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## Supplementary Material

# Event-based quickflow simulation with OpenLISEM in a burned Mediterranean forest catchment

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# Supplementary material

## S1. Study area and experimental design extended description

On 27 August 2008, a wildfire consumed almost 68 ha of forest near the village of Colmeal, located in the municipality of Góis, north-central Portugal (40º08’42” N, 7º59’16” W; 490 m a.s.l.). This fire burned a small catchment of 10 ha, previously dominated by maritime pine (Pinus pinaster Ait.) stands and eucalypt (Eucalyptus globulus Labill.) forest plantations. Land management operations in this catchment have already been extensively described by Vieira et al. (2016) and can be summarized as a combination of three types of land uses (Pine and shrubs, Eucalypt and shrubs, and Eucalypt plantations), and four land operations types (none, contour plowing, downslope plowing, and terracing), creating a “mosaic” of land cover and land management combinations (Fig.1, Fig. S1). As described in Vieira et al. (2018, 2016), vegetation and hydrological recovery in this site were rather limited as a consequence of several historical disturbance events, which might have enlarged the window of disturbance.

*Figure S 1 – Aerial photograph of Colmeal catchment taken 5 months after fire (Source Vieira, 2015).*

The climate of the study area can be characterized as humid mesothermal (Köppen Csb, Peel et al., 2007), with prolonged dry and warm summers. The mean annual temperature and precipitation at the nearest meteorological station (Góis (13I/01G); 10 km) are 12°C and 1133 mm, respectively (SNIRH, 2011). Mean Potential evapotranspiration was estimated as 1011mm according to the Hargreaves and Samani (1985) method. The occurrence of precipitation in this area is more prominent between November and February, while during spring (March-May) rainfall events are characterized for being less frequent but with high rainfall intensity (Vieira et al., 2018).

The geology of the study area consists of pre-Ordovician schists and greywackes (de Brum Ferreira, 1978; Pimentel, 1994), which have given rise to shallow soils typically mapped as Humic Cambisols (Cardoso et al., 1971). The A horizon in the study site has a coarse, sandy loam texture (sand > 70%) and a high stone content (40–46%).

According to field indicators (i.e. canopy and woody debris consumption, litter combustion, ash color, and mineral soil), the burn severity was low-to-moderate since tree canopies and logs were only partially consumed, the litter layer was fully consumed, the ash was black and the mineral soil was unaffected (DeBano et al., 1998; Hungerford, 1996). The 'Twig Diameter Index' (TDI), based on the diameter of the 3 thinnest remaining twigs of each measured shrub, also confirmed that the fire had a moderate severity (TDI=0.5) for an index that varies from 0 (unburned) to 1 (severely burned) (Maia et al., 2012; Vieira et al., 2016).

After the fire, the catchment was instrumented with a hydraulic channel at the outlet of the catchment, equipped with an ultrasonic sensor located over the stream and a rain gauge with a 0.2 mm resolution. Both were connected to a Campbell data logger (CR1000), allowing the continuous measurement of the streamflow and rainfall during 4 post-fire years. Besides the monitoring at the outlet of the catchment, additional field measurements of SMC, runoff, ground cover, and SWR were taken at several points within the Colmeal catchment. SMC was registered continuously at 3-5cm soil depth (Decagon EC-5 Soil Moisture Sensor) at three points, one close to a eucalypt plantation (sm1), another near the pine (sm2), and one located at the outlet (Fig. 1c). Runoff was also assessed in 12 micro-plots (0.25 - 0.5 m2) and monitored with a weekly frequency depending on rainfall during 4 post-fire years (Vieira et al., 2018, 2016). In three distinct land units (Pine unplowed, Eucalypt downslope plowed, Eucalypt contour plowed), four bounded micro-plots (0.25 to 0.50 m2) were randomly installed at the base of each slope, as described by Vieira et al. (2016). This field installation is within the limitations of a plot-based set-up (e.g., Boix-Fayos et al., 2006). The outlets of each micro-plot were connected to 30 or 70 L runoff tanks. From 25 September 2008 until 1 October 2012, surface runoff was measured in each tank at one-week intervals during the first and second monitoring years, while in the third and fourth year, the monitoring frequency decreased, respectively, to two-week and monthly intervals.

At those same micro-plots, ground cover was also assessed monthly, while soil texture, soil depth, and soil roughness were characterized at the end of the monitoring period (Vieira et al., 2018, 2016). Ground cover was described with a square grid (50 × 50 cm; 10 cm grid spacing) laid over the plots by registering the cover category (i.e., stones, bare soil, ash/charred material, litter, and vegetation) at each grid intersection.

SWR was monitored monthly in two representative eucalypt plantations and pine stands outside the drainage area to prevent disturbance as described by Vieira et al. 2016, 2018. The SWR measurements were made along a five-point transect from the bottom to the top of a slope located at the edge of the catchment, at two soil depths (soil surface and 5 cm depth), using the modified 'Molarity of Ethanol Droplet' (MED) test (Doerr, 1998; King, 1981) in agreement to prior SWR studies in the region (Keizer et al., 2008, 2005b, 2005a). The MED test consisted of the application of three droplets of increasing ethanol concentrations to the soil (0, 1, 3, 5, 8.5, 13, 18, 24, and 36%) until infiltration of the majority of the drops of the same concentration within five seconds. The SWR results were given as relative frequency for each SWR class, where class 0 corresponded to very wettable soils, and class 9 to extremely repellent soils (Santos et al., 2016).

# S2. Statistical analysis

## a. Methods

Three statistical models were built to predict Manings's n, Ksat and $\theta s$. One model for all the events (overall), and other two considering wet and dry conditions separately. This methodology attempts to relate the auto calibration results with several additional explanatory variables in an attempt to understand which variables better explain the obtained model calibration.

This statistical analysis was performed in Rstudio with the linear model (Chambers and Hastie, 1992) function lm {stats}, considering as response variables the calibrated Manings's n, Ksat and θs, and the possible explanatory variables: antecedent rainfall index from last 10 days (API, -), baseflow at the beginning of the event (L $s^{-1}$), event rainfall duration (min), maximum rainfall intensity (mm $h^{-1}$), initial soil moisture content (θi, $cm^3$ $cm^{-3}$), time since fire (days), and total event rainfall (mm). A compilation of those explanatory variables can be found in Table 2.

## b. Results

The results of this statistical analysis evidences that separating the dataset from overall to wet and dry conditions leads to an improvement of the statistical model $R^2$ (Table S1) for Ksat and $\theta_s$ for both moisture conditions, and for Maning's n in dry conditions. From the perspective of the response variables, Ksat and $\theta_s$ reached higher $R^2$ performances, however also presented a higher number of variables influencing their prediction in comparison to Maning's n. Generally speakin,g it is clear that wet and dry events are significantly related with distinct combinations of variables besides initial SMC alone, which is the target variable of our hypothesis.

