Supplements

S1 Parameter and process constraints

Table S1: Overview of all parameter constraints applied in the hydrological model for the Mara River Basin

Parameter	Symbol	Formula	Comment
Interception	I_{max}	$I_{max,forest} > I_{max,grass}, I_{max,shrubs}, I_{max,cropland}$ $I_{max,shrubs} > I_{max,grass}, I_{max,cropland}$	Based on perception
Reservoir coefficient	K_s, K_f	$K_s > K_f$	Based on perception
Storage capacity in unsaturated zone	$S_{u,\ max}$	$S_{R,y_i} = \int P_e - E_d \, dt$ $\frac{E_d}{E_a} = \frac{NDVI_D}{NDVI_A} \ thus \ E_d = E_a * \frac{NDVI_D}{NDVI_A}$	Based on NDVI, equivalent to the root zone storage capacity (Gao et al., 2014b) $S_{R,\ yi}$: required storage for year i P_e: accumulated effective rainfall over dry season E_d: accumulated dry season evaporation, calculated assuming a linear relation between the evaporation and the NDVI E_a: actual mean annual evaporation Through a statistical analysis of S_R using the Gumbel distribution, the storage capacity $S_{u,\ max}$ with a return period of 20 years is calculated.
Reservoir coefficient for groundwater system	K_s	$Q_s = Q_{t=0} * \exp\left(-\frac{t}{K_s}\right)$	Based on hydrograph recession analysis Q_s: groundwater discharge
Maximum surface water storage	S_{max}	-	Based on DEM assuming S_{max} is equal to the sink volumes

Table S2: Overview of all process constraints applied in the hydrological model for the Mara River Basin

Process	Symbol	Formula	Comment
Average annual runoff coefficient	C	$C = 1 - \frac{E}{P} = e^{-\frac{E_p}{P}}$	Based on the Budyko using the 95% percentile (hence modelled average annual runoff coefficient should be below the 95-percentile of the observations)
Strickler parameter	c	$Q = c * A * R^{\frac{2}{3}} = u * A$ $A = \frac{Q}{u} = f(d)$ $u = c * R^{\frac{2}{3}} \rightarrow c_{calculated} = \frac{u}{R^{\frac{2}{3}}}$ $c_{calculated,-20\%\ error} < c < c_{calculated,+20\%\ error}$	Based on Strickler formula, cross-section data and a single discharge and velocity measurement at Mines allowing a wide error margin of 25%
Groundwater recharge	R_s	$R_{s,F} > R_{s,C}$, $R_{s,G}$	Based on the assumption that deeper rooting vegetation creates preferential drainage patterns
Annual interception	E_i	$E_{i,F} > E_{i,G}$, $E_{i,S}$	Based on the assumption that the interception is higher in forests than in grassland and shrublands
Fast runoff infiltration	-	$f_{Q_{river}} < 3\ yr^{-1}$	Frequency of river runoff larger than zero; based on interviews less than about 5 times a year water is observed in the river. A storm is considered large as soon as the runoff is larger than 2 mm/d.

