Supporting Information for

Compound flooding from storm surges, rivers, and groundwater - Hydrodynamic modelling in a coastal catchment

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Introduction

This supplementary document contains additional figures and tables relevant to the paper. S-Table 1-3 contains detailed information on the performance of the hydrological model, together with S-Figure 1 which shows the Manning calibration graph. S-Table 4 gives information about the extreme analysis values illustrated in the figures. While S-Table 5- 7 shows the results of the compound analysis in the form of a correlation matrix and count. S-Table 8 shows flooding statistics together with S-Figure 2-5 which shows bar charts of flooding characteristics and a figure with maps of flooding extent.

S-Table 1 Detailed performance for water levels 2008-2020.

STATION NO.	River name and chainage	HIP4PLUS MODEL			RIBE MODEL		
		ME	MAE	RMSE	ME	MAE	RMSE
WL3802	Ribe Aa, 11020	1.06	1.06	1.11	0.00	0.13	0.17
WL3803	Ribe Aa, 10374	0.53	0.56	0.61	-0.03	0.08	0.10
WL3805	Ribe Aa, 16874	2.98	2.98	3.00	0.07	0.18	0.23
WL3836	Stampemølleaa, 1117	-0.04	0.21	0.27	-0.12	0.20	0.25
WL3837	Hjortvadaa, 6713	0.41	0.44	0.53	0.37	0.39	0.47
WL3839	Hjortvadaa, 9055	0.41	0.50	0.61	0.23	0.27	0.35
WL3851	Hjortvadaa, 6966	0.42	0.42	0.45	0.38	0.38	0.41

S-Table 2 Detailed performance for groundwater levels 2008-2020.

WELL NO.	Layer	HIP4PLUS MODEL			RIBE MODEL		
		ME	MAE	RMSE	ME	MAE	RMSE
140.1315_1	6	1.30	1.30	1.32	1.25	1.25	1.28
140.1316_1	8	1.74	1.74	1.78	1.68	1.68	1.73
140.224_1	8	6.46	6.46	6.46	6.28	6.28	6.28
141.766_1	8	-1.25	1.25	1.25	-1.25	1.25	1.25
141.927_1	10	-6.18	6.18	6.24	-6.19	6.19	6.25
142.280_1	6	-2.31	2.31	2.34	-2.31	2.31	2.34
142.559_1	2	-2.06	2.06	2.06	-2.06	2.06	2.06
150.406_1	6	-1.34	1.34	1.34	-1.34	1.34	1.34
150.465_1	6	-0.84	0.84	0.84	-0.84	0.84	0.84
150.532_1	6	0.96	0.96	0.97	0.96	0.96	0.97
150.548_1	6	0.06	0.09	0.16	0.06	0.09	0.16
150.631_1	6	-0.93	0.93	0.94	-0.93	0.93	0.94
150.662_1	8	2.17	2.17	2.18	2.17	2.17	2.18
150.663_1	8	2.46	2.46	2.47	2.46	2.46	2.47
150.679_1	5	0.61	0.99	1.03	0.61	0.99	1.03
151.921_1	8	1.58	1.58	1.58	1.58	1.58	1.58

S-Table 3 Detailed performance for discharge stations in 2008-2020.

STATION NO.	RIVER NAME AND CHAINAGE	ME	MAE	RMSE	STDRES	R(CORRELATION)	R2(NASHSUTCLIFFE)

HIP4PLUS MODEL	Q380019	Jelsaa, -5400	0.02	0.04	0.08	0.08	0.92	0.82
	Q380020	Jelsaa, -6772	0.02	0.05	0.09	0.09	0.83	0.66
	Q380023	Hjortvad Aa, 2182	0.26	0.61	0.97	0.94	0.77	0.47
	Q380024	Ribe Aa, 506	-0.39	1.69	2.75	2.72	0.91	0.78
	Q380097	Gels Aa, 8116	0.04	0.36	0.53	0.52	0.87	0.58
RIBE MODEL	Q380019	Jelsaa, -5400	0.02	0.04	0.08	0.08	0.92	0.82
	Q380020	Jelsaa, -6772	0.02	0.05	0.09	0.09	0.82	0.66
	Q380023	Hjortvad Aa, 2182	0.26	0.61	0.98	0.94	0.77	0.46
	Q380024	Ribe Aa, 506	0.32	1.67	2.68	2.66	0.90	0.79
	Q380097	Gels Aa, 8116	0.04	0.36	0.53	0.52	0.87	0.58

