

Hybridizing Bayesian and variational data assimilation for robust high-resolution hydrologic forecasting

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Supplementary information

Table 1. Parameter assignments and error metrics for all the configurations of Experiment 1 (Blue River), Scenario 1 (October 15th, 1996). Configuration 0 corresponds to the control open-loop model. All other errors are computed using the mean streamflow from the OPTIMISTS ensemble.

Config.	Objs.	n	Δt	p_{samp}	$k_{\text{F-class}}$	Assimilation period			Forecast period		
						NSE _{t2}	NSE _{t1}	MARE	NSE _{t2}	NSE _{t1}	MARE
0	-- No data assimilation --					0.778	0.659	35.8%	0.867	0.708	43.2%
1	1	100	1 d	0.3	false	0.640	0.545	572.6%	0.494	0.395	118.5%
2	1	100	1 d	0.3	true	0.811	0.661	383.8%	0.818	0.656	53.2%
3	1	100	1 d	1.0	false	0.796	0.670	25.2%	0.722	0.630	43.9%
4	1	100	1 d	1.0	true	0.791	0.692	29.9%	0.707	0.564	50.4%
5	1	100	5 d	0.3	false	0.923	0.790	19.0%	0.770	0.645	38.5%
6	1	100	5 d	0.3	true	0.902	0.774	20.5%	0.842	0.696	38.1%
7	1	100	5 d	1.0	false	0.791	0.670	24.5%	0.773	0.650	42.6%
8	1	100	5 d	1.0	true	0.849	0.731	20.3%	0.593	0.542	50.8%
9	1	100	2 w	0.3	false	0.801	0.668	46.0%	0.853	0.690	44.5%
10	1	100	2 w	0.3	true	0.827	0.690	41.9%	0.823	0.687	42.1%
11	1	100	2 w	1.0	false	0.802	0.671	46.5%	0.860	0.700	44.1%
12	1	100	2 w	1.0	true	0.838	0.696	45.2%	0.864	0.702	44.0%
13	1	500	1 d	0.3	false	-1E+2	-5E+0	2E+1	-0.331	0.133	92.0%
14	1	500	1 d	0.3	true	-5E+2	-2E+1	6E+1	-2E+1	-2.388	863.1%
15	1	500	1 d	1.0	false	0.823	0.687	25.9%	0.771	0.657	43.3%
16	1	500	1 d	1.0	true	0.808	0.684	40.5%	0.698	0.553	55.2%
17	1	500	5 d	0.3	false	0.789	0.654	40.0%	0.787	0.625	48.2%
18	1	500	5 d	0.3	true	0.791	0.632	161.4%	0.533	0.518	37.5%
19	1	500	5 d	1.0	false	0.810	0.684	23.5%	0.847	0.697	42.3%
20	1	500	5 d	1.0	true	0.723	0.621	27.4%	0.675	0.584	46.4%
21	1	500	2 w	0.3	false	0.851	0.713	86.7%	0.875	0.729	36.0%
22	1	500	2 w	0.3	true	0.808	0.680	71.9%	0.801	0.652	38.2%
23	1	500	2 w	1.0	false	0.819	0.685	43.7%	0.850	0.704	43.4%
24	1	500	2 w	1.0	true	0.845	0.699	42.9%	0.844	0.698	43.5%
25	2	100	1 d	0.3	false	0.826	0.699	188.4%	0.856	0.711	37.7%
26	2	100	1 d	0.3	true	0.850	0.684	142.3%	0.836	0.618	82.2%

Config.	Objs.	n	Δt	p_{samp}	$k_{\text{F-class}}$	Assimilation period			Forecast period		
						NSE $_{t_2}$	NSE $_{t_1}$	MARE	NSE $_{t_2}$	NSE $_{t_1}$	MARE
27	2	100	1 d	1.0	false	0.762	0.640	29.5%	0.809	0.667	45.7%
28	2	100	1 d	1.0	true	0.783	0.659	29.5%	0.833	0.639	55.8%
29	2	100	5 d	0.3	false	0.837	0.708	25.8%	0.827	0.680	44.6%
30	2	100	5 d	0.3	true	0.868	0.750	19.1%	0.486	0.509	47.4%
31	2	100	5 d	1.0	false	0.735	0.633	30.6%	0.831	0.687	43.3%
32	2	100	5 d	1.0	true	0.776	0.657	26.0%	0.866	0.710	43.0%
33	2	100	2 w	0.3	false	0.785	0.663	42.8%	0.852	0.706	42.0%
34	2	100	2 w	0.3	true	0.792	0.666	41.4%	0.838	0.693	43.6%
35	2	100	2 w	1.0	false	0.777	0.656	43.5%	0.857	0.702	43.6%
36	2	100	2 w	1.0	true	0.800	0.670	40.6%	0.841	0.693	43.7%
37	2	500	1 d	0.3	false	0.772	0.642	340.0%	0.764	0.595	67.6%
38	2	500	1 d	0.3	true	0.521	0.494	713.3%	0.759	0.528	87.5%
39	2	500	1 d	1.0	false	0.770	0.645	28.7%	0.838	0.693	42.9%
40	2	500	1 d	1.0	true	0.770	0.634	181.4%	0.815	0.647	48.4%
41	2	500	5 d	0.3	false	0.858	0.725	50.7%	0.826	0.680	41.8%
42	2	500	5 d	0.3	true	0.878	0.755	38.3%	0.230	0.428	34.7%
43	2	500	5 d	1.0	false	0.755	0.646	29.2%	0.858	0.708	42.7%
44	2	500	5 d	1.0	true	0.766	0.650	26.3%	0.650	0.574	47.1%
45	2	500	2 w	0.3	false	0.860	0.718	45.4%	0.873	0.718	38.6%
46	2	500	2 w	0.3	true	0.881	0.745	60.7%	0.873	0.720	41.2%
47	2	500	2 w	1.0	false	0.799	0.672	42.8%	0.868	0.708	43.2%
48	2	500	2 w	1.0	true	0.793	0.670	43.4%	0.864	0.707	43.3%

Table 2. Parameter assignments and error metrics for all the configurations of Experiment 1 (Blue River), Scenario 2 (January 15th, 1997). Configuration 0 corresponds to the control open-loop model. All other errors are computed using the mean streamflow from the OPTIMISTS ensemble.