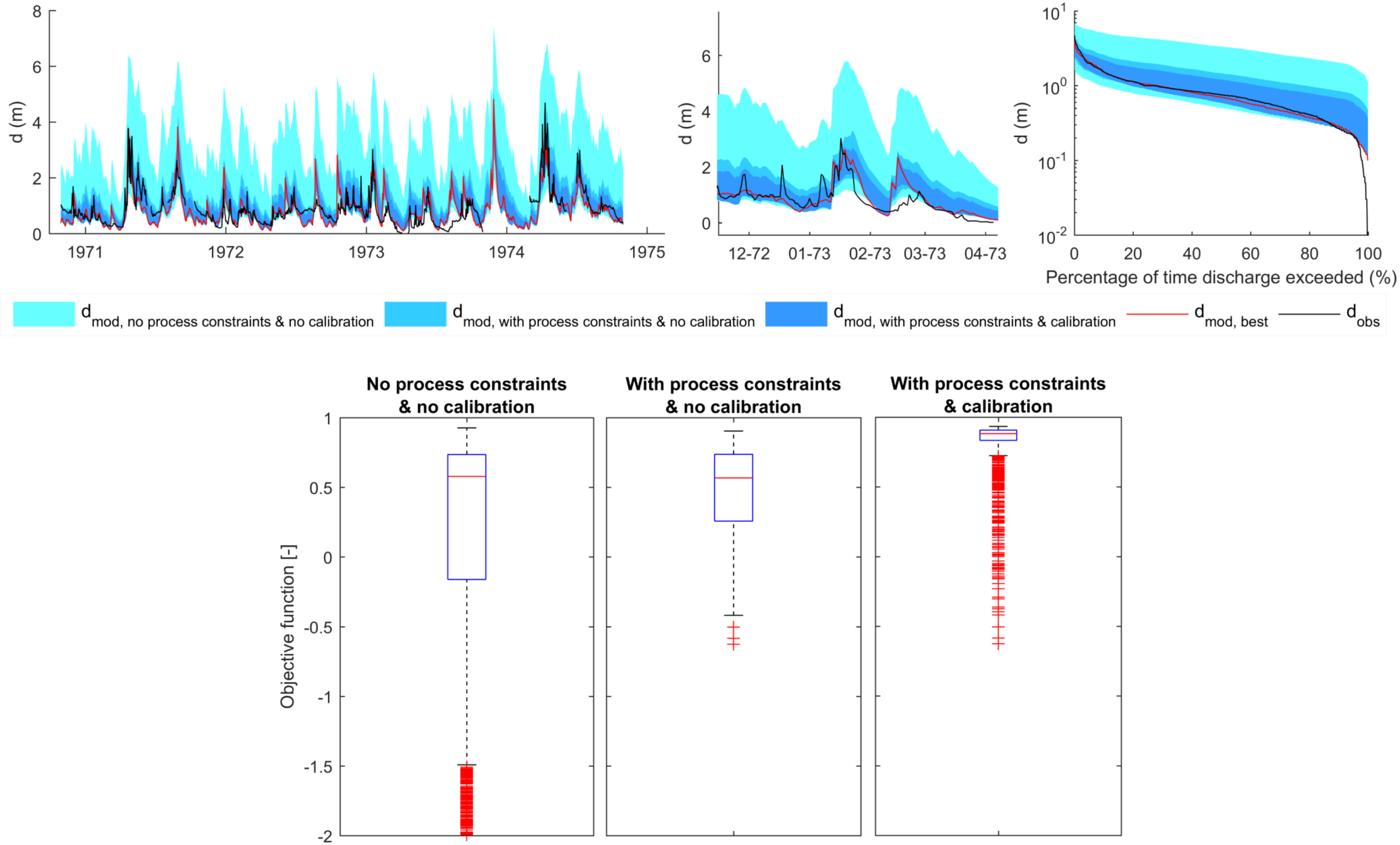

Figure S1: Influence of including process constraints and applying calibration on the modelled water depth using the 5 -/95- percentile as lower/upper limit for the uncertainty range (upper) and on the objective function (lower)

S2 Cross-section graphs

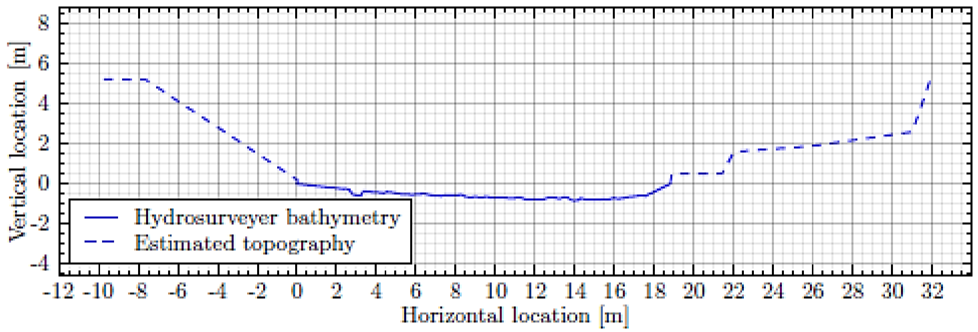

Figure S2: Cross-section at Amala (Rey et al., 2015)

