Title

Predicting the impact of land management decisions on overland flow generation: Implications for cesium migration in forested Fukushima watersheds

Authors

Siirila-Woodburn, Erica R

Steefel, Carl I

Williams, Kenneth H

et al.

Publication Date

2018-03-01

DOI

10.1016/j.advwatres.2018.01.008

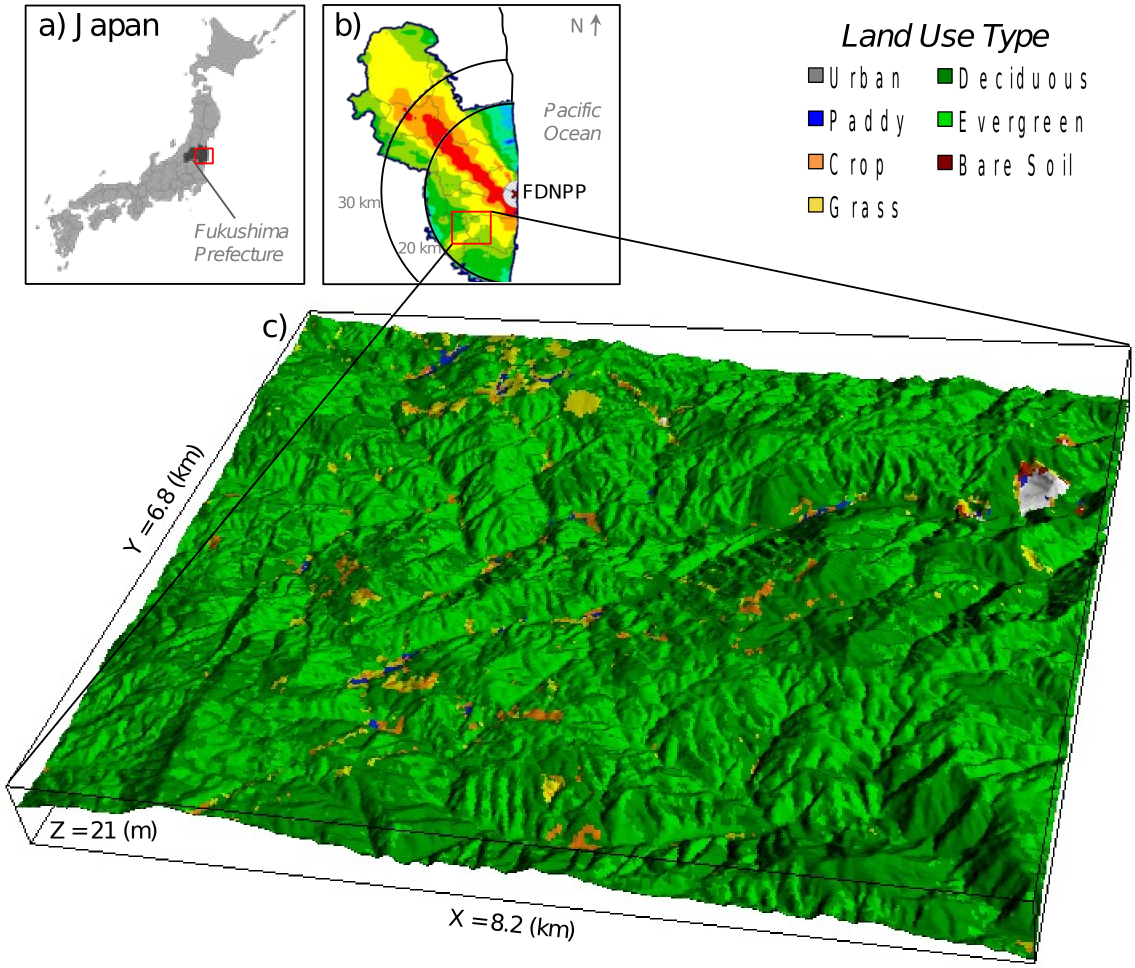

Figure 1. a) Location of the Fukushima Prefecture within Japan and b) the location of the representative watershed relative to the Fukushima Dai-ichi Nuclear Power Plant and the region deposited with the highest amount of ^{137}Cs fallout (red region in Figure b). The size of the high-resolution model is shown in c) in addition to the topographic relief of the region with colors denoting the seven land use types (see key).

