



Temporal dynamics of hydrological impacts of adjustable weirs in an open ditch: an experiment-modeling study on a shallow groundwater environment

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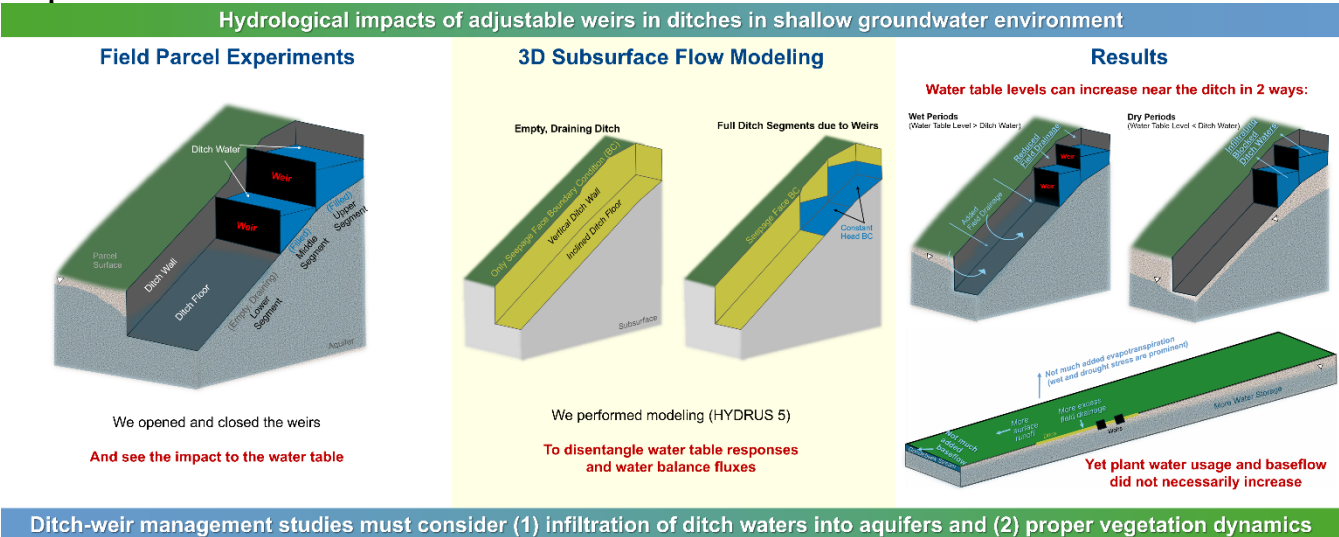
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Abstract. Adjustable weirs have been used to block ditch waters especially during wet seasons to retain more shallow groundwater in agricultural fields and forests. However, to fully verify the effectiveness of weirs, quantifying the weirs' hydrological benefits to vegetation and nearby surface waters is important. Our study quantified the hydrological impacts of these weirs on the water balance across seasons under wet and dry years. We performed field experiments in a 2% sloped parcel with a single ditch and two weirs in Merelbeke-Melle, Belgium. Then, we used a 3D subsurface flow model (HYDRUS 5) to represent the phreatic and vadose zones underlying the regional hillslope. They were calibrated using water table levels monitored across the parcel in 2022–2026, covering both wet and dry years. Afterwards, we simulated separate scenarios for empty and full ditches under shallow and deep rooting depth parameterizations.

The observed water tables show little responses with opening and closing of weirs. Meanwhile, simulations involving weir management exhibited higher water tables especially closer to the ditch due to reduced field drainage that retain more water during wet periods and also infiltration of ditch waters during dry periods. Yet this boosted water availability was partitioned mainly to runoff, storage, and excess (added) field drainage downstream of the weirs. The stream downslope (Gondebeek stream) had only little additional baseflows. Moreover, the vegetation experienced both wet and drought stresses that inhibited uptake of water gained from water management. Thus, hydrological models on weir management should properly consider the presence and sources of infiltrating ditch waters, vegetation dynamics in the field, and the meteorological context (seasonality, interannual variability).



30 **Graphical Abstract**





1 Introduction

To reduce waterlogging, salt accumulation, and flooding, open ditches have been implemented in both agriculture and forest areas worldwide (Luthin, 1957; Nijland et al., 2005; Peacock et al., 2021a; Remm et al., 2013; Yannopoulos et al., 2020). Up to 10.7 million ha of land, or 5% of global drained land area, have been ditched (Peacock et al., 2021b; Silverthorn et al., 2025). However, open ditch drainage can also reduce the shallow phreatic groundwater supply (Astiani et al., 2017; Boelter, 1972; Robinson, 1998). This could be exacerbated by increased abstractions and climate change, the latter of which accelerates the hydrological cycle and is projected to reduce water availability on three-fourths of the globe. Climate change can lead to prolonged droughts from changing precipitation patterns and increasing evaporation rates (Bates et al., 2008; Burke et al., 2006; Ehtasham et al., 2024). As adaptive measures, water losses from open ditches could be regulated to conserve available shallow groundwater in rural areas (Hasselquist et al., 2018; Vlotman and Jansen, 2003; Yimer et al., 2023).

Adjustable (or low grade) weirs have been used to fill open ditches during wet periods, reducing drainage and increasing groundwater levels (and hence water storage) (De Beukelaer-Dossche and Decleyre, 2013; Eggleston et al., 2018; Kröger et al., 2008), surface and subsurface runoff, and flows to nearby surface waters such as streams (Appendix B – Table B1). These impacts can be observed as far as 200 m from the ditch but diminish away from the ditch (Holden et al., 2017; Isomäki et al., 2024; Paavonen et al., 2025). However, quantifying these hydrological impacts through measurements is difficult since the fluxes cannot be easily measured. To address this, various studies combine measurements with model simulations.

However, some of these studies report outcomes in annual scales (Holden et al., 2017; Isomäki et al., 2024). Some studies involving seasonal scales have no supporting models capable of disentangling seasonal water balances. Such studies usually rely on monitored or simulated groundwater levels and ditch discharges to assess weirs' hydrological impacts (Amatya et al., 2003; Holden et al., 2017; Strock and Ranaivoson, 2025). Meanwhile, a study utilizing models capable of disentangling seasonal water balances (Gliege et al., 2016) covered only a year and did not relate these hydrological impacts across seasons (Appendix B – Table B1). Yet relating these impacts across seasons under wet and dry years should help verify the supposed adjustable weirs' hydrological benefits to vegetation (including crops) and nearby surface waters throughout those seasons. Hence, this study aimed to (1) demonstrate seasonal mechanisms that enhance water availability due to adjustable weirs, including reduced field drainage in winters, and then (2) assess the partitioning of this enhanced water availability to various hydrological components within and on the subsequent seasons in wet and dry years.

This study employed field experiments in a 2% inclined agricultural parcel with one ditch, situated along a hillslope including a plateau at the summit and a stream at the hillslope toe (Fig. 1a). To disentangle the water balance under various



weir scenarios during the experimental period (01 August 2022 – 28 February 2026), the whole hillslope and its underlying vadose and phreatic zones were represented using the three dimensional (3D) subsurface flow model (HYDRUS). This study, situated in East Flanders Province, Belgium, considered both wet (2023, 2024) and dry years (2025).

70 2 Materials and Methods

2.1 Study Site

The study site is situated in the Flanders Research Institute for Agricultural, Fisheries and Food Research (ILVO) at the tripoint of Merelbeke-Melle-Oosterzele municipalities in East Flanders Province, Belgium (Appendix A – Fig. A1b, Appendix A – Fig. A1c).

75 2.1.1 Physiography and Phreatic Hydrogeology

The site has a temperate oceanic climate (Peel et al., 2007). Over the years 1991–2020, annual precipitation and reference evapotranspiration for a hypothetical grass surface ranged from 609–995 mm (average: 840 mm) and 618–800 mm (average: 681 mm), respectively. The highest monthly climatic water balances (i.e., difference between monthly precipitation and reference evapotranspiration) occur in November–January, with monthly precipitation of 4–188 mm (average: 80 mm) and
80 monthly reference evapotranspiration of 3–31 mm (average: 17 mm). Meanwhile, the lowest monthly climatic water balances are in May–July with monthly precipitation of 4–194 mm (average: 69 mm) and monthly reference evapotranspiration of 70–152 mm (average: 103 mm) (RMI, 2025).

The site is along a 2% hillslope area, comprising the flank of Gondebeek valley. The hillslope summit is a 33 masl plateau
85 where the Lemberge hamlet of Merelbeke-Melle sits while the hillslope toe consists of the Gondebeek stream below at 11–13 masl and its vertical streambank at 13–15 masl (Fig. 1a). The Gondebeek stream serves as a tributary of the Scheldt River (CIW, 2015).

Its unconfined aquifer consists mainly of Quaternary (mixture of clays, silts, sands, gravels) and Ypresian Aquifer Systems
90 (composite sand and clay layers), overlying the confining Ypresian Aquitard System horizontally at -11 masl (DOV, 2026; Deckers et al., 2019; VITO and Flemish Government, 2021; Tas et al., 2023). The hillslope's detailed hydrostratigraphy is illustrated in Appendix A – Fig. A2.

2.1.2 Experimental Setup

The experiments are conducted in a 9.8 ha agricultural parcel within the Quaternary Aquifer System. It has an inclined ditch
95 (205.0 m long, 1.2–1.9% slope along north-south) on one edge (Fig. 1a, 1b, Appendix A – Fig. A3b). The ditch depth and



ditch floor width are 90 and 160 cm, respectively (Appendix A – Fig. A3c). Two existing field access bridges divide this ditch into upper, middle, and lower ditch segments (46 m, 36 m, and 123 m long, respectively) (Fig. 1a). Underneath these bridges are culverts that link the ditch segments. The experimental period spanned from 01 August 2022 – 28 February 2026.

100 Adjacently upstream these bridges, two KWT KSOS stackable adjustable weirs (KWT water control, The Netherlands) were installed 36 m apart on 27 July 2022 (Fig. 1a, Appendix A – Fig. A3a). Having two weirs enhances the hydrological impact, since it enlarges the distance over which water can be withheld in the sloping ditch. Closing the weirs fills the middle and upper ditch segments with up to 80 cm water at the weir locations (Fig. 1b). The ditch segment's water surface, unlike the inclined ditch floor, is observed to be horizontal (Appendix A – Fig. A3b). This ditch water comes from the drainage from
 105 the parcel itself, a neighboring westward sloping agricultural parcel east of the ditch, the unpaved roads adjacent to the field, and ILVO's 14 chicken coop roofs that discharge water through pipes (Appendix A – Fig. A1a).

These weirs were closed most of the time. However, in 2024–2025, we opened them simultaneously multiple times, leaving 10–15 cm water above the ditch floor just adjacently upstream of the weirs. These opening/closing trials were performed to
 110 change the ditch segments' water levels and monitor the groundwater level responses in the adjacent agricultural field. These openings left the whole ditch draining for several weeks (3–8 weeks), after which the weirs were closed. This ensured ample response time for the adjacent water table and allowed for multiple opening and closing trials throughout the experiment. Note that the upper weir leaked during certain periods, requiring fixing (Appendix A – Fig. A4). The lower ditch segment always drained, since there was no additional weir at the lower end of the ditch.

115 The water table and the upper and middle ditch segments' water levels at the weir locations were monitored hourly during the experimental period in open tubes using standpipe piezometers (Divers from Van Essen Instruments) (Fig. 1a, Table 1). When we opened the weirs, we monitored the changes in ditch waters and water table levels every minute. The water table piezometers were installed at the subplot borders (NW, NC, MC) or in a 2 m wide permanent grass strip adjacent to the ditch
 120 (NE, ME, SE). More piezometers were installed near the ditch to monitor the hydraulic interactions between the aquifer and ditch segments (Fig. 1a, Table 1, Appendix A – Fig. A4). The coordinates (x, y, z) of piezometers and ditch segment endpoints were also precisely recorded using real time kinematic GPS positioning (RTK) (Appendix B – Table B2).

Main crops varied across the field throughout the years, managed independently by the ILVO experimental farm. The top
 125 half of the piezometers NW, NC, and MC was temporarily removed to allow for conventional plowing, sowing and harvest without damaging the piezometers. This contributed to 19%, 21%, and 8% missing observation data, respectively (Appendix B – Table B2). There was no irrigation during the experimental period. The timeline of the crop history and field management actions, along with the subparcel map, are summarized in Appendix A – Fig. A4.



Twelve soil samples were obtained near the piezometers (Fig. 1a) and depths (0–10 cm: 6 samples, 20–30 cm: 4 samples, 70–80 cm: 2 samples) using augers and 100 cm³ Kopecky rings during piezometer installations (Appendix A – Fig. A4). Their pF curves (Appendix A – Fig. A5) were derived using a sandbox (for pF values 0.0, 0.5, 1.0, and 2.0) and ceramic plates (for pF values 2.3, 2.8, 3.4, and 4.2). Their grain size compositions were also estimated using laser diffraction, revealing sandy loam to loam textures as per U.S. Department of Agriculture (USDA) classification (USDA Soil Survey Staff, 2022).

The daily precipitation and reference evapotranspiration data were directly obtained from the closest pixel (Pixel 998) from the 5 km gridded observation data of the Royal Meteorological Institute of Belgium (RMI, 2025). This reference evapotranspiration data is calculated using the Bultot method, tailored specifically for Belgium (Bultot et al., 1983, 1988; Bultot and Dupriez, 1973). According to these records, both wet (2023, 2024) and dry years (2025) were captured in this study. The recorded respective annual precipitation and reference evapotranspiration depths are: 1 041 mm and 724 mm (2023), 948 mm and 647 mm (2024), and 589 mm and 762 mm (2025).

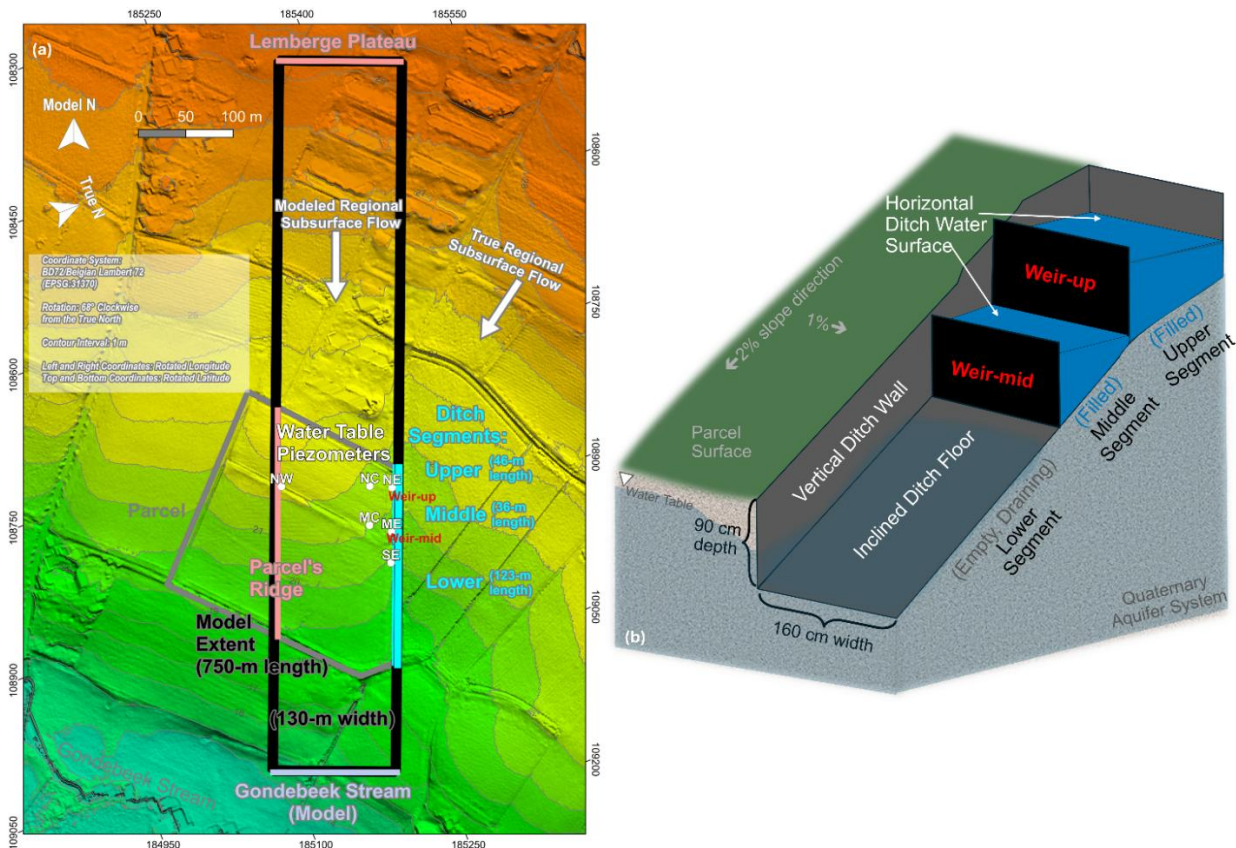


Figure 1. (a) Study area's topographic map (reflected by contours and colors), showing the piezometer locations, main physiographic features, the relative subsurface flow directions, and the model's scope. Note the coordinate rotation denoted by rotated tick marks, done so that the ditch axis aligns with the north-south. Basemap: 1 m resolution obtained from the Digital Flanders Agency (2014) (b) schematic 3D view of the ditch with segments filled due to closed adjustable weirs



Table 1. Details on the study area's piezometers (locations on Fig. 1a). Other specifications are in Appendix B – Table B2.