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Config.	Objs.	n	Δt	p_{samp}	$k_{\text{F-class}}$	Assimilation period			Forecast period		
						NSE $_{t_2}$	NSE $_{t_1}$	MARE	NSE $_{t_2}$	NSE $_{t_1}$	MARE
0		-- No data assimilation --				0.229	0.146	5.4%	-0.122	0.296	47.8%
1	1	100	1 d	0.3	false	-3E+6	-1E+3	7E+1	0.364	0.365	50.4%
2	1	100	1 d	0.3	true	-1E+6	-5E+2	4E+1	-1E+1	-2.022	322.7%
3	1	100	1 d	1.0	false	0.514	0.217	5.3%	-0.871	0.025	65.6%
4	1	100	1 d	1.0	true	0.617	0.410	3.8%	0.809	0.675	23.6%
5	1	100	5 d	0.3	false	0.328	0.211	5.1%	0.523	0.496	20.3%
6	1	100	5 d	0.3	true	0.533	0.407	3.7%	0.348	0.439	37.3%
7	1	100	5 d	1.0	false	0.234	0.255	4.6%	0.769	0.613	20.9%
8	1	100	5 d	1.0	true	0.388	0.321	4.2%	0.301	0.398	23.3%
9	1	100	2 w	0.3	false	0.454	0.280	4.6%	0.400	0.460	36.7%
10	1	100	2 w	0.3	true	0.468	0.241	4.8%	0.092	0.346	44.4%
11	1	100	2 w	1.0	false	0.512	0.341	4.2%	0.500	0.478	35.4%
12	1	100	2 w	1.0	true	0.555	0.323	4.3%	0.299	0.415	39.4%

Config.	Objs.	n	Δt	p_{samp}	$k_{\text{F-class}}$	Assimilation period			Forecast period		
						NSE _{t2}	NSE _{t1}	MARE	NSE _{t2}	NSE _{t1}	MARE
13	1	500	1 d	0.3	false	-7E+6	-2E+3	1E+2	-0.456	0.009	46.9%
14	1	500	1 d	0.3	true	-2E+7	-4E+3	3E+2	-4E+3	-4E+1	6E+1
15	1	500	1 d	1.0	false	0.596	0.428	3.7%	-0.809	-0.059	69.0%
16	1	500	1 d	1.0	true	0.508	0.338	4.2%	0.865	0.699	18.6%
17	1	500	5 d	0.3	false	0.417	0.240	4.9%	0.695	0.543	31.2%
18	1	500	5 d	0.3	true	0.445	0.233	5.0%	0.557	0.537	30.1%
19	1	500	5 d	1.0	false	0.266	0.275	4.5%	0.768	0.660	22.6%
20	1	500	5 d	1.0	true	0.294	0.301	4.4%	0.662	0.596	27.6%
21	1	500	2 w	0.3	false	0.654	0.469	3.3%	0.733	0.622	20.1%
22	1	500	2 w	0.3	true	0.548	0.398	3.8%	0.681	0.564	27.4%
23	1	500	2 w	1.0	false	0.468	0.309	4.3%	0.337	0.426	39.2%
24	1	500	2 w	1.0	true	0.613	0.392	3.8%	0.675	0.570	28.1%
25	2	100	1 d	0.3	false	-3E+1	-2.297	21.9%	0.249	0.353	45.4%
26	2	100	1 d	0.3	true	0.032	0.113	5.8%	0.504	0.534	32.3%
27	2	100	1 d	1.0	false	0.399	0.242	4.9%	-0.328	0.130	56.8%
28	2	100	1 d	1.0	true	0.317	0.360	3.9%	0.351	0.443	20.8%
29	2	100	5 d	0.3	false	0.004	0.071	5.8%	0.842	0.681	20.5%
30	2	100	5 d	0.3	true	0.371	0.211	5.0%	0.732	0.634	21.4%
31	2	100	5 d	1.0	false	0.129	0.181	5.1%	0.767	0.623	25.2%
32	2	100	5 d	1.0	true	0.245	0.262	4.6%	0.839	0.697	19.9%
33	2	100	2 w	0.3	false	0.276	0.136	5.5%	0.269	0.403	40.7%
34	2	100	2 w	0.3	true	0.571	0.352	4.1%	0.507	0.491	34.3%
35	2	100	2 w	1.0	false	0.282	0.147	5.4%	0.413	0.456	36.7%
36	2	100	2 w	1.0	true	0.502	0.297	4.4%	0.498	0.496	34.0%
37	2	500	1 d	0.3	false	-7.039	-1.196	14.9%	0.720	0.555	22.7%
38	2	500	1 d	0.3	true	-0.197	0.060	6.3%	0.408	0.454	21.7%
39	2	500	1 d	1.0	false	0.186	0.280	4.4%	0.768	0.609	26.2%
40	2	500	1 d	1.0	true	0.510	0.374	3.9%	0.516	0.469	37.5%
41	2	500	5 d	0.3	false	-5E+1	-3.945	32.8%	0.708	0.582	31.2%
42	2	500	5 d	0.3	true	0.291	0.210	5.0%	0.596	0.547	29.9%
43	2	500	5 d	1.0	false	0.244	0.261	4.6%	0.806	0.681	21.1%
44	2	500	5 d	1.0	true	0.186	0.252	4.6%	0.796	0.675	20.9%
45	2	500	2 w	0.3	false	0.383	0.235	4.8%	0.465	0.476	35.3%
46	2	500	2 w	0.3	true	0.603	0.392	3.8%	0.512	0.495	34.0%
47	2	500	2 w	1.0	false	0.354	0.206	5.0%	0.494	0.471	35.7%
48	2	500	2 w	1.0	true	0.521	0.327	4.2%	0.649	0.588	27.5%

Table 3. Parameter assignments and error metrics for all the configurations of Experiment 1 (Blue River), Scenario 3 (February 24th, 1998). Configuration 0 corresponds to the control open-loop model. All other errors are computed using the mean streamflow from the OPTIMISTS ensemble.

