase the burden of work for the family members who remain behind to manage the family farm (Ulrich 2014). This feeds into the larger discussion about how LSLAs, by turning farmers into employees, may contribute to food insecurity and to the erosion of rural livelihoods (D'Odorico et al 2017).

Water sources and quantities used

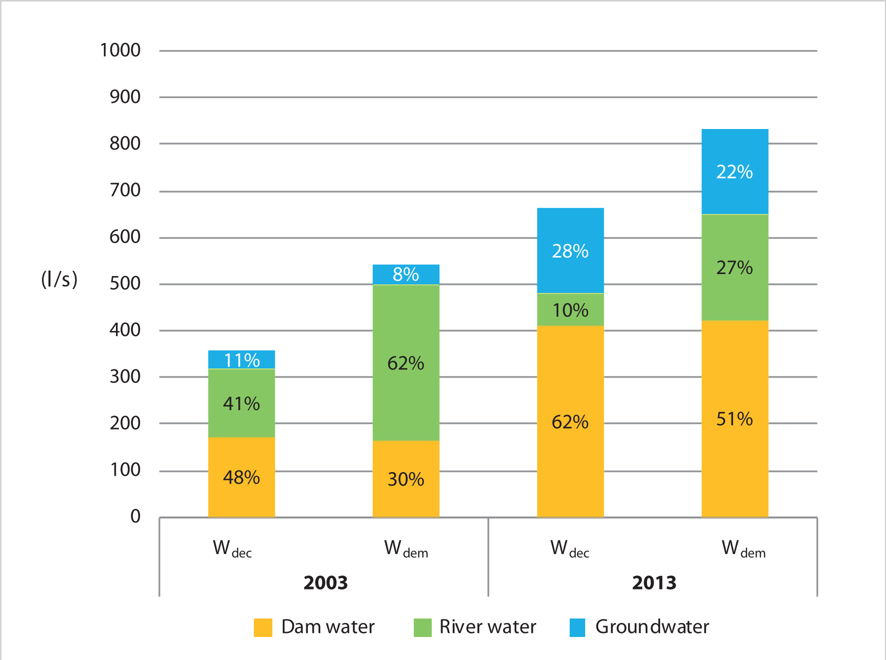
The commercial horticulture sector in the study area is characterized by year-round irrigated crop production for export markets. Although there is an increasing focus on flower production, vegetable horticulture remains important, with crops destined for European markets subject to great seasonality. Demand for vegetables is highest during the European winter, which coincides with the dry season in the study area; this creates higher demand for water when it is most scarce. While the seasonality of production has decreased recently because of the shift to floriculture, with water requirements becoming more constant throughout the year, the horticulture sector's overall demand for irrigation water has increased since 2003. Especially during times of low water availability, this pattern of high and steady water demand raises important questions about where commercial horticulture farms obtain their water—whether from rivers, captured rainwater, or groundwater—and what quantities they use during the dry season.

Our calculations indicate that, for the horticulture sector as a whole in the study area, estimated dry season water use between 2003 and 2013 increased by as much as 85% (from 357 to 663 L/s, based on W_{dec}) but at least 53% (from 544 to 833 L/s, based on W_{dem}) (Figure 3). This increase is consistent with the sector's productive growth. Similarly, the estimated average dry season water use per farm ha increased from 12.8 L/s (W_{dec}) or 19.4 L/s (W_{dem}) in 2003 to 20.1 L/s (W_{dec}) or 23.8 L/s (W_{dem}) in 2013. This is due to the increasing size of the remaining vegetable farms and to the general intensification of production resulting from the shift to floriculture. On most vegetable farms, the effective cultivated area varies significantly throughout the year, depending on market demand and crop rotation. On flower farms, by contrast, the area under cultivation remains unchanged throughout the year, as perennial flower crops enable continuous cultivation of the same area.

Although the horticulture sector's total (absolute) water use has increased, its dependence on river water has decreased, both as a share of all water sources and in absolute terms. For example, as shown in Figure 3, the share of river water use has decreased by 31–35%. At the same time, the shares of dam water and groundwater use have increased by 14–21% and 14–17%, respectively. In sum, even though horticulture's dry season water use has grown overall, its use of river water has diminished—in absolute terms and as a percentage—in favor of dam water and groundwater.