Piezometer Name	Whose level recorded	Justification for Location
NW (North-West)	Water table	Middle of field parcel, near parcel's ridge crest
NC (North-Center)	Water table	Intermediate distance from upper ditch segment
MC (Middle-Center)	Water table	Intermediate distance from middle ditch segment
NE (North-East)	Water table	Next to upper ditch segment
ME (Middle-East)	Water table	Next to middle ditch segment
SE (South-East)	Water table	Next to lower ditch segment
Weir-up (Upper Ditch's Weir)	Ditch water	Adjacently upstream of upper ditch segment's weir
Weir-mid (Middle Ditch's Weir)	Ditch water	Adjacently upstream of middle ditch segment's weir

2.2 Numerical Model Setup

150 To encompass the ditch, surface, subsurface storage, and Gondebeek stream, the whole hillslope was represented in a three dimensional (3D) domain (Fig. 2a). The subsurface-ditch hydrology was modeled in HYDRUS 5 (Šejna et al., 2022; Šimůnek et al., 2022a). Any hydrodynamic movement of runoff and surface water in ditches and streams were not simulated in this study.

2.2.1 Subsurface Water Movement

155 The HYDRUS code simulates vadose and phreatic water movement in 3D porous media by numerically solving the modified Richards equation for variably saturated anisotropic media, neglecting air phase and thermal gradient driven flow (Richards, 1931; Šimůnek et al., 2022a), shown in Eq. (1).

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i} \left[K \left(K_{ij}^A \frac{\partial h}{\partial x_j} + K_{iz}^A \right) \right] - S \quad (1)$$

$$K(h, x, y, z) = K_s(x, y, z) K_r(h, x, y, z)$$

165 Where θ is the volumetric water content [$L^3 L^{-3}$], t is time [T], x_i ($i=1,2,3$) are the spatial coordinates [L], S is the sink term [$L^3 L^{-3} T^{-1}$] that considers root water uptake, K_{ij}^A are the dimensionless anisotropy tensor K^A components, h is the pressure head [L], K is the unsaturated hydraulic conductivity function [LT^{-1}], K_r is the relative hydraulic conductivity [-], and K_s is the saturated hydraulic conductivity [LT^{-1}]. Einstein's notation applies for indices appearing twice in Eq. (1).

The water retention curve and unsaturated hydraulic conductivity function are represented by the van Genuchten-Mualem model, shown in Eq. (2) (Mualem, 1976; Van Genuchten, 1980).

$$\theta(h) = \begin{cases} \theta_r + \frac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases}$$

$$K(h) = K_s S_e^L \left[1 - (1 - S_e^{-1/m})^m \right]^2 \quad (2)$$



$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

$$m = 1 - \frac{1}{n}, n > 1$$

where the θ_s and θ_r are the saturated and residual soil water content, respectively. K_s is the saturated hydraulic conductivity [L T⁻¹]. S_e is the effective degree of saturation. The α [L⁻¹] and n [-] are water retention curve functions' empirical parameters. Together with the tortuosity and pore connectivity parameter L , these empirical parameters influence the hydraulic functions' shape. In the model setups, L was set to 0.5, the value frequently applied for inorganic material (Dettmann et al., 2014; Mualem, 1976). The Richards equation is then solved numerically at each node using Galerkin-type linear finite element (FE) schemes.

Constant (pressure) heads are system independent boundary conditions (BCs) of Dirichlet type, shown in Eq. (3)

$$h(x, y, z, t) = \psi(x, y, z, t) \text{ for } (x, y, z) \in \Gamma_D \quad (3)$$

where Γ_D indicates Dirichlet type boundary segment and ψ [L] are prescribed functions of x, y, z (Šimůnek et al., 2022a).

Seepage faces are outflow zones defined using uniform zero pressure heads and no-flow (zero flux) zones when adjacent to the flow domain's saturated and unsaturated parts, respectively. Seepage fluxes are calculated whenever water leaves through seepage faces (Šimůnek et al., 2022a).

For the root water uptake, the water volume removed from a unit soil volume per unit time (sink term, S) is defined using Eq. (4) (Feddes et al., 1978; Šimůnek et al., 2022a)

$$S(h) = \alpha(h)S_p \quad (4)$$

where the $\alpha(h)$ [-] is the water stress response function, which is a prescribed function of the water pressure head ($0 \leq \alpha \leq 1$) and S_p [T⁻¹] is the potential water uptake. When $h > h_1$ (above the anaerobiosis point, leading to wet stress) or $h < h_4$ (below the permanent wilting point, leading to drought stress), the water uptake is zero. Water uptake is optimal (i.e., at maximum) when $h_3 < h < h_2$ and decreases linearly when $h_2 < h < h_1$ (leading to wet stress) or $h_4 < h < h_3$ (leading to drought stress) (Feddes et al., 1978). The pressure head thresholds h_1, h_2, h_3, h_4 depend on the vegetation species (Rabbel et al., 2018; Taylor and Ashcroft, 1972; Wesseling et al., 1991).

S_p is further defined in Eq. (5) as:

$$S_p = S_t T_p b(x, y, z) \quad (5)$$



where S_t is the soil surface where transpiration occurs [L^2], T_p is the potential transpiration rate [LT^{-1}], and $b(x,y,z)$ is the normalized water uptake distribution [L^{-3}], which reflects S_p 's spatial variation throughout the root zone. The $b(x,y,z)$ is based on normalized root distributions $b'(x,y,z)$ shown in Eq. (6) (Šimůnek et al., 2022a):

$$b(x, y, z) = \frac{b'(x, y, z)}{\int_{\Omega_R} b'(x, y, z) d\Omega} \quad (6)$$

$$\int_{\Omega_R} b(x, y, z) d\Omega = 1$$

where Ω_R is the root zone region or domain. Solving for T_p by combining Eq. (5) and Eq. (6) leads to Eq. (7):

$$T_p = \frac{1}{S_t} \int_{\Omega_R} S_p d\Omega \quad (7)$$

The actual water uptake is obtained by combining Eq. (4) and Eq. (5), leading to Eq. (8):

$$S(h, x, y, z) = \alpha(h, x, y, z) b(x, y, z) S_t T_p \quad (8)$$

and then integrated to obtain the actual transpiration rate [LT^{-1}], T_a , shown in Eq. (9):

$$T_a = \frac{1}{S_t} \int_{\Omega_R} S(h, x, y, z) d\Omega = T_p \int_{\Omega_R} \alpha(h, x, y, z) b(x, y, z) d\Omega \quad (9)$$

2.2.2 Hillslope and Subsurface Extent

The model domain was expanded beyond the parcel's extent in 3D to overcome the uncertainties from parameterizing in- and outfluxes along the parcel's bounds besides the ditch (Di Ciacca, 2020). This expanded domain's bounds are based on the occurrences of physiographic and hydrogeologic features such as the Lemberge plateau, Gondebeek stream, parcel's ridge, ditch, and the Egemkapel clay, all of which can easily justify the model boundary conditions (BCs) (Fig. 1a, Table 2).



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Table 2. Setup's bounds, associated physiographic features, and representing boundary conditions (BC). All constant heads were set under equilibrium with lowest nodes to properly represent surface waters in the ditch and in Gondebeek.

Domain Side	Orientation	Feature	Boundary Condition (BC)	Justification for Selected BC	Model Coordinates (x[m]; y[m]; z[masl])
Top (Surface)	Inclined	Hillslope Surface	Atmospheric	Drives meteorological forcings and vegetation's transpiration (root water uptake). Permits calculations of surface runoff	(0–130; 0–750; 15–31)
North (Hillslope Summit)	Vertical	Lemberge plateau	No-flow	Recharge Divide	(0–130; 750; 30–31)
West (Parcel's Ridge Side)	Vertical	Parcel's ridge	No-flow	Recharge Divide	(0; 0–750; 15–31)
	Vertical	Rest of the face	No-flow	Recharge Divide	
East (Ditch Side)	Inclined	Ditch Floor (Exposed)*	Seepage Face*	Exposed to Atmosphere	All ditch segments: (130–130.8; 152–277 [lower], 277–312 [middle], 312–359 [upper]; 17.9–21.1 [top] 17.0–20.2 [floor])
	Inclined	Ditch Floor (Filled)*	Constant Head*	Ditch Water	
	Vertical	Ditch Wall (Exposed)*	Seepage Face*	Exposed to Atmosphere	
	Vertical	Ditch Wall (Filled)*	Constant Head*	Ditch Water	
	Vertical	Below the Ditch	No-flow	Discharge Divide	
	Vertical	Rest of the face (not within or under the ditch)	No-flow	Recharge/Discharge Divide	
South (Hillslope Toe)	Vertical	Bank above Gondebeek stream	No-flow (> 12.5 masl)	All flows along hillslope would be forced to be drained on the longitudinal Gondebeek stream, easing flux calculations along the Gondebeek stream	(0–130; 0; 12.5–15.0)
	Vertical	Gondebeek stream (Longitudinal Section)	Constant Head (1 m, 11.5–12.5 masl)	Represents a static horizontal 1 m water level below the cliff. This ensures that any changes in stream's baseflow fluxes will only arise from changes in water table levels in response to meteorological forcings and ditch-weir dynamics.	(0–130; 0; 11.5–12.5)
	Vertical	Below Gondebeek stream	No-flow (< 11.50 masl)	Discharge Divide	
Bottom (Phreatic Zone's Bottom)	Horizontal	Horizontal Hydrogeologic Contact with underlying Egemkapel clay (DOV, 2026; Deckers et al., 2019; VITO and Flemish Government, 2021)	No-flow (3 masl)	Egemkapel clay is an inferred aquitard (Geets et al., 2000; Jacobs et al., 1997; Steurbaut, 1998; Steurbaut et al., 2017)	(0–130; 0–750; 3)

*Variables manipulated by changing the assigned BC's extent



The 3D setup is a right trapezoidal prism with a top face (surface) representing the general hillslope, vertical faces, and a 130 m by 750 m horizontal base representing the phreatic zone's bottom (Fig. 2a). The origin (0 m, 0 m, 0 masl) is at the domain's southwest at sea level, thus having only positive values for x- and y-coordinates. Four physiographic features define the domain's extent at x- and y-axis: the Gondebeek stream at the south ($y = 0$ m), plateau at the north ($y = 750$ m), parcel's ridge at the west ($x = 0$ m), and the ditch at the east ($x = 130$ m) (Fig. 1a). At the domain's top surface is the hillslope itself, determined by interpolating the elevations of piezometers (Table 1), top of ditch walls, Lemberge plateau (northern edge of model domain at 30–31 masl), and Gondebeek stream's bank (southern edge expressed as constant horizontal line at 15 masl) in the HYDRUS 5 Graphical User Interface (Šejna et al., 2022). This top surface is sloping down generally at 2% southwards towards the Gondebeek stream and 1% eastwards towards the ditch. Meanwhile, the domain's bottom ($z = 3$ masl) is based on the horizontal contact with the Egemkapel clay (DOV, 2026; Deckers et al., 2019; VITO and Flemish Government, 2021), inferred to be an aquitard layer within the Ypresian Aquifer System (Geets et al., 2000; Jacobs et al., 1997; Steurbaut, 1998; Steurbaut et al., 2017). Hence, this study's domain includes only the upper portion of the Ypresian Aquifer System whose stratigraphic horizontal bottom lies actually deeper (-11 masl). This is done to reduce the domain nodes (and thus computational demand) and also the uncertainties in the hydraulic properties arising from the Ypresian Aquifer System's stratigraphic heterogeneity (DOV, 2026; Deckers et al., 2019; VITO and Flemish Government, 2021; Lebbe et al., 1992; Tas et al., 2023) (Appendix A – Fig. A2).

We conceptualized the regional subsurface flow being oriented downslope, parallel to the ditch. It begins from as far as the Lemberge plateau in the north and the parcel's ridge in the west and discharges either to the Gondebeek stream southwards or to the study area's ditch eastwards (Fig. 2a). The recharge and discharge divides are defined based on topographic highs (plateau, ridge) and lows (stream, ditch). With this conceptualization, we can represent the whole hillslope and its subsurface with a simple prismatic geometry (note however that the real orientation of regional subsurface flow is actually oblique to the ditch (Fig. 1a).

Only the Gondebeek stream's longitudinal section, further simplified into a single vertical plane ($y = 0$ m), is represented in the model's south side (Table 2, Fig. 2a, 2b). By disregarding the stream's cross section and detailed geomorphology (e.g., presence of meanders), less nodes are needed, thus reducing computational demands.

Through the assigned top atmospheric BC across the whole hillslope surface (9.8 ha) (Table 2, Fig. 2b), the model was forced with the precipitation and reference evapotranspiration's daily records from the RMI (2025). Meanwhile, surface runoff is calculated and separated from the subsequent mass balance calculations whenever the pressure head instantly reaches zero at any location across the surface (Šimůnek and Šejna, 2021).



For the ditch, we represented it as a half ditch whose floor is 80 cm wide and its wall is 90 cm high (Fig. 2c–e). With this half ditch configuration, all possible wetted perimeters from zero to full ditch water levels can thus be simulated. The ditch is divided into three segments (upper, middle, lower) separated by the two weirs. The segments have varying inclinations based on the ditch floor segment endpoints plotted and interpolated in HYDRUS 5 with elevations based on the RTK measurements (1.2%, 1.9%, and 1.7% slopes for upper, middle, and lower segments, respectively).

2.2.3 Mesh Structure and Observation Nodes

We used a triangular prismatic finite element (FE) mesh for the 3D setup, providing flexibility to refine the mesh structures in highly dynamic zones or interfaces like the ditch. This enhances accuracy in simulating hydraulic interactions between the ditch and the adjacent aquifer. Targeted mesh refinement allows for fewer FE nodes and thus lower computational demand than a completely refined model. We assigned observation nodes to FE nodes at the piezometer and weir locations, allowing for comparison of simulated and monitored water levels. Table 3 contains the details on the mesh structure, along with the observation node placements.