Config.	Objs.	n	Δt	p_{samp}	$k_{\text{F-class}}$	Assimilation period			Forecast period			
						NSE _{t2}	NSE _{t1}	MARE	NSE _{t2}	NSE _{t1}	MARE	
0	--	No data assimilation				--	0.315	0.192	70.3%	-1E+1	-2.519	40.3%
1	1	100	1 d	0.3	false	-0.218	0.034	152.0%	-1E+3	-4E+1	427.9%	
2	1	100	1 d	0.3	true	-0.464	-0.059	136.6%	-1E+1	-2.495	40.3%	
3	1	100	1 d	1.0	false	0.253	0.386	33.7%	-7.384	-2.041	34.9%	
4	1	100	1 d	1.0	true	0.403	0.379	56.1%	-4E+1	-5.775	74.5%	
5	1	100	5 d	0.3	false	0.247	0.433	25.6%	-5.781	-0.978	22.9%	
6	1	100	5 d	0.3	true	0.057	0.432	17.5%	-0.319	-0.209	13.6%	
7	1	100	5 d	1.0	false	0.209	0.411	29.0%	-4.083	-1.383	27.3%	
8	1	100	5 d	1.0	true	0.002	0.421	16.0%	0.302	0.360	6.8%	
9	1	100	2 w	0.3	false	0.199	0.390	33.3%	-3.279	-1.197	24.9%	
10	1	100	2 w	0.3	true	0.014	0.418	17.0%	-0.287	-0.083	12.3%	
11	1	100	2 w	1.0	false	0.239	0.383	35.4%	-5.720	-1.754	31.5%	
12	1	100	2 w	1.0	true	-0.008	0.414	16.3%	0.285	0.304	7.7%	
13	1	500	1 d	0.3	false	-0.855	-0.064	123.9%	-1E+1	-3.189	48.4%	
14	1	500	1 d	0.3	true	-5E+3	-7E+1	9E+1	-4E+6	-1E+3	1E+2	
15	1	500	1 d	1.0	false	0.280	0.395	33.4%	-8.686	-2.167	36.8%	
16	1	500	1 d	1.0	true	0.048	0.431	15.2%	0.035	0.325	6.8%	
17	1	500	5 d	0.3	false	0.111	0.455	17.7%	-1.759	-0.485	15.7%	
18	1	500	5 d	0.3	true	0.116	0.442	19.8%	-3.878	-1.084	22.9%	
19	1	500	5 d	1.0	false	0.214	0.420	27.6%	-4.184	-1.443	27.9%	
20	1	500	5 d	1.0	true	-0.010	0.421	15.2%	-0.275	0.098	9.3%	
21	1	500	2 w	0.3	false	0.123	0.457	16.7%	-1.284	-0.222	13.4%	
22	1	500	2 w	0.3	true	0.000	0.420	15.7%	-0.327	0.088	10.3%	
23	1	500	2 w	1.0	false	0.206	0.392	32.8%	-4.693	-1.571	29.2%	
24	1	500	2 w	1.0	true	-0.011	0.413	16.4%	0.385	0.467	5.5%	
25	2	100	1 d	0.3	false	-0.156	0.179	74.0%	-6E+1	-6.952	90.9%	
26	2	100	1 d	0.3	true	0.014	0.292	50.7%	-1.904	-0.272	14.6%	
27	2	100	1 d	1.0	false	0.260	0.407	30.7%	-5.529	-1.672	30.7%	
28	2	100	1 d	1.0	true	0.102	0.380	29.4%	-1.515	-0.509	15.9%	
29	2	100	5 d	0.3	false	0.218	0.406	30.5%	-2.345	-0.915	21.8%	
30	2	100	5 d	0.3	true	0.033	0.404	21.3%	-0.605	-0.013	11.6%	
31	2	100	5 d	1.0	false	0.239	0.398	32.4%	-5.079	-1.642	30.2%	
32	2	100	5 d	1.0	true	0.002	0.403	19.4%	-0.370	0.002	11.3%	
33	2	100	2 w	0.3	false	0.268	0.377	37.1%	-5.231	-1.635	30.2%	
34	2	100	2 w	0.3	true	0.050	0.431	17.2%	0.055	0.312	7.5%	
35	2	100	2 w	1.0	false	0.253	0.364	39.3%	-6.679	-1.948	33.6%	
36	2	100	2 w	1.0	true	0.053	0.425	19.2%	-0.709	-0.255	14.4%	
37	2	500	1 d	0.3	false	-0.127	0.185	72.1%	-1.810	-0.453	15.4%	
38	2	500	1 d	0.3	true	-0.221	0.179	120.8%	-3E+2	-2E+1	197.3%	
39	2	500	1 d	1.0	false	0.270	0.414	29.5%	-6.369	-1.731	31.8%	

Config.	Objs.	n	Δt	p_{samp}	$k_{\text{F-class}}$	Assimilation period			Forecast period		
						NSE_{t_2}	NSE_{t_1}	MARE	NSE_{t_2}	NSE_{t_1}	MARE
40	2	500	1 d	1.0	true	0.021	0.427	15.5%	-0.433	0.036	10.0%
41	2	500	5 d	0.3	false	0.195	0.451	22.0%	-0.667	-0.125	12.6%
42	2	500	5 d	0.3	true	0.088	0.444	18.3%	-0.992	0.045	10.9%
43	2	500	5 d	1.0	false	0.197	0.407	29.8%	-2.852	-1.116	23.9%
44	2	500	5 d	1.0	true	0.043	0.432	16.8%	0.354	0.344	7.1%
45	2	500	2 w	0.3	false	0.182	0.456	20.6%	-0.224	-0.105	12.0%
46	2	500	2 w	0.3	true	0.001	0.423	15.6%	0.105	0.270	8.1%
47	2	500	2 w	1.0	false	0.245	0.379	36.1%	-5.616	-1.747	31.4%
48	2	500	2 w	1.0	true	0.034	0.431	16.5%	0.230	0.188	9.1%

Table 4. Parameter assignments and error metrics for all the configurations of Experiment 2 (Indiantown Run), Scenario 1 (July 26th, 2009). Configuration 0 corresponds to the control open-loop model. All other errors are computed using the mean streamflow from the OPTIMISTS ensemble.

