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Coupling a large-scale hydrological model (CWatM v1.1) with a high-resolution groundwater flow model (MODFLOW 6) to assess the impact of irrigation at regional scale

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1. Model validation on discharge stations in Bhima

In Bhima, CWatM-MODFLOW successfully reproduces weekly streamflow in five discharge stations. The Kling-Gupta Efficiency (*KGE*) values are 0.75, 0.68, 0.54, 0.76, and 0.66 from upstream to downstream. Simulated and observed streamflow data are presented on Figure S1.

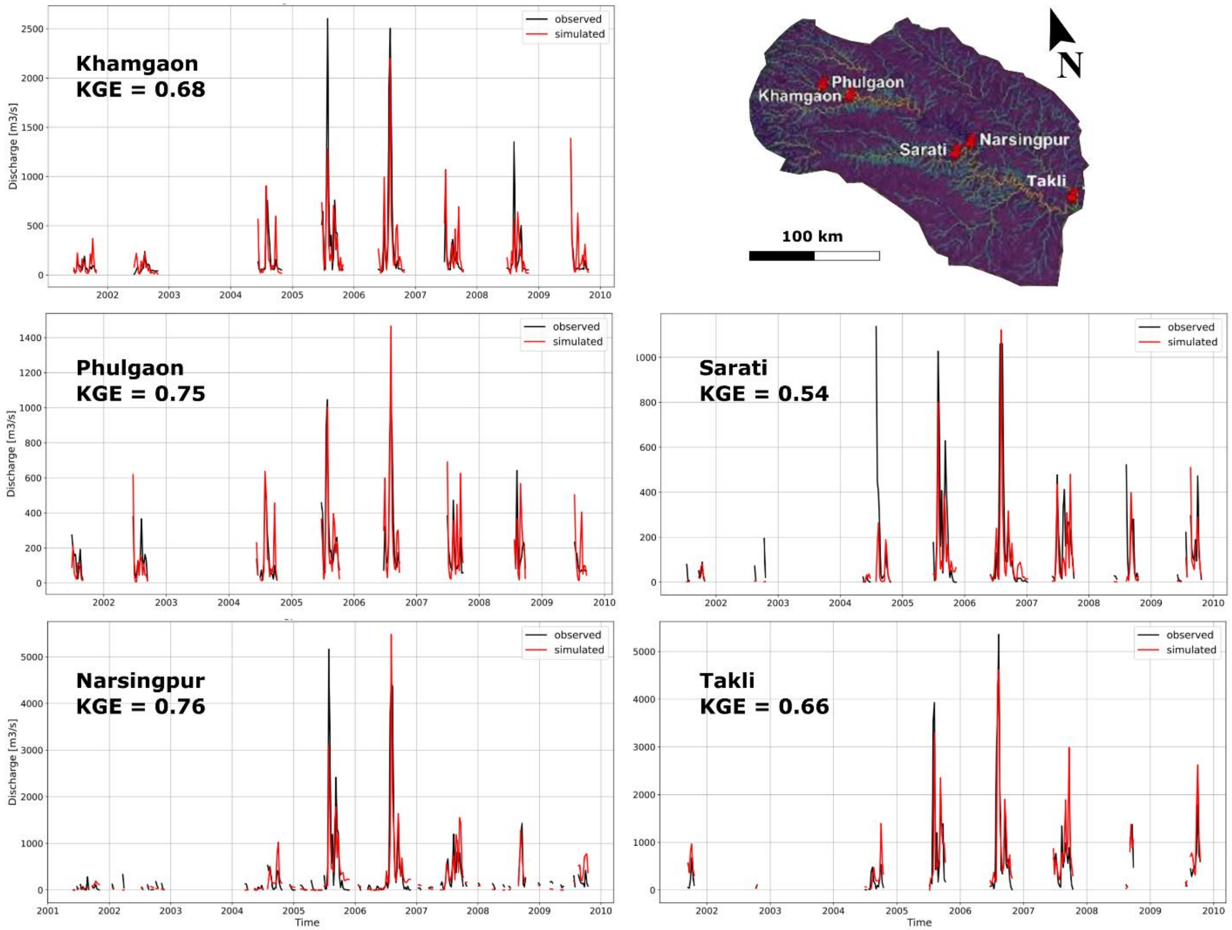

Figure S1: Comparison between observed and simulated weekly discharge at five discharge stations located in the Bhima basin. The figure in the upper left corner shows the stations locations.

2. Impact of irrigation in summer 2003 in Seewinkel

The impact of irrigation during summer 2003 is illustrated in Figure S2. As expected, the impact of irrigation is more pronounced during summer 2003 than the annual average because pumping and irrigation occur during this season. Moreover, 2003 is very dry, so pumping demand is higher than usual.