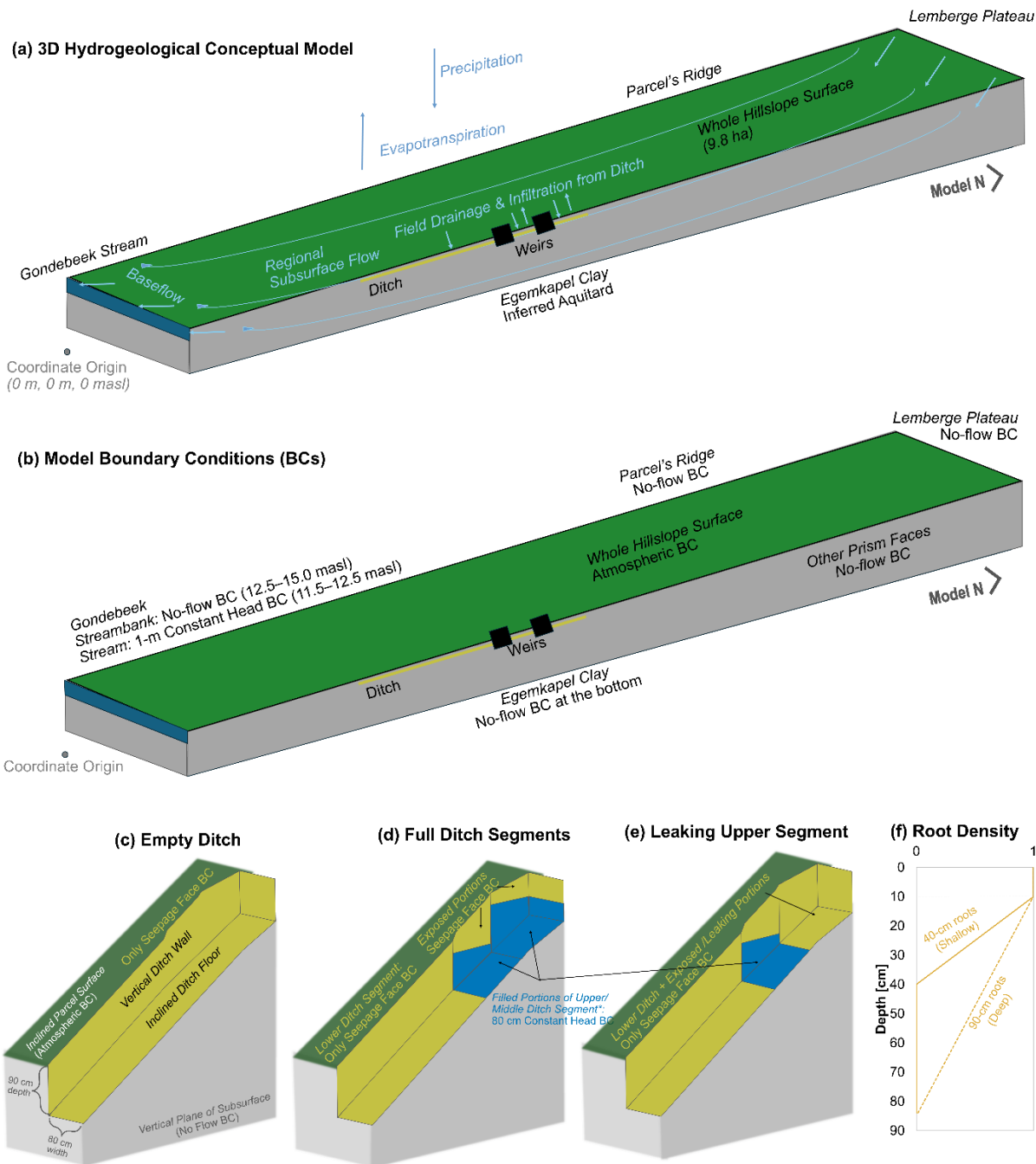


Figure 2. (a) 3D Conceptualization of this study's flow systems along with recharge and discharge divides (b) corresponding model boundary conditions (BCs) for the whole 3D hillslope and in the open ditch, with cases for (c) absent or opened weirs, (d) fully operational weirs that filled upper and middle segments, and (e) with a leaking upper weir (f) Model root density distribution for 40 (shallow) and 90 cm (deep) roots

*For each ditch segment with constant head (wall and floor): set to equilibrium from lowest FE node. Head values ≥ 0 are only considered; when head values < 0 , the nodes are reassigned with seepage face BC



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Table 3. Model specifics and justifications

Simulations		
Process	• Water Flow • Root Water Uptake • No Root Growth	To simulate subsurface water flow with transpiration from a static vegetation (grass). This ensures that transpiration flux changes would solely be brought by meteorological forcings and ditch-weir dynamics under each rooting depth case.
Model Domain		
Spatial Resolution (x- and y-axis)	• 19-m targeted size of triangular prismatic FE • Stretched with factor of 3 along y-axis • 4.0 m along ditch wall, along y-axis • 1.5 m along the end of ditch's (half-) floor, along y-axis	This results in denser node distribution along the x-axis, allowing to accurately represent the subsurface flow perpendicular to the ditch. These generate finer mesh resolution towards the ditch. This allows for properly representing filled and exposed portions along the ditch wall and floor, including the appropriate orientations (i.e., inclined ditch wall and floor, horizontal water surface) (Fig. 1b, 2c–e).
Spatial Resolution (z-axis)	• 5 cm at 0–3.5 m depths • 50 cm at 3.5 m downwards to the Egemkapel clay	Finer resolution on shallow zones allows to represent simulated shallow water table changes and ditch water levels more accurately. The 3.5-m boundary provides leeway to accurately represent receding water tables (whose largest observed depth is 2.5 m from surface in the northwest Piezometer (NW)).
Temporal Resolution of Simulation Outputs	Daily	Based on temporal resolution of recorded precipitation and reference evapotranspiration from the RMI (2025).
Observation Node Locations	Within each parcel piezometer locations (Fig. 2): • the FE node closest to 18.3 masl Within the weir locations: at the ditch floor • 19.1 masl (middle ditch segment) • 19.8 masl (upper ditch segment)	The value 18.3 masl is arbitrarily selected to record simulated pressure heads with minimal influences from both simulated regional groundwater flow and near-surface dynamics unrelated to the ditch-weir setup (e.g., root water uptake). To obtain the water table levels (i.e., hydraulic heads), these recorded pressure heads were then added to that closest node's actual elevation. To record simulated ditch water levels at weir locations along the ditch floor. To obtain the ditch water levels (hydraulic heads), these recorded pressure heads were then added to 19.1 or 19.8 masl for the middle or upper ditch segments, respectively.
Hydraulic Parameters of the Model Material		
Hydraulic Model Type	Single Porosity van Genuchten-Mualem model (Mualem, 1976; Van Genuchten, 1980)	The model material represents both Quaternary and Ypresian aquifer systems, which are generally unconsolidated porous formations (DOV, 2026; Deckers et al., 2019; VITO and Flemish Government, 2021; Tas et al., 2023)
θ_r	0.0009 cm ³ cm ⁻³	Optimized by fitting the water retention data using the RETC code (Van Genuchten et al., 1991) with the van Genuchten-Mualem model shown in Eq. (2) (Mualem, 1976; Van Genuchten, 1980). Values were taken from the last fitting iteration before the residual water content (θ_r) was fixed to 0. The water retention data was based on the pF curves derived using sandbox and ceramic plates of 12 soil samples (Appendix A – Fig. A5).
θ_s	0.42 cm ³ cm ⁻³	
α	0.0139 cm ⁻¹	
n	1.3318	
$K_{sx} (= K_{sy})$	Aquifer: 140 cm d ⁻¹	The initial value used was 48 cm d ⁻¹ , which is the effective horizontal K_s of Quaternary Aquifer System and Ypresian Aquifer System's top permeable layer (Yd 6) (Appendix B – Table B3) (Lebbe et al., 1992; Tas et al., 2023). We then increased this to 140 cm d ⁻¹ to manually calibrate under the Dynamic scenario (40 cm roots) against the observed groundwater levels. This value will not differ much even when corrected for hillslope's inclinations (i.e., $K_{sx} \cos(2\%) \approx K_{sx}$).
	Ditch Walls and Floors: 14 cm d ⁻¹	We reduced the aquifer's hydraulic conductivity by a factor of 10 to consider potential impacts of clogging from debris (soil, plant parts, etc.).



<i>Anisotropy</i> (K_{sz}/K_{sx})	0.016	Ratio of thickness-weighted geometric means of vertical and horizontal K_s of Quaternary Aquifer System and Ypresian Aquifer System's Yd 6 layer (Appendix B – Table B3) (Lebbe et al., 1992; Tas et al., 2023)
<i>L</i>	0.5	Default value for inorganic material (Dettmann et al., 2014; Mualem, 1976)
Vegetation Parameters		
<i>LAI</i> (temporally constant)	1.57	Italian ryegrass' average temporal LAI estimated from plot experiments (Pinza et al., 2025)
<i>rExtinct</i>	0.463	Prescribed value in HYDRUS (Šimůnek et al., 2022b)
<i>P0</i> or <i>h1</i>	-10 cm	Prescribed values for grass in the Feddes et al. (1978) model (Taylor and Ashcroft, 1972; Wesseling et al., 1991)
<i>P0pt</i> or <i>h2</i>	-25 cm	
<i>P2H</i> or <i>h3</i> *	-300 cm	*h3 is based on Eq. (10) (Šimůnek et al., 2022a): $h3 = \begin{cases} P2H + \frac{P2L - P2H}{r2H - r2L}(r2H - T_p), & r2L < T_p < r2H \\ P2L, & T_a \leq r2L \\ P2H, & T_a \geq r2H \end{cases} \quad (10)$
<i>P2L</i> or <i>h3</i> *	-1 000 cm	
<i>P3</i> or <i>h4</i>	-8 000 cm	
<i>r2H</i>	0.5 cm d ⁻¹	Prescribed values in HYDRUS. A ω_c value of 1 disables root water uptake compensation (Šimůnek et al., 2022a).
<i>r2L</i>	0.1 cm d ⁻¹	
<i>Critical stress index</i> (ω_c)	1	
Other Boundary Condition Parameters		
<i>hCritA</i>	-20 000 cm	Arbitrarily set, falling within the prescribed range of -15 000 to -100 000 cm (Šimůnek and Šejna, 2018)

2.2.4 Vegetation

The daily reference evapotranspiration values obtained from the RMI (2025) were then partitioned to daily potential transpiration (T_p) and potential soil evaporation (E_p) based on Beer's Law shown in Eq. (11) (Ritchie, 1972).

$$T_p = ET_0(1 - e^{-rExtinct(LAI)})$$

$$E_p = ET_0 - T_p = ET_0 e^{-rExtinct(LAI)} \quad (11)$$

where $rExtinct$ is the radiation extinction coefficient, equal to 0.463 (Šimůnek et al., 2022b), and LAI is the leaf area index. Despite the spatiotemporal variations in the actual field vegetation during the experimental period (Appendix A – Fig. A4), this study simulated hypothetical grass transpiration across the whole hillslope with a constant LAI of 1.57, which is the Italian ryegrass (*Lolium multiflorum*) average temporal LAI estimated from plot experiments (Pinza et al., 2025). Default Feddes root water uptake parameter values for grasses in HYDRUS were also used (Table 3) (Feddes et al., 1978; Šimůnek et al., 2008). The rooting depth distributions were further assumed to be fixed in time. All these simplifications on vegetation parameterizations were performed to limit the ways vegetation variations can drive transpiration flux changes, already subject to meteorological forcings and ditch-weir dynamics. Only the grass rooting depth distributions were varied (i.e., shallow vs deep), each applied identically across the whole 9.8 ha inclined surface. Rooting depth variations alone were proven to suffice in significantly influencing transpiration flux changes and hence the water budget (Pinza et al., 2025).

The shallow root distribution (40 cm depth) was derived from the reported Italian ryegrass' root biomass distribution in loamy clay Cambisol under temperate oceanic climate (Durand et al., 2010; Kunrath et al., 2015) and in loam under



300 phytotron conditions (Lambrechts et al., 2014). Meanwhile, the deep root distribution (90 cm, matching the ditch's depth) is similar to the Italian ryegrass' root distribution in non-compacted sandy soils under temperate oceanic climate (Pinza et al., 2025) (Fig. 2f).

2.2.5 Ditch-weir Dynamics

305 In the field, the ditch segments have been occasionally filled or empty throughout the experimental period by closing and opening the weirs. In the model, we simulated this by instantaneously switching between empty (seepage face only) and filled ditch segments (80 cm water level + seepage face above the water level) across subperiods, respectively (Appendix B – Table B4). These simulated subperiods were based on the observed ditch water levels in the upper and middle ditch segments i.e., Dynamic Scenario, aggregated on a daily time step (Table 4). Simulated pressure heads at the end of a subperiod were used as initial conditions for the next subperiod. We also considered the subperiods when the upper weir
 310 leaked (Fig. 2e, Appendix B – Table B4).

Table 4. Simulated scenarios and representing boundary condition (BC) Types.

Scenario	Concept	BC Types
Dynamic	Simulates ditch segments that have been occasionally filled and emptied in accordance with the observed ditch water levels Based on subperiods of observed daily ditch water levels per ditch segment (Appendix B – Table B4). The leaking periods of upper weir were also considered (Appendix A – Fig. A4).	For each subperiod: • If the observed ditch segment water levels < 40 cm: treat as empty i.e., Seepage Face only (Fig. 2c) • If the observed ditch segment water levels $\geq$ 40 cm (Fig. 2d, 2e): treat as filled i.e., ○ Seepage Face (all nodes above 0 cm constant pressure head level) ○ Constant Head = 80 cm (assigned under equilibrium from the ditch segment's lowest node) Before 05 April 2024, the upper ditch segment was not yet monitored (Appendix A – Fig. A4). Thus, its simulated ditch water levels were assumed to be the same with the middle segment.
Empty Static	Simulates what if the ditches had <i>always</i> been empty during the experimental period (i.e., what if weirs had always been left open or the ditch never had weirs)	• Seepage Face only (Fig. 2c)
Full Static	Simulates what if the ditch segments had <i>always</i> been full with maximum water level possible (i.e., 80 cm) during the experimental period (i.e., what if weirs had always been closed and ditch water levels never declined anytime)	• Constant Head = 80 cm (assigned under equilibrium from the ditch segment's lowest node) • Seepage Face (all nodes above 0 cm constant pressure head level) (Fig. 2d)



2.2.6 Calibration of Hydraulic Properties

The multiple hydrostratigraphic units underlying the hillslope were simplified into a single model material throughout the whole domain. This heterogeneity was represented using a single anisotropy factor based on the effective horizontal and vertical hydraulic conductivities of the Quaternary Aquifer System and the Ypresian Aquifer System's Yd 6 layer (Appendix B – Table B3). This simplification overcomes the uncertainties from the large variabilities on the hydraulic properties of both Quaternary and Ypresian Aquifer Systems, the latter being composed of both permeable and less permeable sublayers (DOV, 2026; Deckers et al., 2019; VITO and Flemish Government, 2021; Lebbe et al., 1992; Tas et al., 2023) (Appendix A – Fig. A2). Moreover, this bypasses the potential need for denser mesh structure when representing any supposed hydrogeologic contacts (Šimůnek and Šejna, 2009). The ditch and aquifer also share the same hydraulic properties except for the saturated hydraulic conductivity of the ditch floor and ditch walls (reduced to 10% of aquifer's) (Table 3). This is to consider potential clogging of the ditch floors and walls by eroded soil or plant litter. Even with these simplifications, we managed to simulate realistic groundwater levels and water fluxes, which was the aim of the simulations.

We used the measured groundwater level data to adjust the saturated hydraulic conductivity of the simulated soil-groundwater system. For parameter adjustments, we used the entire time series in the Dynamic Scenario with grass that has 40 cm rooting depth. This scenario was the closest to reality, although still simplified, given the prominence of shallow rooted crops (yellow peas and green peas in 2022; spring barley in 2023; turnip as cover crop in 2023 and 2024; and potato in 2025) and fallow conditions during the months before sowing and after harvesting (Appendix A – Fig. A4). The water retention parameters were measured using sandbox and pressure plate measurements and fitted based on the van Genuchten function using RETC (Van Genuchten et al., 1991) (Table 3). All these hydraulic parameter values were used consistently for all subsequent scenarios under 40- and 90 cm rooting depth parameterizations.

We implemented a spin-up period using the 11 months (01 September 2021 – 31 July 2022) preceding the model simulations. During the spin-up period, the whole ditch was represented using only seepage face BC (Fig. 2c).

2.3 Scenario Analyses

Under the same experimental period, we also simulated the Dynamic Scenario under 90 cm rooting depth to assess the effect of rooting depth on the water balance. Moreover, we added two hypothetical scenarios ("Empty Static" and "Full Static") under separate 40 and 90 cm rooting depth parameterizations. These scenarios reflect the impact of having constantly empty and full ditch segments in the simulations, respectively. They involved manipulating the ditch water levels for the upper and middle segments using seepage faces BC for the Empty Static Scenario (Fig. 2c), combined with constant head BC for the Full Static Scenario (Fig. 2d, Table 4). The resulting head distribution from prior model spin-ups was also used as the initial

conditions for all these scenarios. The whole modeling workflow from model setup to scenario analyses is summarized in Fig. 3.