Config.	Δt	Objs.	n	p_{samp}	w_{root}	Assimilation period			Forecast period		
						NSE _{t2}	NSE _{t1}	MARE	NSE _{t2}	NSE _{t1}	MARE
0	-- No data assimilation --					0.478	-0.015	24.9%	0.022	-0.003	54.3%
1	1 h	2	100	0.25	60%	-9E+04	-1E+02	2.8E+01	0.067	-0.759	197.1%
2	1 h	2	100	0.25	95%	-2E+03	-3E+01	7.4E+00	0.365	0.193	73.5%
3	1 h	2	100	1.00	60%	-1E+01	-3.324	98.3%	0.279	-0.360	143.9%
4	1 h	2	100	1.00	95%	-1.455	-0.862	44.9%	0.346	-0.099	107.0%
5	1 h	2	200	0.25	60%	-2E+05	-1E+02	3.4E+01	0.075	-0.769	196.1%
6	1 h	2	200	0.25	95%	-3E+03	-3E+01	6.8E+00	0.357	0.275	62.2%
7	1 h	2	200	1.00	60%	-1E+01	-3.900	111.6%	0.284	-0.330	143.5%
8	1 h	2	200	1.00	95%	-2.320	-1.192	54.1%	0.341	-0.182	120.1%
9	2 w	2	100	0.25	60%	0.471	0.208	18.1%	0.317	0.381	43.2%
10	2 w	2	100	0.25	95%	0.099	-0.001	23.2%	0.320	0.375	44.3%
11	2 w	2	100	1.00	60%	0.571	0.371	13.3%	0.292	0.393	38.3%
12	2 w	2	100	1.00	95%	0.572	0.353	14.1%	0.323	0.373	45.7%
13	2 w	2	200	0.25	60%	0.531	0.295	15.5%	0.327	0.367	47.0%
14	2 w	2	200	0.25	95%	0.520	0.305	15.4%	0.312	0.380	42.6%
15	2 w	2	200	1.00	60%	0.360	0.211	17.5%	0.322	0.338	50.1%
16	2 w	2	200	1.00	95%	0.427	0.175	18.7%	0.332	0.357	49.0%
17	1 h	1	100	0.25	60%	-5E+02	-3E+01	7.0E+00	-0.429	-1.338	2.8E+00
18	1 h	1	100	0.25	95%	-5E+01	-7.655	196.9%	0.094	-0.736	193.1%
19	1 h	1	100	1.00	60%	-1E+01	-3.201	96.0%	0.314	-0.269	132.4%
20	1 h	1	100	1.00	95%	-9.818	-3.016	90.8%	0.290	-0.354	142.2%
21	1 h	1	200	0.25	60%	-2E+05	-6E+02	1.4E+02	-5E+01	-7.699	1.4E+01
22	1 h	1	200	0.25	95%	-1E+05	-4E+02	9.7E+01	-5E+01	-7.337	1.4E+01
23	1 h	1	200	1.00	60%	-1E+01	-3.965	113.2%	0.254	-0.447	153.8%
24	1 h	1	200	1.00	95%	-1E+01	-3.601	103.3%	0.283	-0.374	144.9%
25	2 w	1	100	0.25	60%	0.453	0.071	21.8%	0.320	0.373	44.2%
26	2 w	1	100	0.25	95%	0.279	-0.053	24.6%	0.329	0.368	46.3%
27	2 w	1	100	1.00	60%	0.500	0.177	18.9%	0.331	0.369	46.3%
28	2 w	1	100	1.00	95%	0.358	0.041	22.2%	0.330	0.364	47.4%
29	2 w	1	200	0.25	60%	0.494	0.177	18.8%	0.324	0.366	46.3%
30	2 w	1	200	0.25	95%	0.362	0.036	22.3%	0.329	0.362	47.4%
31	2 w	1	200	1.00	60%	0.452	0.158	19.2%	0.329	0.362	46.7%
32	2 w	1	200	1.00	95%	0.480	0.155	19.4%	0.333	0.362	47.2%

Table 5. Parameter assignments and error metrics for all the configurations of Experiment 2 (Indiantown Run), Scenario 2 (August 26th, 2009). Configuration 0 corresponds to the control open-loop model. All other errors are computed using the mean streamflow from the OPTIMISTS ensemble.