S-Table 4 Extreme analysis for sea level and precipitation. Precipitation values in parenthesis indicates the summed precipitation across the moving average period.

	PRECIPITA-TION MM/DAY	SEA LEVEL M. A. SL.	RIVER LOCATIONS M. A. SL.							
LOC	catchment	WL3804	WL3805	marsh1	marsh2	bRibe	WL3802	WL3803	aRibe	Lowl
Q90	8.6	1.0	0.5	0.6	0.7	0.8	0.9	2.3	2.3	2.4
Q95	12.5	1.2	0.8	0.8	1.0	1.0	1.1	2.3	2.3	2.4
Q99	22.0	1.8	1.3	1.3	1.4	1.4	1.4	2.5	2.6	2.6
T2	31.3	3.1	2.0	2.0	2.0	2.0	2.0	2.5	2.6	2.6
T5	37.8	3.6	2.3	2.3	2.3	2.3	2.3	2.7	2.7	2.8
T10	42.3	4.0	2.4	2.4	2.4	2.4	2.4	2.8	2.8	2.9
T20	46.8	4.3	2.5	2.5	2.5	2.5	2.5	2.9	2.9	3.0
T50	52.7	4.8	2.6	2.6	2.6	2.6	2.6	3.0	3.0	3.1
T100	57.4	5.2	2.6	2.7	2.7	2.7	2.7	3.1	3.1	3.1

S-Table 5 Spearman rank correlation of precipitation and river events for different buffers

		POSITIVE BUFFER - DAYS BEFORE RIVER EVENT								
		0	1	2	3	4	5	6	7	8
NEGATIVE BUFFER - DAYS AFTER RIVER EVENT	0	0.18	0.27	0.23	0.25	0.25	0.25	0.25	0.23	0.22
	1	0.20	0.27	0.23	0.25	0.25	0.25	0.25	0.23	0.22
	2	0.20	0.23	0.23	0.25	0.25	0.25	0.25	0.23	0.22
	3	0.20	0.25	0.25	0.25	0.25	0.25	0.25	0.23	0.22
	4	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.23	0.22
	5	0.21	0.25	0.25	0.25	0.25	0.25	0.25	0.23	0.22
	6	0.20	0.25	0.25	0.25	0.25	0.25	0.25	0.23	0.22
	7	0.19	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22
	8	0.19	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22

S-Table 6 Spearman rank correlation of sea level and river events for different buffers