*Table S 1 - – Statistical linear regression for Manning's n, Ksat and $\theta_s$ inputs with auxiliary antecedent rainfall index (API, -), baseflow (bf, $L\ s^{-1}$), rainfall duration (dur, min), maximum rainfall intensity (Imax, $mm\ h^{-1}$) , initial soil moisture content (θi, $cm^3\ cm^{-3}$), time since fire (time, days), and total event rainfall (rain, mm).*

| | Manning's n | | | | Ksat | | | | θs | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Auxiliary variables | Estimate | T value | p-value | Auxiliary variables | Estimate | T value | p-value | Auxiliary variables | Estimate | T value | p-value |
| overall | *Adjusted R-squared: 0.23* | | | | *Adjusted R-squared: 0.51* | | | | *Adjusted R-squared: 0.19* | | | |
| | Intercept | 0.29 | 9.12 | < 0.001 | Intercept | -37.11 | -5.10 | < 0.001 | Intercept | 0.33 | 13.06 | < 0.001 |
| | API | -0.0027 | -4.85 | < 0.001 | API | 0.87 | 10.06 | < 0.001 | dur | -0.00026 | -3.85 | < 0.001 |
| | dur | 0.00021 | 4.40 | < 0.001 | dur | 0.21 | 7.92 | < 0.001 | time | -0.00010 | -2.15 | < 0.01 |
| | θi | 1.04 | 5.21 | < 0.001 | $I_{max}$ | 1.87 | 8.99 | < 0.001 | rain | 0.0056 | 5.40 | < 0.001 |
| | | | | | rain | -2.75 | -7.08 | < 0.001 | | | | |
| dry | *Adjusted R-squared: 0.72* | | | | *Adjusted R-squared: 0.95* | | | | *Adjusted R-squared: 1.00* | | | |
| | Intercept | 0.31 | 11.08 | < 0.001 | Intercept | 36.29 | 9.08 | < 0.001 | Intercept | 0.35 | $4.99e^{+14}$ | < 0.001 |
| | bf | -0.073 | -8.07 | < 0.001 | API | -0.41 | -2.68 | < 0.01 | API | -0.0028 | $-1.01e^{+14}$ | < 0.01 |
| | $I_{max}$ | -0.0030 | -4.13 | < 0.001 | bf | 21.99 | 12.67 | < 0.001 | bf | 0.018 | $5.75e^{+13}$ | < 0.001 |
| | θi | -1.98 | 9.77 | < 0.001 | dur | -0.13 | -7.34 | < 0.001 | dur | 0.0023 | $7.04e^{+14}$ | < 0.001 |
| | time | 0.00037 | 5.08 | < 0.001 | $I_{max}$ | 0.60 | 4.95 | < 0.001 | $I_{max}$ | 0.013 | $6.21e^{+14}$ | < 0.001 |
| | | | | | θi | -52.14 | -3.29 | < 0.001 | θi | $-5.06e^{-15}$ | -1.80 | < 0.05 |
| | | | | | time | -0.19 | -13.41 | < 0.001 | time | -0.00039 | $-1.55e^{+14}$ | < 0.001 |
| | | | | | rain | 1.78 | 4.65 | < 0.001 | rain | -0.043 | $-6.24e^{+14}$ | < 0.001 |
| wet | *Adjusted R-squared: 0.21* | | | | *Adjusted R-squared: 0.81* | | | | *Adjusted R-squared: 0.75* | | | |
| | Intercept | 0.095 | 0.69 | 0.4953 | Intercept | 66.75 | 3.15 | < 0.001 | Intercept | -0.015 | -0.19 | 0.8531 |
| | dur | 0.00033 | 4.36 | < 0.001 | bf | 0.74 | 5.50 | < 0.001 | API | -0.0022 | -8.65 | < 0.001 |
| | θi | 1.17 | 2.14 | < 0.01 | dur | 0.22 | 9.30 | < 0.001 | dur | -0.00029 | -5.77 | < 0.001 |
| | | | | | $I_{max}$ | 3.20 | 13.33 | < 0.001 | $I_{max}$ | -0.0021 | -4.57 | < 0.001 |
| | | | | | θi | -438.60 | -5.08 | < 0.001 | θi | 0.76 | 4.08 | < 0.001 |
| | | | | | rain | -3.01 | -9.60 | < 0.001 | time | 0.00054 | 4.59 | < 0.001 |
| | | | | | | | | | rain | 0.0061 | 9.52 | < 0.001 |

## S3. Event characterization and classification

From the sixteen selected events, seven were classified as occurring in dry conditions (Table 2) while the remaining nine were classified as occurring in wet conditions.