The decreased use of river water for dry season irrigation is also clearly visible in Table 2, which shows the number of farms relying on different water sources or combinations thereof. The availability of dam water has particularly strongly increased. Storage dams may be filled either by rainwater harvested from greenhouse rooftops, which is often the case on flower farms, or by floodwater during the rainy season. In both cases, interviewees indicated that surface evaporation is a major challenge. Table 2 also illustrates the increased use of groundwater for irrigation, which may be problematic in the long term if it remains unmonitored and without an impact assessment.

FIGURE 3 Dry season (February) water use by commercial horticulture in the study area, 2003 and 2013.



Declining dry season river flows

Two key findings emerged from analyses of commercial horticulture's possible impact on the declining median February flows of 4 rivers—Naro Moru, Burguret, Teleswani, and Timau (Figure 1)—in the decades 1981–1990 (before commercial horticulture started in the study area) and 2003–2008/2012 (when the sector was established but still growing).

TABLE 2 Water sources used by commercial horticulture farms in the study area, 2003 and 2013.[a)]

	Number of farms in 2003	Number of farms in 2013
Water source		
Rivers only	8	4
Groundwater only	1	7
Dam water only	0	2
Rivers and groundwater	2	2
Rivers and dam water	13	7
Dam water and groundwater	1	6
Rivers, dam water, and groundwater	3	4
No data	0	3
Total number of farms	28	35

[a)] Source: survey data.

First, the likely impact of commercial horticulture on declining median February flows varied greatly from river to river. In absolute terms, river water abstraction for commercial horticulture ranged from 1.7 L/s (Timau River, W_{dec}) to 27.1 L/s (Naro Moru River, W_{dem}) in 2013, while the relative contribution of the sector to declining median February flows ranged from 2.2% (Timau River, W_{dec}) to 32.5% (Naro Moru River, W_{dem}), as seen in Table 3. The 4 rivers vary greatly in the area under horticulture and number of farms drawing water. The most important factors determining the impact of commercial horticulture on rivers, however, are the availability and size of water storage facilities and (to a lesser extent) access to groundwater. Without access to dam water or groundwater, horticulture's growing demand for dry season irrigation water would place heavy pressure on the rivers (Figure 4).

The second key finding is that median February flows had already started to decline in 3 of the 4 rivers prior to the establishment of commercial horticulture. As seen in Table 3 and Figure 4, river abstractions by commercial horticulture farms have likely contributed less to the depletion of these rivers than initially assumed. Hence, other factors must also be contributing to the declining levels of river water in recent decades. These factors include abstractions by other water users—including small-scale farmers (Aeschbacher et al 2005; Liniger et al 2005; Dell'Angelo et al 2016)—as well as (to a lesser extent) growing urban settlements. The past 30 years have seen a slight increase in rainfall (Schmocker et al 2016), while glacier melt from Mt. Kenya makes only a minor

TABLE 3 Dry season (February) river water abstractions by commercial horticulture farms and river water flows in the study area.[a]

	Naro Moru River[b]	Burguret River[b]	Teleswani River[c]	Timau River[c]
Farms				
Number	2	3	4	2
Area under cultivation	91 ha	75 ha	131 ha	193 ha
Median February river flow				
1981–1990	407 L/s	346 L/s	180 L/s	116 L/s
2003–2008/12	324 L/s	150 L/s	83 L/s	37 L/s
Farm water abstractions and declines in median February river flow				
Decline in median flow[d]	83 L/s (20.5%)	196 L/s (56.6%)	97 L/s (53.7%)	79 L/s (68.6%)
Farms' estimated water abstraction[e]				
W_{dec}	2.6 L/s	9.9 L/s	6.2 L/s	1.7 L/s
W_{dem}	27.1 L/s	23.9 L/s	19 L/s	4.3 L/s
Farms' contribution to river flow decline				
W_{dec}	3.08%	5.03%	6.41%	2.18%
W_{dem}	32.49%	12.21%	19.65%	5.38%

[a]Data sources: this survey; Natural Resource Management (NRM3)/Centre for Training and Research in Arid and Semi-arid Lands Development (CETRAD) database.
[b]Discharge data are available for 2003–2012.
[c]Discharge data are available only for 2003–2008.
[d]Data from 1981–1990 to 2003–2008 or 2003–2012, depending on the river.
[e]Data from 2013.

contribution to river flows in the study area (Decurtins 1992). It is also possible that increased use of groundwater has contributed to lower median February river flows; this is a question that urgently needs further research.