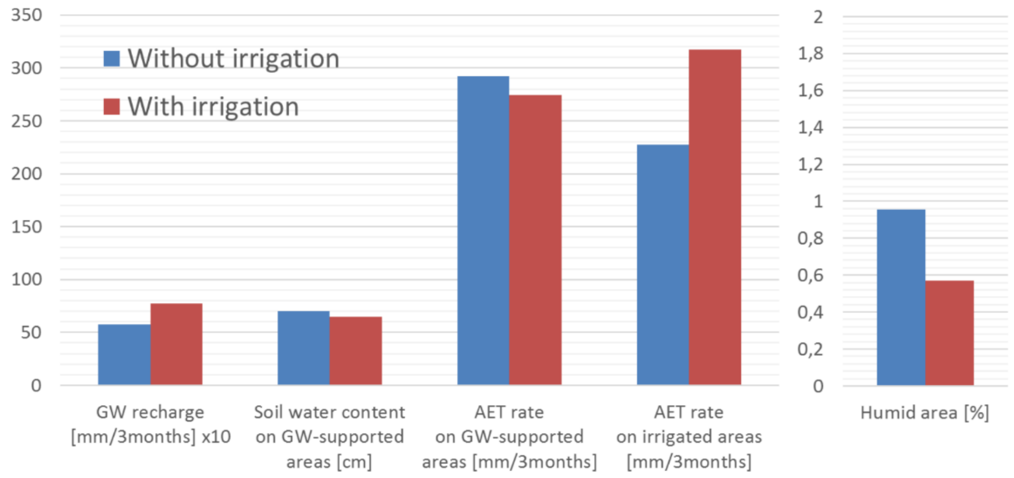

Figure S2: Comparison of some indicators obtained from CWatM-MODFLOW simulation in Seewinkel with and without irrigation during the dry summer 2003 (June, July, and August). Note that units are different for each variable. Areas were considered humid when groundwater supported soils for at least 1 month.

3. Impact of irrigation settings

We tested the sensitivity of CWatM-MODFLOW in Seewinkel and Bhima to two irrigation settings: the irrigation efficiency factor and the spatial density of pumping wells. Irrigation efficiency would mainly impact groundwater pumping rates to compensate for irrigation losses. The spatial density of pumping well would concentrate more or less imposed pumping rates within pumping wells. Both settings would potentially impact the water table and the comparison of the water table observed in the monitoring well network. This would result in different evapotranspiration rates in irrigated lands (due to irrigation loss) and in groundwater-supported areas due to the modification of the water table.

In Seewinkel, irrigation efficiency was set to 0.7 in CWatM-MODFLOW and the spatial density of pumping wells was one pumping well per 1 km². We tested three additional settings, listed below:

- Scenario 1: irrigation efficiency = 0.6, one pumping well per 1 km²
- Scenario 2: irrigation efficiency = 0.8, one pumping well per 1 km²
- Scenario 3: irrigation efficiency = 0.7, one pumping well per 0.04 km²

The results are presented in the following table and figure:

Table S1: Impact of several scenarios in Seewinkel on groundwater (GW) pumping, evapotranspiration, and mean water table depth in monitoring wells.

	GW pumping [mm/yr]	Evapotranspiration rate from irrigated land [mm/yr/m^2]	Evapotranspiration rate from groundwater-supported areas [mm/yr/m^2]	Mean water table depth in boreholes [m]
Standard version	31	544	573	2
Scenario 1	34	560	572	2,1
Scenario 2	28	533	574	2
Scenario 3	33	547	573	2

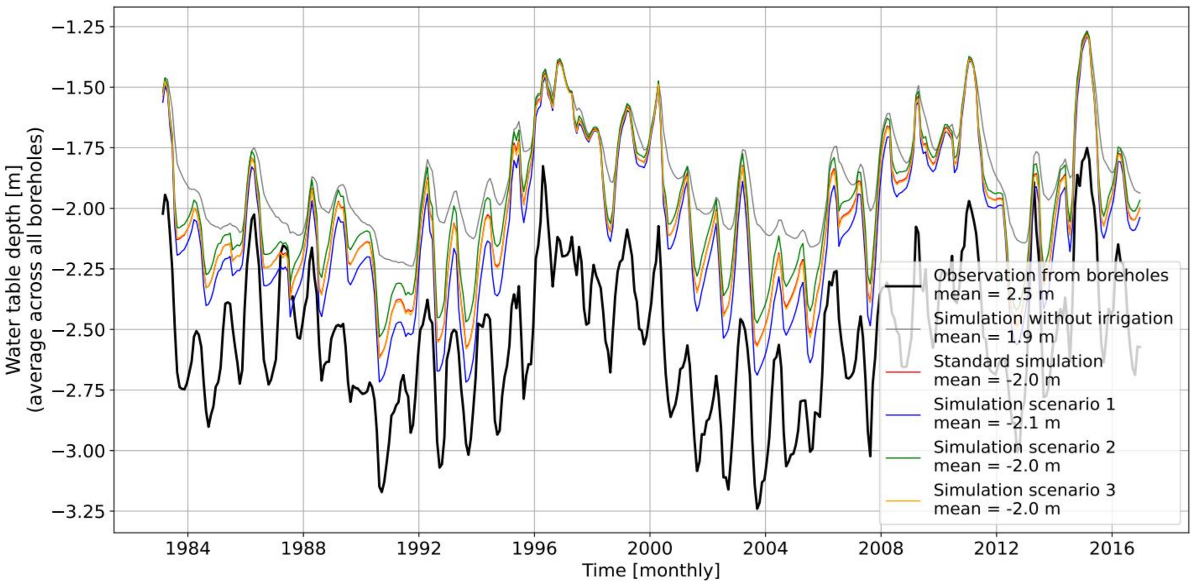

Figure S3: Comparison between observed and simulated water table depth with different scenarios in Seewinkel. Black lines represent observed data. Water table depth fluctuations are aggregated from 62 boreholes.