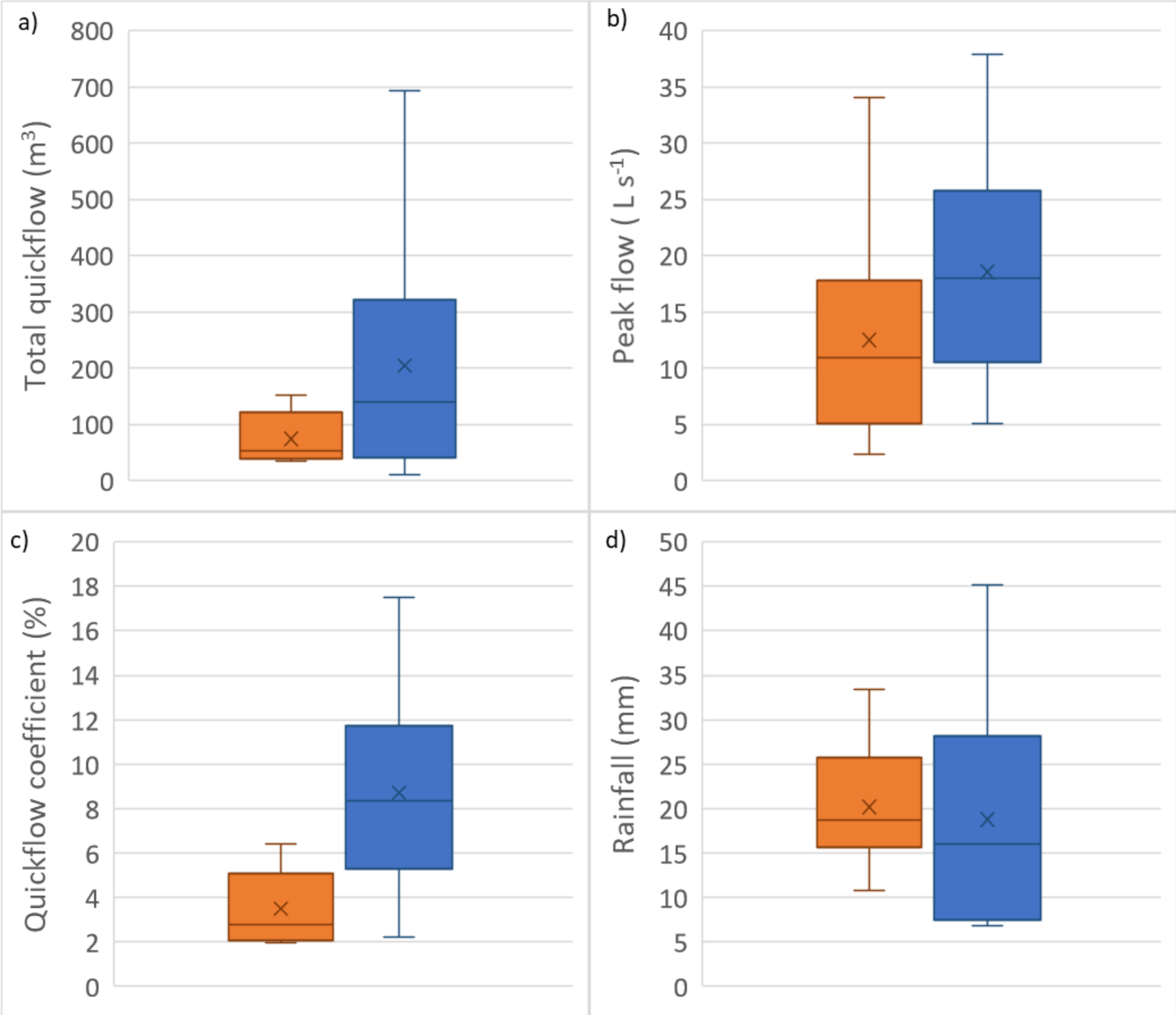


*Figure S 2 - Box plots of a) total quickflow (n=16), b) peak flows (n=32), c) runoff coefficient (n=16), and d) rainfall (n=16) for all the events under the classification of dry (orange) and wet (blue) moisture conditions. Error bars represent maximum and minimum values reached, median is represented by middle horizontal boxplot bar, and average is represented by cross.*

The events occurring in wetter conditions constantly presented greater median and maximum total quickflow, peak flow, and quickflow coefficient when compared to the dry events (Fig. S2). Median rainfall, however, was similar between dry and wet events, although wetter events presented a higher variability (Fig. S2d).

Further analysis revealed that the quickflow response of the events classified as wet generated a greater response for the same rainfall than that of the events classified as dry (Fig. S3). Total quickflow in wetter conditions was better related to rainfall (R2=0.95) than in drier conditions (R2=039). In addition, a close relationship between SMC and baseflow at the outlet was found (Fig. S3b).

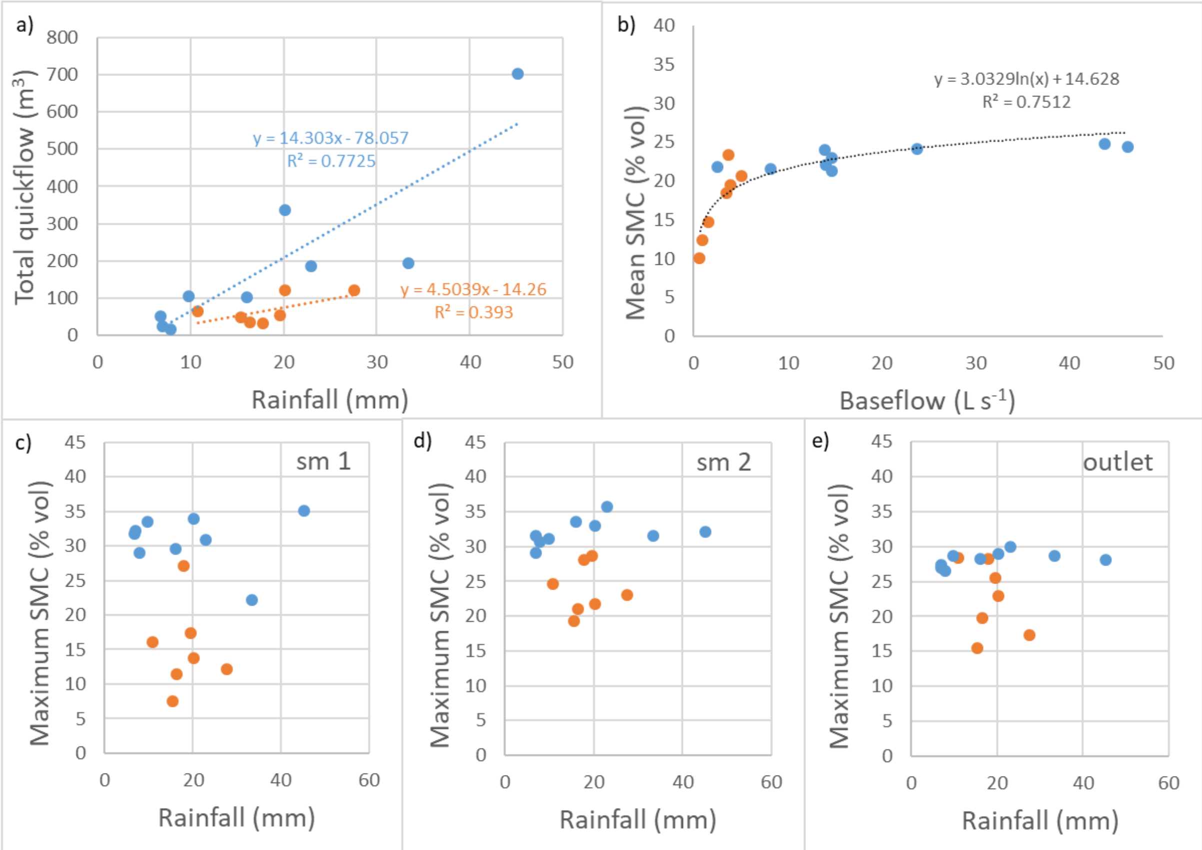


*Figure S 3 - General hydrological characterization of the studied events within wetter (blue) and drier (orange) conditions, a) total quickflow versus rainfall, b) mean catchment SMC versus baseflow, and maximum SMC versus rainfall for c) sm1, d) sm2, and e) outlet locations, obtained by sensors located 3-5cm soil depth.*

As expected, SMC seemed to reach higher values during wet than dry events at the sm1 and sm2 points (Fig. S3c and Fig. S3d) independently of the total rainfall amount. At the outlet however, these differences were not so clear (Fig. S2e).

Since SWR measurements were not performed at the beginning of each event, SWR data (Fig. S3) was only useful to identify periods where SWR likely affected the hydrological response (events a-d), and other moments where this would be unlikely (events k-o). Unfortunately, due to the low temporal and spatial resolution of this data, it was not possible to assess if SWR affected the hydrological response at catchment scale or the wet and dry classification, especially during transition periods from repellent to wettable and vice versa.

