Supporting Material for "RUFIDAM: A Rapid Urban Flood Inundation and Damage Assessment Model"

S1 Impact Zones (IZs) generation

The main input data for the pre-processing step is the digital elevation model (DEM) of the floodplain domain. Each cell in the DEM raster file is considered as an impact cell. The ArcPy module (ESRI, 2012) of ArcGIS^{TM} software was used within the Python programming language to automate this pre-processing step. The hydrology toolbox is used to delineate IZs by first calculating the flow direction and then delineating a raster of basins and converting them to a polygon shapefile of IZs. At this stage, those IZs that are smaller than the minimum IZ area (specified as model parameter), are selected and merged with their neighbours that have the largest areas in the neighbourhood using the Eliminate tool in ArcGIS (Figure S1). By converting the polygons of IZs into polylines, a shapefile can be extracted that includes the neighbouring information of IZ polygons. Each line in the extracted polyline feature represents the boundary of two neighbouring IZs. Using the Stack Profile tool, the elevation data along each line (one point per grid cell) is extracted from the DEM. The minimum elevation of each profile is the communication level of two neighbouring IZs. The *Zonal Statistics as Table* tool is used to extract impact cell elevation values within each IZ. Given the water elevation, the stored volume in each IZ can be calculated as the difference between water level and impact cell elevation and their area. The location of the nodes in 1D models are linked to the IZs using the Spatial Join tool. All the extracted data is then stored in a database on disk to be used by the rapid flood inundation model.
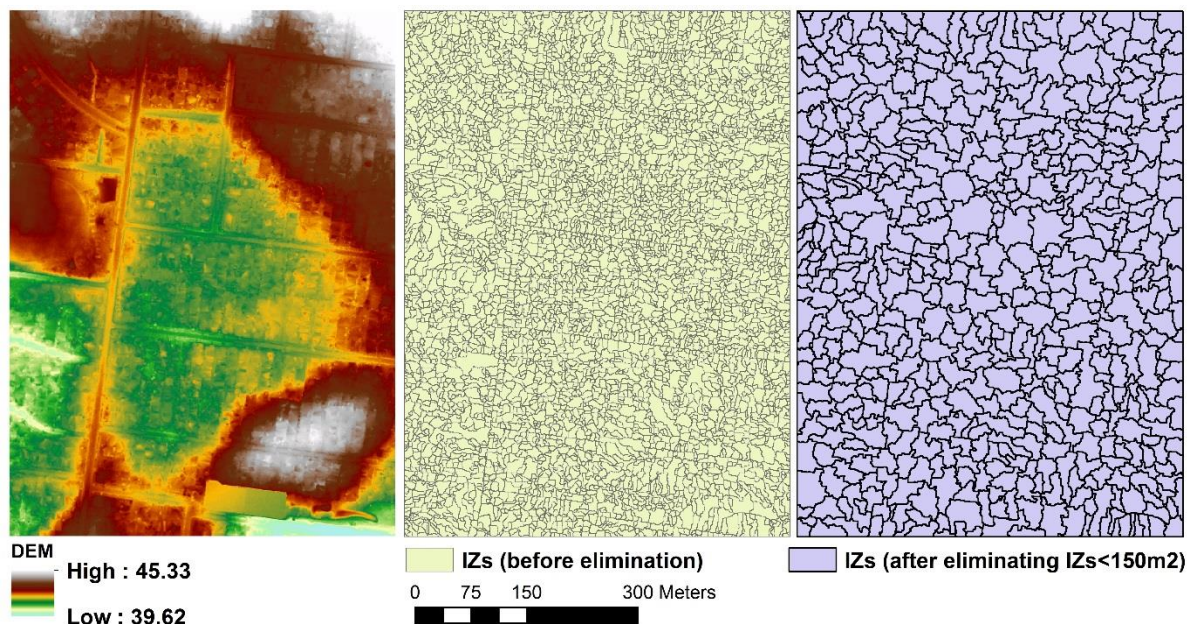

DEM
High : 45.33
Low : 39.62

IZs (before elimination)

0   75   150   300 Meters

IZs (after eliminating IZs<150m2)

Figure S1. Example of the generated Impact Zones (IZs) from a 1m resolution DEM (left) and after eliminating IZs that are smaller than 150m^2

