# River Water Shortage in a Highland–Lowland System

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## A Case Study of the Impacts of Water Abstraction in the Mount Kenya Region





*In the past decade, water shortage on the western and northern slopes of Mount Kenya and particularly in the adjoining lowland areas has reached a severity not experienced before. Rapid population growth and rising demand for irrigation are increasing the pressure on water resources, as can be demonstrated by an inventory of water abstractions from the Naro Moru River. A total of 98 abstraction points were documented within a river section of only 30 km, providing water to about 30,000 people. However, about 97% of the abstracted water is used for irrigation of 9% of the total catchment area. In 2002, about 30% of the annual discharge and 80 to 100% of the low flow discharge of the Naro Moru River was abstracted by furrows, gravity pipes, and pumps.*

*The highland–lowland system of the Upper Ewaso Ng'iro Basin, with Mount Kenya functioning as a crucial water tower, has reached and repeatedly exceeded the limits of water availability in the past decade. In contrast to the heavily decreasing low flow discharge, the mean discharge does not show any decreasing tendency. This is due to higher flood flows, which may be induced by accelerated runoff generation due to land use change. The present study seeks to support Water Users' Associations (WUAs, ie self-help initiatives aiming to mitigate conflicts over the allocation of water) by providing them with up-to-date information about demand, supply and use of river water, as well as tools and methods for improving water management.*

***Keywords:*** *Highland–lowland system; water tower; water shortage; water abstraction; water management; irrigation; small-scale farming; Mount Kenya.*

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### Introduction

The Upper Ewaso Ng'iro Basin—an area of about 15,200 km$^2$ stretching from Mount Kenya (5199 m) in the south to the plains of northern Kenya—has experienced a highly dynamic socioeconomic development over the past 100 years. The traditional pastoralists were superseded by white colonists at the beginning of the 20th century. After Kenya gained independence in 1963, the "White Highlands" became an open frontier for African immigration and settlement. Intensive small-scale irrigation farming, unadapted cultivation methods and crops, as well as the rapidly growing number of inhabitants have since been increasing the pressure on natural resources in general, and on water resources in particular. Furthermore, throughout the 1990s most of the remaining large-scale farms in the foothills of Mount Kenya were transformed into highly technical, export-oriented horticultural enterprises. As a result of these dramatic land use changes, over the past decade the perennial rivers have reached and already repeatedly exceeded their water supply limits during the low flow period (Liniger 1995; Ojany and Wiesmann 1998; Wiesmann et al 2000).