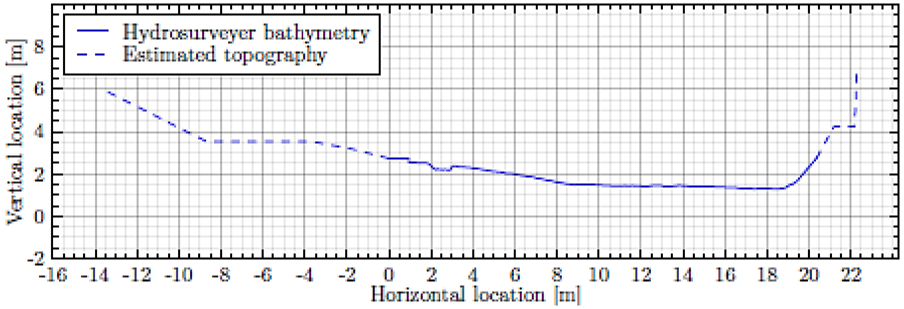

Figure S3: Cross-section at Nyangores Bomet Bridge (Rey et al., 2015)

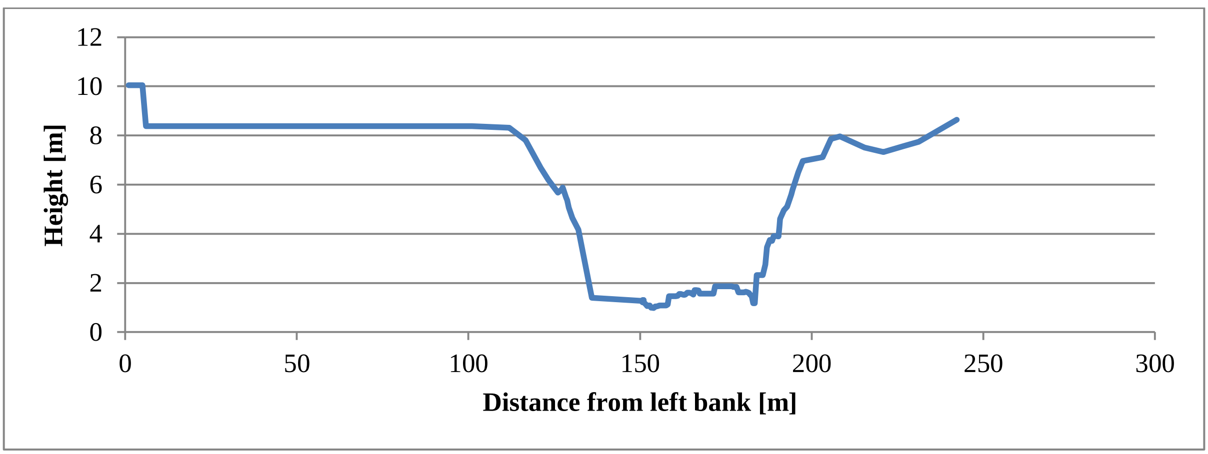

Figure S4: Cross-section at Mara Mines based on field measurements in 2015

S3 Validation results

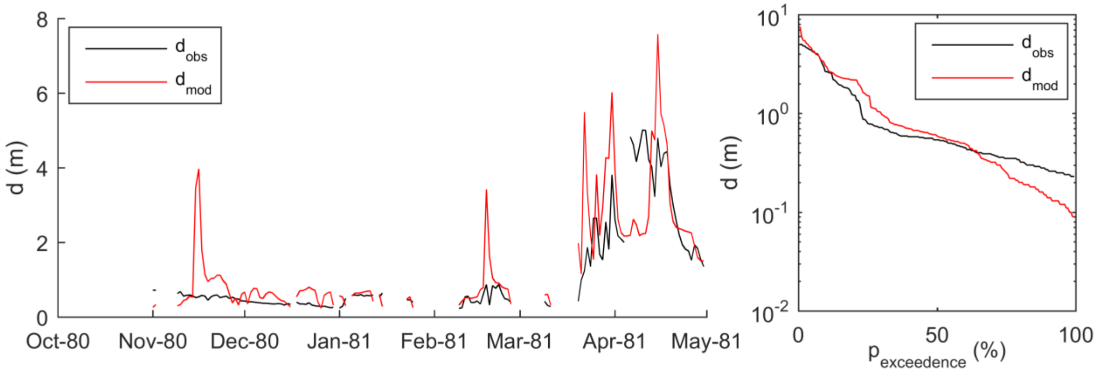

Figure S5: Model results at Mines during validation: water depth time series and water depth exceedance