S2 Rapid flood inundation model routine

A flow diagram of the adapted RFSM in this study is given in Figure S2~~1~~. At the start of the simulation, all IZs are dry. The routine starts with spreading the surcharge volume of the first manhole. Due to the nature of the routine, the order of selecting manholes has no impact on the final calculated flood extent. Initially the IZ that locates the first surcharging manhole becomes active. Water level is then raised to the lowest communication point(s) greater than the current water level (which is initially zero). If the located neighbour has the same water level as the active IZ, they merge together and stay active for the next iteration. Otherwise, the active IZ will flow to the found IZ(s). The total flood volume spread over IZs is calculated and if it is equal or greater than the surcharge volume of manhole one, the spreading process starts for manhole 2 after changing the status of active IZ(s) to inactive. Otherwise, all active IZ(s) become inactive and selected IZs become active (except the merged IZs that should remain active). If the condition of the located IZ is dry, it becomes active for the next iteration. Otherwise, it means that the selected IZ(s) is already flowing to another IZ. The algorithm then searches for all inactive IZs that are receiving flow from the selected IZ but not flowing to any neighbouring IZs and change their condition to active. The next iteration starts with filling water in active IZs and spilling to the selected neighbouring IZs. Finally, the total flood volume is equal or greater than the total flood volume from the surcharging manholes, the algorithm stops and creates flood extent and depth maps.

The filling/spilling routine described here only accounts for volume transfers, but, in reality, the movement of water from one IZ to another requires an extra driving head, Δz, to overcome friction and other head loss (Krupka, 2009). Therefore, when estimating the maximum water level in each IZ, an additional head should be added above the level of the lowest link. The value of Δz can either be set constant for all links in the domain or it can be calculated for each link individually to account for the local flow conditions (Krupka, 2009). In this study we used the constant extra head approach.
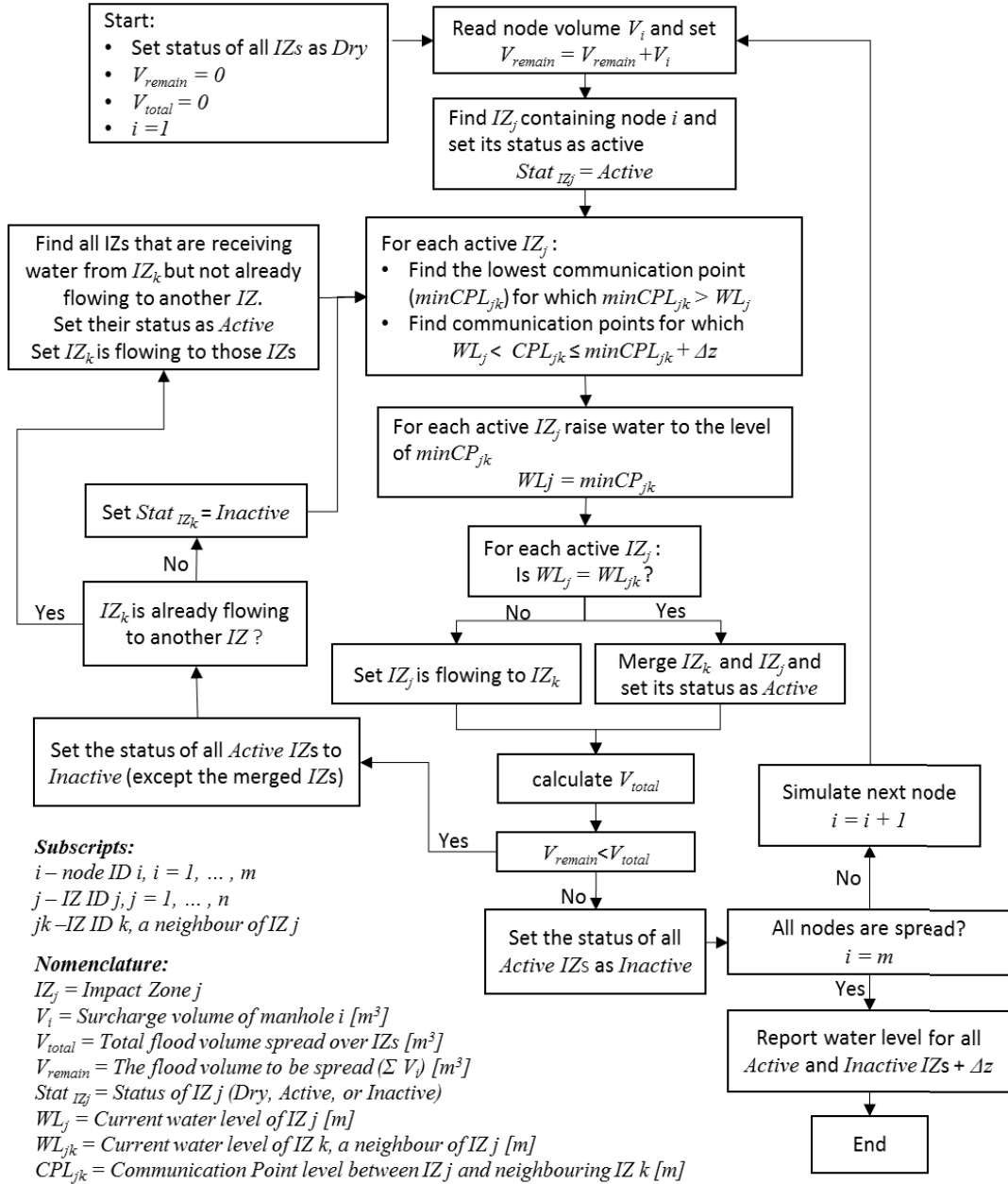
Start:
- Set status of all *IZs* as *Dry*
- $V_{remain} = 0$
- $V_{total} = 0$
- $i = 1$