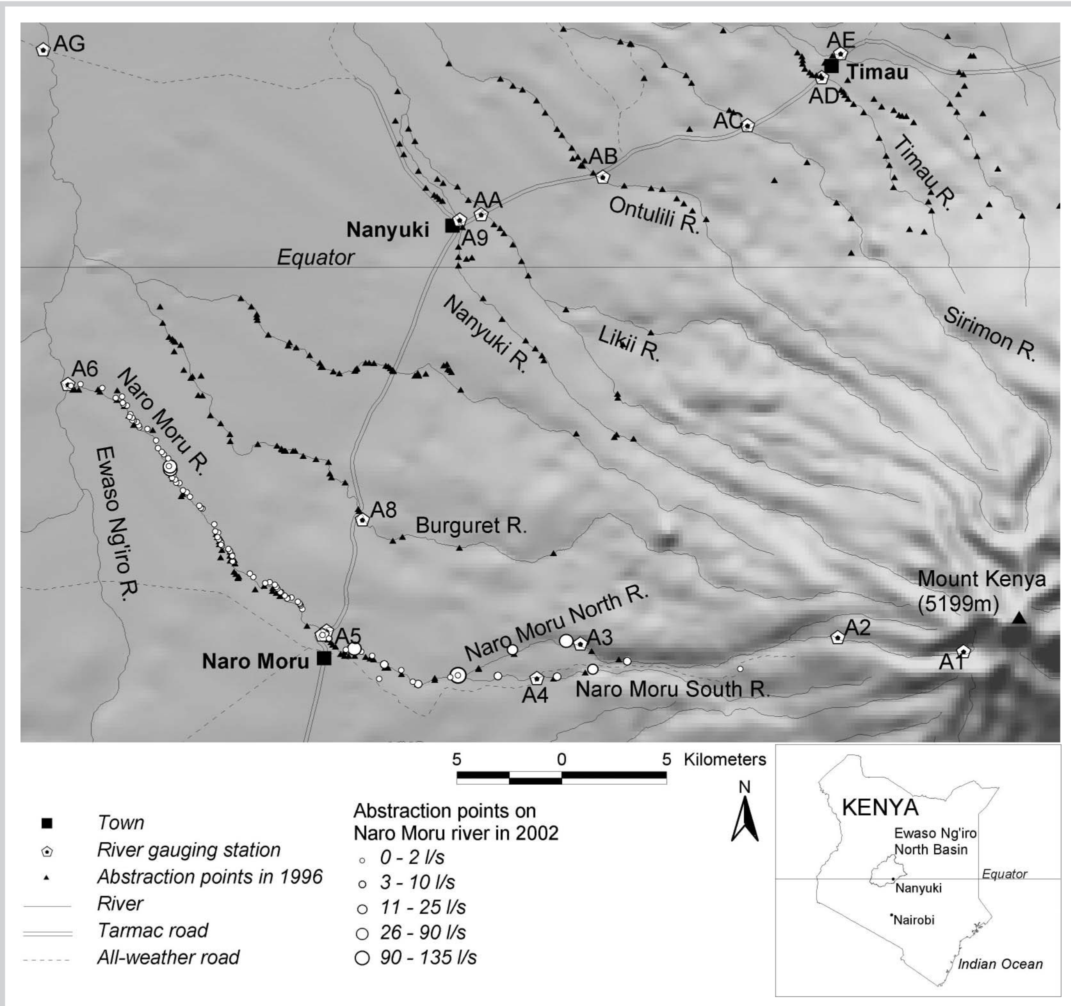
The Upper Ewaso Ng'iro Basin is a typical highland–lowland system, exhibiting to a high degree all the characteristics of such systems: great ecological diversity, steep vertical gradients, dominance of gravity-controlled processes, and a great sensitivity to human intervention. Mount Kenya serves as a natural water tower for its semiarid and arid surroundings (Liniger et al 1998; Viviroli et al 2003). However, the allocation of the available water resources is a key problem in the region and has repeatedly led to open conflicts between upstream and downstream users. In neighboring catchments, eg Burguret, Nanyuki and Likii, Water Users' Associations (WUAs) have been successfully introduced and now have an important role in terms of allocating water resources and mitigating conflicts between different stakeholders (Kiteme and Gikonyo 2002; Liniger et al 2005, in this issue). The Naro Moru WUA however—although established in 2003—is currently too weak to significantly influence present developments in the catchment.

This study documents the increasing pressure on water resources, providing data—among others—on water demand, abstraction amounts, and measured and natural river discharge (≅ discharge without water abstractions). Moreover, the study introduces methodologies and tools developed to support WUAs (Aeschbacher 2003).

### Study area

The Naro Moru River is the southernmost tributary to the Upper Ewaso Ng'iro River, which drains the northern and western slopes of Mount Kenya, the northern Aberdares, and the Laikipia plains (Figure 1). Despite its large size (173 km$^2$), the Naro Moru catchment accounts for only 1.1% of the Upper Ewaso Ng'iro Basin; it can nevertheless be taken as a representative example reflecting all the typical strains and challenges of this region, such as a wide variety of different stakeholders with different interests, highland–lowland interdependence, unequally distributed natural resources, unreliable rainfall patterns and quantities, decreasing river discharge during low flow periods, conflicts

**FIGURE 1** Map of the Ewaso Ng'iro catchment and tributaries from the northwestern slopes of Mount Kenya, showing abstraction points and volume in the Naro Moru catchment. (GIS compilation and layout by Gudrun Schwilch and Jos Aeschbacher, data source: Topographic Maps 1:250,000, Government of Kenya, and NRM[3] Database)




between upstream and downstream users, and a political vacuum due to its remoteness.

Over its length of only about 57 km, the Naro Moru River flows through a variety of landscapes and ecological systems: from its spring situated in the alpine zone, just below the nival top of Mount Kenya, it passes through the wet moorlands above the timberline, a belt of tropical rainforest, and the semi-humid footzone, before it finally merges with the Ewaso Ng'iro River on the semiarid Laikipia High Plateau (1800 m asl). Below the forest line, the water deficit due to low precipitation has to be compensated by river water (Ojany and Wiesmann 1998). Up to the early 1990s, the Naro Moru played its role reliably as a perennial water source, but in the past decade it has repeatedly run dry over extended periods.