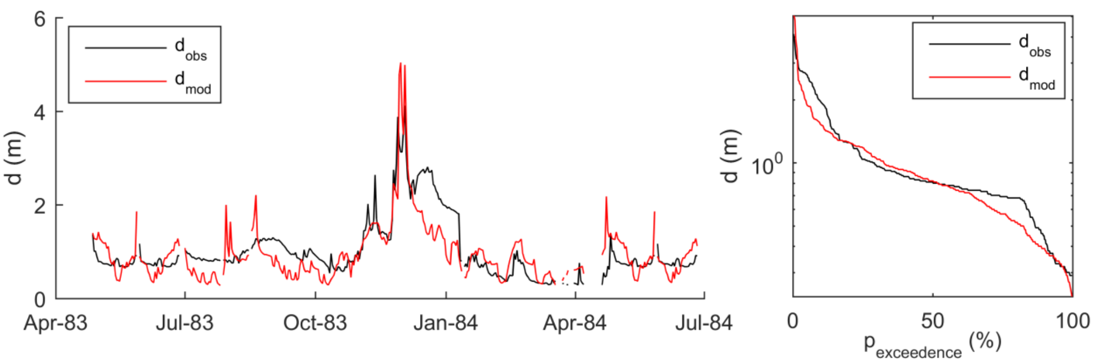

Figure S6: Model results at Mines during validation: water depth time series and water depth exceedance

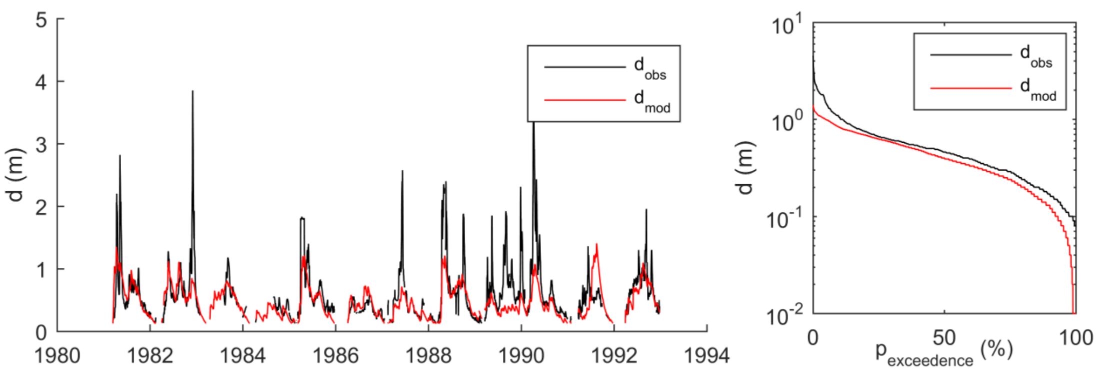

Figure S7: Model results at Nyangores during validation: water depth time series and water depth exceedance