Read node volume V_i and set
$V_{remain} = V_{remain} + V_i$

Find IZ_j containing node i and set its status as active
$Stat_{IZj} = Active$

Find all IZs that are receiving water from IZ_k but not already flowing to another *IZ*.
Set their status as *Active*
Set IZ_k is flowing to those IZs

For each active IZ_j:
- Find the lowest communication point ($minCPL_{jk}$) for which $minCPL_{jk} > WL_j$
- Find communication points for which $WL_j < CPL_{jk} \leq minCPL_{jk} + \Delta z$

For each active IZ_j raise water to the level of $minCP_{jk}$
$WL_j = minCP_{jk}$

Set $Stat_{IZk} = Inactive$

IZ_k is already flowing to another *IZ* ?   No → Yes

For each active IZ_j:
Is $WL_j = WL_{jk}$?   No   Yes

Set IZ_j is flowing to IZ_k

Merge IZ_k and IZ_j and set its status as *Active*

Set the status of all *Active IZs* to *Inactive* (except the merged IZs)

calculate V_{total}

Yes ← $V_{remain} < V_{total}$ No ↓

Set the status of all *Active IZs* as *Inactive*

Simulate next node
$i = i + 1$

No

All nodes are spread?
$i = m$ Yes

Report water level for all *Active* and *Inactive IZs* + Δz

End

Subscripts:
i – node ID i, i = 1, ... , m
j – IZ ID j, j = 1, ... , n
jk – IZ ID k, a neighbour of IZ j

Nomenclature:
IZ_j = Impact Zone j
V_i = Surcharge volume of manhole i [m³]
V_{total} = Total flood volume spread over IZs [m³]
V_{remain} = The flood volume to be spread (ΣV_i) [m³]
$Stat_{IZj}$ = Status of IZ j (Dry, Active, or Inactive)
WL_j = Current water level of IZ j [m]
WL_{jk} = Current water level of IZ k, a neighbour of IZ j [m]
CPL_{jk} = Communication Point level between IZ j and neighbouring IZ k [m]