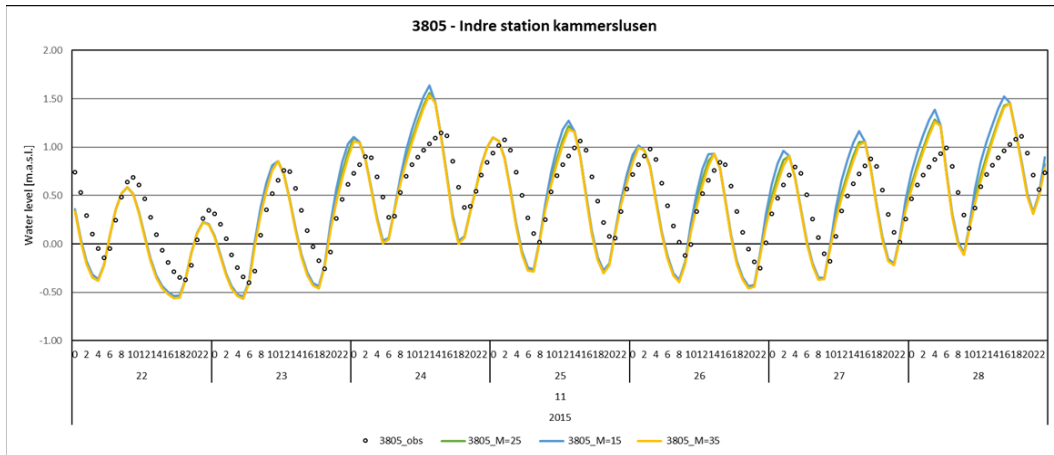|		POSITIVE BUFFER - DAYS BEFORE RIVER EVENT																
		0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
NEGATIVE BUFFER - DAYS AFTER RIVER EVENT	0	0.38	0.26	0.30	0.31	0.34	0.35	0.36	0.38	0.39	0.39	0.39	0.42	0.42	0.41	0.42	0.41	0.41
	0.5	0.40	0.34	0.37	0.37	0.39	0.39	0.40	0.42	0.43	0.42	0.42	0.44	0.44	0.44	0.43	0.43	0.43
	1.0	0.47	0.38	0.41	0.41	0.42	0.42	0.43	0.45	0.46	0.46	0.46	0.46	0.47	0.46	0.46	0.46	0.46
	1.5	0.47	0.39	0.42	0.42	0.43	0.43	0.44	0.45	0.46	0.46	0.45	0.46	0.46	0.46	0.46	0.46	0.45
	2.0	0.47	0.40	0.43	0.43	0.43	0.43	0.44	0.46	0.46	0.46	0.45	0.46	0.46	0.46	0.46	0.46	0.46
	2.5	0.49	0.43	0.45	0.44	0.44	0.44	0.45	0.47	0.47	0.46	0.46	0.47	0.47	0.47	0.46	0.46	0.46
	3.0	0.49	0.43	0.45	0.45	0.45	0.45	0.46	0.47	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.46	0.46
	3.5	0.48	0.43	0.45	0.45	0.45	0.45	0.46	0.47	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.46	0.46
	4.0	0.48	0.44	0.45	0.45	0.45	0.45	0.46	0.48	0.48	0.48	0.47	0.47	0.48	0.48	0.47	0.47	0.47
	4.5	0.48	0.44	0.46	0.46	0.46	0.47	0.48	0.48	0.49	0.48	0.48	0.48	0.48	0.48	0.48	0.47	0.47
	5.0	0.48	0.45	0.47	0.47	0.47	0.47	0.48	0.49	0.49	0.49	0.48	0.49	0.49	0.49	0.49	0.49	0.48
	5.5	0.47	0.44	0.46	0.46	0.46	0.46	0.47	0.48	0.48	0.48	0.47	0.48	0.48	0.48	0.48	0.48	0.47
	6.0	0.46	0.43	0.45	0.45	0.45	0.45	0.46	0.47	0.47	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
	6.5	0.44	0.42	0.44	0.44	0.44	0.44	0.45	0.46	0.46	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	7.0	0.44	0.42	0.44	0.44	0.44	0.44	0.45	0.46	0.46	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	7.5	0.44	0.42	0.44	0.44	0.44	0.45	0.45	0.46	0.46	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	8.0	0.44	0.43	0.45	0.45	0.46	0.46	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47

S-Table 7 Count of multivariante and preconditioned compound events for each of the river event types in percentage and (count)