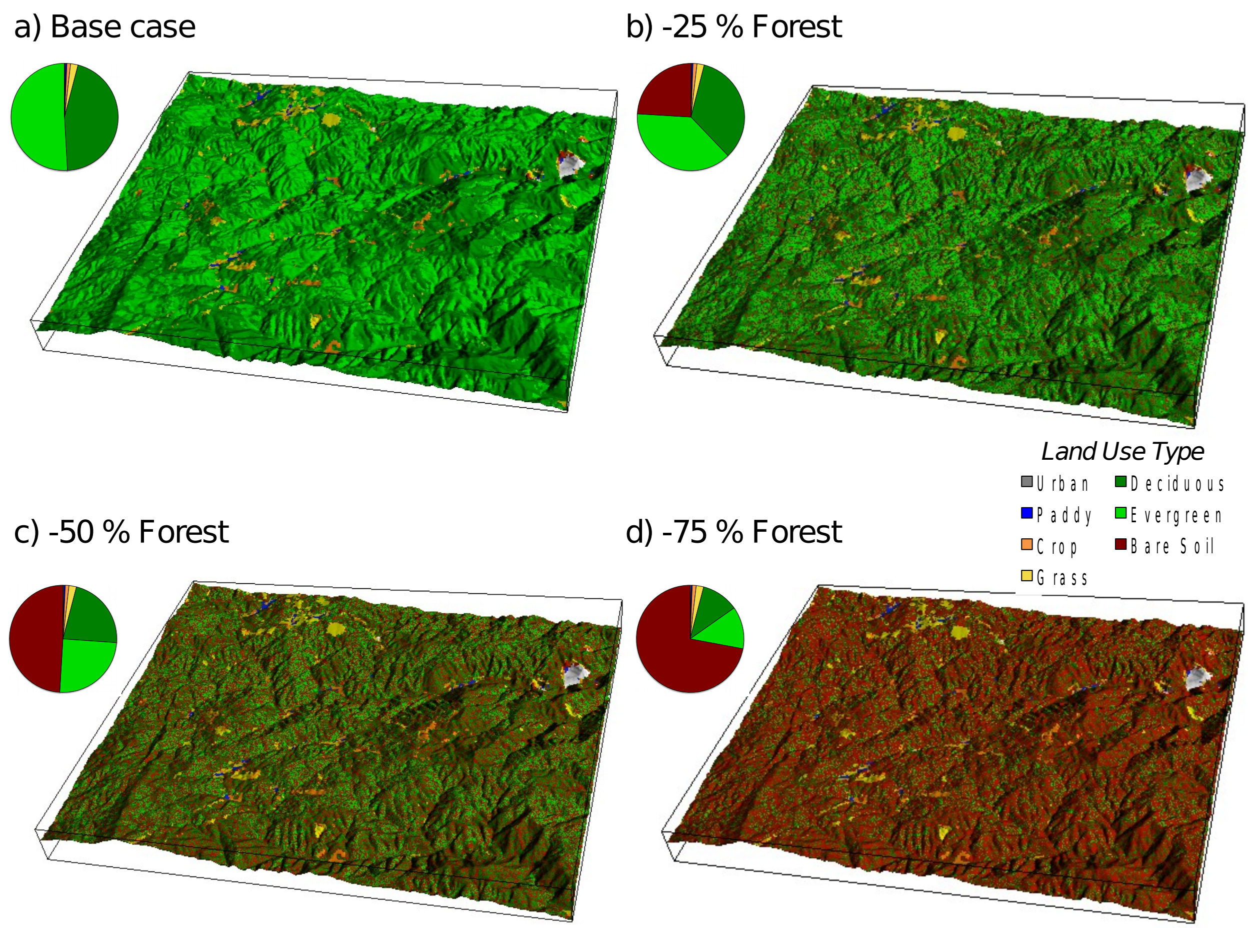

Figure 2. Reduction of forest cover from the base case simulation (a) for the three forest thinning, risk management scenarios (b-d). For each scenario, a color-coded pie-diagrams illustrates the breakdown of the seven LULC types (see key).

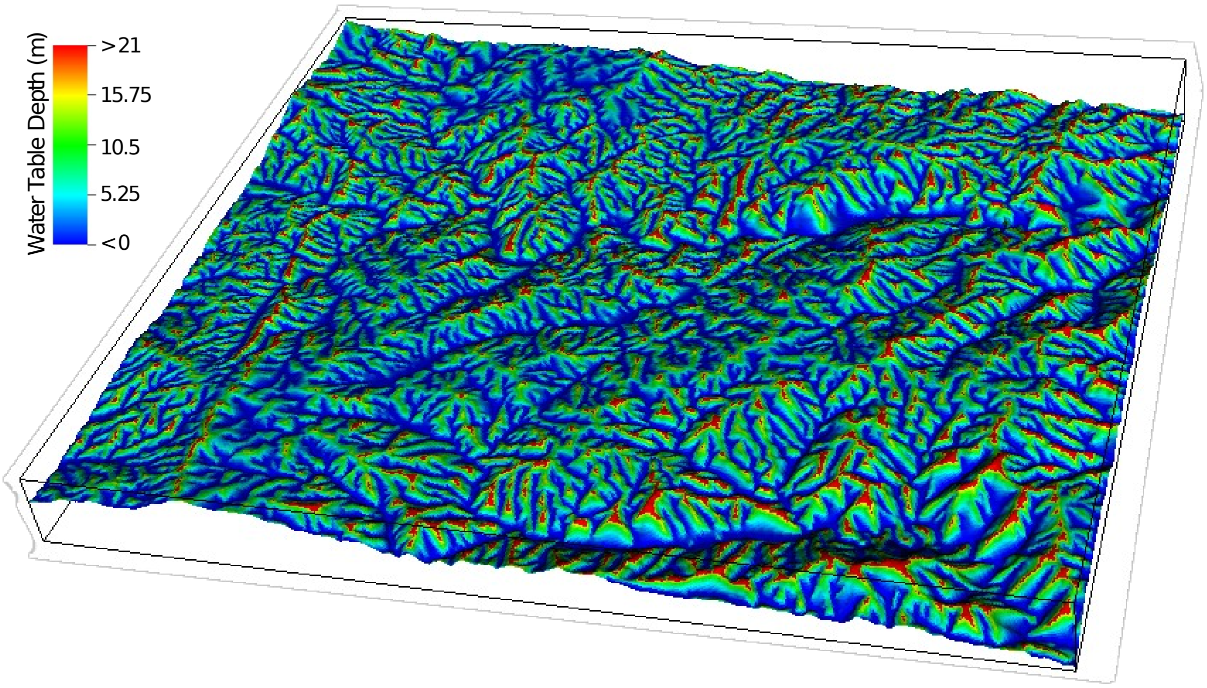

Figure 3. Spatial distribution of water table depth below the land surface after the spin-up condition is reached.