Water conflicts and mitigation efforts

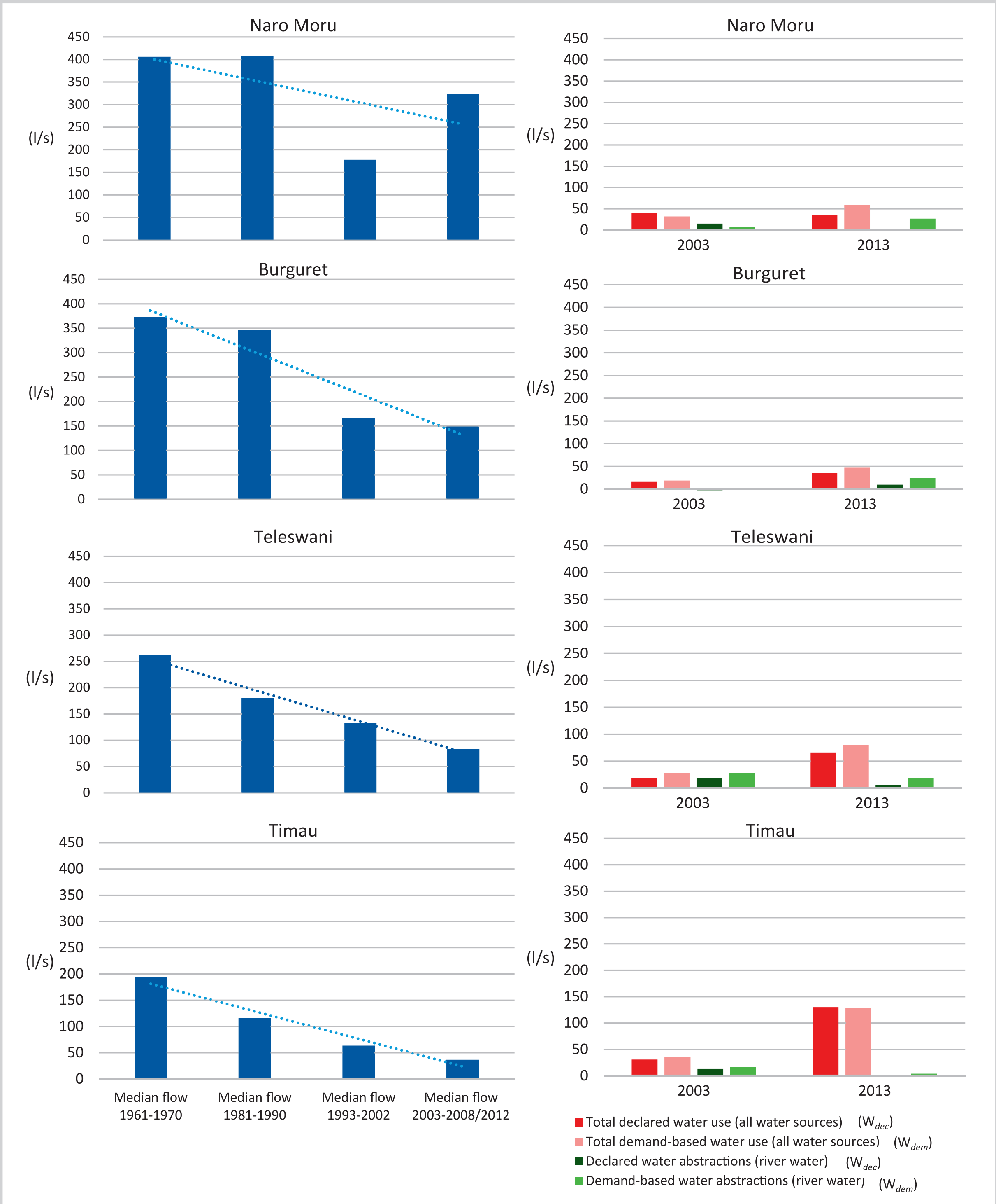
The commercial horticulture sector is well aware of the risks of conflict over water resources in the study area. The highly visible large-scale farms are often blamed for declining river flows by other water users due to perceived inequality in water allocation (Dell'Angelo et al 2016). Various conflict-mitigating strategies have helped considerably to reduce the potential for conflict. One crucial strategy has been the establishment of water resource user associations along the rivers, which manage and allocate river water. All the interviewed commercial horticulture farms in the study area participate in the associations. This finding is in line with previous research on water reform in Kenya (Baldwin et al 2016).