Figure S2~~1~~. Flowchart for the adapted rapid flood spreading algorithm

Figure S3 shows an example of the filling and merging process for a case where flooding originates from an IZ that is located within a large natural depression. As shown in this Figure, the impact zones are merging together as the flood extent grows and at step 7, we can see that the local depression becomes one single IZ formed by merging the 6 initial IZs.
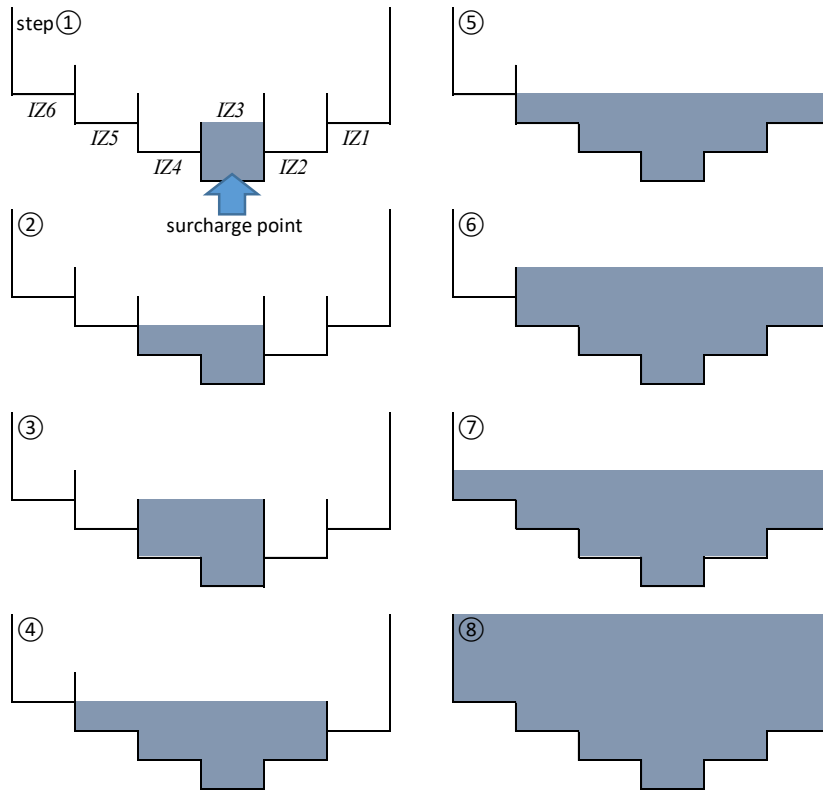
Figure S3. Process of filling and merging of impact zones located within a larger depression

S3. Impact Zones (IZs) specifications

Table S1 shows the number of initially identified IZs and final IZs after elimination for each catchment. The number of IZs were reduced by merging IZs that have areas smaller than 150m^2. The minimum IZ area parameter was selected based on the Sensitivity Analysis results.

Table S1. Number of initially created and final IZs (after merging IZs that have area smaller than 150m^2)

	area	number of initially generated IZs	number of IZs after elimination (minim IZ are = 150 m^2)	minimum IZ area	average IZ area	maximum IZ area
	[ha]	[thousands]	[thousands]	[m^2]	[m^2]	[m^2]
Catchment 1	760	950.8	112.0	150	220	1589
Catchment 2	987	1,047.5	136.0	150	249	1835
Catchment 3	78	118.4	14.2	150	206	1125

S3̶4̲ Typical time series pattern for SIP1 experiment

Figure S4̶2̲ shows the typical surcharge time series considered for all source points as input to MIKE FLOOD. In order to generate the inflow time series, we multiplied the total surcharge volume of each node by the time series pattern.
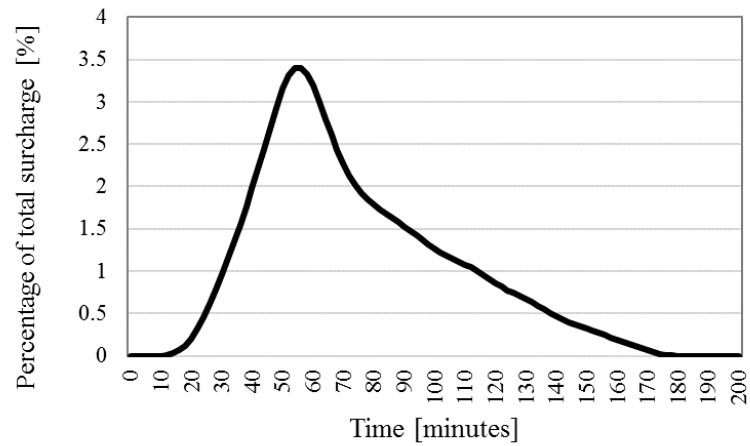