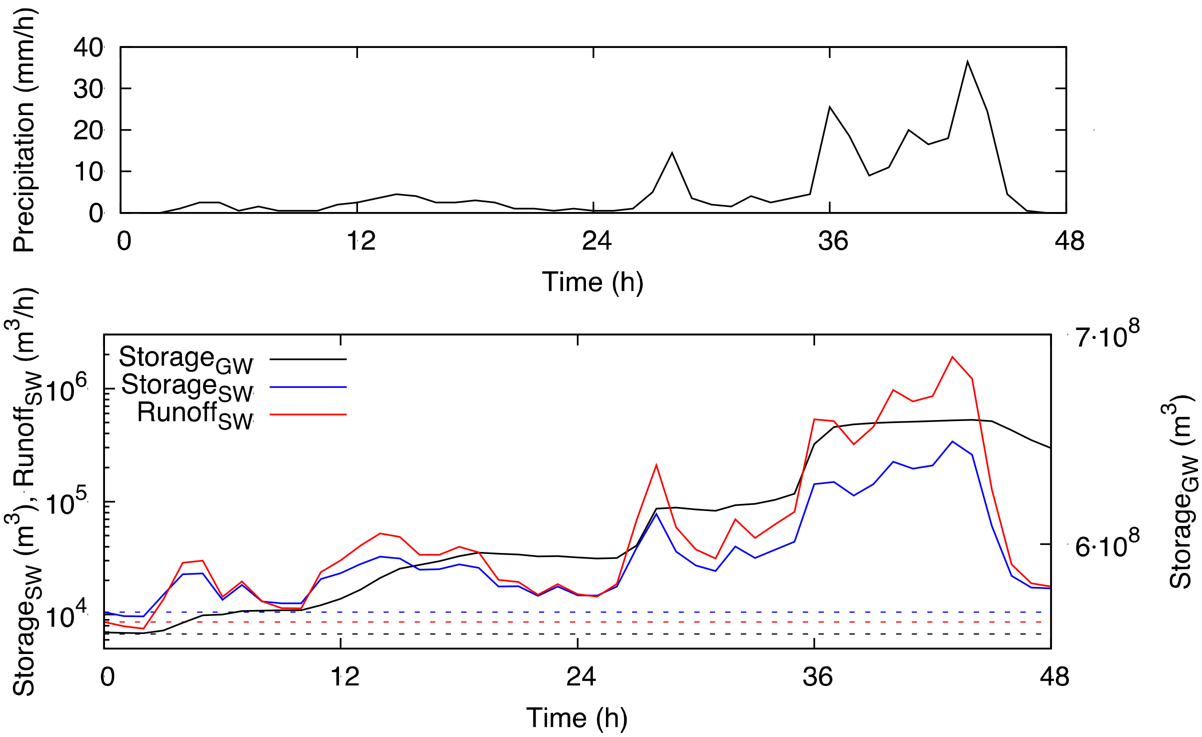

Figure 4. Evolution of surface water storage, groundwater storage, and surface water runoff during the 48-hour simulation (see color key and note different y-axes). Dashed lines indicate the initial condition of each metric at the end of the spin-up simulation (see color key). The magnitude of the precipitation-forcing signal is shown for reference (top graph).