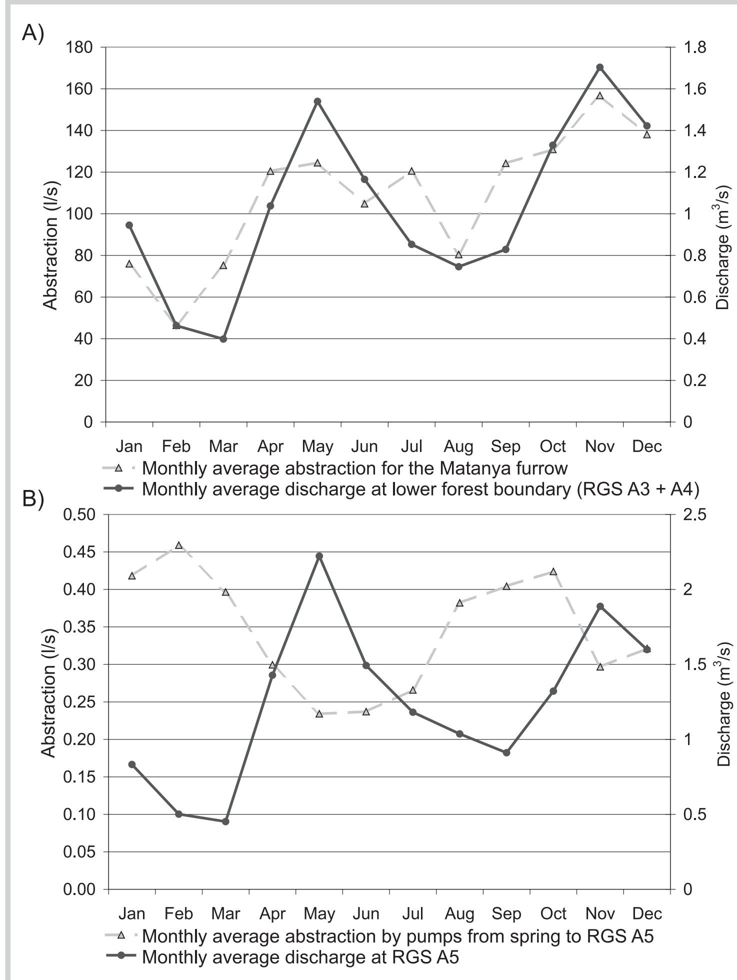
The Naro Moru is the best-documented river in the Upper Ewaso Ng'iro Basin, with a hydrometeorological monitoring network consisting of 7 river gauging stations (RGS), 8 rain gauges, and 4 evaporation pans (Decurtins 1992). The management and processing of the physical data monitoring network of the whole Upper Ewaso Ng'iro Basin is in the hands of the Natural Resource Monitoring, Modelling and Management (NRM[3]) project, which emerged from the Kenyan–Swiss Laikipia Research Programme (LRP) (Ojany and Wiesmann 1998).

## Data and methodology

The water shortage in the Naro Moru catchment is mainly due to increasing water abstraction activities. The quantification and temporal development of abstraction amounts is, therefore, of major interest in this investigation. This information, in combination with river discharge monitoring, is needed to supply WUAs with data on the actual availability of water.

The present study is based on data from rainfall gauging, river discharge measurement, and river water abstraction monitoring. While discharge is automatically gauged, and rainfall gauging data are collected daily at various forest stations, schools and private farms, the

**FIGURE 2** Correlation between river discharge and abstraction at different river gauging stations (RGS, A3-A5) using (a) furrow abstraction and (b) pump abstraction. While furrow abstraction is similar to discharge, pump abstraction is inversely proportional to river discharge.




collection of abstraction data, by contrast, is much more complex and time-consuming. The objective of an abstraction documentation campaign is to gather detailed information about all abstraction systems operated along a river, including data on:

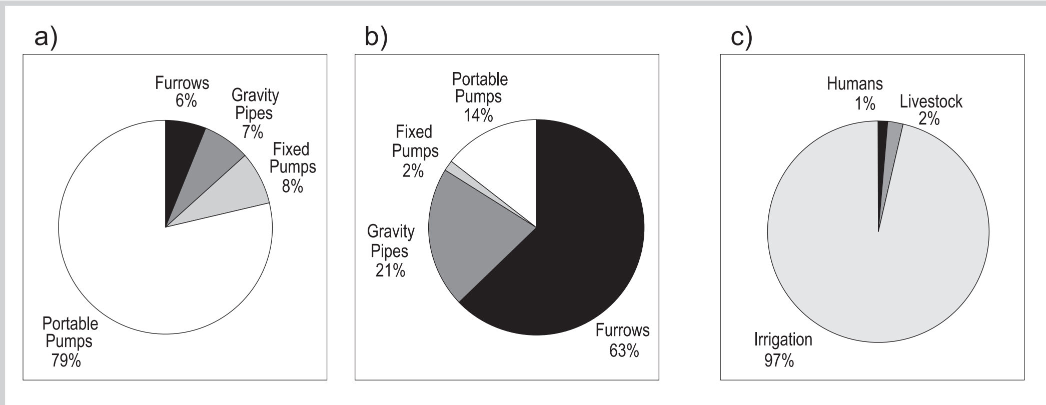
- Georeference and ownership;
- Principal water uses;
- Legal status of abstraction;
- Type of abstraction;
- Irrigation and diversion methods;
- Area under irrigation;
- Quantity of abstracted water; and
- Water quality.

Three abstraction documentation campaigns were previously carried out in the Naro Moru catchment, each with a completely different set-up: a snapshot campaign in 1983 without information about abstraction quantities; a campaign with continuous gauging of the furrows in 1991; and a detailed monitoring of all abstractions in 1994–1997. The campaign for the present study, finally, was carried out in 2002.

Abstraction points can be classified into 3 categories according to the abstraction system used. A thorough analysis of the monitoring data collected from 1994 to 1997 yielded a set of typical abstraction characteristics for each of these categories:

- *Furrows:* A concrete weir diverts the river water into a furrow dug into the earth to channel the water to its destination over a distance of several kilometers. Furrows generally abstract as much water as possible from the river; nevertheless, this is hardly ever sufficient to satisfy the demand of all project members. The main limiting factors are river discharge and, less important, the maximum transport capacity of the furrows during flood flows. Furrow abstraction quantity linearly depends on river discharge: eg the Matanya furrow shows a correlation coefficient of 0.83 and a stability index of 0.69 (a=5%). The abstraction quantity of each furrow can be extrapolated using the corresponding equation based on monthly averaged river discharge (Figure 2a).
- *Gravity pipes:* A concrete weir diverts the river water into an iron or PVC pipe of 15–30 cm in diameter and 2–7 km in length. The abstracted water is usually stored in tanks with a volume of up to 225 $m^3$; from there, it is distributed through smaller pipes to the participating households. Two limiting factors have a negative impact on the efficiency of gravity pipes: one is the limited transport capacity of the pipe system, which depends on diameter, slope, and frictional resistance. Secondly, storage tanks are too small to store surplus water from the rainy seasons for use during the dry seasons. Abstraction amounts for gravity pipes remained on a relatively constant level between 1994 and 1997. Therefore we assumed that they abstract a continuous amount near their maximum capacity throughout the year.
- *Pumps:* They are either fixed or portable and run with petrol, diesel, or kerosene. River water is normally pumped from the river directly onto the adjacent cropland for irrigation purposes. The primary limiting factor for abstraction through pumps is the relatively high cost of diesel or petrol; pumps are only operated when rainwater fails to meet the needs of the crops, which occurs mainly during the dry seasons. Comparison of river discharge—which is basically dependent on rainfall—with abstraction amounts for pump systems could support this statement, showing a correlation coefficient of –0.78 and a stability index of 0.60 on a level of significance of 95%, thus indicating a reciprocal proportionality (Figure 2b). Based on the values of 1994 to 1997, an

**FIGURE 3** Abstraction systems along the Naro Moru River according to (a): number of abstraction points and (b) quantity of water abstracted, for the year 2002. The purposes of abstraction are shown in (c), in percent of total abstraction amount.




average monthly proportion of the maximum abstraction quantity was calculated for further use in the extrapolation tool.

Based on these extrapolation methods and assumptions, a tool consisting of an MS Access module, AbstrCalcTool, was developed to automate the calculation of daily abstraction quantities. AbstrCalcTool extrapolated the information about abstraction quantities gathered during the 2002 campaign back to the year 1985 on a daily basis. Additionally, it was used to estimate the daily discharge above each abstraction point (Aeschbacher 2003).