Figure S4̲. Typical surcharge time series pattern

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[1] Surface Inundation Prediction

S5 Static vs. dynamic 1D drainage network simulation (SVD experiment)

Figures S53 compares maximum water levels obtained in the static 1D drainage network simulations with ponding and spilling configurations, against those obtained from a dynamic (1D-2D MIKE FLOOD) simulation for all catchments and return periods. Figure S64 does this same comparison for link flow volumes.
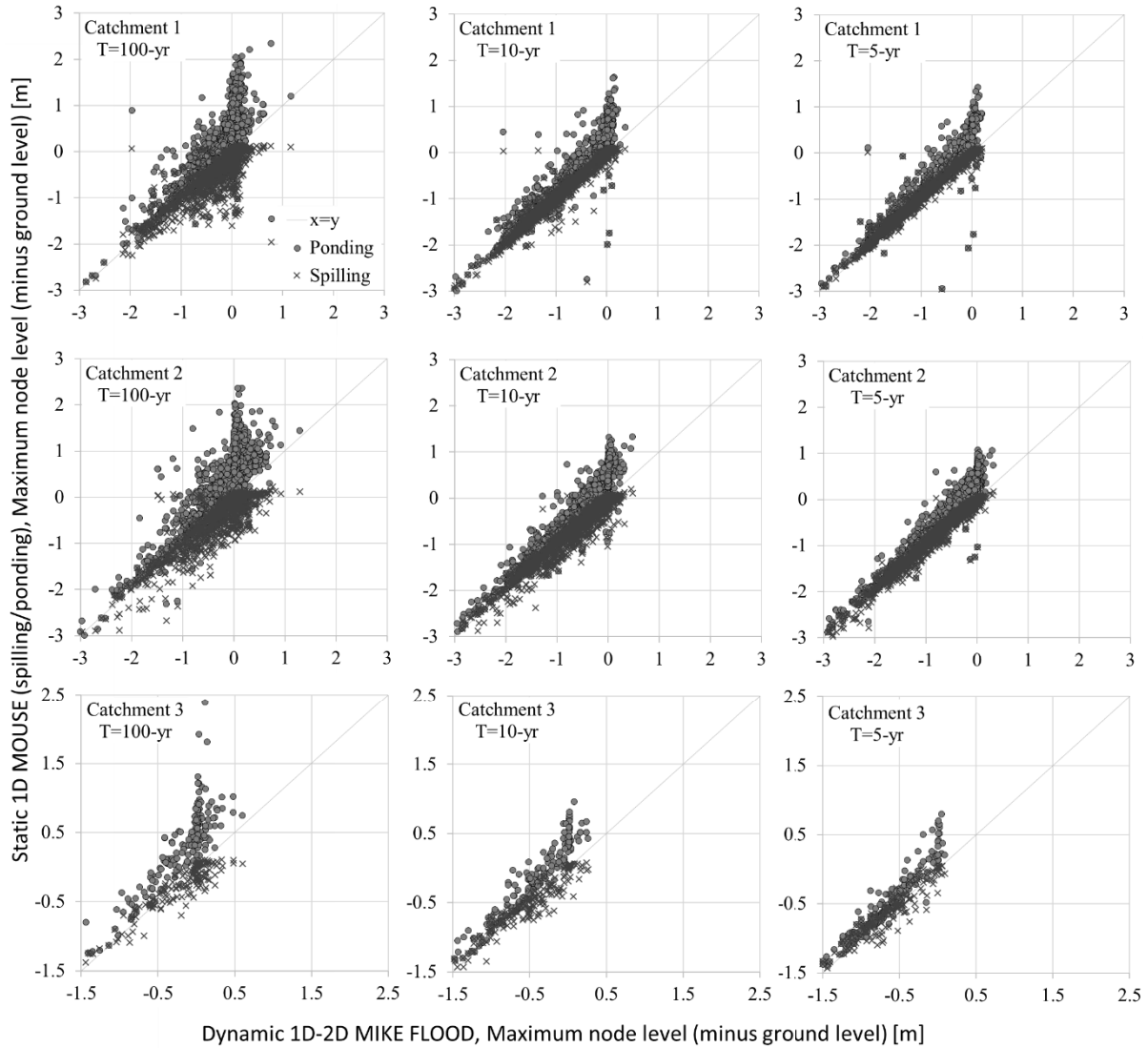