Mean water table fluctuation anomalies are not impacted by the three scenarios, where scenario 1 shows the largest difference (*nRMSE* = 56% compared to 52% with the standard version). Mean water table depth is not significantly impacted due to the evapotranspiration rate in groundwater-supported areas (Table S1).

In Bhima, irrigation efficiency was set to 0.7 (0.6 for paddy fields) in CWatM-MODFLOW and the spatial density of pumping wells was one pumping well per 0.0625 km². We tested three additional different settings, as listed below:

- Scenario 1: irrigation efficiency = 0.6, one pumping well per 0.0625 km²
- Scenario 2: irrigation efficiency = 0.8, one pumping well per 0.0625 km²
- Scenario 3: irrigation efficiency = 0.7, one pumping well per 0.025 km²

The results are presented in the following table and figure:

Table S2: Impact of several scenarios in Bhima on groundwater (GW) pumping, evapotranspiration, and mean water table depth in monitoring wells.

	GW pumping [mm/yr]	Evapotranspiration rate from irrigated land [mm/yr/m^2]	Evapotranspiration rate from groundwater-supported areas [mm/yr/m^2]	Mean water table depth in boreholes [m]
Standard version	107	735	752	4.5
Scenario 1	128	777	729	5.8
Scenario 2	98	712	762	4.2
Scenario 3	107	736	752	4.6

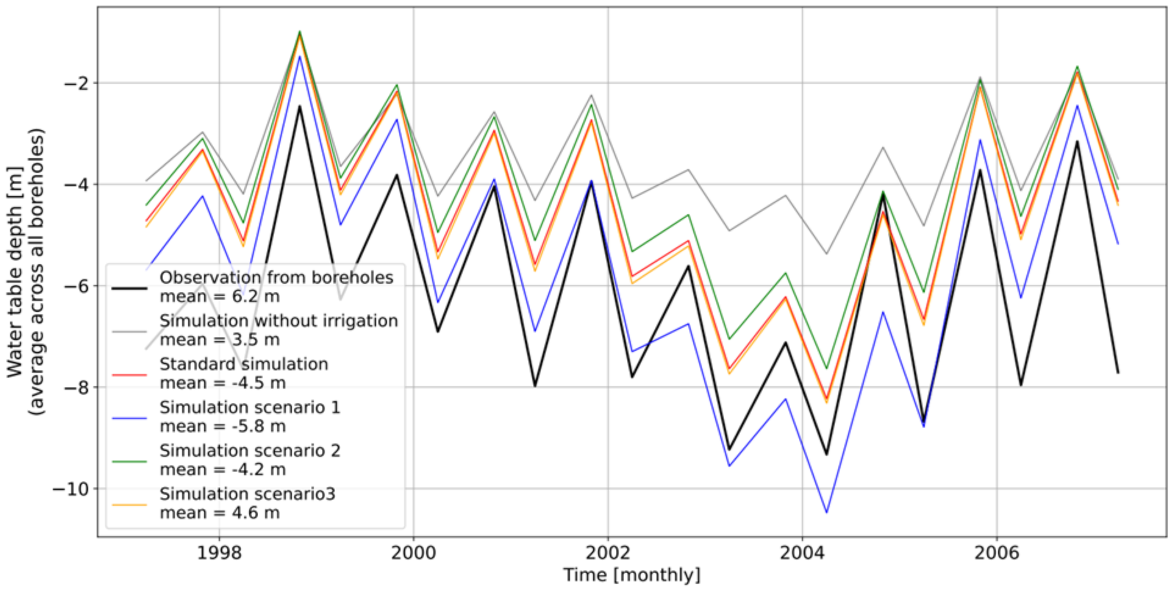

Figure S4: Comparison between observed and water table depth simulated with different scenarios in Bhima. Black lines represent observed data. Water table depth fluctuations are aggregated from 351 boreholes.

While the model with more irrigation (scenario 1) improves mean water table depth (blue line in Figure S), the criteria for water table fluctuations is slightly degraded (*nRMSE* = 51% compared to 40% with the standard version). The impact of the spatial density of the pumping well on water table depth and water table fluctuations is very low. Scenarios 2 and 3 do not show a significant impact on mean water table depth or evapotranspiration rate in groundwater-supported areas (Table S2). Due to lower water tables in scenario 1, the evapotranspiration rate in groundwater-supported areas is more impacted and falls from 752 to 729 mm/yr/m^2.