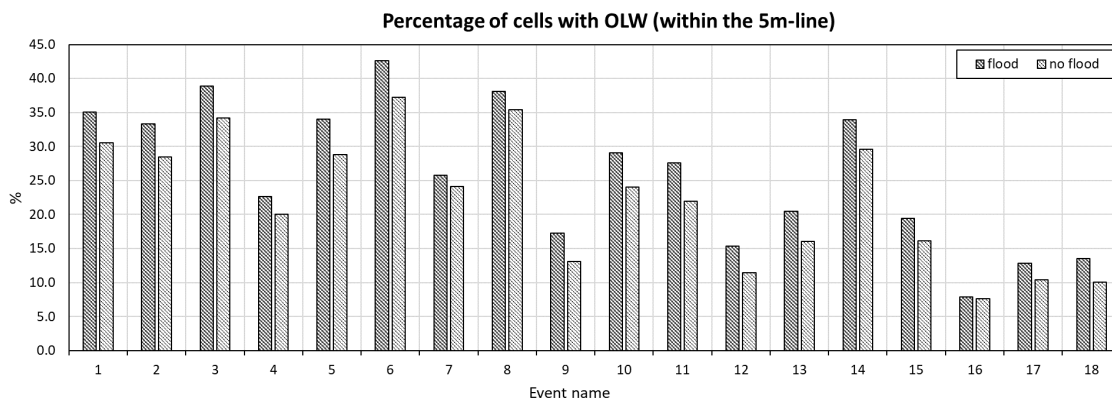| RIVER EVENT	ALL	MULTIVARIATE	PRECONDITIONED	BOTH	NO COMPOUND EVENT
Q90	110	52% (57)	3% (3)	1% (1)	45% (49)
Q95	95	61% (58)	4% (4)	6% (6)	28% (27)
Q99	30	67% (20)	0% (0)	27% (8)	7% (2)
T2	11	18% (2)	18% (2)	45% (5)	18% (2)
T5	6	0% (0)	17% (1)	67% (4)	17% (1)
T10	2	0% (0)	0% (0)	100% (2)	0% (0)
T20	0	0% (0)	0% (0)	0% (0)	0% (0)
T50	0	0% (0)	0% (0)	0% (0)	0% (0)
T100	0	0% (0)	0% (0)	0% (0)	0% (0)

S-Table 8 Flooding statistics

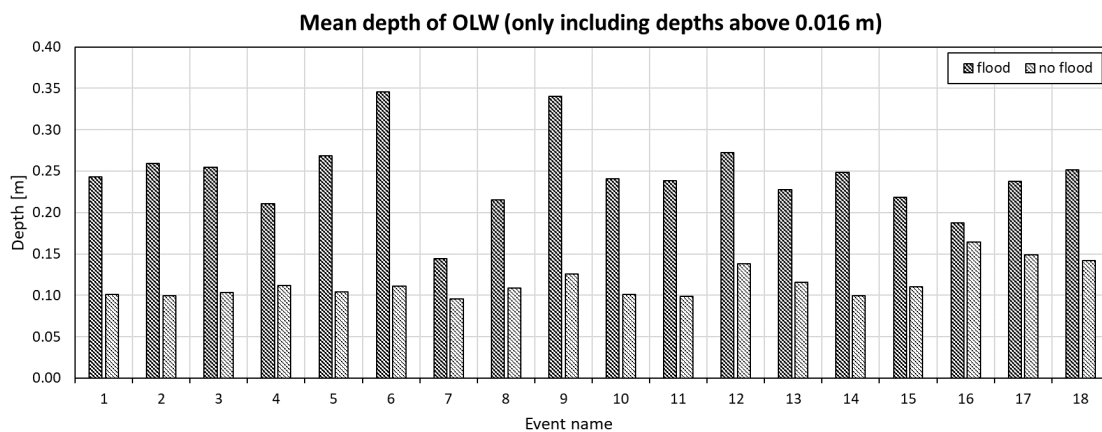| NO	DATES		TYPE	MEAN DEPTH [M]	PERCENTAGE OF CELLS WITH OL WATER [%]	MAX WATER DETPH [M]	MEAN VOLUME [M³ WATER]	PERCENTAGE GW CONTRI-BUTION	CLOS-ING TIME [HR]
	START	STOP							