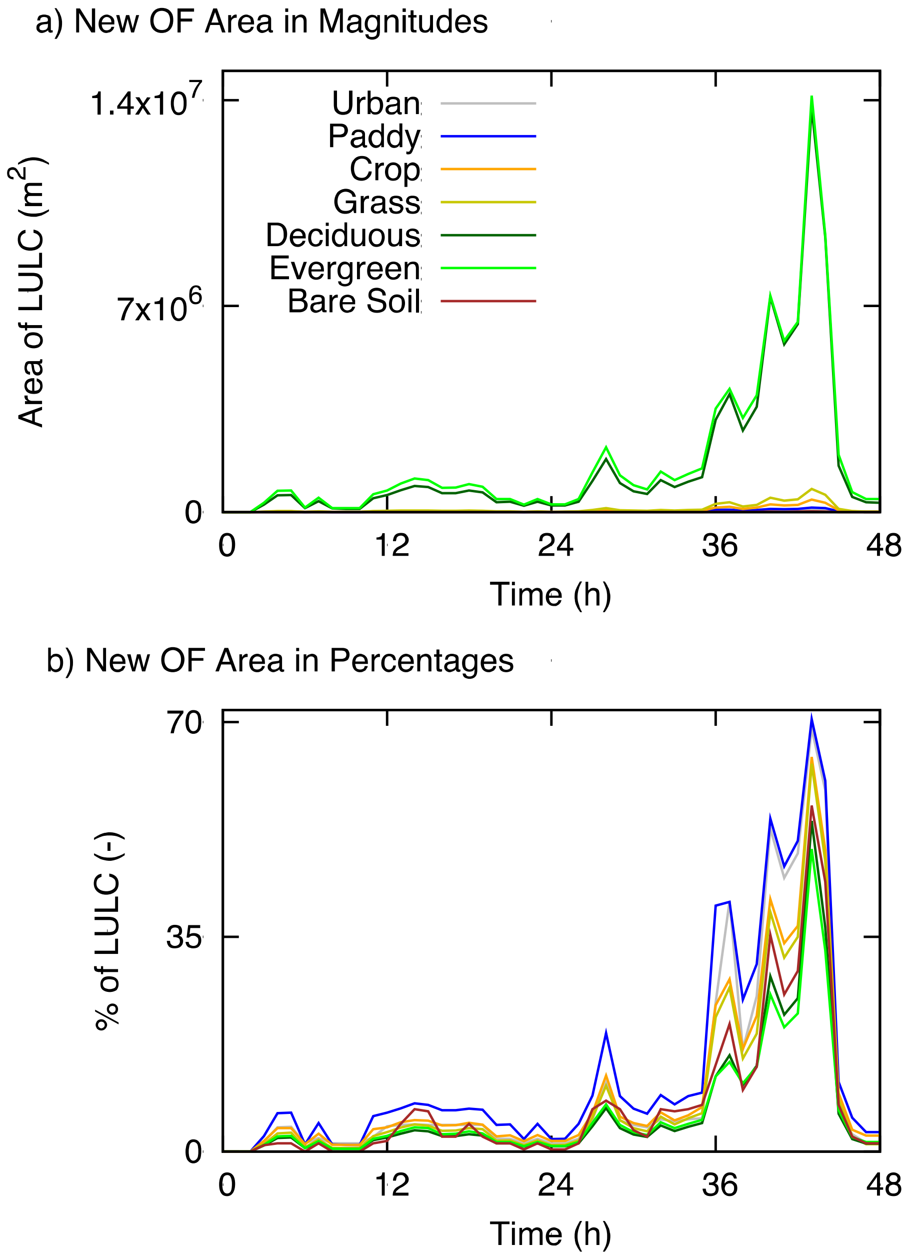

Figure 5. Evolution of new overland flow (OF) area during the 48-hour simulation, differentiated by LULC as shown in the color key in a). Results are shown as magnitudes of LULC area in a) and percentages of each LULC total area in b).

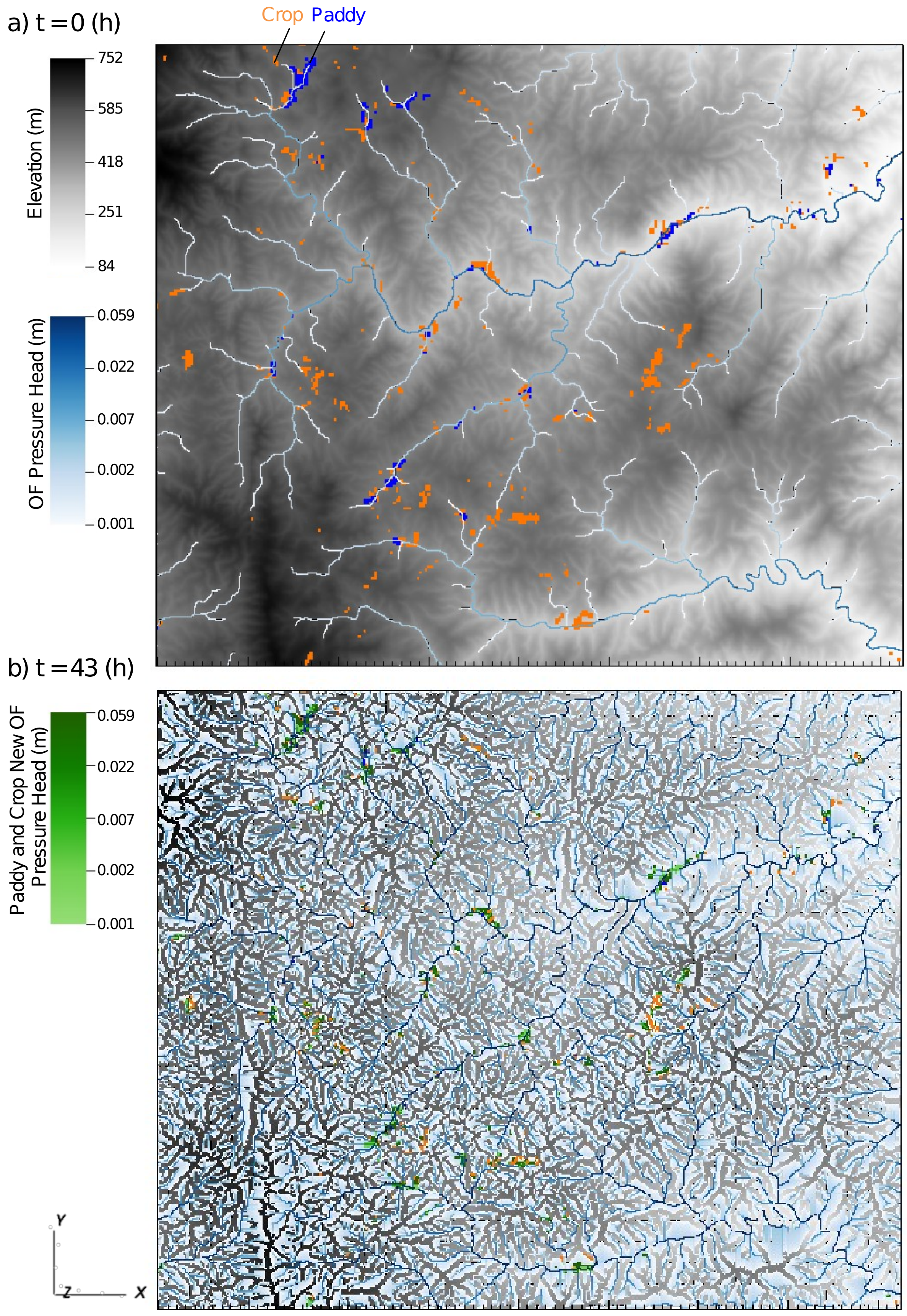
a) t = 0 (h)
Crop
Paddy
Elevation (m)
752
585
418
251
84
OF Pressure Head (m)
0.059
0.022
0.007
0.002
0.001
b) t = 43 (h)
Paddy and Crop New OF Pressure Head (m)
0.059
0.022
0.007
0.002
0.001
Y
Z
X