## Results

The 2002 Naro Moru abstraction documentation campaign was carried out from 29 July to 16 August. A total of 98 abstraction points were documented along the Naro Moru River. The abstracted water serves to irrigate a total area of about 15 km$^2$, which amounts to about 9% of the total catchment area. The Naro Moru catchment has approximately 30,000 inhabitants (NRM[3] 2003), most of them living in Naro Moru Town or in settlements situated near the river. The livestock population is estimated at 30,000–35,000.

### Types of abstraction system

Gravity pipes generally dominate in the upper part of the catchment, using the relatively high slope gradients. Installation of such systems is only worthwhile if the gradient is high enough. By contrast, furrows can only be used in flatter areas: an all too rapid flow would eventually destroy the furrow by eroding its bed and banks. Furrows are therefore found in the middle and lower parts of the catchment. Throughout the catchment, a majority of the abstraction points are operated with portable pumps. During the 2002 campaign, a total of 71 pumps were recorded along the stretch between the tarmac road and the confluence of the Naro Moru with the Ewaso Ng'iro (about 22 km).

Although portable pumps are very numerous and account for 79% of all abstraction points (Figure 3a), they play a minor role with regard to the amount of water abstracted: indeed, all pumps together account for only 16% of the abstracted water (Figure 3b), while furrows (63%) and, to a lesser degree, gravity pipes (21%) consume disproportionally high amounts of water compared to their number (Figures 3a and b). This is primarily due to the size of the respective projects: Furrows and gravity pipes usually belong to settlement schemes or cooperative societies with up to 5000 project members, whereas portable pumps normally serve a single plot with a few acres of cropland and one household.

Another important indicator when assessing water management is the purpose of abstraction. 97% of the total abstracted water was used for irrigation purposes, while domestic use, which includes water supply for about 30,000 people, accounted for only 1% (Figure 3c). Although this quantity is proportionally low, downstream users could not meet their domestic water needs during drought times in the past few years because the river had dried up further upstream. If the total abstraction amount of irrigation water were reduced by 1%, the amount of water available for domestic use would almost double.

### Abstraction quantity

The average total abstraction quantity for the year 2002 amounts to 504 l/s (furrows: 318 l/s; gravity pipes: 106 l/s; pumps: 80 l/s) with a daily maximum of 899 l/s (14 May) and a minimum of 187 l/s (28 September).

The Naro Moru catchment experienced heavy immigration as early as the 1970s, unlike the adjacent catchment to the north. This is why the total abstraction quantity has been relatively high ever since the early 1980s (Decurtins 1992). While the abstraction quantity continued to increase slightly but steadily over the last 20 years, the actual demand for water increased heavily, indicating that the pressure on remaining water