Figure S5. Comparison of maximum water level at nodes in 1D ponding and spilling simulations against dynamic (1D-2D MIKE FLOOD) results for all catchments and return periods.
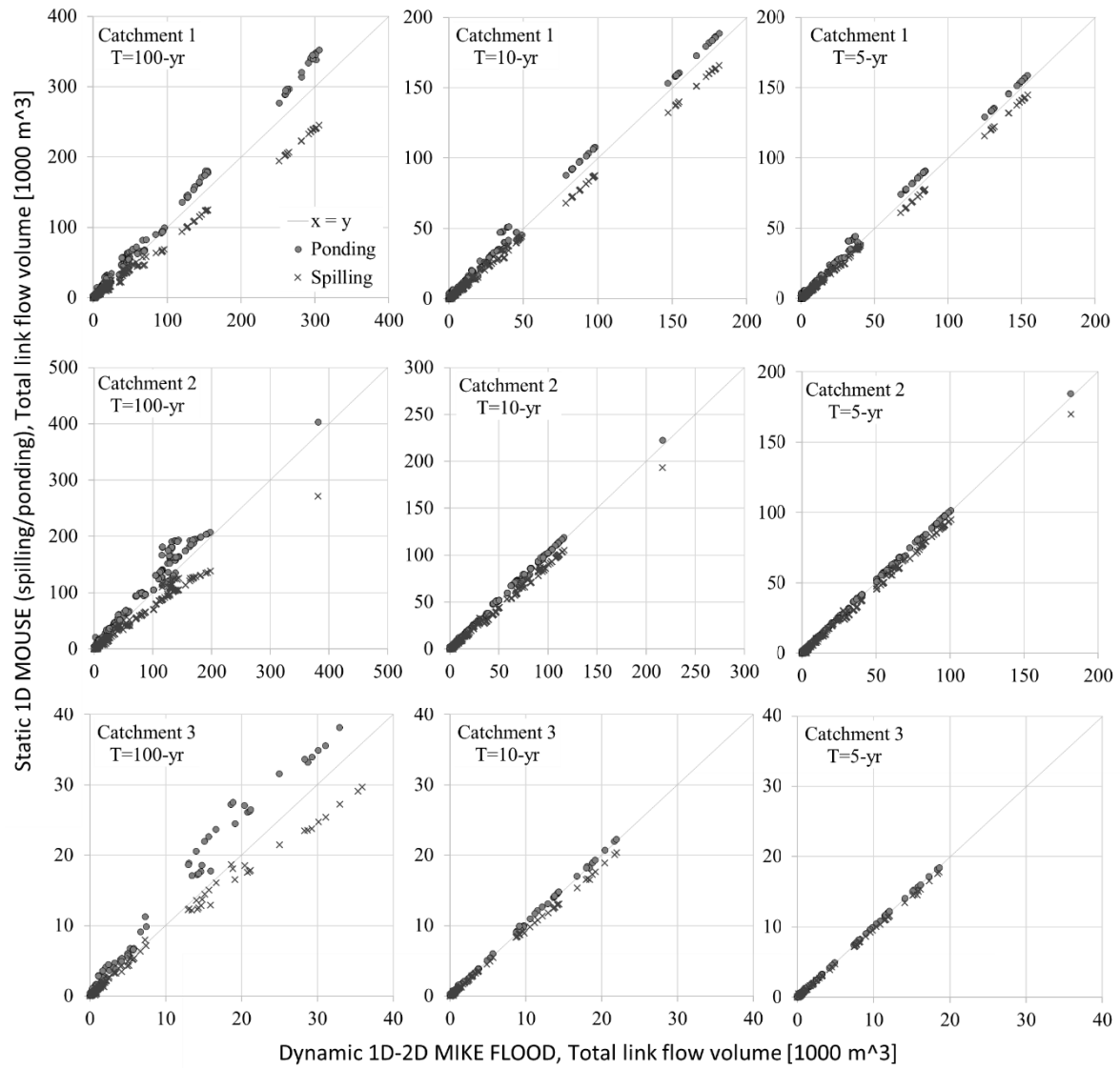
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Figure S6. Comparison of total link flows in 1D ponding and spilling simulations against dynamic (1D-2D MIKE FLOOD) results for all catchments and return periods.