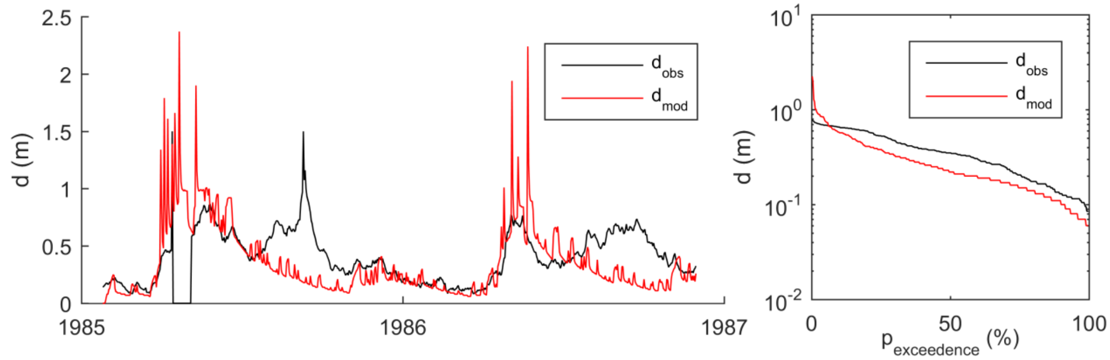

Figure S8: Model results at Amala during validation: water depth time series and water depth exceedance

S4 Data quality

S4.1 Discharge and water level data

At the gauging stations, the reliability of the discharge series was assessed by back-analysing the rating curve. As both the water levels and discharge series are available, the rating curves can be recalculated for each series (method 1). In addition, the rating curve has been estimated based on the water level data and cross-section data (see supplement B) using the Strickler equation: $Q = k * i^{\frac{1}{2}} * A * R^{\frac{2}{3}}$, where k is the roughness, i the slope, A the cross-sectional area and R the hydraulic radius (method 2). Hence, two methods where applied to derive the rating curve:

- Method 1: Rating curve recalculated from the recorded water level and discharge time series
- Method 2: Rating curve estimated with the recorded water level data and cross-section data using the Strickler equation. The roughness was calibrated.

This analysis showed that the two methods did not correspond at Bomet, in the Nyangores (Figure S10). At Kapkimolwa, in the Amala, the rating curve changed multiple times, however the results of both methods were similar for high flows. At Mines, the discharge data formed a cloud around the cross-section based estimated discharge. In addition, a sensitivity analysis showed that changes in the cross-section, river width and bank slope, were negligible compared to the anomalies observed between both methods. In addition, the velocity at Mines was calculated based on the entire recorded discharge and water level data and the cross-section data; this maximum velocity was below 1 m/s Figure S9, whereas a velocity of 2.13 m/s and discharge of 529.3 m^3/s was measured in the field in 2012 (GLOWS-FIU, 2012). Therefore, at all three stations, there are significant uncertainties in the rating curve and therefore the discharge data as well. Figure S10 also presents the geometric rating curve based on the hydrological model.

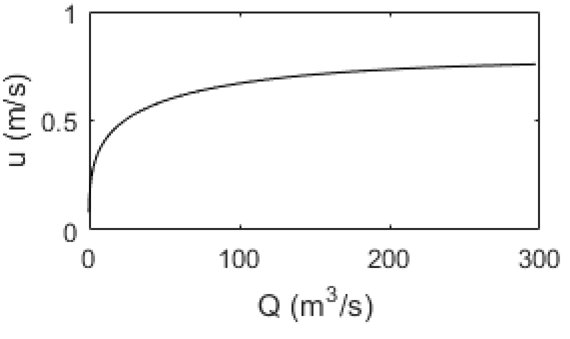

Figure S9: Cross-section average flow velocity – discharge graph at Mines for the entire time period available (1970-2012). This velocity was calculated based on the recorded discharge, water depth and cross-section data