Config.	Δt	Objs.	n	p_{samp}	w_{root}	Assimilation period			Forecast period		
						NSE _{t2}	NSE _{t1}	MARE	NSE _{t2}	NSE _{t1}	MARE
0	--	No data assimilation --				-0.926	-0.963	68.0%	-0.428	-0.733	58.3%
1	1 h	2	100	0.25	60%	-8E+02	-2E+01	8.5E+00	-5.171	-2.290	104.3%
2	1 h	2	100	0.25	95%	-2E+02	-7.769	3.9E+00	-0.581	-0.517	46.2%
3	1 h	2	100	1.00	60%	0.672	0.570	16.1%	-1.459	-1.065	66.7%
4	1 h	2	100	1.00	95%	0.637	0.643	11.4%	-0.971	-0.799	57.0%
5	1 h	2	200	0.25	60%	-5E+03	-3E+01	1.0E+01	-1E+01	-3.291	134.0%
6	1 h	2	200	0.25	95%	-3E+02	-9.816	5.0E+00	-1.156	-0.797	54.9%
7	1 h	2	200	1.00	60%	0.708	0.518	19.2%	-1.493	-1.082	67.2%
8	1 h	2	200	1.00	95%	0.657	0.625	12.9%	-1.259	-0.966	63.0%
9	2 w	2	100	0.25	60%	-0.607	-0.154	35.9%	0.322	0.118	25.8%
10	2 w	2	100	0.25	95%	0.041	0.013	29.1%	0.248	0.070	27.1%
11	2 w	2	100	1.00	60%	0.122	0.096	25.6%	0.048	-0.067	31.1%
12	2 w	2	100	1.00	95%	-0.113	-0.164	35.1%	0.451	0.212	23.2%
13	2 w	2	200	0.25	60%	0.186	0.161	23.5%	0.051	-0.089	32.1%
14	2 w	2	200	0.25	95%	0.118	0.088	26.0%	0.132	-0.010	29.4%
15	2 w	2	200	1.00	60%	-0.019	-0.052	30.9%	0.255	0.077	26.9%
16	2 w	2	200	1.00	95%	0.022	-0.030	30.3%	0.279	0.085	26.8%
17	1 h	1	100	0.25	60%	-3.015	-2.226	138.7%	-2E+01	-4.216	164.2%
18	1 h	1	100	0.25	95%	-0.028	-0.550	61.0%	-7.080	-2.694	115.6%
19	1 h	1	100	1.00	60%	0.539	0.542	14.8%	-1.544	-1.083	66.8%
20	1 h	1	100	1.00	95%	0.565	0.442	21.7%	-2.307	-1.433	78.4%
21	1 h	1	200	0.25	60%	-5E+03	-1E+02	4.6E+01	-6E+02	-2E+01	8.5E+00
22	1 h	1	200	0.25	95%	-1E+04	-1E+02	4.9E+01	-7E+02	-2E+01	9.4E+00
23	1 h	1	200	1.00	60%	0.538	0.548	16.1%	-2.240	-1.396	77.8%
24	1 h	1	200	1.00	95%	0.551	0.594	12.7%	-2.089	-1.318	74.2%
25	2 w	1	100	0.25	60%	0.272	0.414	15.6%	-0.859	-0.577	46.7%
26	2 w	1	100	0.25	95%	0.307	0.422	14.7%	-0.779	-0.494	43.5%
27	2 w	1	100	1.00	60%	0.230	0.300	18.2%	-0.501	-0.368	39.8%
28	2 w	1	100	1.00	95%	0.220	0.268	19.4%	-0.475	-0.359	39.6%
29	2 w	1	200	0.25	60%	0.296	0.460	14.6%	-0.757	-0.527	45.2%
30	2 w	1	200	0.25	95%	0.377	0.485	13.8%	-0.916	-0.564	45.7%
31	2 w	1	200	1.00	60%	0.207	0.285	18.8%	-0.493	-0.348	39.0%
32	2 w	1	200	1.00	95%	0.202	0.278	18.9%	-0.525	-0.382	40.3%

Table 6. Parameter assignments and error metrics for all the configurations of Experiment 3 (Indiantown Run), Scenario 1 (July 26th, 2009). Configuration 0 corresponds to the control open-loop model. All other errors are computed using the mean streamflow from the OPTIMISTS ensemble.

Config.	Δt	p_{samp}	g	Assimilation period			Forecast period		
				NSE _{t2}	NSE _{t1}	MARE	NSE _{t2}	NSE _{t1}	MARE
0	-- No data assimilation --			0.478	-0.015	24.9%	0.022	-0.003	54.3%
1	1 h	0.4	0.5	-1E+05	-2E+02	5.2E+01	0.359	0.286	60.6%
2	1 h	0.4	1.0	-5E+03	-3E+01	8.3E+00	0.366	0.271	63.1%
3	1 h	1.0	0.5	-3.682	-1.729	64.1%	0.358	-0.069	107.8%
4	1 h	1.0	1.0	-2.038	-1.146	50.9%	0.371	0.031	94.3%
5	6 h	0.4	0.5	-6E+02	-1E+01	2.9E+00	0.354	0.307	57.1%
6	6 h	0.4	1.0	-9E+02	-1E+01	317.4%	0.357	0.291	59.9%
7	6 h	1.0	0.5	-2.107	-1.230	52.0%	0.357	0.086	84.0%
8	6 h	1.0	1.0	-1.431	-0.889	43.0%	0.361	0.292	60.1%
9	1 d	0.4	0.5	-2E+02	-4.030	119.4%	0.351	0.312	56.1%
10	1 d	0.4	1.0	-2E+03	-6.205	171.3%	0.350	0.340	52.3%
11	1 d	1.0	0.5	-1.406	-0.891	42.8%	0.353	0.325	55.0%
12	1 d	1.0	1.0	-1.440	-0.893	42.9%	0.352	0.315	56.6%
13	3.5 d	0.4	0.5	-3E+03	-7.748	2.1E+00	0.337	0.311	54.2%
14	3.5 d	0.4	1.0	-6E+01	-1.096	49.0%	0.328	0.337	50.2%
15	3.5 d	1.0	0.5	0.224	0.067	22.1%	0.331	0.306	55.4%
16	3.5 d	1.0	1.0	0.058	-0.095	25.6%	0.333	0.360	48.8%
17	2 w	0.4	0.5	-8E+01	-1.527	59.6%	0.339	0.326	54.1%
18	2 w	0.4	1.0	0.133	-0.190	28.1%	0.333	0.357	49.0%
19	2 w	1.0	0.5	0.399	0.242	16.3%	0.301	0.394	40.2%
20	2 w	1.0	1.0	0.560	0.340	14.4%	0.308	0.389	41.3%
21	4 w	0.4	0.5	-0.743	-0.735	42.0%	0.355	0.112	79.6%
22	4 w	0.4	1.0	-1.469	-1.161	52.2%	0.358	0.047	87.4%
23	4 w	1.0	0.5	-2.873	-1.763	66.4%	0.355	0.033	90.8%
24	4 w	1.0	1.0	-0.577	-0.622	39.2%	0.351	0.159	74.2%

Table 7. Parameter assignments and error metrics for all the configurations of Experiment 3 (Indiantown Run), Scenario 2 (August 26th, 2009). Configuration 0 corresponds to the control open-loop model. All other errors are computed using the mean streamflow from the OPTIMISTS ensemble.