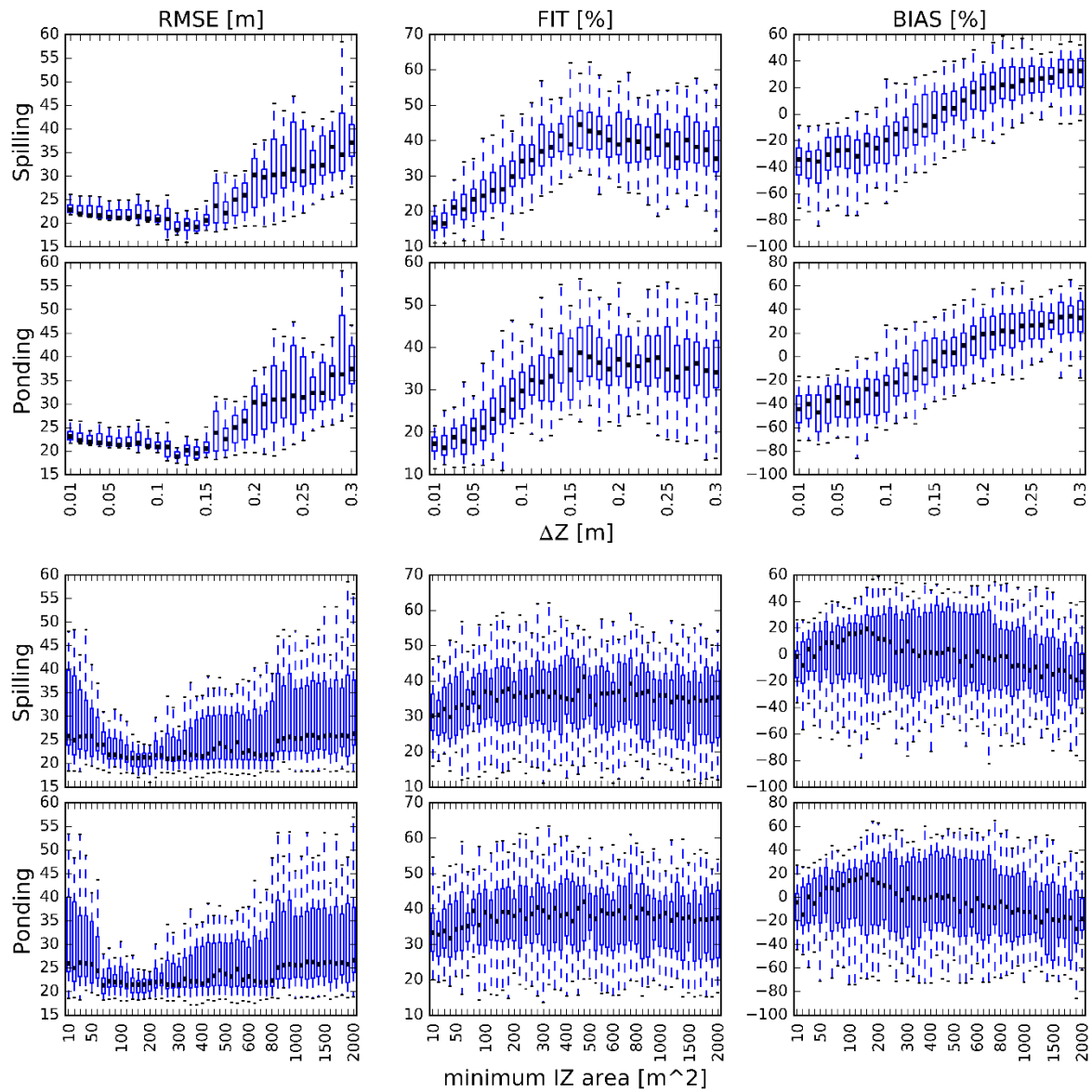# S6. Model parameter sensitivity analysis using the hydraulic performance indicators

Figure S7. Boxplots of RMSE, Fit and Bias indexes for different 1D model configurations, as well as varying constant head (Δz) and minimum IZ area parameters. Black lines indicate the mean value.