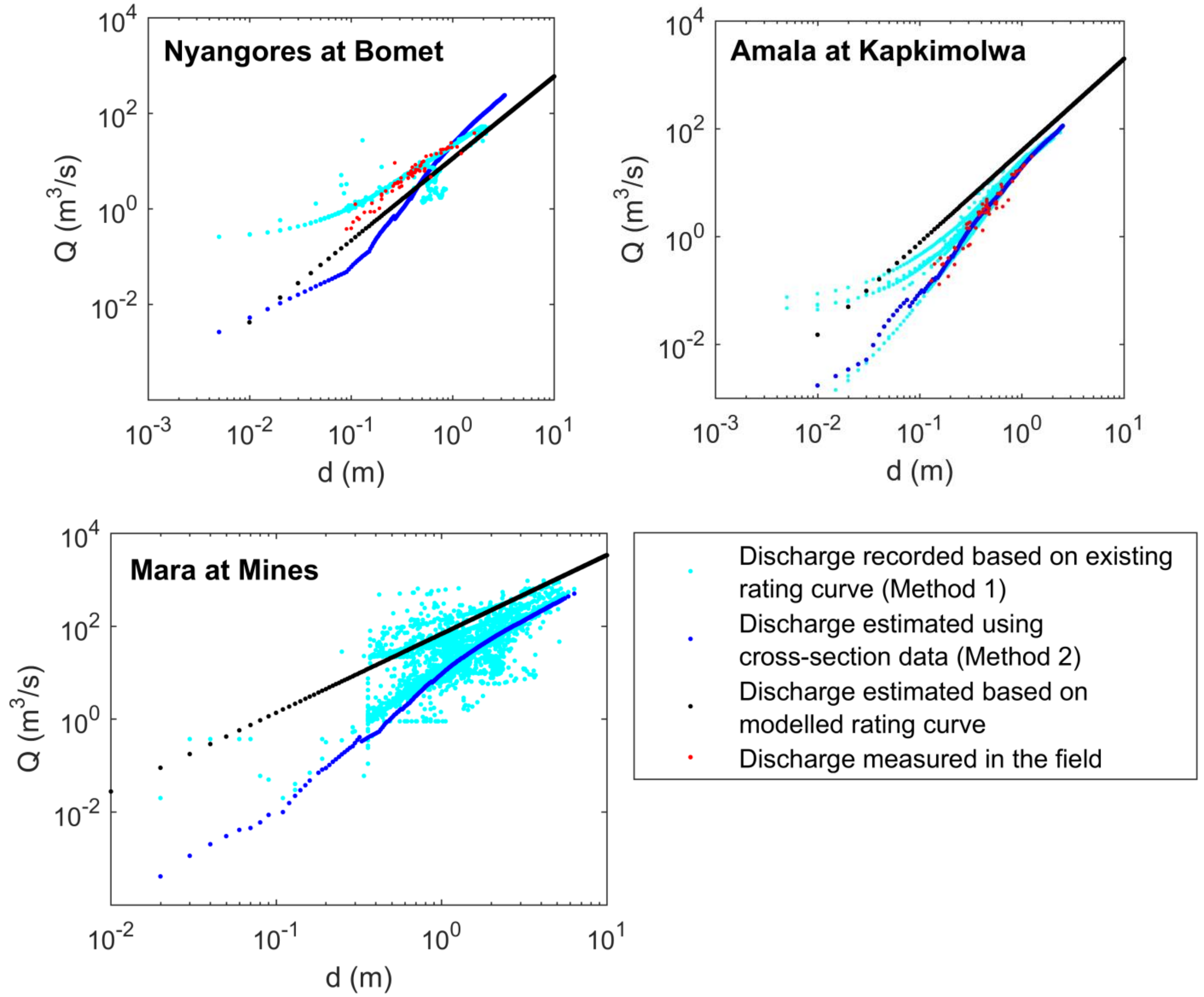

Figure S10: Discharge - water depth graphs for the three main river gauging stations in the Mara River Basin. 1) Recorded discharge and water level time series between 1960 and 2010 (light blue), 2) discharge estimations based on the cross-section (dark blue), 3) discharge calculated with the geometric rating curve based on the hydrological model results for the time period 1970 - 1980 (Nyangores), 1991 - 1992 (Amala) and 1970 - 1974 (Mines), see section on model results (black) and 4) discharge field measurements from the Nile Decision Support Tool (NDST) for the time period 1963 - 1989 (Nyangores) and 1965 - 1992 (Amala), no data was available for Mines (red)

S4.2 Precipitation data

To assess the quality of the data, a double mass curve analysis was done. With this analysis, the cumulative annual rainfall of a station was plotted against the average annual cumulative rainfall of all stations. This curve should be approximately a straight line otherwise the station data is inconsistent and unreliable. As a result of this analysis, inconsistencies were found in 11 out of the 28 stations.