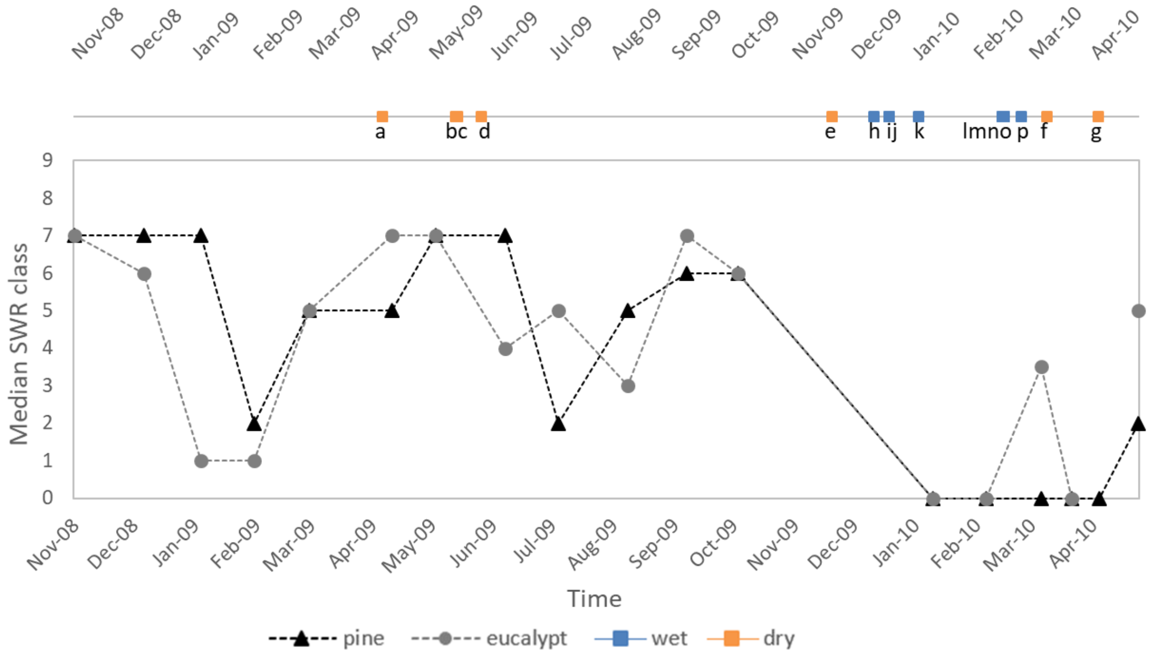


*Figure S 4 - Median SWR class obtained from field measurements at pine and eucalypt land uses during the study period. Note wet (blue) and dry (orange) event identification in the timeline.*

S4. Graphical representation of the measured and simulated quickflow at the outlet and spatial surface runoff predictions in the catchment for individual events.

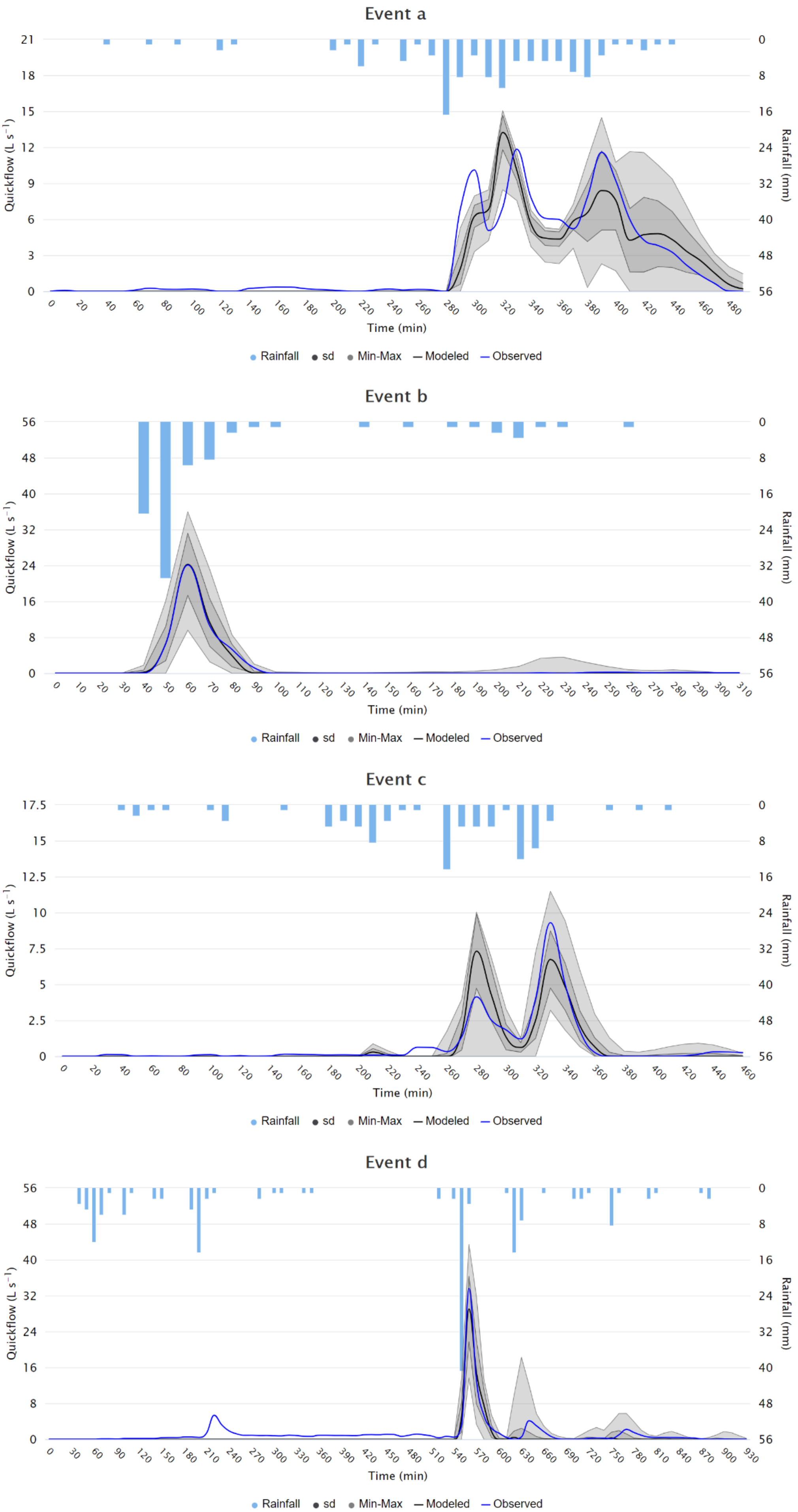


*Figure S 5 - OpenLISEM quickflow predictions variation for a, b, c and d events simulation following 1000 MCMC iterations.*