Figure 6. The spatial distribution of the paddy and crop LULC types (bright blue and orange colors, respectively) in relation to the elevation map of the watershed is shown in gray-scale. Overland flow pressure head is shown in blue-scale at a) the beginning of the simulation (t = 0 h) and b) at the peak of the precipitation signal (t = 43 h). Paddy and crop pressure head of new overland flow are shown in green-scale in b) where paddy and crop regions not colored in green reflect the location of these land types least susceptible to overland flow generation.

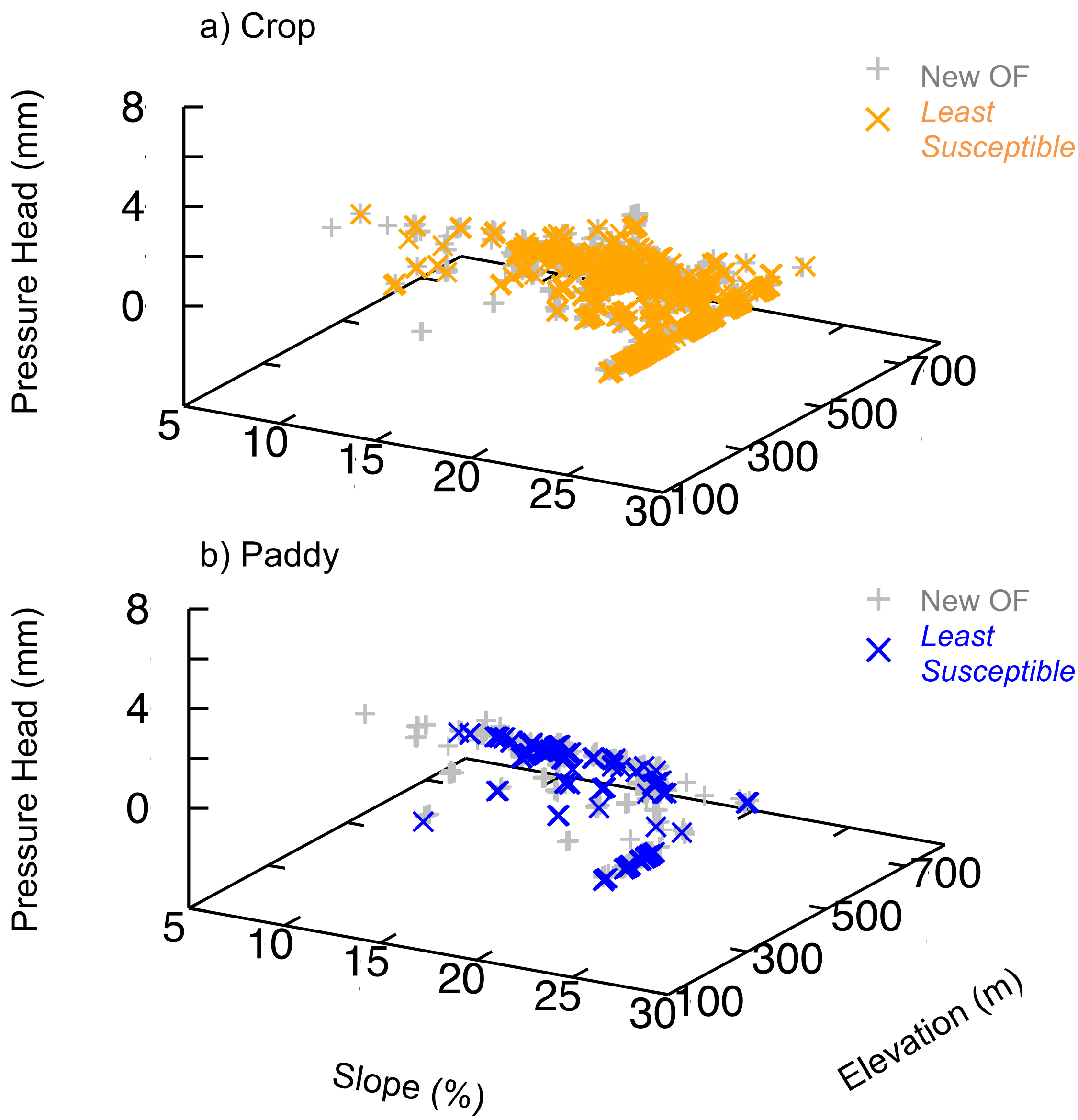

Figure 7. Correlation of overland flow pressure head, slope, and elevation of regions characterized by new OF pressure head during the peak of the storm (t = 43 h) shown as gray points. Crop (a) and paddy (b) regions least susceptible to new OF are shown as orange and blue points, respectively.