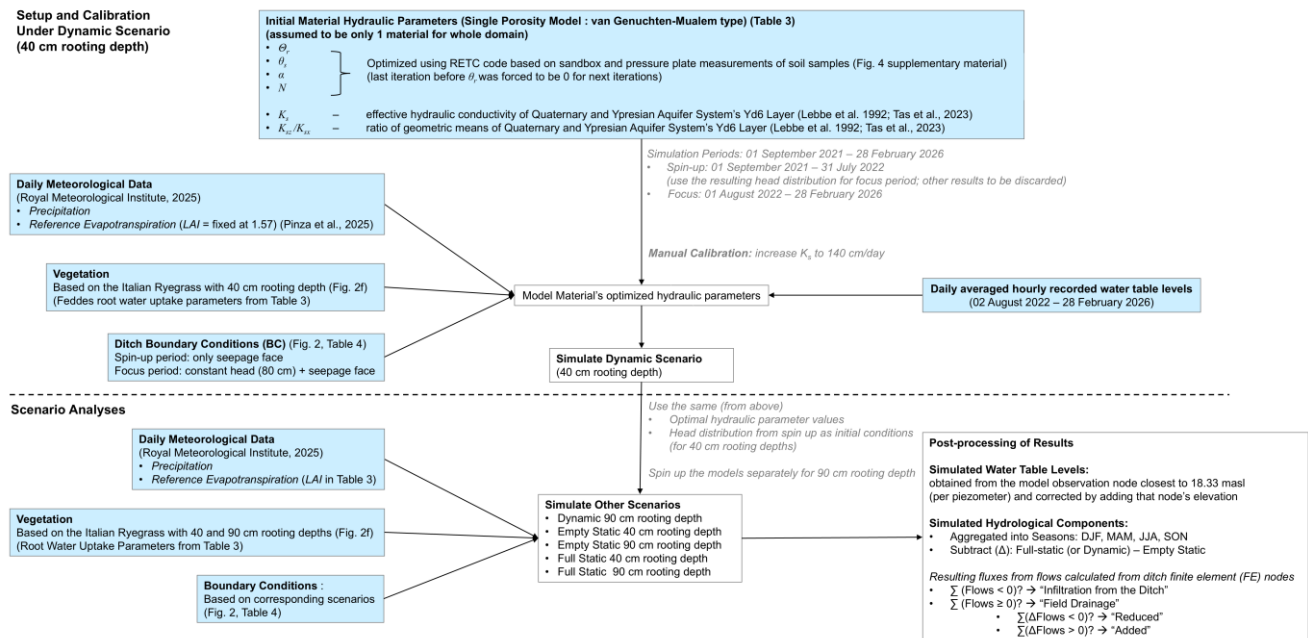


Figure 3. Modeling workflow of this study.
Abbreviations: DJF = December–January–February; MAM = March–April–May; JJA = June–July–August; SON = September–October–November.

3 Results

3.1 Observed and Simulated Water Levels

In a maximum of three days after closing a weir, the observed water level in the proximity of the weirs rose to 80 cm. During summer, the filled segments consecutively dry out if no new rainfall arrives, due to infiltration in the adjacent parcel. Conversely, after opening the weir, the ditch water levels instantly declined to the ditch floor. Despite these frequent ditch water changes, there is very little response in the observed water tables recorded from the piezometers (Fig. 4). Therefore, we use the model simulations to disentangle systemic groundwater dynamics and small responses due to weir management.

The simulations under the Dynamic Scenario captured the observations well during wet periods, including the peaks in most winters and troughs during the wet summer and autumn of 2024 (Fig. 4). These simulations also captured the amplitude/magnitude of the observed groundwater levels' fluctuation across the parcel where fluctuations were the smallest nearest to the ditch (Fig. 1a). However, all simulations underestimate the water table rises after rainfall events during and at the end of dry periods, especially during autumn 2022, summer–autumn 2023, and dry winter 2026. The setup with shallow



roots (40 cm) also simulated generally higher water table levels than the deep roots (90 cm) (Fig. 4) especially during drier years (2023, 2025) and summers–autumns. This shows that rooting depths matter a lot in these types of model simulations.

One must realize, however, that the scenarios remain very simplified representations of reality. The model represents the vegetation as “static grass” (Table 2). In reality, there were different crops in space and time (Appendix A – Fig. A4), which certainly leads to a mismatch between simulations and observations (Fig. 4). Their evaluation metrics are in Appendix B – Table B5.

As expected, the scenarios with filled ditch segments generally simulated higher water tables than the scenario with always empty ditch segments (Empty Static scenario). Constantly filled segments (Full Static scenario) yielded higher water tables than occasionally filled segments (Dynamic scenario). These increases in water table levels vary spatiotemporally. These increases are largest near the ditch (i.e., eastwards) during summer–autumn, reaching 100 and 150 cm for the shallow- and deep rooted cases, respectively, 1–2 meters away from the ditch. Conversely, these increases diminish with distance from the ditch (i.e., westwards) and during winter. Moreover, during the dry seasons under the Empty Static scenario, simulated water table levels dropped below the ditch floor, after which the decline slowed.

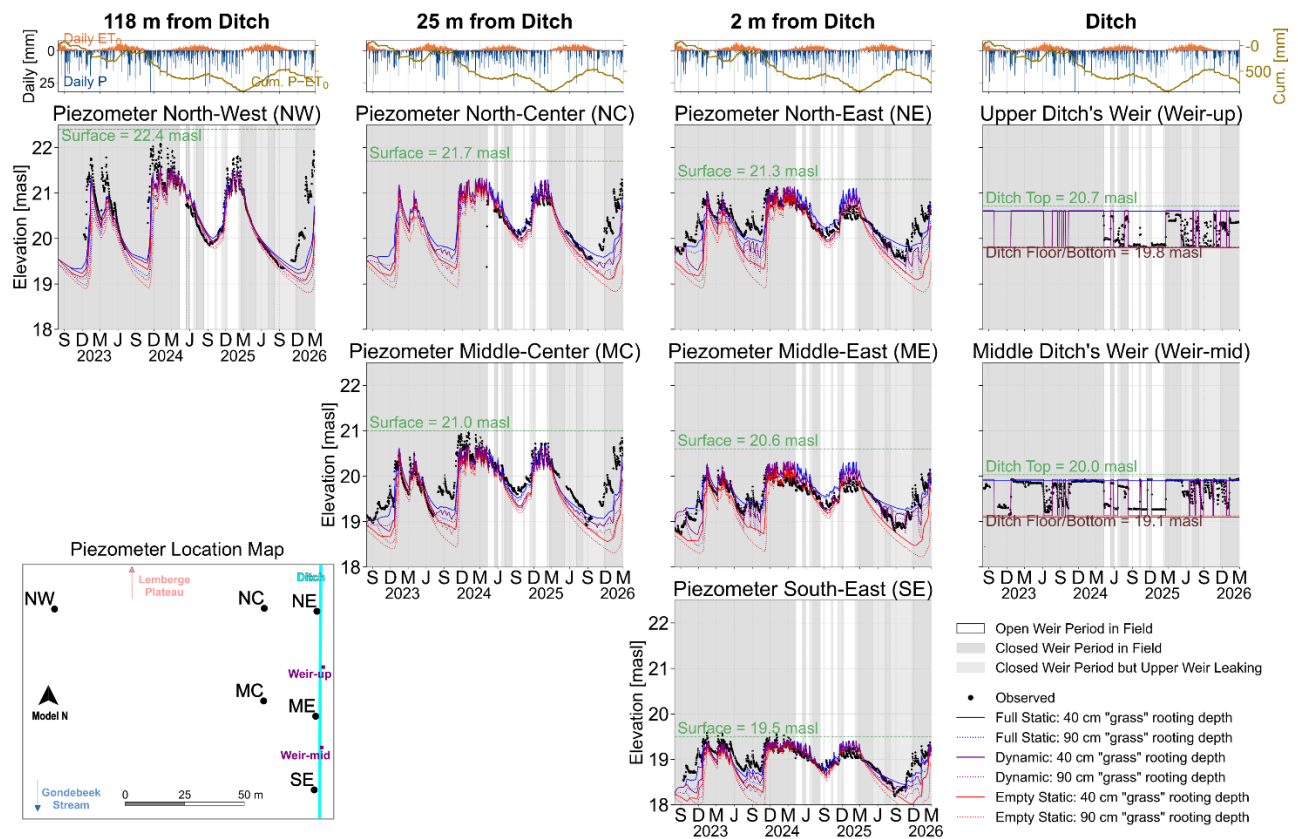


Figure 4. Daily observed (black dots) and simulated (colored lines) water table and ditch water levels with hypothetical grass roots under various scenarios. “S”, “D”, “M”, “J” pertain to September, December, March, and June.

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3.2 Scenario Analyses

3.2.1 Water Budgets of Scenarios

The *Field Drainage* (flow from the aquifer to the ditch) (Fig. 5b) was obtained by summing all positive values of volume flows calculated in the FE nodes comprising the ditch (Fig. 6f). Meanwhile, the *Infiltration from Ditches* (flow from the ditch to the aquifer due to the filled ditch water levels being higher than the adjacent water table) (Fig. 5d–e, Appendix A – Fig. A8) was based on the summed negative values of volume flows in the ditch’s FE nodes, reported as absolute values (Fig. 6g). The summed calculated volume flows of these processes, along with the hillslope’s other hydrologic processes, were all divided by the whole hillslope surface area (9.8 ha) (Fig. 5). This retains the proportions of these hydrologic processes’ contributions to the whole hillslope system. Note that in HYDRUS 5, positive and negative values denote flows out and into the model domain, respectively (Šimůnek et al., 2022a).

For all scenarios, most of the seasonal outflows are in actual evapotranspiration (100–300 mm) (Fig. 6b), followed by the baseflow i.e., flow from the aquifer to the Gondebeek stream (40–75 mm) and then surface runoff (0–65 mm) (Fig. 6d–e). Processes related to the ditch such as field drainage and infiltration from the ditch have smaller fluxes, ranging only 0–20 mm and 0–10 mm respectively under both rooting depths (Fig. 6f–g). Moreover, constantly full ditch segments contributed to higher ditch infiltration than occasionally filled segments (Fig. 6g). Compared to shallow roots, the deeper roots resulted in higher evapotranspiration during dry summers 2023 and 2025 by +35 mm (Fig. 6b). Deeper roots also led to lower values of water storages by -8 to -60 mm, lower baseflows by -0.2 to -6 mm during dry years 2023 and 2025 (Fig. 6c, 6e), runoff in winters 2022–2023 and 2025–2026 and autumn 2023 by -6 to -10 mm (Fig. 6d), and field drainages in 2023 by -4 mm. In the wet year 2024, all these fluxes were generally similar for shallow and deep rooting depths (Fig. 6). These showed that the partitioning of inflows (into actual evapotranspiration, runoff, baseflow, field drainage, and storage) depends on rooting depth, seasonality, and interannual variability (i.e., dry vs wet year).

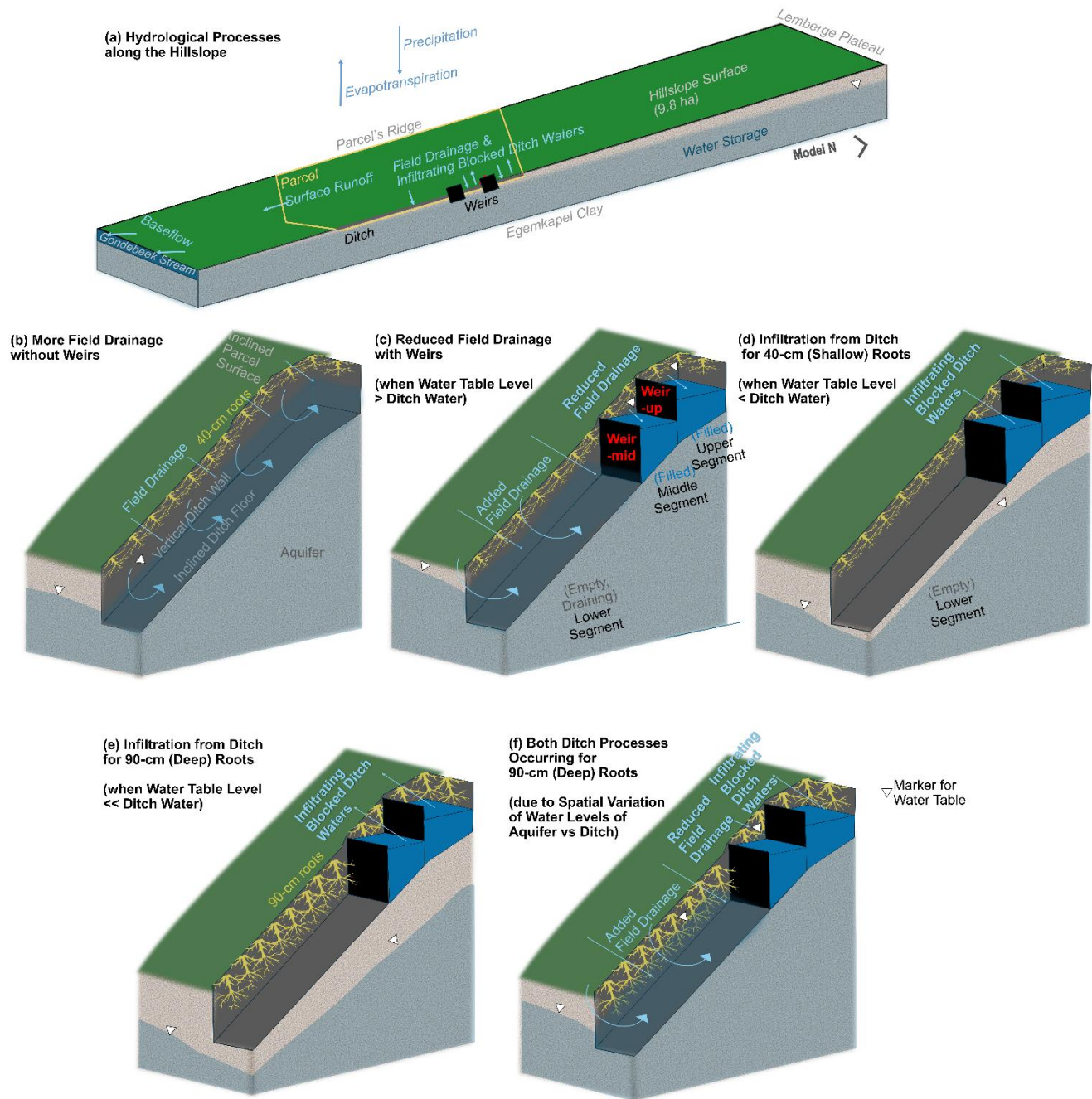


Figure 5. Hydrological components simulated in this study (a) along the hillslope, and open ditch-aquifer interactions (b) without weirs and (c–f) with weirs, under various cases of water table levels and rooting depths. Subfigures (b–f) show the half-ditch in 3D views

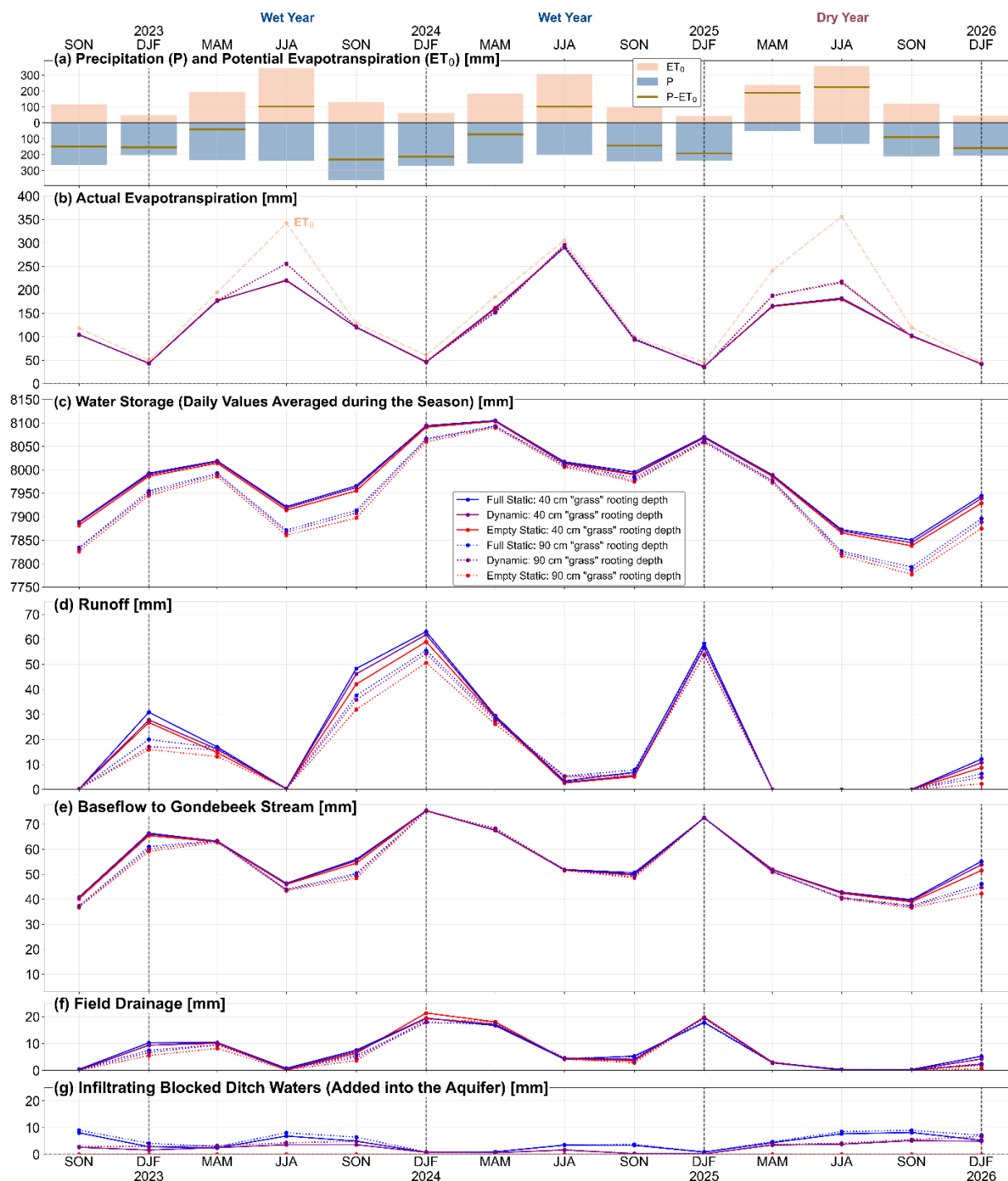


Figure 6. Fluxes and storages for rooting depths of 40 cm (shallow) and 90 cm (deep) under the Dynamic, Full Static, and Empty Static scenarios. The complete seasonal water balances are in Appendix A – Figure A6.