Config.	Δt	p_{samp}	g	Assimilation period			Forecast period		
				NSE_{t_2}	NSE_{t_1}	MARE	NSE_{t_2}	NSE_{t_1}	MARE
0	-- No data assimilation --			-0.926	-0.963	68.0%	-0.428	-0.733	58.3%
1	1 h	0.4	0.5	-1E+03	-1E+01	6.2E+00	-0.133	-0.204	37.1%
2	1 h	0.4	1.0	-6E+02	-8.948	4.4E+00	-1.516	-0.967	60.3%
3	1 h	1.0	0.5	0.604	0.686	8.0%	-0.352	-0.459	46.3%
4	1 h	1.0	1.0	0.664	0.596	14.0%	-1.591	-1.133	68.3%
5	6 h	0.4	0.5	-1E+02	-4.849	2.7E+00	-1.270	-0.769	52.7%
6	6 h	0.4	1.0	-2E+01	-0.391	57.4%	-0.371	-0.393	42.1%
7	6 h	1.0	0.5	0.529	0.634	8.6%	-1.098	-0.679	49.6%
8	6 h	1.0	1.0	0.494	0.606	9.2%	-0.388	-0.460	45.5%
9	1 d	0.4	0.5	-7.399	0.020	39.8%	-0.830	-0.563	46.2%
10	1 d	0.4	1.0	0.475	0.444	14.3%	-0.213	-0.286	38.6%
11	1 d	1.0	0.5	0.398	0.432	14.7%	-1.096	-0.717	51.5%
12	1 d	1.0	1.0	0.453	0.512	11.9%	-0.656	-0.501	44.9%
13	3.5 d	0.4	0.5	-1.056	0.047	27.5%	-0.706	-0.465	42.7%
14	3.5 d	0.4	1.0	0.296	0.366	15.6%	-0.690	-0.437	41.6%
15	3.5 d	1.0	0.5	0.028	0.076	24.9%	-0.454	-0.402	41.9%
16	3.5 d	1.0	1.0	0.122	0.149	22.7%	-0.522	-0.376	40.0%
17	2 w	0.4	0.5	-2E+01	-0.396	50.0%	0.094	-0.044	30.5%
18	2 w	0.4	1.0	-0.002	-0.062	31.7%	0.358	0.140	25.3%
19	2 w	1.0	0.5	-0.157	-0.171	35.0%	0.340	0.108	26.4%
20	2 w	1.0	1.0	0.032	-0.024	30.2%	0.301	0.109	26.0%
21	4 w	0.4	0.5	0.379	0.491	11.4%	-1.398	-0.877	56.6%
22	4 w	0.4	1.0	0.330	0.424	13.4%	-1.281	-0.834	55.4%
23	4 w	1.0	0.5	0.308	0.397	14.1%	-0.907	-0.653	49.8%
24	4 w	1.0	1.0	0.327	0.425	13.2%	-1.159	-0.771	53.4%

Table 8. ANOVA table for Experiment 1 for the improvements in MARE with respect to the default model. DF: degrees of freedom; Adj SS: adjusted sum of squares; Adj MS: adjusted mean sum of squares; Sims.: n ; Optimization: p_{samp} ; F-kernels: $k_{\text{F-class}}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	49	8.093	0.165	4.610	0.000
Scenario	2	1.046	0.523	14.610	0.000
Linear	6	3.240	0.540	15.080	0.000
Objs.	1	0.275	0.274	7.660	0.007
Sims.	1	0.005	0.005	0.140	0.704
TimeStep	2	2.499	1.249	34.890	0.000
Optimization	1	0.460	0.460	12.860	0.001
F-kernels	1	0.001	0.001	0.040	0.850
2-Way Interactions	14	2.292	0.164	4.570	0.000
Objs.*Sims.	1	0.000	0.000	0.000	0.961
Objs.*TimeStep	2	0.507	0.253	7.080	0.001
Objs.*Optimization	1	0.119	0.119	3.330	0.071
Objs.*F-kernels	1	0.011	0.010	0.290	0.590
Sims.*TimeStep	2	0.025	0.013	0.350	0.704
Sims.*Optimization	1	0.019	0.019	0.540	0.464
Sims.*F-kernels	1	0.157	0.157	4.390	0.039
TimeStep*Optimization	2	1.172	0.586	16.370	0.000
TimeStep*F-kernels	2	0.106	0.053	1.470	0.234
Optimization*F-kernels	1	0.176	0.176	4.910	0.029
3-Way Interactions	16	1.001	0.063	1.750	0.051
Objs.*Sims.*TimeStep	2	0.005	0.002	0.070	0.935
Objs.*Sims.*Optimization	1	0.000	0.000	0.010	0.918
Objs.*Sims.*F-kernels	1	0.000	0.000	0.010	0.923
Objs.*TimeStep*Optimization	2	0.233	0.116	3.250	0.043
Objs.*TimeStep*F-kernels	2	0.001	0.001	0.020	0.985
Objs.*Optimization*F-kernels	1	0.012	0.012	0.320	0.572
Sims.*TimeStep*Optimization	2	0.082	0.041	1.150	0.321
Sims.*TimeStep*F-kernels	2	0.291	0.146	4.070	0.020
Sims.*Optimization*F-kernels	1	0.227	0.227	6.340	0.013
TimeStep*Optimization*F-kernels	2	0.149	0.074	2.070	0.131
4-Way Interactions	9	0.439	0.049	1.360	0.216
Objs.*Sims.*TimeStep*Optimization	2	0.007	0.004	0.100	0.903
Objs.*Sims.*TimeStep*F-kernels	2	0.002	0.001	0.020	0.978
Objs.*Sims.*Optimization*F-kernels	1	0.037	0.037	1.020	0.315
Objs.*TimeStep*Optimization*F-kernels	2	0.010	0.005	0.130	0.874
Sims.*TimeStep*Optimization*F-kernels	2	0.384	0.192	5.370	0.006
5-Way Interaction	2	0.075	0.038	1.050	0.354
Objs.*Sims.*TimeStep*Optimization*F-kernels	2	0.075	0.038	1.050	0.354
Error	94	3.366	0.036		
Total	143	11.460			

Table 9. ANOVA table for Experiment 2 for the improvements in NSE_{ℓ_2} with respect to the default model. DF: degrees of freedom; Adj SS: adjusted sum of squares; Adj MS: adjusted mean sum of squares; Candidates: n ; Roots: w_{root} .