A network analysis was done to assess the spatial correlation between the precipitation stations that were consistent with each other based on the double mass curve analysis. On average the spatial correlation between all stations was 0.6, however the spatial correlation varied in space and time depending on the stations (Figure S11) and the time period used. This change in time and space was confirmed by more detailed analyses of the coefficient of variation using simple statistical formulas and Kriging interpolated precipitation maps (Figure S12). As shown in Figure S12, the southern part of the basin which happens to be the dryer part, has the largest uncertainty in the areal representation of the precipitation.

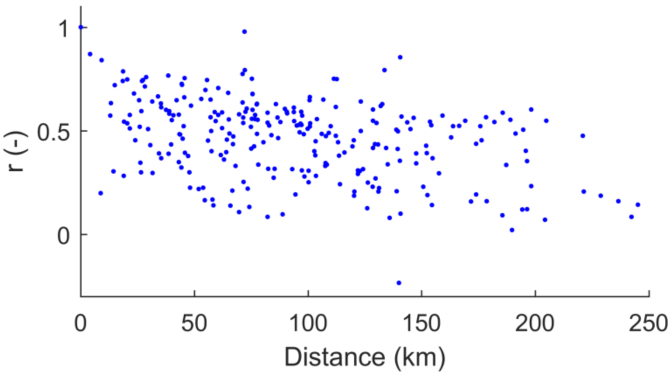

Figure S11: Spatial correlation between all individual precipitation stations plotted against their distance

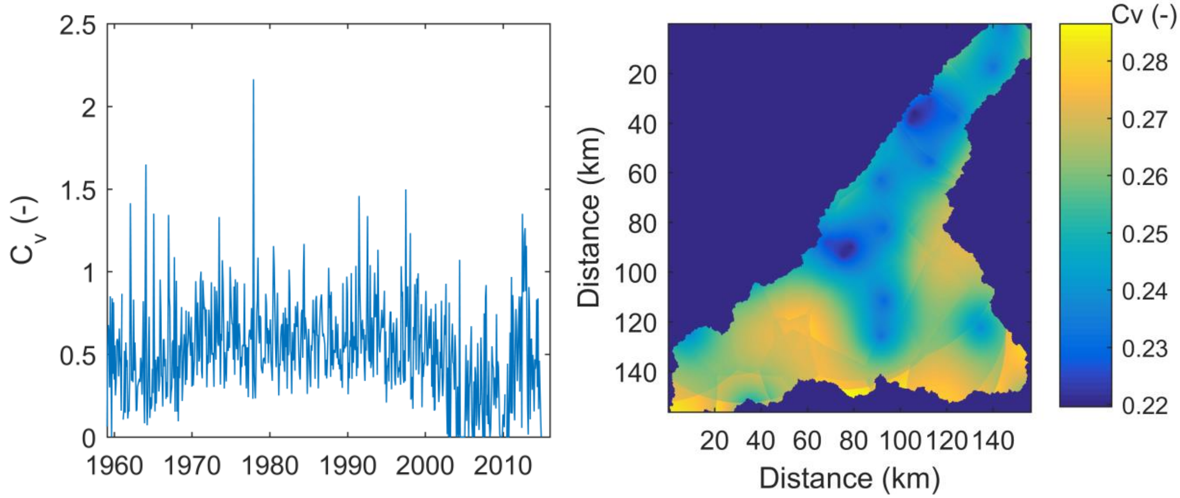

Figure S12: Coefficient of variation C_v of monthly rainfall based on: A) simple statistical formulas and B) Kriging variance of monthly precipitation station data averaged over the time period 1960 - 2010