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Abbreviations: ET_0 = reference evapotranspiration, P = precipitation; DJF (Winter) = December–January–February, MAM (Spring) = March–April–May, JJA (Summer) = June–July–August, SON (Autumn) = September–October–November.



3.2.2 Impacts of Weirs to Hydrological Components

To calculate the impact of weirs on the hydrological components (Fig. 5), we subtracted the fluxes between Full Static (or Dynamic) and Empty Static scenarios from Fig. 6 (Fig. 7). For the field drainages (i.e., positive values of volume flows in ditch's FE nodes for both scenarios), their differences can be related to (1) *Reduced Field Drainage*, representing the extra water retained from reducing open ditch drainage with weirs, and (2) *Added Field Drainage*, representing the extra water drained into the open downstream part of the ditch due to the higher groundwater levels caused by the closed weirs in the upper segments. For these two processes, we subtracted the volume flows between the Full Static (or Dynamic) and Empty Static scenarios node per node along the ditch. To calculate the *Reduced Field Drainage*, we summed up all negative values of these obtained node differences across the ditch FE surfaces per season (reported as absolute values in Fig. 7g). To calculate the *Added Field Drainage*, we similarly summed up all positive values of these obtained node differences (Fig. 7f). Afterwards, we divided these summed flows of both processes by the whole hillslope surface area (9.8 ha).

With the weirs present, both (1) water retention from reduced field drainage and (2) infiltration from ditches with weirs contributed to the increase in water availability within the hillslope system throughout the experimental period (Fig. 5c–e). In winters 2023–2024 and 2024–2025, water retention from reduced field drainage mainly contributed to the water availability increase (Fig. 7g), partitioned to water storage, surface runoff (Fig. 7c–d), and added field drainage especially in the lower ditch segment (Fig. 7f, Appendix A – Fig. A8). During summers–autumns in 2022–2024, the infiltration from ditches had a larger contribution in water availability increase (Fig. 7h), also partitioned into water storage, surface runoff, and added field drainage (Fig. 7c–d, f). In the whole dry year 2025 when both the observed and simulated water tables were low (Fig. 4), the infiltration from ditches had also more contribution, partitioned mostly to storage and slightly to runoff, field drainages and baseflows in winter and also slightly to actual evapotranspiration in spring–summer (Fig. 7b–f). For the other seasons of 2025, extra baseflows and changes in actual evapotranspiration never exceeded 1 mm (Fig. 7b, e).

The infiltration from the ditch corresponds to the total amount of water refilling the upper and middle (half) ditch segments due to closed weirs. In Fig. 7h, we indicate the total amount of these refilled waters every season, estimated based on the ditch segment dimensions and maximum ditch water level heights (then divided by 9.8 ha, the hillslope surface area) and the number of refilling times based on observed ditch water levels per segment (Fig. 4). During autumn 2022, winter 2022–2023, summer 2023, and the wet year 2024, the simulated infiltration from the ditch (Dynamic Scenario, 40 cm rooting depth) is similar to the total refilling amount. In those times, summers–autumns generally had the highest infiltration (3–4 mm). During the dry period of March 2025 – March 2026, the simulated seasonal ditch infiltration (3–5 mm) slightly overestimates the refilling amounts (2–4 mm) every season (Fig. 7h). This could be due to generally low water table levels near the ditch simulated in 2025, driving more water to infiltrate the aquifer from the ditch (Fig. 4, Fig. 5d–e).

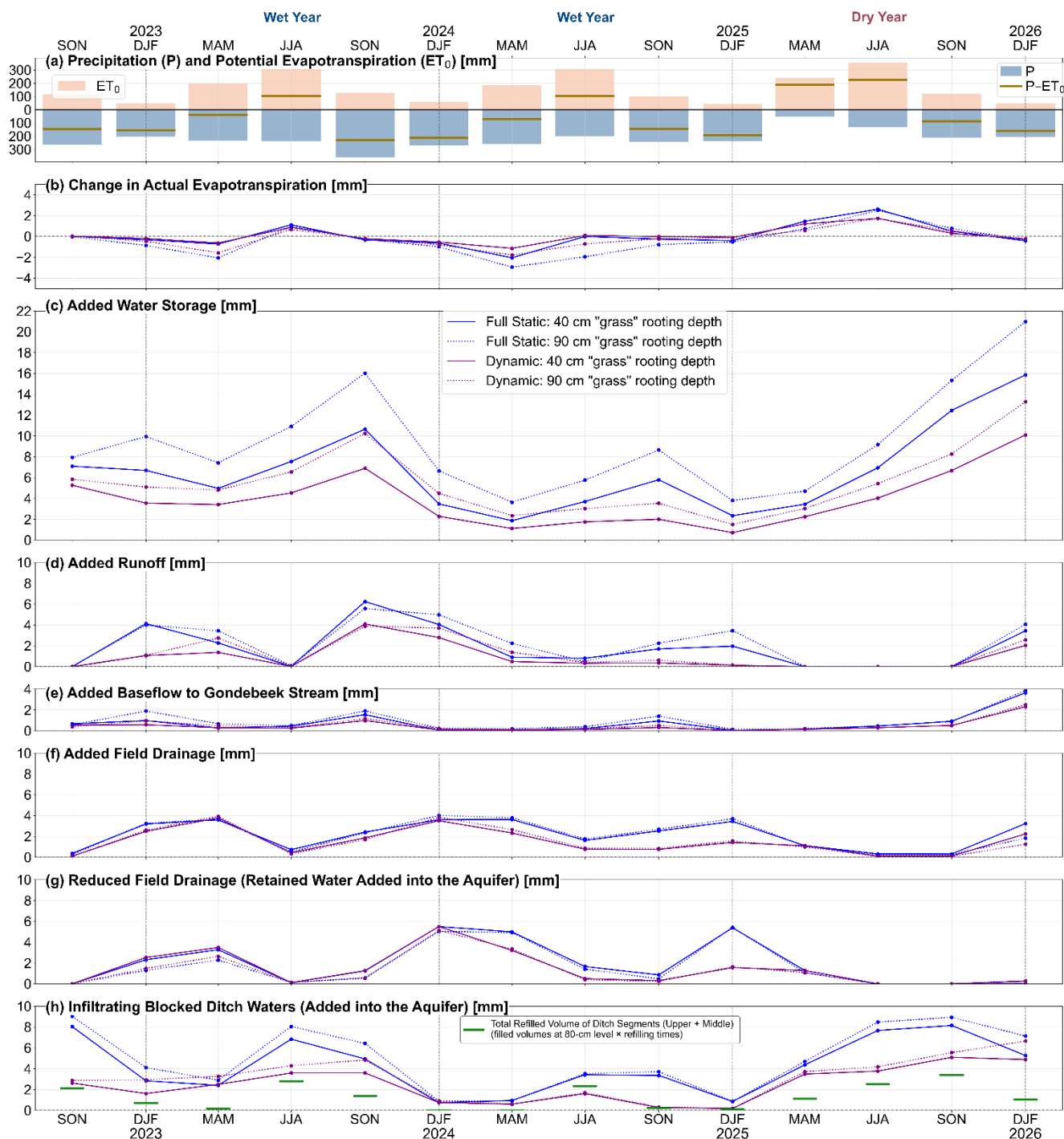


Figure 7. Differences in fluxes and storages (b–f) due to weir management (g–h) between Full Static (or Dynamic) and Empty Static scenarios per rooting depth parameterization. The complete seasonal water balances are in Appendix A – Fig. A7.

Abbreviations: ET_0 = reference evapotranspiration, P = precipitation; DJF (Winter) = December–January–February, MAM (Spring) = March–April–May, JJA (Summer) = June–July–August, SON (Autumn) = September–October–November.



4 Discussion

4.1 Partitioning of Added Water Availability by the Weirs

Table 5 shows the overall water balance for the whole experimental period (1 August 2022 – 28 February 2026). If ditches had always been open (Empty Static Scenario), precipitation would have been allocated to actual evapotranspiration of shallow rooted vegetation, baseflow to Gondebeek stream, storage, runoff, and field drainage. If roots had been deeper, actual evapotranspiration could increase, but baseflow, runoff, and field drainages would have decreased. Weir management would further increase storage, runoff, field drainage, and (slightly) baseflows especially during wet years and seasons (Fig. 7d–f, Table 5).

Table 5. Overall water balances [mm] across scenarios during the experimental period 01 August 2022 – 28 February 2026

Hydrologic Processes in Water Balance [mm]	40 cm Rooting Depth			90 cm Rooting Depth		
	Empty Static	Dynamic	Full Static	Empty Static	Dynamic	Full Static
(a) Precipitation	3143	3143	3143	3143	3143	3143
(b) Actual Evapotranspiration	1820	1821	1821	1922	1920	1917
(c) Baseflow to Gondebeek Stream	784	790	794	749	757	763
(d) Runoff	244	257	270	205	221	235
(e) Field Drainage	98	99	102	84	89	91
(f) Infiltrating Blocked Ditch Waters	0	38	63	0	46	74
(g) ΔWater Storage (final day – initial day)	166	173	176	176	187	192
Mass Balance Error i.e., (a) + (f) – (b) – (c) – (d) – (e) – (g)	30	40	43	6	15	18
Other Derived Fluxes and Volumes [mm]						
(h) Added Field Drainage	-	21	30	-	21	29
(i) Reduced Field Drainage	-	20	27	-	17	23
(j) Total refilling volume based on ditch water levels and ditch dimensions	-	18	-	-	18	-

Actual evapotranspiration did not change much even with weir management. This shows that simulated higher water tables caused by weir management (Fig. 4) did not necessarily translate to hydrological benefits for the vegetation (Fig. 7b, 7e). This was also demonstrated in the weir management study of Gliege et al. (2016). In our study, this could be explained by either actual evapotranspiration being already close to the evapotranspiration demand as in the case of summer 2024 (Fig. 6b) or the presence of water stress. The presence of wet stress during wet springs 2023 and 2024 inhibited uptake of water gained from the weir management, hence the negative changes in actual evapotranspiration due to weirs (Fig. 5f). This wet stress during springs 2023 and 2024 is evidenced by weighted averaged pressure heads ($h > -25$ cm, the h_2) on root zones of both 40- and 90 cm rooting depths, mapped by Pinza et al. (2026). Moreover, the presence of drought stresses during summers 2023 and 2025 also reduced the water uptake below the optimal maximum. Only localized areas usually closest to the ditch had their root water uptakes improved to their optimal maximum by the gained water from the weir management,



leading to little boosts in actual evapotranspiration. Maps of the root zones' weighted averaged pressure heads (Pinza et al., 2026) also show the prominence of drought stress (i.e., $h < h_3$) and the local areas with improved uptakes by weir management (i.e., $h > h_3$) (note: values of h_3 can be determined using Eq. (10)). These imply that in verifying weir management's hydrologic impacts using numerical simulations, it is important to demonstrate not only the rises in water tables but also the impacts to water balance components. Without models able to disentangle water balances, generalizing these hydrological benefits might be difficult. Moreover, knowing the vegetation dynamics in the site is also important especially when influenced by the weir management. Vegetation dynamics include vegetation species and distribution, history, growth, and responses under spatiotemporally dynamic soil hydrology (such as the water stresses in our study). In fact, field observations on the adjustable weir management's effect on the vegetation dynamics have not yet been reported. Thus, vegetation dynamics can be very challenging to incorporate into the model, but this helps accurately verify how much the vegetation and other outflow components (e.g., nearby surface waters) can actually benefit from weir management. Especially in this climate change context, we also recommend simulating vegetations' responses with weir management under both future wet and dry climate scenarios. This is to consider that some regional hydrologic models that incorporate these small scale water retention measures to watershed management do not include certain vegetation responses such as wet stress and vegetation growth brought by the water retention measure (Allen et al., 1998; Burke et al., 2006; De-Ville et al., 2024). In many other regional hydrological models, vegetation is even treated as a static component (Gu et al., 2024; Jayathilake and Smith, 2020; Kordrostami et al., 2025).

4.2 Presence of Infiltration from the Ditch

Adjustable weirs are perceived to reduce field drainage to open ditches, promoting water retention (Appendix B – Table B1). However, during dry periods when the ditch waters blocked by the weirs are higher than the adjacent water table, these ditch waters can also infiltrate into the neighboring parcel, thus also increasing water table levels (Fig. 5d–e). These infiltrating ditch waters significantly increase water availability, which according to the overall water balance of simulations (Table 5), contributed two to three times that of water retention from reduced field drainage during the experimental period. Even the total refilled ditch volume during the experimental period (18 mm) is close to the amounts of retained water from reduced field drainages (20 mm for the 40 cm roots under the Dynamic Scenario (Table 5)). All these imply that open ditch-aquifer interactions should be treated as two way when modeling adjustable weir management.

4.3 Limitations of this Study

The ditch waters blocked by the weirs were parameterized simply based on the observed water levels. However, these water levels are also a function of fluxes of sources not included in our model. Outside the parcel (the map in Appendix A – Fig. A1a), other potential sources are (1) the field drainage from another adjacent parcel that slopes down westward, situated east of the ditch, (2) the roof drainage of 14 discharging chicken coops upstream, and (3) runoff from the roads near the ditch. Estimating their fluxes (or flows) would help quantify their temporal contributions in filling the ditch. For the subsurface



field drainage (i.e., groundwater seeping out of the ditch) from the other parcel, the water table levels in that parcel can be monitored. To quantify the fluxes of subsurface field drainage from that parcel, these water levels can be used to perform numerical simulations similar to our study's approach or to calculate fluxes using analytic equations for flow in unconfined aquifers. For the flows of roof drainage and infiltration excess runoff from the roads, our parcel, and the adjacent parcel, their contributing surface areas and rainfall intensities (i.e., Rational Formula) can be used. As the meteorological forcings in our study were of daily resolution, our study would have difficulty simulating infiltration excess runoff (Mertens et al., 2002; Šimůnek and Weihermüller, 2018).

All these quantified contributions to the ditch could have been useful to assess the capacity of weir management in the ditch to indirectly attenuate and retard peak discharges of Gondebeek stream. Under the Empty Static scenario, all the flows from these external sources, surface runoff and field drainage from our parcel can be conceptualized to end up rapidly in the Gondebeek stream. Under the Dynamic (or Full Static) scenarios, only the runoff, added field drainage from our parcel (Fig. 5c), and the external sources contributing downstream of the weirs (lower ditch) can quickly feed the Gondebeek stream. Hence for each scenario, the daily fluxes of these surface flows, along with the baseflows, can be summed up to obtain the daily hydrographs of Gondebeek stream. If significant infiltration excess runoff feeds the ditch and surface waters downstream, finer temporal resolution of precipitation might be needed as well to properly simulate this runoff. These hydrographs can then be analyzed across the scenarios to evaluate the attenuation and retardation potential of weirs (in the ditch) on Gondebeek stream, similar to the approach of Rehman et al. (2024) (Appendix B – Table B1). These, however, are beyond this study's scope.