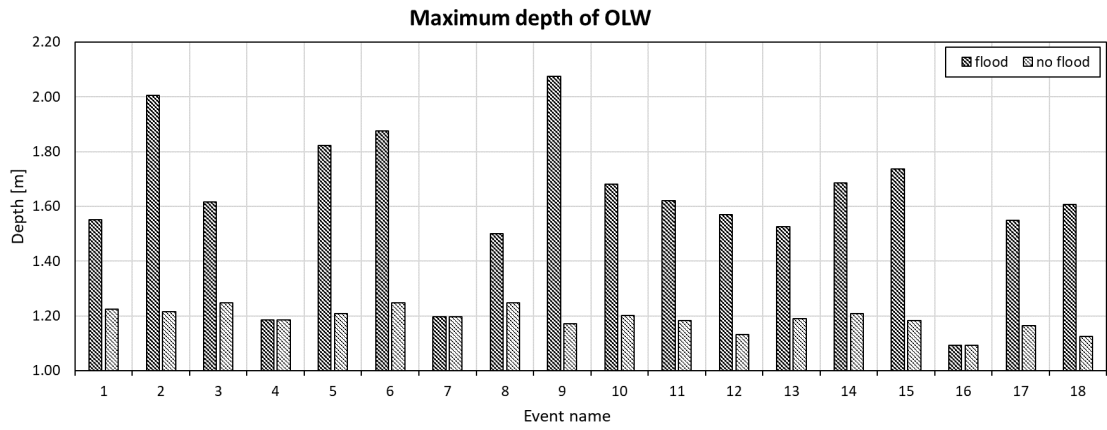|									
1	10-01-2002	14-03-2002	T10	0.24	35%	1.55	6.54E+06	36%	21
2	05-11-2006	08-02-2007	T10	0.26	33%	2.01	6.61E+06	33%	19
3	26-11-1999	14-01-2000	T5	0.25	39%	1.62	7.59E+06	36%	22
4	09-12-2015	05-01-2016	T5	0.21	23%	1.19	3.65E+06	47%	11
5	08-02-2020	25-03-2020	T5	0.27	34%	1.82	6.99E+06	33%	23
6	11-10-1998	27-11-1998	T5	0.35	43%	1.87	1.13E+07	28%	21
7	31-01-1999	02-04-1999	T5	0.14	26%	1.20	2.84E+06	62%	9
8	04-12-1994	13-03-1995	T5	0.22	38%	1.50	6.28E+06	47%	19
9	22-12-2004	29-01-2005	T2	0.34	17%	2.07	4.50E+06	28%	32
10	10-12-2014	04-02-2015	T2	0.24	29%	1.68	5.36E+06	35%	33
11	08-01-1993	07-02-1993	T2	0.24	28%	1.62	5.04E+06	33%	20
12	02-12-2011	15-01-2012	T2	0.27	15%	1.57	3.21E+06	38%	25
13	26-01-2000	02-04-2000	T2	0.23	20%	1.53	3.57E+06	40%	34
14	03-12-1993	17-02-1994	T2	0.25	34%	1.69	6.45E+06	35%	10
15	05-01-2008	15-02-2008	T2	0.22	19%	1.74	3.25E+06	42%	34
16	12-01-2011	23-01-2011	T2	0.19	8%	1.34	1.13E+06	85%	22
17	28-02-1994	10-04-1994	T2	0.24	13%	1.55	2.33E+06	51%	10
18	22-01-2016	13-02-2016	T2	0.25	14%	1.61	2.60E+06	42%	24