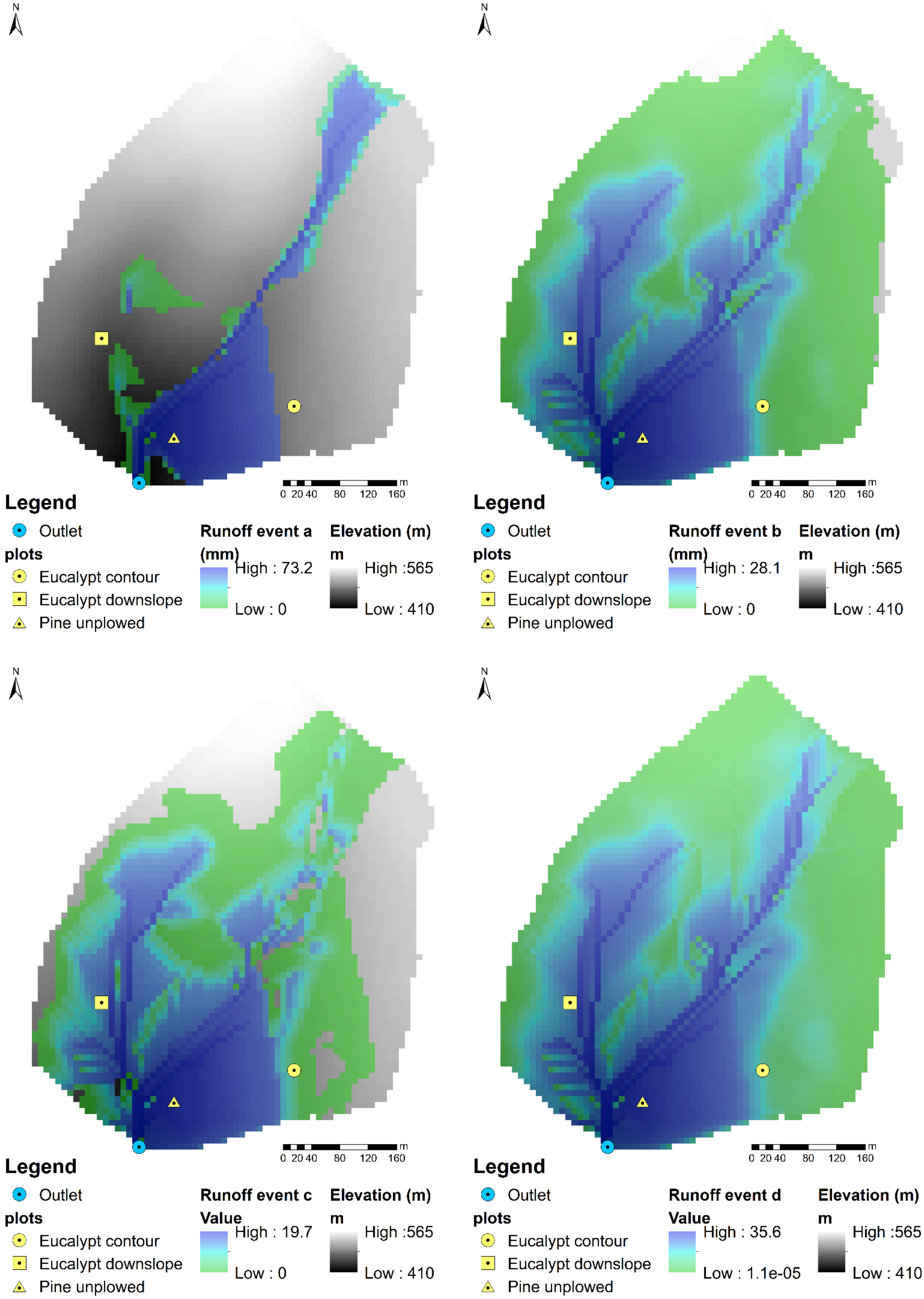


*Figure S 6 - OpenLISEM spatial runoff predictions for events a, b, c and d for optimal parameterization set.*

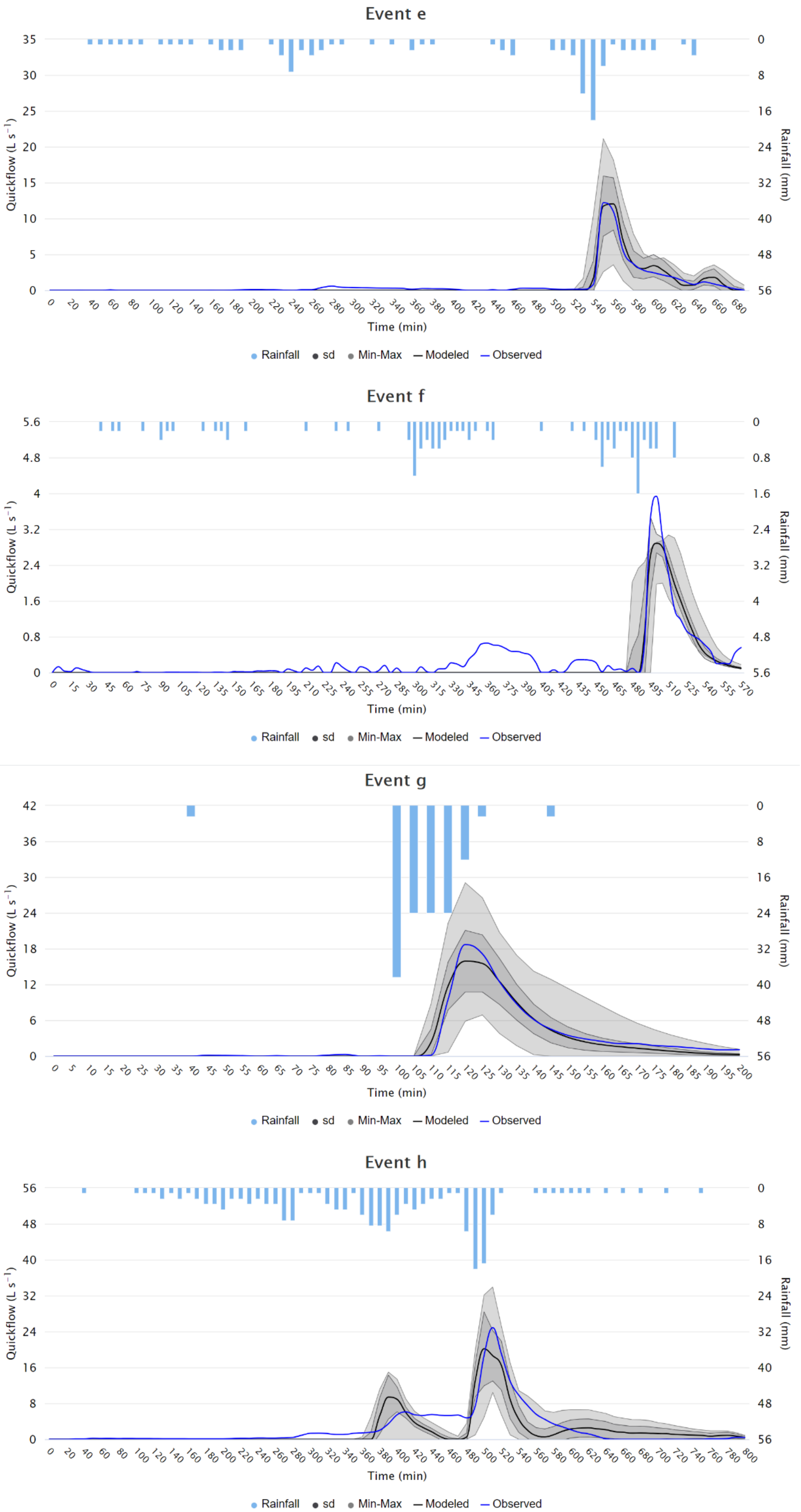


*Figure S 7 - OpenLISEM quickflow predictions variation for e, f, g, and h events simulation following 1000 MCMC iterations.*