Horticulture farms' diversification of water sources has been an important measure to save river water for other users in the critical dry season and thus to prevent conflict. Moreover, interviewed horticulturalists described how captured floodwater or harvested rainwater grants them exclusive use and crucial independence from river water supplies, particularly during the dry season. The captured excess water is stored in plastic-lined ponds dug into the ground (Studer and Liniger 2013). Access to groundwater has a similar conflict-mitigation effect, although the impact of excessive drilling of boreholes on groundwater supplies and river replenishment remains unknown and may have its own negative consequences. Most horticulture farms have access to dam water, boreholes, or some combination (Table 2), meaning that these key conflict-mitigating strategies are implemented reasonably well.

Synthesis and conclusion

Africa is the most-targeted continent for LSLAs. Although LSLAs are not necessarily a new phenomenon in the Kenyan highlands, the commercial horticulture sector in the study area has grown tremendously in the past 2 decades. It has done so in a context increasingly dominated by small-scale farmers, and as such, Mt. Kenya has reemerged as a prime example of the socioenvironmental competition and conflict between small-scale and large-scale agricultural production systems. The commercial horticulture sector has a strong socioeconomic influence on the surrounding communities, especially by providing jobs. Many small-scale farmers have been complementing their livelihoods

FIGURE 4 Declining trend of dry season (February) median river flows 1961–2012 (left) and water use 2003 and 2013 (right). (Data sources: this survey, Natural Resource Management (NRM3)/Centre for Training and Research in Arid and Semi-arid Lands Development database)



with income from off-farm employment, thus reducing their vulnerability to erratic and insufficient rainfall. The local infusion of capital has produced economic multiplier effects, in addition to the broader benefits of foreign direct investment and foreign exchange earnings generated by exports. At the same time, there are some concerns that this has led to an erosion of rural livelihoods by turning small scale-farmers into employees, raising questions about contrasting visions of development (D'Odorico et al 2017).

Production of agricultural commodities for export markets under perennial irrigation schemes has direct hydrological implications for the Mt. Kenya region (see also Dell'Angelo et al 2018). The tension between large- and small-scale farms is often exacerbated when natural resources, especially water, grow scarce. When river levels noticeably decline, commercial farms are often blamed first for overexploiting water resources, highlighting the importance of addressing (perceived) inequality in water use and allocation (Dell'Angelo et al 2016). In response to such concerns, the commercial horticulture sector in the study area has implemented various measures to lessen pressure on rivers during the dry season, to stay viable, and to mitigate conflict. Above all, horticulture farms have sought to diversify their water sources. This has included the addition of water storage dams on farms, collection of rainwater from greenhouse rooftops, and sourcing of groundwater. Many farms have also introduced efficient, semicomputerized drip irrigation systems that greatly minimize water loss. Implementing these solutions further helps them secure an independent water supply and ensures their economic sustainability. It also gradually removes them from the hydropolitical line of fire, in combination with their active membership in water resource user associations, where potential conflicts may be mitigated or even reduced (Baldwin et al 2016).

Nevertheless, other reasons for concern remain. In particular, the growing use of groundwater might not be a sustainable long-term way for commercial farms to secure water and mitigate water-related conflicts. The interactions between the various aquifers and river replenishment remain unknown, and excessive use of groundwater could have devastating consequences in the long term. Further studies in this area are urgently needed. It is important to maintain continuous, long-term monitoring of river water levels, water abstractions, and irrigation practices as well as to invest in research and observation of groundwater levels. The monitoring of water availability and use as well as the identification of critical thresholds of overuse are key to improved water and land management, and ultimately to maintaining local peace. To prevent or reduce water-related conflicts, the combination of technological fixes, increased efficiency, and active involvement of all interested stakeholders in water user associations has proven its value in the past. It has the potential to be scaled up in the study area and in Kenya as a whole, with potential application in other water-scarce areas throughout East Africa.

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