Given that surface runoff has not been observed under the regular management of the parcel for crops (Appendix A – Fig. A4), our study might have simulated high runoff values. This could be likely due to how HYDRUS treats runoff, which becomes separated from further mass balance calculations after being calculated from any excess precipitation that cannot infiltrate due to saturated subsurface zones and from water tables emerging anywhere on the surface (i.e., saturation excess runoff) (Šimůnek and Šejna, 2021). With this, calculated surface runoff easily accumulates in time.

5 Conclusion

Quantifying hydrological impacts of adjustable weirs is essential to assess the effectiveness of these weirs, helping verify the hydrological benefits to vegetation and nearby surface waters. This study thus performed numerical modeling of 3D subsurface water flow on an experimental parcel situated on a 2% hillslope in HYDRUS 5 in 2022–2026, encompassing both dry and wet years. This study simulated water table levels and disentangled the seasonal water balance components under weir vs no weir scenarios.



535 With weirs, field drainages are reduced, retaining more water in the aquifer particularly during wet years and seasons.
Additionally, infiltration from the ditch segments to the aquifer also contributes to the increase in water availability during
dry years and seasons. Moreover, these increases in water availability are partitioned mainly to water storage, runoff, and
field drainage but only a little to baseflows to surface waters and vegetation. Water stresses (wet and drought) experienced
by the vegetation have limited its uptake of water gained from weir management. Thus, to completely assess the weir's
540 hydrological impacts, we highlight the importance of using numerical models that can disentangle the seasonal impacts not
only on the water table levels but also on the water balance across wet and dry years. These numerical models should also be
capable of simulating infiltration of ditch waters (along with the fluxes or flows from contributing sources) to the aquifer
along with vegetation dynamics based on field evidence.

Appendix A: Additional Figures

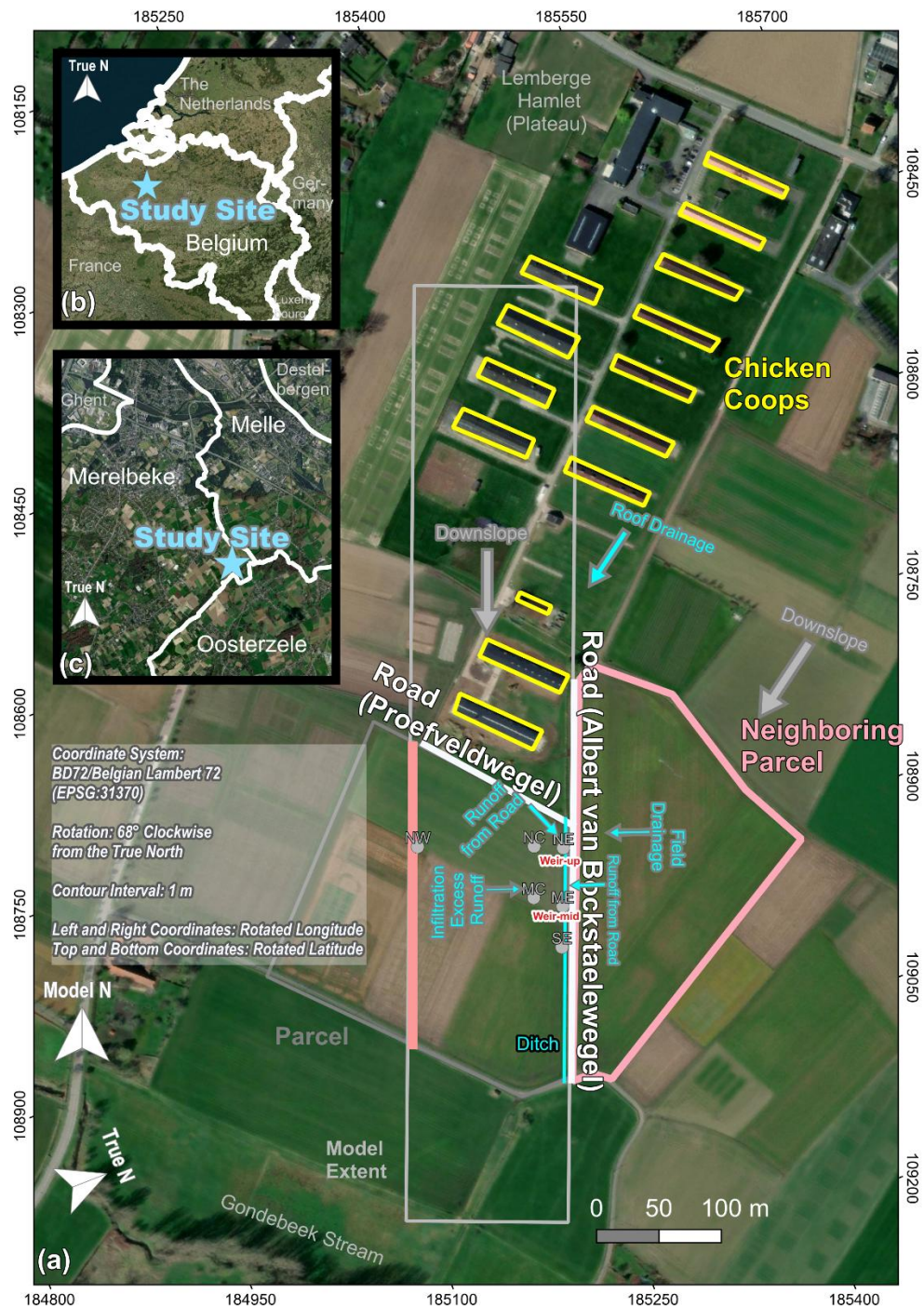


Figure A1 (a) Extended map of the study area, mainly showing the sources of ditch waters aside from this study's parcel. Note the coordinate rotation denoted by rotated tick marks, done so that the ditch axis aligns with the north-south (b) Inset location relative to nearby countries and (c) municipalities. Basemap: Bing Virtual Earth (©Microsoft, 2026)

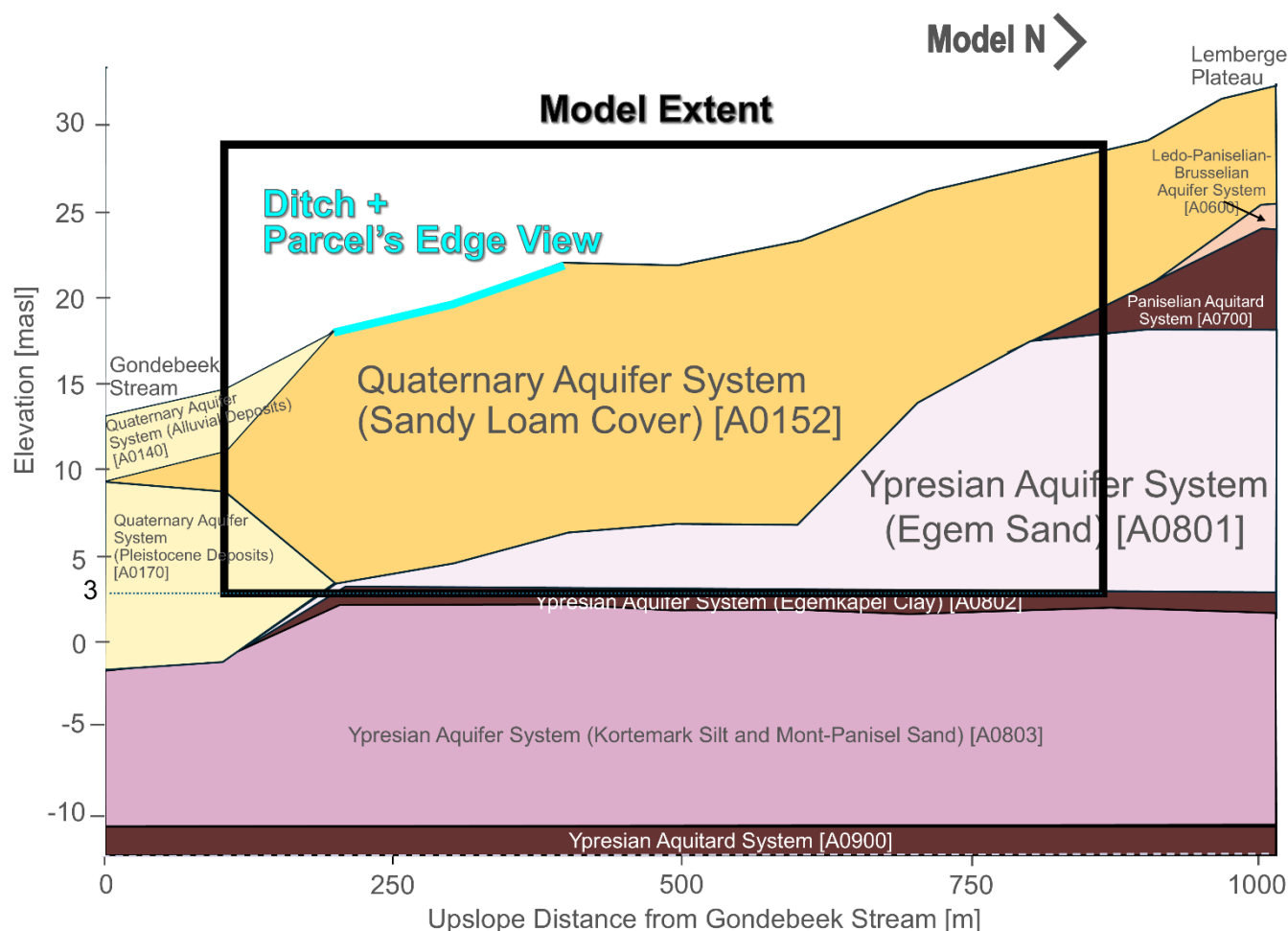
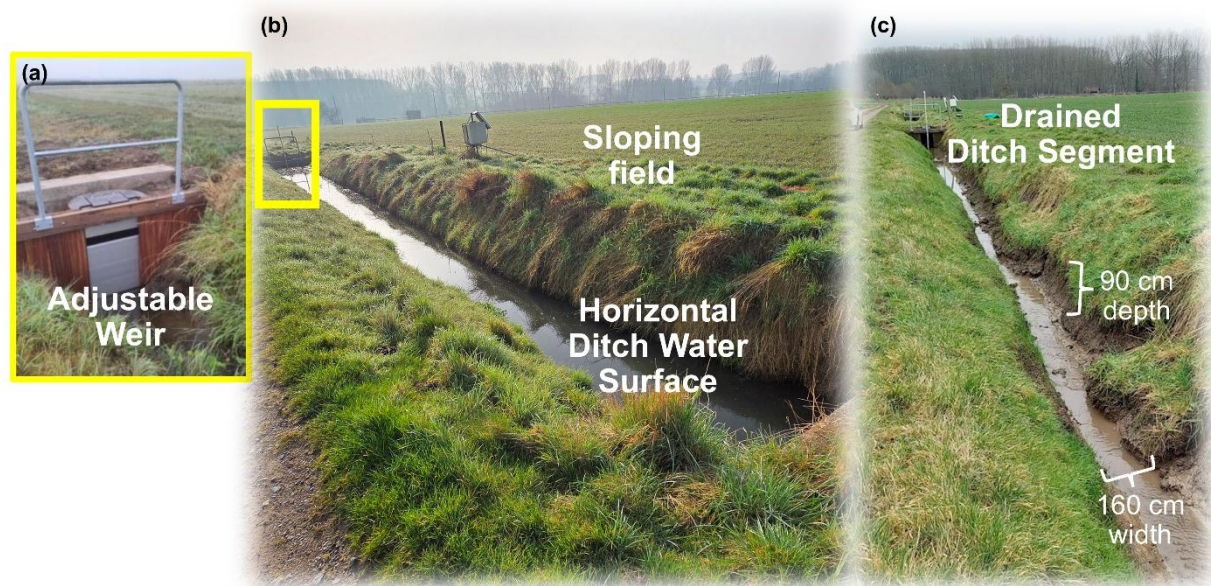


Figure A2. Schematic hydrogeologic cross section of the Lemberge-Gondebeek hillslope area and its whole unconfined aquifer above the Ypresian Aquitard System. This unconfined aquifer consists mainly of Ypresian and Quaternary Aquifer System, the horizontal Ledo-Paniselian-Brusselian Aquifer and Paniselian Aquitard upslope. Its transect is along the ditch's orientation (i.e., model's north-south) (Fig. 1). The dark colored layers represent the aquitards. Adapted from DOV (2026); Deckers et al. (2019); VITO and Flemish Government (2021) with 100 m horizontal resolution. The codes in brackets [A0xxx] are the hydrogeological codes used for Flanders, Belgium (Deckers et al., 2019).



560 **Figure A3.** Ditch and adjustable weir setup (a) The adjustable weir, (b) Filled ditch segment, showing that the (horizontal) ditch water surface is not parallel with the (inclined) field, and (c) the ditch segment already emptied by opening of the weir.