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	32	65.769	2.055	3.450	0.000
Scenario	1	11.325	11.325	19.020	0.000
Linear	5	40.151	8.030	13.490	0.000
Time_step	1	25.442	25.442	42.730	0.000
Objectives	1	7.834	7.834	13.160	0.001
Candidates	1	0.866	0.866	1.450	0.237
Optimization	1	5.274	5.274	8.860	0.006
Roots	1	0.735	0.735	1.230	0.275
2-Way Interactions	10	9.786	0.979	1.640	0.140
Time_step*Objectives	1	1.096	1.096	1.840	0.185
Time_step*Candidates	1	0.697	0.697	1.170	0.288
Time_step*Optimization	1	3.586	3.586	6.020	0.020
Time_step*Roots	1	0.575	0.575	0.970	0.333
Objectives*Candidates	1	0.395	0.395	0.660	0.421
Objectives*Optimization	1	1.635	1.635	2.750	0.108
Objectives*Roots	1	0.801	0.801	1.350	0.255
Candidates*Optimization	1	0.522	0.522	0.880	0.356
Candidates*Roots	1	0.015	0.015	0.020	0.876
Optimization*Roots	1	0.464	0.464	0.780	0.384
3-Way Interactions	10	3.644	0.364	0.610	0.792
Time_step*Objectives*Candidates	1	0.475	0.475	0.800	0.379
Time_step*Objectives*Optimization	1	1.025	1.025	1.720	0.199
Time_step*Objectives*Roots	1	0.581	0.581	0.980	0.331
Time_step*Candidates*Optimization	1	0.372	0.372	0.620	0.435
Time_step*Candidates*Roots	1	0.000	0.000	0.000	0.980
Time_step*Optimization*Roots	1	0.664	0.664	1.120	0.299
Objectives*Candidates*Optimization	1	0.296	0.296	0.500	0.486
Objectives*Candidates*Roots	1	0.025	0.025	0.040	0.839
Objectives*Optimization*Roots	1	0.172	0.172	0.290	0.595
Candidates*Optimization*Roots	1	0.034	0.034	0.060	0.813
4-Way Interactions	5	0.861	0.172	0.290	0.915
Time_step*Objectives*Candidates*Optimization	1	0.437	0.437	0.730	0.398
Time_step*Objectives*Candidates*Roots	1	0.028	0.028	0.050	0.831
Time_step*Objectives*Optimization*Roots	1	0.267	0.267	0.450	0.508
Time_step*Candidates*Optimization*Roots	1	0.073	0.073	0.120	0.728
Objectives*Candidates*Optimization*Roots	1	0.056	0.056	0.090	0.761
5-Way Interaction	1	0.003	0.003	0.010	0.944
Time_step*Objectives*Candidates*Optimization*Roots	1	0.003	0.003	0.010	0.944
Error	31	18.457	0.595		
Total	63	84.226			

Table 10. ANOVA table for Experiment 2 for the improvements in NSE_{ℓ_1} with respect to the default model. DF: degrees of freedom; Adj SS: adjusted sum of squares; Adj MS: adjusted mean sum of squares; Candidates: n ; Roots: w_{root} .

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	32	39.898	1.247	13.330	0.000
Scenario	1	0.105	0.105	1.120	0.298
Linear	5	30.924	6.185	66.140	0.000
Time_step	1	23.271	23.271	248.860	0.000
Objectives	1	3.714	3.714	39.720	0.000
Candidates	1	0.208	0.208	2.220	0.146
Optimization	1	2.923	2.923	31.260	0.000
Roots	1	0.807	0.807	8.630	0.006
2-Way Interactions	10	6.188	0.619	6.620	0.000
Time_step*Objectives	1	0.836	0.836	8.930	0.005
Time_step*Candidates	1	0.128	0.128	1.360	0.252
Time_step*Optimization	1	2.229	2.229	23.840	0.000
Time_step*Roots	1	0.665	0.665	7.110	0.012
Objectives*Candidates	1	0.022	0.022	0.230	0.635
Objectives*Optimization	1	1.077	1.077	11.520	0.002
Objectives*Roots	1	0.651	0.651	6.960	0.013
Candidates*Optimization	1	0.079	0.079	0.850	0.364
Candidates*Roots	1	0.002	0.002	0.020	0.900
Optimization*Roots	1	0.500	0.500	5.350	0.028
3-Way Interactions	10	2.244	0.224	2.400	0.030
Time_step*Objectives*Candidates	1	0.050	0.050	0.530	0.470
Time_step*Objectives*Optimization	1	0.825	0.825	8.820	0.006
Time_step*Objectives*Roots	1	0.530	0.530	5.660	0.024
Time_step*Candidates*Optimization	1	0.046	0.046	0.500	0.487
Time_step*Candidates*Roots	1	0.001	0.001	0.010	0.942
Time_step*Optimization*Roots	1	0.566	0.566	6.050	0.020
Objectives*Candidates*Optimization	1	0.014	0.014	0.150	0.703
Objectives*Candidates*Roots	1	0.000	0.000	0.000	0.963
Objectives*Optimization*Roots	1	0.211	0.211	2.250	0.143
Candidates*Optimization*Roots	1	0.003	0.003	0.030	0.867
4-Way Interactions	5	0.412	0.082	0.880	0.506
Time_step*Objectives*Candidates*Optimization	1	0.030	0.030	0.320	0.576
Time_step*Objectives*Candidates*Roots	1	0.000	0.000	0.000	0.992
Time_step*Objectives*Optimization*Roots	1	0.290	0.290	3.100	0.088
Time_step*Candidates*Optimization*Roots	1	0.016	0.016	0.170	0.685
Objectives*Candidates*Optimization*Roots	1	0.076	0.076	0.810	0.374
5-Way Interaction	1	0.026	0.026	0.280	0.603
Time_step*Objectives*Candidates*Optimization*Roots	1	0.026	0.026	0.280	0.603
Error	31	2.899	0.094		
Total	63	42.797			

Table 11. ANOVA table for Experiment 2 for the improvements in MARE with respect to the default model. DF: degrees of freedom; Adj SS: adjusted sum of squares; Adj MS: adjusted mean sum of squares; Candidates: n ; Roots: w_{root} .