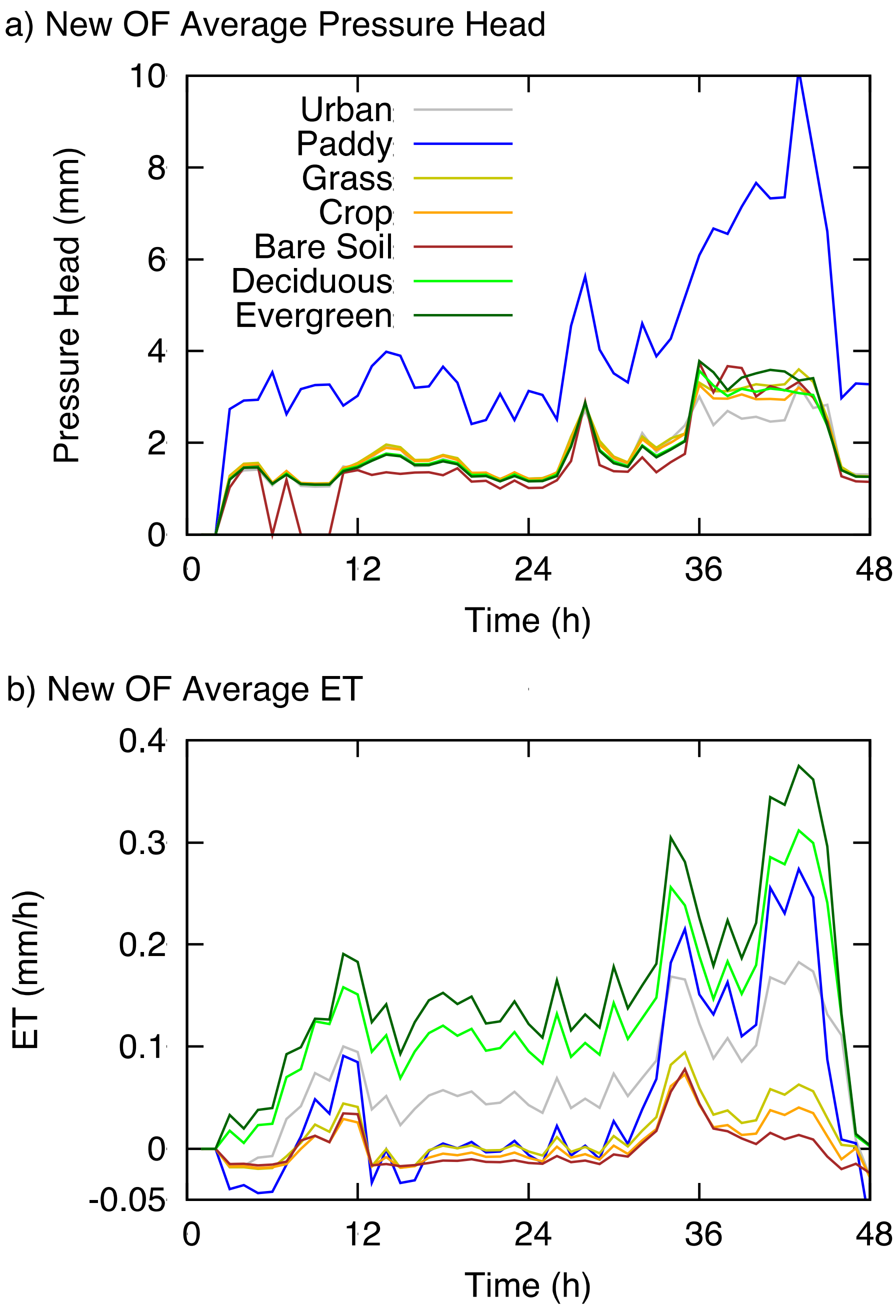

Figure 8. Evolution of domain averaged new overland flow (OF) a) pressure head and b) evapotranspiration (*ET*) during the 48-hour simulation, differentiated by LULC (as shown in the color key).