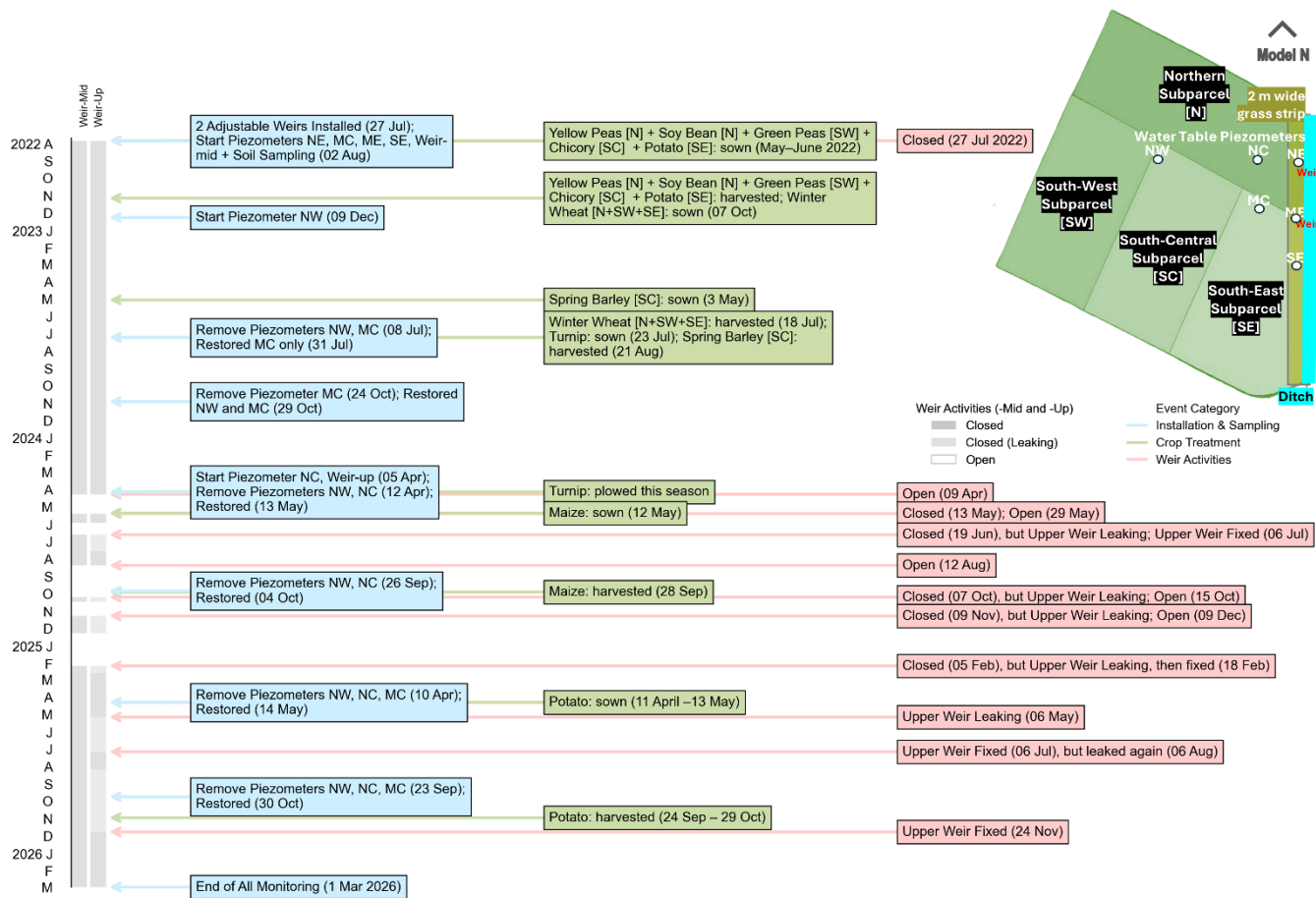
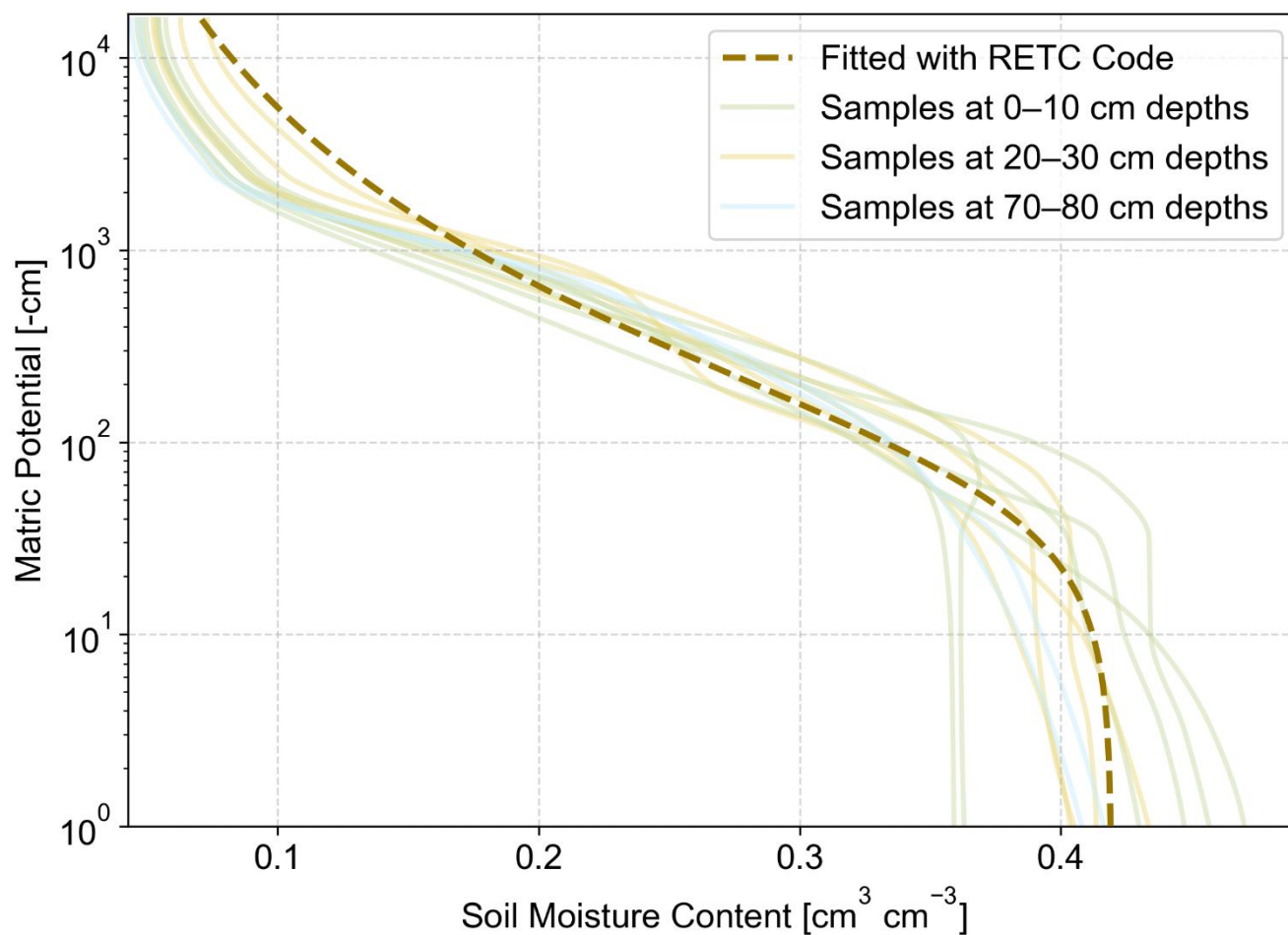
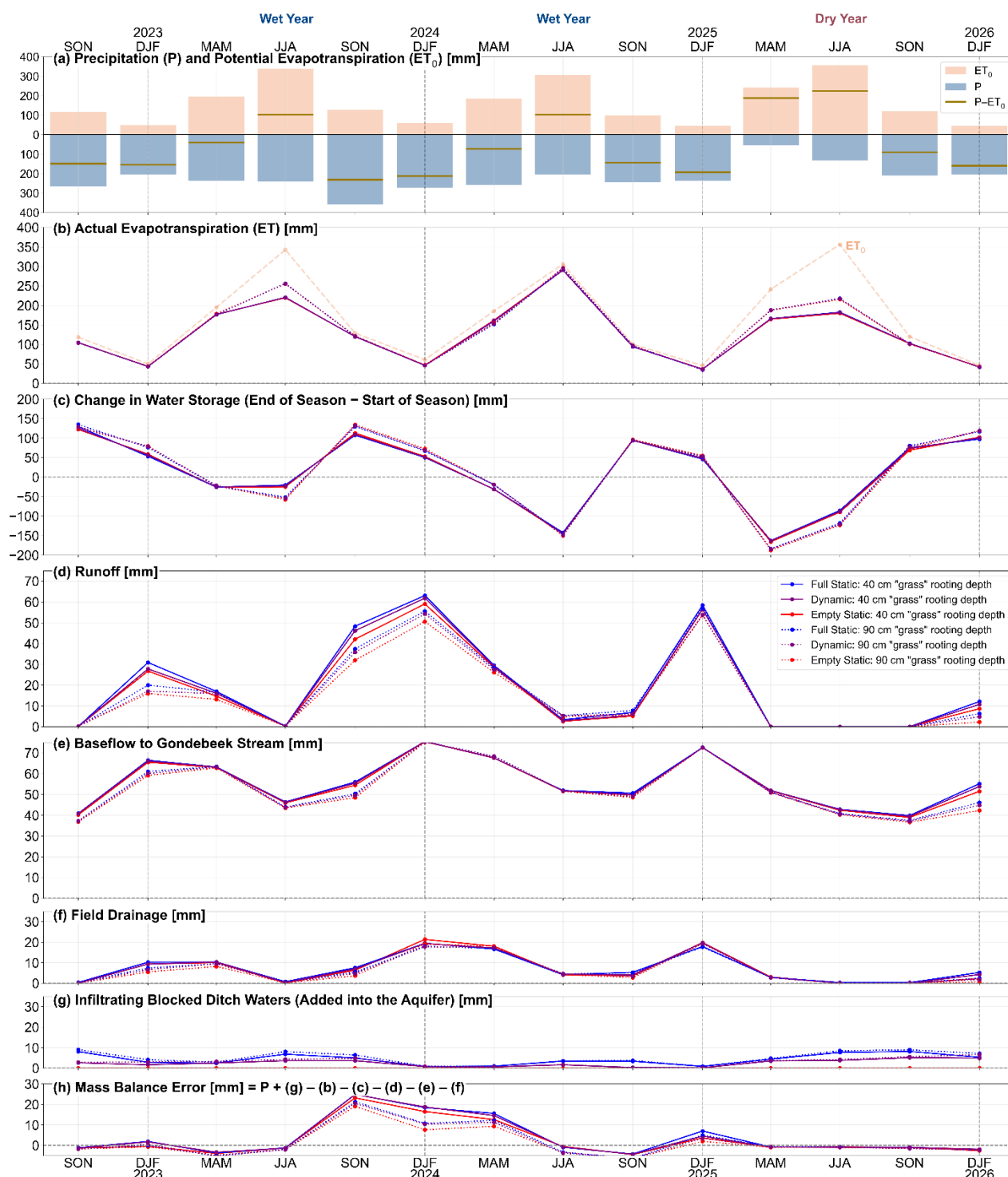


Figure A4. Timeline of the whole experiment (27 July 2022 – 01 March 2026) along with the subparcel map. Letters in square brackets under the “Crop treatment” pertain to the subparcel to which the specified crop belongs in the upper right map. Crops: yellow peas (*Lathyrus aphaca*), soy bean (*Glycine max*), green peas (*Pisum sativum*), chicory (*Cichorium intybus*), potato (*Solanum tuberosum*), spring barley (*Hordeum vulgare*), winter wheat (*Triticum aestivum*), turnip (*Brassica rapa* subsp. *rapa*), maize (*Zea mays*)



570 **Figure A5.** Model material's water retention curve fitted using RETC code (Van Genuchten et al., 1991) with the van Genuchten-Mualem model shown in Eq. (2) (Mualem, 1976; Van Genuchten, 1980). Its optimized hydraulic parameter values are in Table 3. At the background are 12 soil samples's pF curves (six at 0–10, four at 20–30, and two at 70–80 cm depths), obtained from sandbox and pressure plate measurements.



575

Figure A6. Seasonal water balance across scenarios per rooting depth
Abbreviations: ET_0 = reference evapotranspiration, P = precipitation; DJF (Winter) = December–January–February, MAM (Spring) = March–April–May, JJA (Summer) = June–July–August, SON (Autumn) = September–October–November.

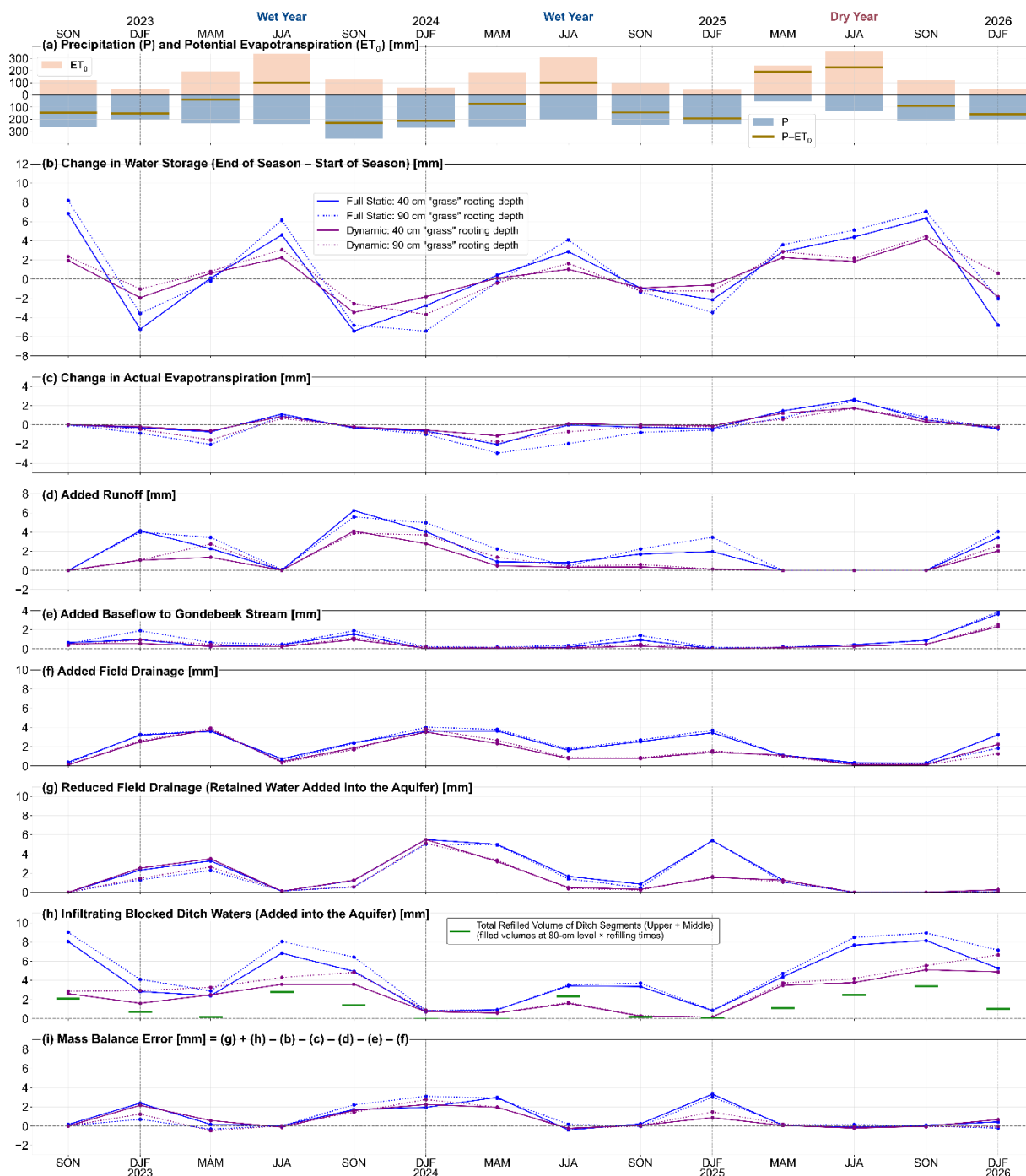


Figure A7. Full seasonal water balances involving added hydrological contributions (a–e) by weir management (f–g) under Full Static and Dynamic scenarios (per rooting depth parameterization). The reported values in (a–g) are differences between Full Static (or Dynamic) and the Empty Static Scenario.

Abbreviations: ET_0 = reference evapotranspiration, P = precipitation, DJF (Winter) = December–January–February, MAM (Spring) = March–April–May, JJA (Summer) = June–July–August, SON (Autumn) = September–October–November

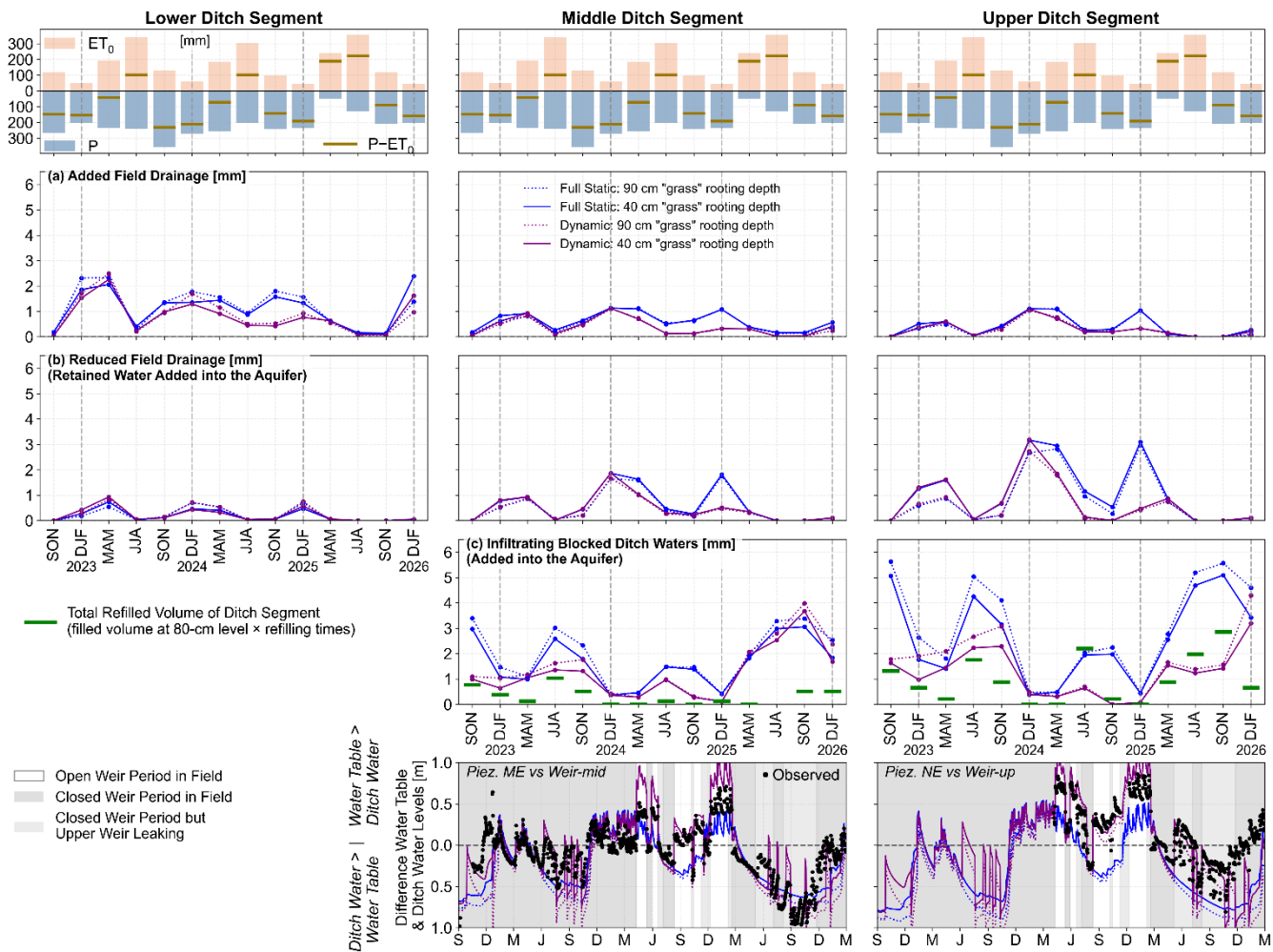


Figure A8. Additional contributions of weirs per ditch segment (b–c). Differences between Full Static (or Dynamic) and Empty Static scenarios per rooting depth parameterization are reported here
Abbreviations: ET_0 = reference evapotranspiration, P = precipitation; DJF (Winter) = December–January–February, MAM (Spring) = March–April–May, JJA (Summer) = June–July–August, SON (Autumn) = September–October–November.