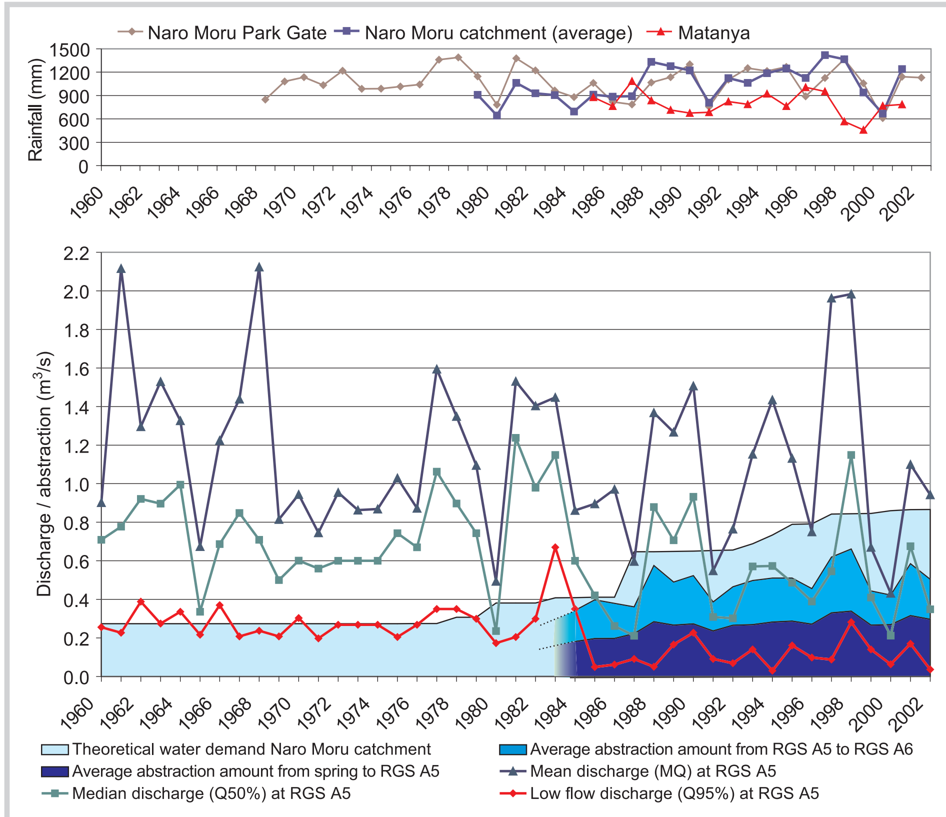



**FIGURE 4** Variations in annual rainfall and discharge according to different parameters (MQ = mean discharge, Q50% = median discharge, Q95% = low flow discharge) in comparison with water demand and modeled abstraction amounts (1985–2002) since the beginning of river discharge gauging in 1960.

**TABLE 1** Total amount of river water abstracted in the Naro Moru catchment during different seasons, compared to amount and percentage of this water abstracted legally.

| Naro Moru catchment (2002) | Flood flow (May/Nov) | Normal flow (Jan/Mar/Apr/Jun/Oct/Dec) | Low flow (Feb/Jul/Aug/Sep) |
|---|---|---|---|
| Average total abstraction (l/s) | 804.2 | 513.3 | 337.8 |
| Permitted abstraction amount (l/s) | 163 | 14 | 14 |
| Permitted abstraction as percentage of total amount | 20.3 | 2.7 | 4.1 |

resources has still been growing. Figure 4 reveals a striking fact: the total abstraction quantity for the entire basin shows a significant correlation with the river discharge (correlation coefficient of 0.91, $R^2$=0.83, a=5%) while abstraction points in the upper part of the catchment (above the tarmac road) are not significantly dependent on river flow (correlation coefficient of 0.63, $R^2$=0.40, a>5%).