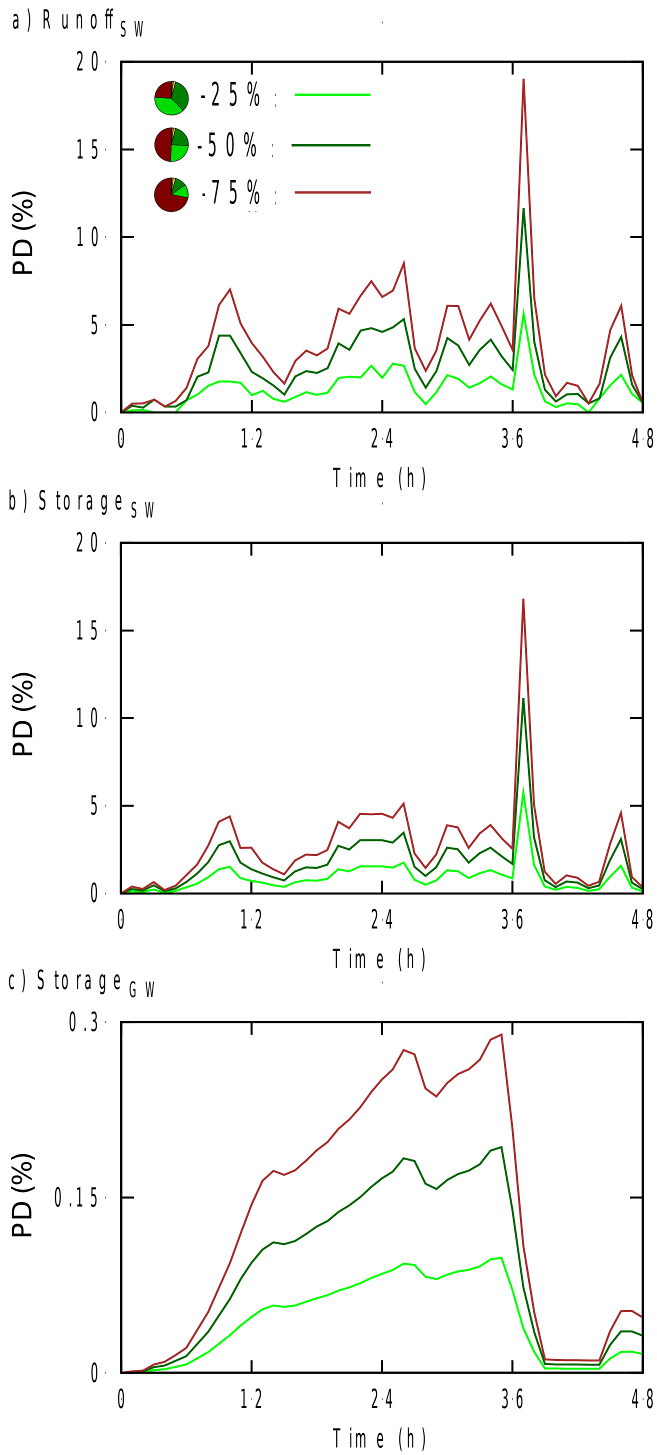

Figure 9. Evolution of the percent difference (*PD*) between risk management and base case simulations for the following water budget metrics: a) surface water runoff (*Runoff$_{SW}$*), b) surface water storage (*Storage$_{SW}$*), and c) groundwater storage (*Storage$_{GW}$*).

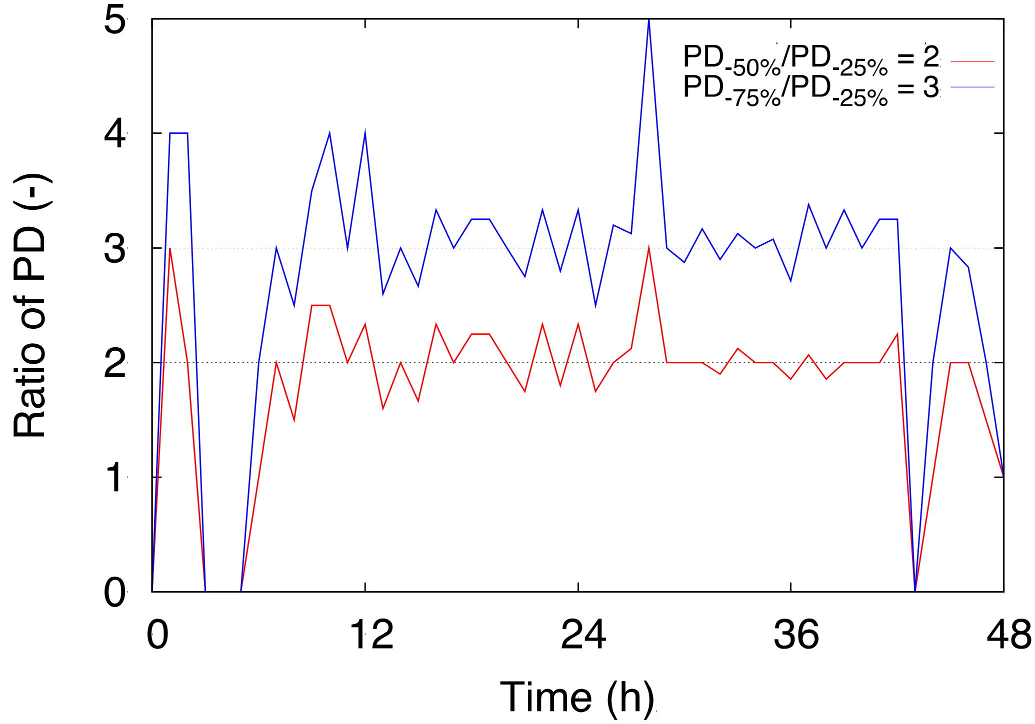

Figure 10. Example ratios of *Runoff$_{SW}$ PD* (shown in Figure 9a), illustrating the non-linearity of the system through time.