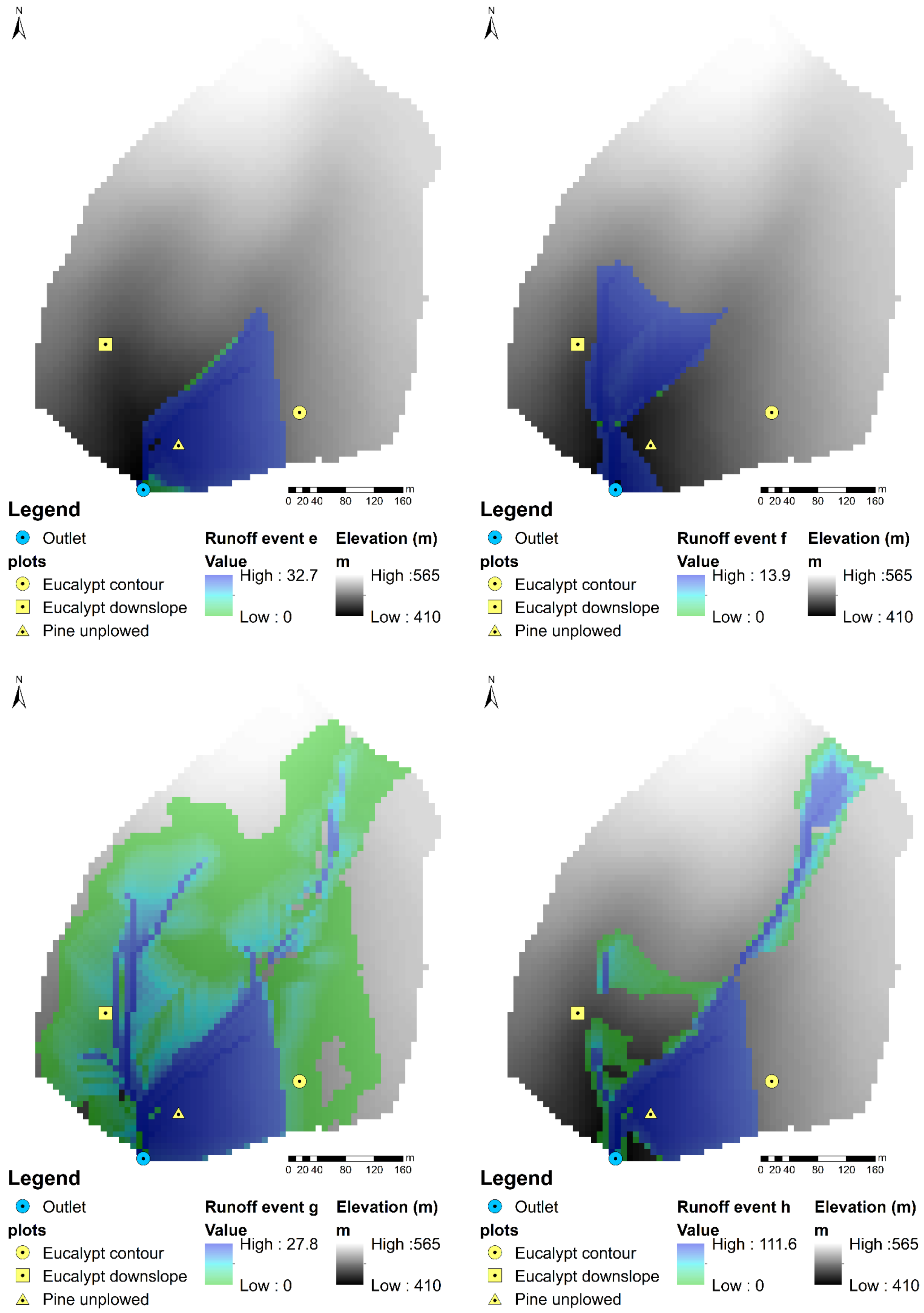


*Figure S 8 - OpenLISEM spatial runoff predictions for events e, f, g and h for optimal parameterization set.*