## Legal status of abstraction points

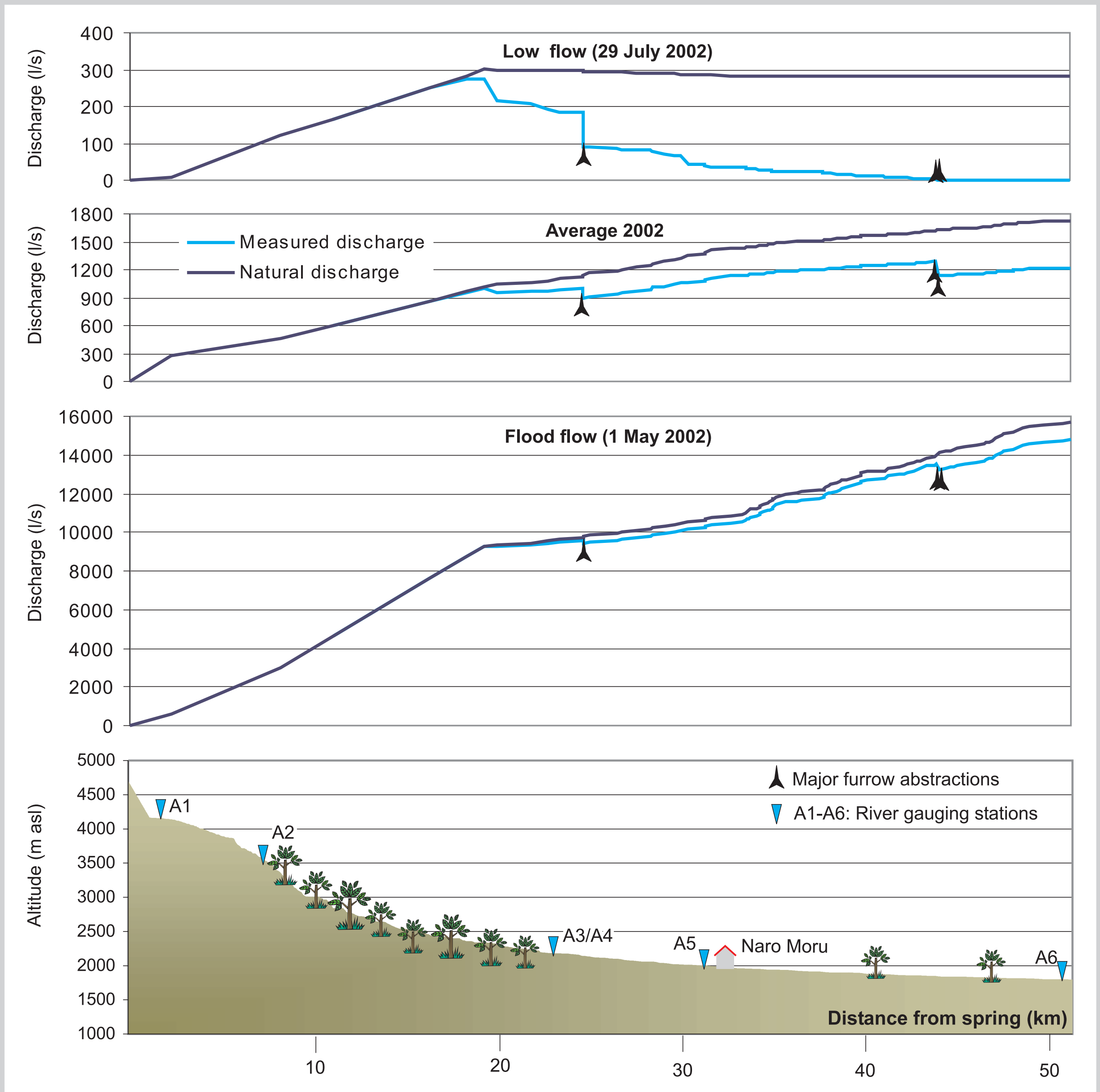
Although most of the water is abstracted through furrows and gravity pipes with a legal permit and registration number at the Ministry of Water (MOW), de facto less than 20% of the total abstraction quantity is abstracted in a legal manner, as the abstraction limits set in the permits are exceeded several times, in particular during the low flow season. One has to assume that, of the total amount of water abstracted in the Naro Moru catchment, around 80% is abstracted without permission during flood flow, and up to as much as 98% during low flow (Table 1).

## Natural river discharge

Natural river discharge is the discharge that would theoretically be available in the absence of any human impact on the river. It provides continuous information about the naturally available water resources in the catchment and represents a critical threshold, the exceeding of which implies that domestic needs can no longer be entirely satisfied. Figure 5 illustrates natural and measured river discharge in 3 different water supply situations: flood flow (bottom), average discharges for the year 2002 (middle), and low flow (top) with the river drying up almost 10 km upstream of the confluence with the Ewaso Ng'iro.

As illustrated in Figure 4 and Table 2, the annual mean discharge (MQ) at river gauging station A5 shows a very high variability due to the climatic pattern of this

**FIGURE 5** Profile of the Naro Moru River: comparison between natural and measured discharge under different circumstances. While the abstraction amounts—the area between the two curves—play only a minor role during the flood flow season, their impact is all the more significant during the low flow seasons, when the river dries up long before reaching the confluence with the Ewaso Ng'iro River. The 3 major furrows abstract up to 75% of the total abstraction amount.




region. In contrast, the long-term average seems to be more or less stagnant between 1.12 $m^3/s$ (1985–2002) and 1.18 $m^3/s$ (1960–1984). The median discharge (Q50%, ie the flow available on 50% of the days per year) and particularly the low flow discharge (Q95%) have, however, significantly decreased in the meantime.

## Discussion

The characteristics of a highland–lowland system (Wiesmann et al 2000) now have a quantitative back-up for the meso-scale Naro Moru catchment. The water shortage is increasing exponentially throughout the lower parts of the catchment. While upstream users abstract an almost constant amount from the river, downstream users can only satisfy their needs during periods and years of water abundance, a fact reflected in the close dependency of downstream abstractions on river discharge (Figure 4).