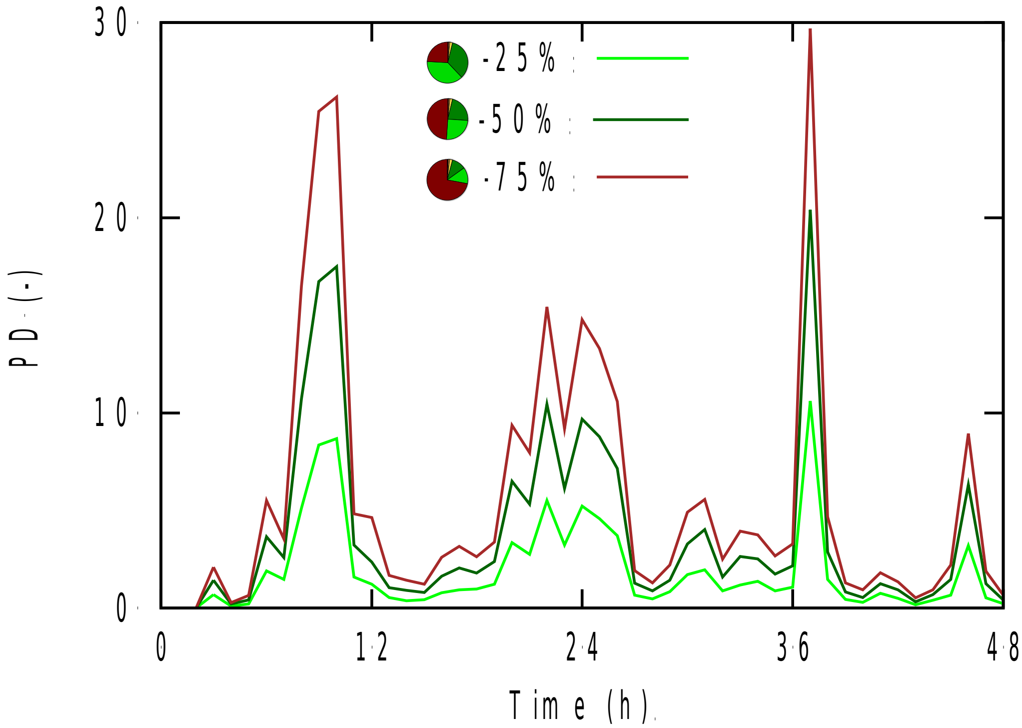

Figure 11. Evolution of the percent difference (*PD*) between risk management and base case simulations for domain averaged new overland flow (OF) area. *PD* of domain averaged new OF volume (not shown) exhibit similar trends.

Study	***Code Used***	***Location***	***Scale***	***Motivation***	***Treatment of Water-Energy Budget Component***						
					Saturated GW	Vadose Zone	Root Zone	SW	Vegetation	Rainfall / ET	Atmospheric Energy Flux
[1] Loague, et al., 2005	InHM[a]	Chickasha, Oaklahoma, USA	0.1 (km^2)	Erosion Transport	X	X		X		X	
[2] Liu et al., 2007	MIKE SHE/MIKE 11	Tarim Basin, China	91.16 (km^2)	Response Characteristics of Overland Flow	X	X	X	X	X	X	
[3] Sudicky et al., 2008	InHM	Laurel Creek, Ontario, Canada	17 (km^2)	Tracer Transport	X	X		X		X	
[4] Gautheir et al., 2009	CATHY[b]	Annapolis Valley, Nova Scotia, Canada	8 (km^2)	Stream Flow Magnitude	X	X		X		X	
[5] Shen and Phanikumar, 2010	PAWS[c]	Grand River Watershed, Michigan, USA	1169 (km^2)	Stream Flow Magnitude	X	X	X	X	X	X	X
[6] Huntington and Niswonger, 2012	GSFLOW[d]	Lake Tahoe, Nevada, USA	54 (km^2)	Stream Flow Magnitude, Timing with Climate Change	X	X	X	X	X	X	X
[7] Cornelissen	HydroGeoSphere	Wüstebach Catchment,	0.27 (km^2)	Effect of Spatial	X	X	X	X	X	X	

et al., 2013		Germany		Variability on Soil Moisture							
[8] Manoli et al., 2014	CATHY	North Carolina, USA	5x10^{-5} (km^2)	Tree Root Water Competition	x	x	x	x	x	x	x
[9] Camporese et al., 2015	CATHY	Mirranatwa, Victoria, Australia	0.48 (km^2)	Stream Flow Magnitude	x	x	x	x	x	x	
[10] This Study	ParFlow[e]	Fukushima Prefecture, Japan	56.54 (km^2)	Sediment-bound cesium-137 Transport	x	x	x	x	x	x	x

Table 1. Example watershed simulations utilizing integrated hydrologic models and the evolution of how various components of the water-energy budget were treated in each study.
[a]Integrated Hydrology Model [b]CATchment Hydrology model, [c]Process-based Adaptive Watershed Simulator, [d]USGS Coupled Groundwater and Surface Water Flow Model , [e]Parallel Flow.

Parameter	***Value***	***Units***
Number of cells: *nx, ny, nz*	665, 553, 5	
Cell discretization: *dx, dy, dz*	12.4, 12.4, variable (0.3, 0.7, 5, 5, 10 from the land surface downward)	(m)
Hydraulic Conductivity, *K:* Layers 1 and 2 (top 1.0 m) Layers 3-5 (bottom 20 m)	 3.6×10^{-2} 3.6×10^{-3}	 (m/h) (m/h)
Porosity, θ: Layers 1 and 2 (top 1.0 m) Layers 3-5 (bottom 20 m)	 0.3 0.2	
Van Genuchten: α, *N*:	3.5, 2.0	
Manning: *n*	5.5×10^{-6}	$(h/m^{1/3})$
Specific storage: *SS*	1.0×10^{-5}	$(1/m^3)$
Average P-ET forcing	3.1	(mm/d)
Stem Area Index Crop Paddy	 2.0 1.5	 (-) (-)
Displacement Height Crop Paddy	 0.3 1.1	 (m) (m)

Table 2. Parameterization used in the numerical watershed model.