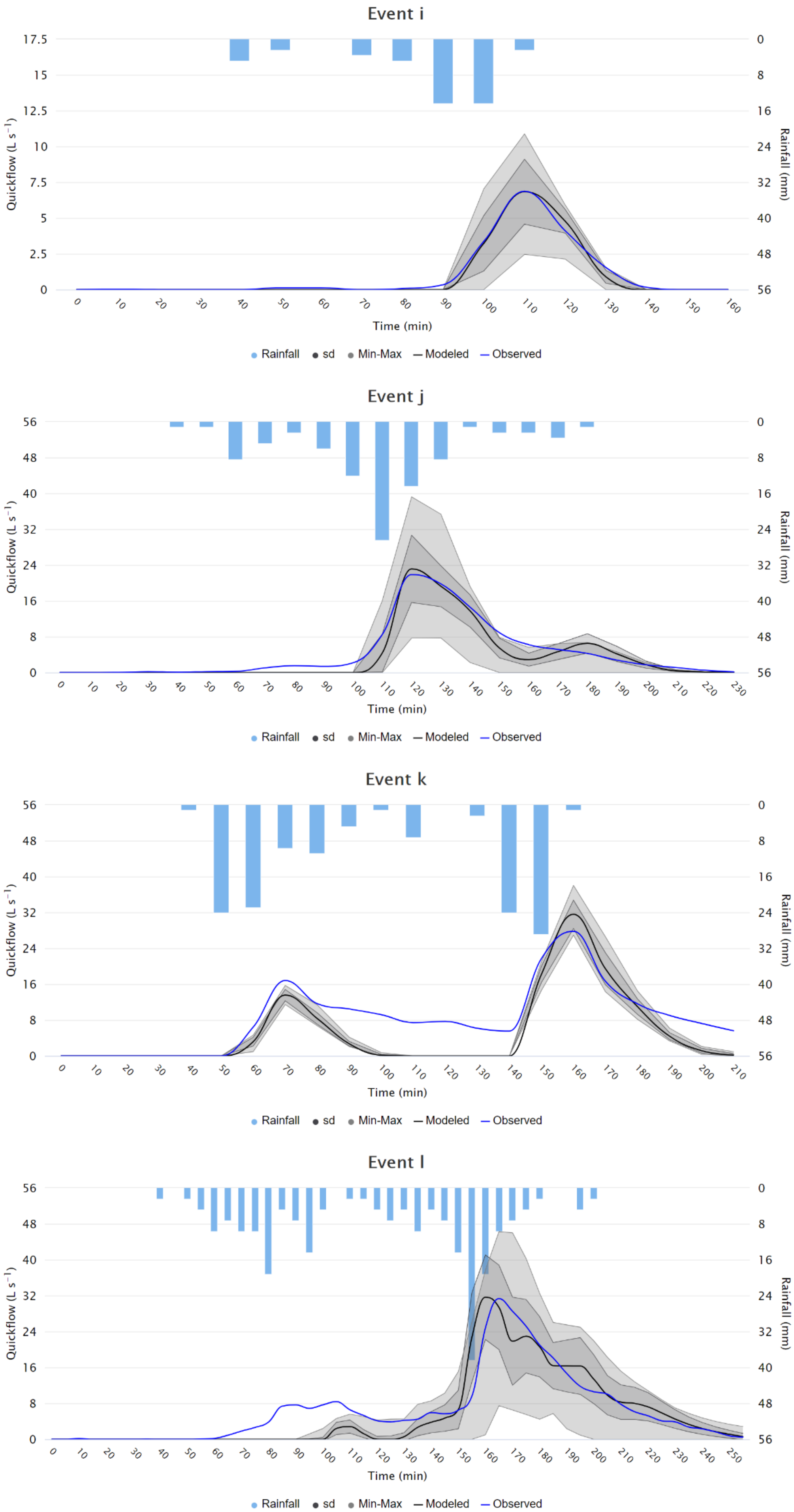


*Figure S 9 - OpenLISEM quickflow predictions variation for i, j, k, and l events simulation following 1000 MCMC iterations.*

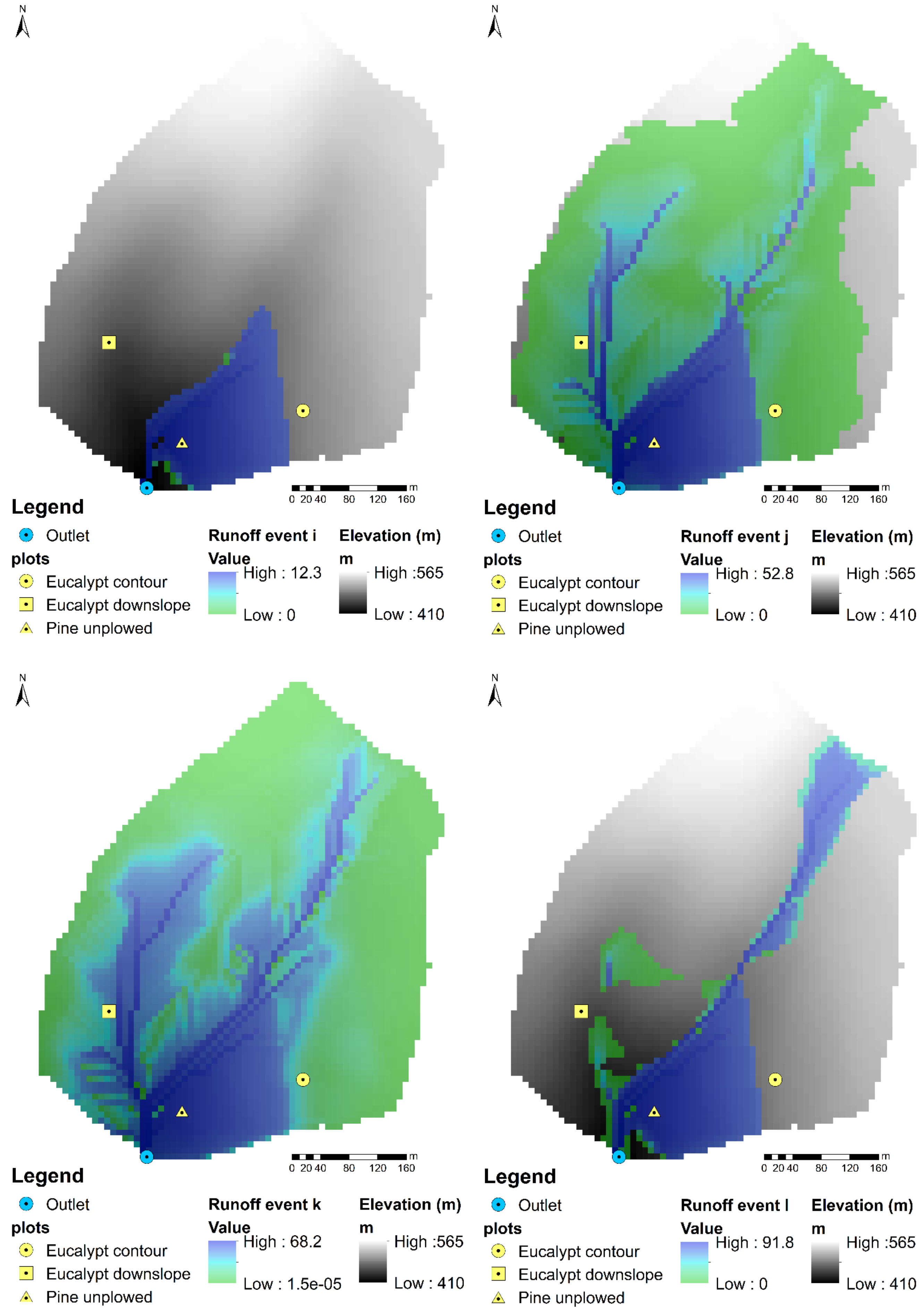


*Figure S 10 - OpenLISEM spatial runoff predictions for events i, j, k and l for optimal parameterization set.*