A rather exciting outcome of this study is the fact that, despite the increasing amounts of water abstracted, the mean discharge does not show any decreasing tendency. As rainfall data do not reveal a trend, the reason for this unexpected interrelation must be looked for within changes in runoff formation. Notter (2003) assessed the impact of land use change on streamflow by applying a rainfall–runoff model in the Naro Moru catchment, and found out that small-scale farming has an increasing influence on the average river discharge due to higher flood flows: if the savannah and footzone were to be completely converted into small-scale farming areas, the increase would total +16%. This aspect is also supported by the fact that median discharge is significantly decreasing while mean discharge remains stagnant (Table 2). In other words, the flow is generally lower; however, this is compensated by higher flood flows.

The decrease in low flow discharge—the actual critical factor for the continuous supply of water—is even more significant. Apparently, the slight increase in the average quantity abstracted over the last 15 years has induced a disproportionally high impact on low flows. The reason for this interdependence is believed to be the heavily increasing number of portable pumps in the same time period. In contrast to furrow abstractions and gravity pipes, portable pumps can abstract water even from a very low water level or from ponds. Furthermore, they are used mainly during the dry periods and thus exert enormous additional pressure on water resources, even though they only abstract an average total of 80 l/s.

Over the past decade, the total abstraction quantity has most probably reached its limits. During the field campaign, several abandoned fields were observed in the lowest part of the catchment, while new fields with abstraction systems were documented just below the tarmac road. It seems that the establishment of new cropland on the mountain slopes implies having to abandon cropland downstream sooner or later, so that the total cropped area remains more or less constant at a (maximum) size, but becomes more and more concentrated upstream.

The abstraction monitoring and extrapolation methods presented have been successfully applied within the Naro Moru catchment. They could be applied to other areas if adapted to the different circumstances. Comparison of abstraction amounts estimated by the AbstrCalcTool with gauged values from previous monitoring campaigns has rendered a deviation range of ±15%, which is acceptable for the credibility of the database.

## Outlook

The legal situation concerning abstraction activities is certainly one of the core problems in the region and should be given utmost priority. So far, water was abstracted in more or less lawless circumstances. The currently rather inactive Naro Moru WUA urgently needs to be reactivated in order to fill the power vacuum. Experiences made in the course of this study, such as the interdependence recorded between river discharge and abstraction quantities, could provide an entry point for introducing a flexible water allocation system based on the continuously gauged discharge at the lower forest boundary.

**TABLE 2** Comparison between discharge parameters (based on measured values) in 1960–1984 and in 1985–2002. While the mean discharge is almost stagnant, the median discharge and particularly the low flow discharge show considerable differences, indicating a change in water distribution.

| River gauging station A5 ($m^3/s$) | 1960–1984 | 1985–2002 |
|---|---|---|
| Mean discharge (MQ) | 1.18 | 1.12 |
| Median discharge (Q50%) | 0.74 | 0.51 |
| Low flow discharge (Q95%) | 0.29 | 0.11 |

Further efforts should envisage increasing the efficiency of water use, eg by promoting water-saving irrigation methods such as drip irrigation. According to Phocaides (2001) and Sijali (2001), the water-saving potential of drip irrigation compared to furrow and sprinkler irrigation is estimated between 25% (sprinklers) and 40% (furrows). The only way to widely introduce this system along the rivers—where farmers commonly use highly inefficient flood irrigation—would be by implementing a water pricing system (UN-DESA 1992; Echavarria et al 2004).

The investigations presented here were conducted in the Naro Moru catchment and benefited from a unique monitoring system in the Mount Kenya region. A comparison of water abstraction assessments indicates that in the neighboring catchments on the northwestern slopes of Mount Kenya, increasing abstraction and decreasing low flow discharge have been proceeding even more rapidly than in the Naro Moru catchment

**FIGURE 6** The dried-up Naro Moru river, approximately halfway between river gauging stations A5 and A6 (UTM 37: 9989340, 272844) on 27 July 2002. (Photo by Jos Aeschbacher)

(NRM[3] 2003). The results of the Naro Moru need to be compared with those of other rivers in the Mount Kenya area and in the Eastern and Southern African regions as well as with rivers in other tropical mountain systems (Wilk et al 2001; Allan et al 2002; Bruijnzeel 2003). Additionally, the impacts of land use and land use change need to be assessed and combined with water abstraction accounting, in order to assess the overall human impact on water resources (Notter 2003; MacMillan and Liniger 2005).

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