Appendix B: Additional Tables

Table B1. Experimental and modeling studies on adjustable weir usage impacts on water balance components. The reported outcomes are based on differences between the case with and without filled ditch waters.

Abbreviations: *GWL*=groundwater/water table levels, *ET*=actual evapotranspiration, *R*=runoff, *ΔS*=final time of storage – initial time of storage, *Q_{inf}*= ditch infiltration, *Q_{baseflow}*= baseflow (groundwater flow from aquifer to the stream), *Q_{stream}*= stream discharge, *Q_{ditch}*= ditch discharge, *ΔS*=subsurface storage (final minus initial)

Soil Type	Vegetation	Study Area's Size and Open-Ditch Characteristics	Location	Monitored Hydrological Variables and Flow Model/ Type of Data Analyses	Outcome of Simulated Ditch-weir Hydrological Impacts (with weir – no weir)	Cited Study
No mention	Cut-grass, soft rush, swamp smartweed	No mention on study area's size Ditch: 0.76–0.84% slope 3.37–4.56 m width 32.2–33.5 m length	University of Mississippi Field Station (USA)	Monitored variables: <i>specific conductance every 5 minutes</i> Field experimental setup only involving salt tracers and chemographs	<u>Minute scales:</u> Increase: <i>GWL, ΔS</i> (only inferred from increase in time needed to return to base conductance values)	Kröger et al. (2008)
Loamy Sand, Loam	Barley (for 2016)	2.3 ha, <0.2% slope Hypothetical open ditch with 1.5 m depth at the model's left grid Has also existing controlled drainage: 15 m drain spacing, 0.98–1.18 m depth	Sievi experimental field, Northern Ostrobothnia (Finland)	Monitored variables: <i>Q_{ditch}, GWL</i> (Salo et al., 2021) FLUSH (2D) - Water level in the ditch assumed to be constant - Hypothetical ditch assumed to be the only path for lateral groundwater outflow	<u>Annual scale for 4 years</u> (2012, 2013, 2016, 2018) [%, mm for <i>GWL</i>]: Increase: <i>GWL</i> (+0.6 to +0.8), <i>ET</i> (+0.7 to +2.3), Decrease: <i>R</i> (-1 to -3) <u>When combined with controlled drainage:</u> Increase: <i>ET</i> (+5.4 to +12) Decrease: <i>R</i> (-9.4 to -13.8)	Isomäki et al. (2024)
Peatland	Blanket peatland assemblage (common heather, hare's tail cotton grass, bog mosses)	2 ha 7–9% slope 12 parallel ditches 11–26 m spacing 7–9% slope 84–107 m lengths 0.10–1.53 m depths	Migneint blanket peatland, upper Conwy catchment, North Wales (UK)	Monitored variables: <i>Q_{ditch}, GWL</i> Field experimental setup only involving flow duration curves	<u>Annual scales (2011–2015) [%]:</u> Increase: <i>GWL</i> (time weighted average < +2 cm) <i>Q_{ditch}</i> (years after restoration, based on shorter dry periods and more gently sloping flow duration curves) <i>R</i> (no estimated values, only observed to persist with blocking of ditches)	Holden et al. (2017)
Fine, sandy loam	Loblolly pine	25 ha, <0.1% slope 4 parallel ditches 100 m spacing 1.2–1.6 m depth	Carteret County, North Carolina (USA)	Monitored variables: <i>Q_{ditch}, GWL</i> DRAINLOB (DRAINMOD version for drained forested watersheds) Simulated weirs are of sharp crested V-notch type; geometry of weirs considered (crest height, angle of V-notch weir)	<u>Annual and seasonal scale for 4 years [m]:</u> Increase: <i>GWL</i> (+0.07 as yearly average; +0.13 during wet periods)	Amatya et al. (2003)



Soil Type	Vegetation	Study Area's Size and Open-Ditch Characteristics	Location	Monitored Hydrological Variables and Flow Model/ Type of Data Analyses	Outcome of Simulated Ditch-weir Hydrological Impacts (with weir – no weir)	Cited Study
<u>Seasonal scales (2017–2023) [%]:</u>						
Loam (well and poorly drained)	Corn and soybean	132 ha 0–2% slope (poorly draining soil) 2%–6% slope (well drained soil) Ditch: 0.1% slope 1.5 m width 1.2 m depth	University of Minnesota, Southwest Research and Outreach Center, Lamberton, Minnesota (USA)	Monitored variables: Q_{ditch} Field experimental setup only involving statistical analyses of mean daily Q_{ditch} (weir vs no weir case)	Decrease: Q_{ditch} (-58% from June to August, -41% from September to November) Increase: ΔS (only inferred from decreased ditch outflows)	Strock and Ranaivoson (2025)
<u>20 day scales</u> [mm, cumulative] With 50 cm ditch water levels:						
Gley sand	Grass (pasture)	2D transect 105 m by 6.2 m 2 ditches parallel to the stream; inflow to the nearby ditch (10 m from stream) can be controlled by a weir. The other ditch, 110 m away from the stream, has uncontrollable inflows. The weir is at the agricultural area's upstream. Ditch depths are not specified	Near Koselmühlenfließ stream, Baruther Urstromtal (Germany)	Monitored variables: Q_{ditch} , Q_{stream} , GWL HYDRUS 2D The ditch's wall and floor: • Variable head BC • No-flow BC when inactive	16 May–12 June 2011 Increase: $Q_{baseflow}$ (+5), ΔS (+22), Q_{inf} (+20) Decrease: ET (-28) 12 October –1 December 2011 Increase: ΔS (+6), Q_{inf} (+1) Decrease: $Q_{baseflow}$ (-1), ΔS (-5) Negligible: ET 26 April–22 May 2012 Increase: $Q_{baseflow}$ (+3), ΔS (+28), Q_{inf} (+12) Decrease: ET (-32)	Gliege et al. (2016)
<u>Hourly scales for 11 days</u>						
Alluvial peatland (sandy loam, sand, clay) (Swinnen et al., 2021)	Moss, sedges, grass, carr forest (Swinnen et al., 2021)	791 ha Model mesh size of 0.5 m for the ditches. Ditches' dimensions in the field are not specified	Dijle River Floodplains, Belgium	Modeled variables: Q_{ditch} TELEMAC 2D 1 m by 1 m resolution for the floodplain	Based on the design flood hydrographs for 13–24 July 2021 (All Ditches Blocked – No Ditch Blocked): Decrease: Q_{stream} peaks (return period = 2 years) Increase: Q_{stream} at recession period, flood water depth at maximum 1 m (return period = 2 years) Negligible: Q_{stream} , flood water depth at any hour (return period = 100 years i.e., exceptionally high flooding)	Rehman et al. (2024)



Table B2. Piezometer and ditch endpoint specifications. The HYDRUS Coordinates are based on Fig. 2

	NW	NC	NE	MC	ME	SE	Lowest Ditch Floor Point	Weir- mid	Weir- up	Highest Ditch Floor Point
True Easting [m] (BD72/Belgian Lambert 72)	108812	108846	108856	108884	108899	108929	108837	108913	108880	109028
True Northing [m] (BD72/Belgian Lambert 72)	185203	185290	185312	185275	185294	185291	185244	185292	185305	185323
HYDRUS Easting [m]	10	103	127	104	127	127	130.0– 130.8	130	130	130.0–130.8
HYDRUS Northing [m]	335	337	336	296	290	257	152	277	312	359
Elevation of Surface [masl]	22.4	21.7	21.3	21.0	20.6	19.5	17.0	19.1	19.8	20.2
Height of Piezometer Casing from the Surface [m]	0.38	0.42	0.56	0.68	0.43	0.63	n/a	1.62	1.66	n/a
Rope Length [m]	3.51	2.74	3.24	3.66	2.42	3.26	n/a	2.53	2.74	n/a
Total Number of Observations	953	551	1302	1207	1301	1294	n/a	n/a	n/a	n/a
Missing Number of Observations from Temporary Removal*	223	143	n/a	98	n/a	n/a	n/a	n/a	n/a	n/a
%Missing from / Temporary Removal*	19%	21%	n/a	8%	n/a	n/a	n/a	n/a	n/a	n/a

*The top half of piezometers were temporarily removed to protect the piezometers from the concurrent conventional plowing, sowing and harvesting activities.

Table B3. Mean and raw horizontal (K_{sx} and K_{sy}) and vertical K_{sz} saturated hydraulic conductivity values in this study area as per Lebbe et al. (1992); Tas et al. (2023). The ones in bold and italics are the final values used in this study's model setup.

Hydrostratigraphic Unit	Sublayers Names	Thickness [m]	K_{sx} (= K_{sy}) [cm d ⁻¹]	K_{sz} [cm d ⁻¹]
Quaternary Aquifer System		8	25	0.04
	Yd 6	5	86	50
	Yd 5	1.5	2	2
Ypresian Aquifer System	Yd 4	9.5	111	98
	Yd 3	6	0.2	0.07
	Yd 2	4	126	0.1
	Yd 1	16	4	2.7
Effective K_{sx} (= K_{sy}) (Thickness weighted Arithmetic Means) of Quaternary Aquifer System and Ypresian Aquifer System's Yd 6 layer			48	n/a
(Thickness weighted) Geometric Means of Quaternary and Ypresian Aquifer System's Yd 6 layer			40	0.6
<i>Model material's anisotropy ratio</i> <i>i.e., Ratio of the K_{sz}'s and K_{sx}'s Geometric Means above</i>				0.016



Table B4. Dynamic scenarios' subperiods for 40 and 90 cm rooting depths.

Date Range	Subperiod Number*	Upper and Middle Ditch Segments' Status
01 Sep 21 – 31 Jul 22	0 (spin-up)	Empty
01 Aug 22 – 28 Sep 22	1	Filled
29 Sep 22 – 22 Dec 22	2	Empty
23 Dec 22 – 08 Jun 23	3	Filled
09 Jun 23 – 20 Jul 23	4	Empty
21 Jul 23 – 16 Aug 23	5	Filled
17 Aug 23 – 24 Aug 23	6	Empty
25 Aug 23 – 07 Sep 23	7	Filled
08 Sep 23 – 16 Sep 23	8	Empty
17 Sep 23 – 26 Sep 23	9	Filled
27 Sep 23 – 11 Oct 23	10	Empty
12 Oct 23 – 09 Apr 24	11	Filled
10 Apr 24 – 13 May 24	12	Empty
14 May 24 – 28 May 24	13	Filled
29 May 24 – 19 Jun 24	14	Empty
20 Jun 24 – 22 Jul 24	15	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
23 Jul 24 – 11 Aug 24	16	Filled
12 Aug 24 – 09 Oct 24	17	Empty
10 Oct 24 – 15 Oct 24	18	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
16 Oct 24 – 16 Nov 24	19	Empty
17 Nov 24 – 09 Dec 24	20	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
10 Dec 24 – 18 Feb 25	21	Empty
19 Feb 25 – 06 May 25	22	Filled
07 May 25 – 17 Jun 25	23	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
18 Jun 25 – 23 Jun 25	24	Empty
24 Jun 25 – 05 Jul 25	25	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
06 Jul 25 – 09 Jul 25	26	Filled
10 Jul 25 – 16 Jul 25	27	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
17 Jul 25 – 20 Jul 25	28	Empty
21 Jul 25 – 05 Aug 25	29	Filled
06 Aug 25 – 14 Aug 25	30	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
15 Aug 25 – 29 Aug 25	31	Empty
30 Aug 25 – 16 Oct 25	32	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
17 Oct 25 – 20 Oct 25	33	Empty
21 Oct 25 – 02 Nov 25	34	Filled
03 Nov 25 – 23 Nov 25	35	Filled for Middle Ditch, Empty for Upper Ditch due to Leaking Weir
24 Nov 25 – 24 Dec 25	36	Filled
25 Dec 25 – 07 Jan 26	37	Empty
08 Jan 26 – 28 Feb 26	38	Filled

*Here, we reduced the number of simulated subperiods by replacing all subperiods with constant water levels lasting only for a maximum of 3 days with the surrounding days' water levels.



Table B5. Model evaluation metrics, comparing observations vs simulations under the Dynamic Scenario under various hypothetical grass rooting depths (except for the means, pertaining to individual scenarios)

Evaluation Metric	NW	NC	NE	MC	ME	SE
Number of Observations	953	551	1302	1207	1301	1294
Missing Number of Observations due to Temporary Removal	224	143	n/a	99	n/a	n/a
Mean (Observed) [masl]	20.62	20.34	20.34	19.91	19.53	18.93
Mean (Dynamic: 40 cm rooting depth) [masl]	20.37	20.17	20.20	19.67	19.57	18.87
Mean (Dynamic: 90 cm rooting depth) [masl]	20.17	20.04	20.06	19.53	19.46	18.76
Mean (Full Static: 40 cm rooting depth) [masl]	20.43	20.29	20.35	19.77	19.69	18.93
Mean (Full Static: 90 cm rooting depth) [masl]	20.24	20.18	20.24	19.64	19.61	18.84
Mean (Empty Static: 40 cm rooting depth) [masl]	20.30	20.04	20.00	19.52	19.30	18.75
Mean (Empty Static: 90 cm rooting depth) [masl]	20.08	19.88	19.81	19.34	19.14	18.61
Coefficient of Determination (R^2) 40 cm rooting depth	0.59	0.57	0.70	0.73	0.73	0.58
Coefficient of Determination (R^2) 90 cm rooting depth	0.37	0.43	0.57	0.60	0.61	0.45
Nash-Sutcliffe Efficiency (NSE) 40 cm rooting depth	0.44	0.25	0.30	0.43	0.62	0.52
Nash-Sutcliffe Efficiency (NSE) 90 cm rooting depth	-0.19	-0.50	-0.51	-0.24	0.27	0.04
Kling-Gupta Efficiency (KGE) 40 cm rooting depth	0.76	0.69	0.62	0.80	0.78	0.75
Kling-Gupta Efficiency (KGE) 90 cm rooting depth	0.61	0.51	0.47	0.65	0.61	0.65
Root Mean Square Error (RMSE) 40 cm rooting depth [m]	0.54	0.39	0.31	0.37	0.21	0.26
Root Mean Square Error (RMSE) 90 cm rooting depth [m]	0.79	0.55	0.46	0.54	0.30	0.37
Mean Absolute Error (MAE) 40 cm rooting depth [m]	0.33	0.24	0.22	0.28	0.17	0.18
Mean Absolute Error (MAE) 90 cm rooting depth [m]	0.49	0.35	0.33	0.40	0.21	0.26
Mean Error (ME) 40 cm rooting depth [m]	-0.25	-0.16	-0.14	-0.23	0.03	-0.07
Mean Error (ME) 90 cm rooting depth [m]	-0.45	-0.30	-0.28	-0.38	-0.07	-0.17



615 **Code Availability**

HYDRUS 5 (version 5.05), used for the simulations of subsurface water flow, is a proprietary software package commercially available and acquirable from the PC-PROGRESS Site (<https://www.pc-progress.com/en/Default.aspx?hydrus-pricing>, last access: 14 September 2026).

620 **Data Availability**

Daily meteorological observation data (precipitation, reference evapotranspiration) are publicly available for download at the Royal Meteorological Institute website (<https://opendata.meteo.be/download>) with the grid number 998. The observed and simulated water table levels and daily (raw) simulated fluxes will be made available after publishing.

625 **Author Contributions**

Conceptualization and Supervision: SG, JS, JV; Data Curation: JGP, ELR; Visualization: JGP, SG, JV; Writing – original draft preparation: JGP; Formal Analysis, Methodology, Investigation, Writing – review: all authors

Competing Interests

The authors declare that they have no conflict of interest.

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