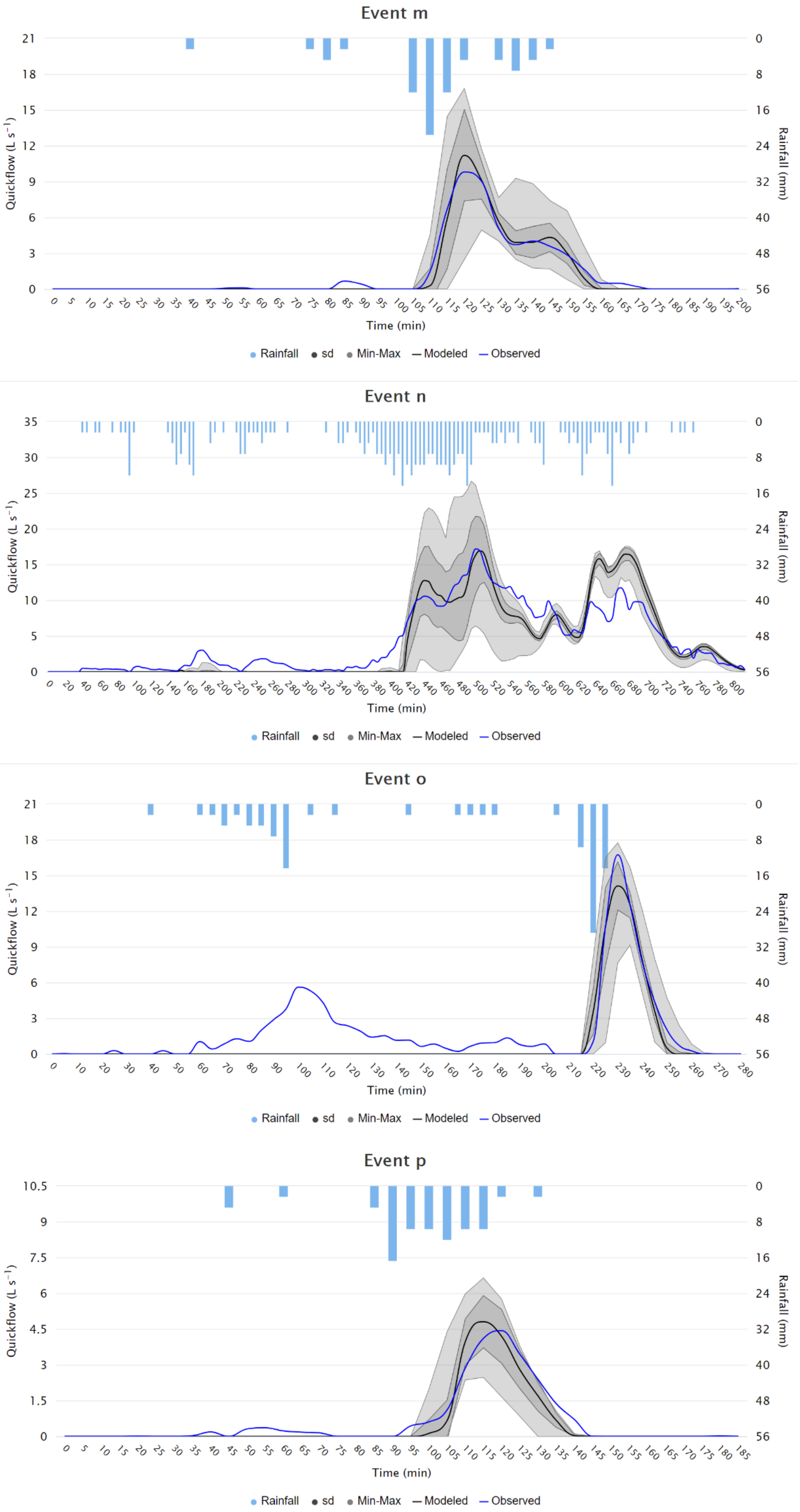


*Figure S 11 - OpenLISEM quickflow predictions variation for m, n, o, and p events simulation following 1000 MCMC iterations.*

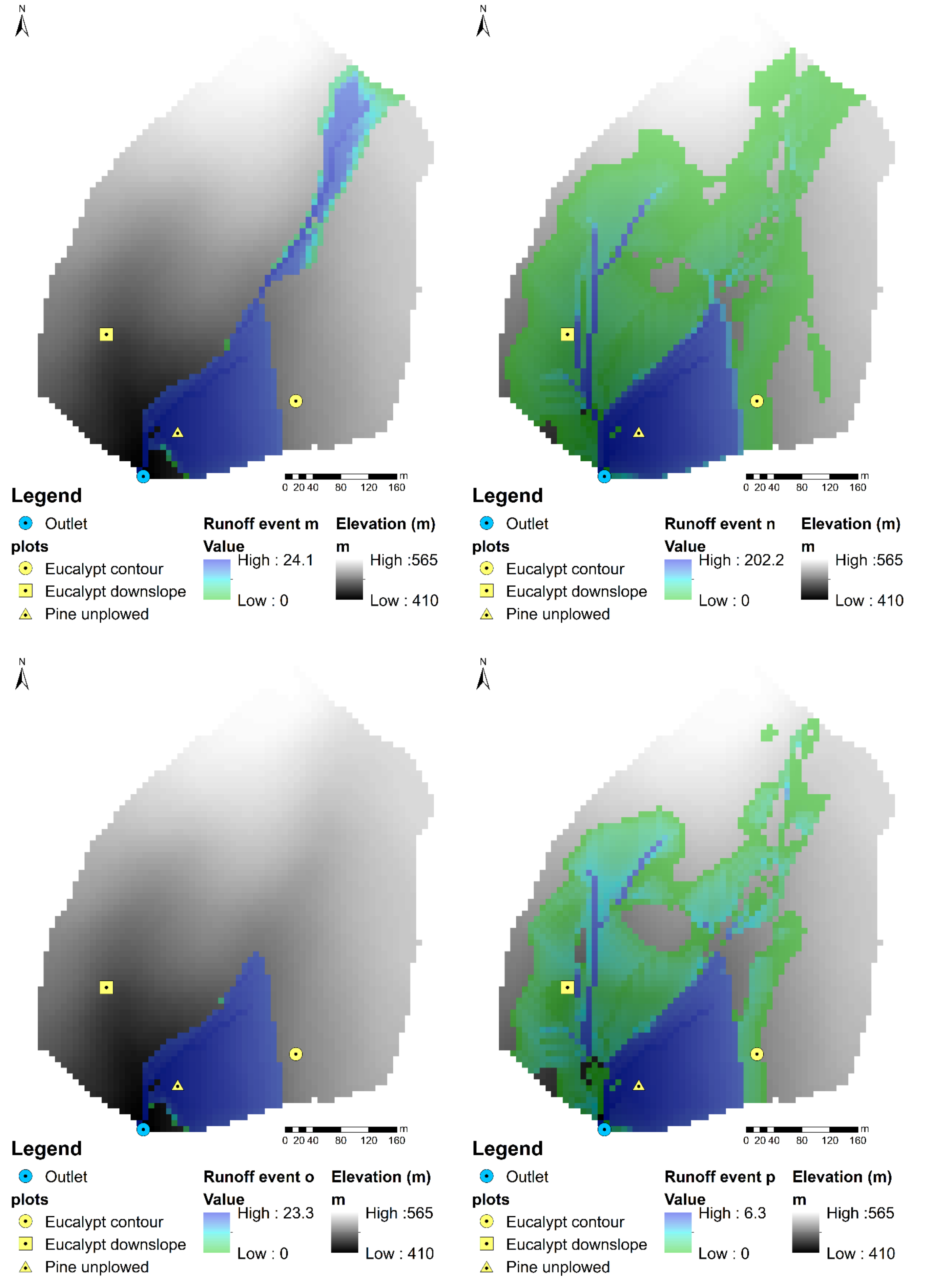


*Figure S 12 - OpenLISEM spatial runoff predictions for events m, n, o and p for optimal parameterization set.*

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