S-Figure 1: Calibration of the Manning number
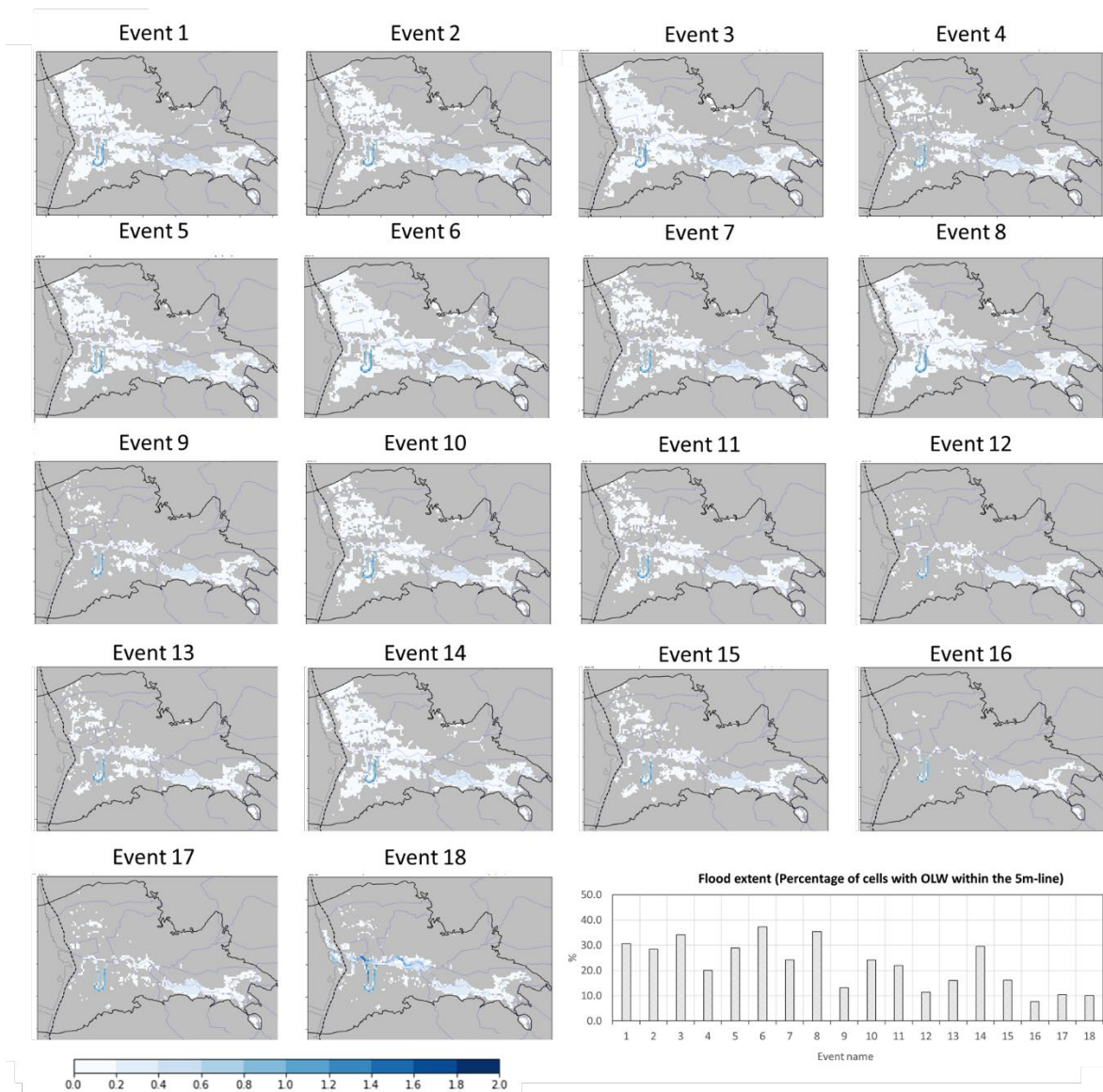

S-Figure 2: Percentage of overland water on terrain (flooding) for the area within the 5 meter line, with overbank spilling (flood) and without overbank spilling (no flood)

S-Figure 3: Mean depth of overland water on terrain (flooding), with overbank spilling (flood) and without overbank spilling (no flood)

S-Figure 4: Maximum depth of overland water on terrain (flooding), with overbank spilling (flood) and without overbank spilling (no flood)

S-Figure 5: Maximum overland flooding from the Ribe Flood model for the 18 largest river events identified from the Ribe model without allowing overbank spilling in the flood model. The dotted black line shows the location of the dike.