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	32	27.446	0.858	16.570	0.000
Scenario	1	2.191	2.191	42.320	0.000
Linear	5	18.024	3.605	69.630	0.000
Time_step	1	13.747	13.747	265.540	0.000
Objectives	1	1.943	1.943	37.530	0.000
Candidates	1	0.254	0.254	4.910	0.034
Optimization	1	1.567	1.567	30.270	0.000
Roots	1	0.513	0.513	9.910	0.004
2-Way Interactions	10	5.046	0.505	9.750	0.000
Time_step*Objectives	1	1.148	1.148	22.180	0.000
Time_step*Candidates	1	0.186	0.186	3.600	0.067
Time_step*Optimization	1	1.448	1.448	27.970	0.000
Time_step*Roots	1	0.502	0.502	9.700	0.004
Objectives*Candidates	1	0.108	0.108	2.090	0.159
Objectives*Optimization	1	1.001	1.001	19.320	0.000
Objectives*Roots	1	0.223	0.223	4.300	0.047
Candidates*Optimization	1	0.118	0.118	2.270	0.142
Candidates*Roots	1	0.005	0.005	0.100	0.756
Optimization*Roots	1	0.308	0.308	5.950	0.021
3-Way Interactions	10	1.880	0.188	3.630	0.003
Time_step*Objectives*Candidates	1	0.145	0.145	2.800	0.105
Time_step*Objectives*Optimization	1	0.910	0.910	17.580	0.000
Time_step*Objectives*Roots	1	0.201	0.201	3.880	0.058
Time_step*Candidates*Optimization	1	0.117	0.117	2.260	0.143
Time_step*Candidates*Roots	1	0.008	0.008	0.150	0.703
Time_step*Optimization*Roots	1	0.294	0.294	5.690	0.023
Objectives*Candidates*Optimization	1	0.112	0.112	2.170	0.151
Objectives*Candidates*Roots	1	0.016	0.016	0.310	0.580
Objectives*Optimization*Roots	1	0.064	0.064	1.240	0.274
Candidates*Optimization*Roots	1	0.012	0.012	0.230	0.638
4-Way Interactions	5	0.253	0.051	0.980	0.448
Time_step*Objectives*Candidates*Optimization	1	0.100	0.100	1.930	0.175
Time_step*Objectives*Candidates*Roots	1	0.009	0.009	0.170	0.686
Time_step*Objectives*Optimization*Roots	1	0.063	0.063	1.220	0.278
Time_step*Candidates*Optimization*Roots	1	0.016	0.016	0.300	0.586
Objectives*Candidates*Optimization*Roots	1	0.066	0.066	1.270	0.269
5-Way Interaction	1	0.053	0.053	1.020	0.321
Time_step*Objectives*Candidates*Optimization*Roots	1	0.053	0.053	1.020	0.321
Error	31	1.605	0.052		
Total	63	29.051			

Table 12. ANOVA table for Experiment 3 for the improvements in NSE_{ℓ_2} with respect to the default model. DF: degrees of freedom; Adj SS: adjusted sum of squares; Adj MS: adjusted mean sum of squares; Samples: p_{samp} .

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	24	7.368	0.307	1.710	0.102
Scenario	1	3.551	3.551	19.770	0.000
Linear	7	2.313	0.330	1.840	0.128
Time_step	5	2.310	0.462	2.570	0.055
Samples	1	0.002	0.002	0.010	0.915
Greed	1	0.000	0.000	0.000	0.973
2-Way Interactions	11	1.483	0.135	0.750	0.682
Time_step*Samples	5	0.144	0.029	0.160	0.975
Time_step*Greed	5	1.321	0.264	1.470	0.238
Samples*Greed	1	0.019	0.019	0.110	0.748
3-Way Interactions	5	0.021	0.004	0.020	1.000
Time_step*Samples*Greed	5	0.021	0.004	0.020	1.000
Error	23	4.132	0.180		
Total	47	11.500			

5 Table 13. ANOVA table for Experiment 3 for the improvements in NSE_{ℓ_1} with respect to the default model. DF: degrees of freedom; Adj SS: adjusted sum of squares; Adj MS: adjusted mean sum of squares; Samples: p_{samp} .

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	24	2.158	0.090	2.290	0.026
Scenario	1	0.000	0.000	0.000	0.971
Linear	7	1.644	0.235	5.980	0.000
Time_step	5	1.625	0.325	8.270	0.000
Samples	1	0.017	0.017	0.440	0.514
Greed	1	0.002	0.002	0.040	0.843
2-Way Interactions	11	0.501	0.046	1.160	0.366
Time_step*Samples	5	0.156	0.031	0.790	0.564
Time_step*Greed	5	0.344	0.069	1.750	0.163
Samples*Greed	1	0.000	0.000	0.000	0.999
3-Way Interactions	5	0.013	0.003	0.070	0.997
Time_step*Samples*Greed	5	0.013	0.003	0.070	0.997
Error	23	0.904	0.039		
Total	47	3.062			

Table 14. ANOVA table for Experiment 3 for the improvements in MARE with respect to the default model. DF: degrees of freedom; Adj SS: adjusted sum of squares; Adj MS: adjusted mean sum of squares; Samples: p_{samp} .

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	24	1.438	0.060	6.780	0.000
Scenario	1	0.643	0.643	72.820	0.000
Linear	7	0.630	0.090	10.190	0.000
Time_step	5	0.605	0.121	13.700	0.000
Samples	1	0.021	0.021	2.320	0.141
Greed	1	0.005	0.005	0.530	0.473
2-Way Interactions	11	0.152	0.014	1.570	0.175
Time_step*Samples	5	0.115	0.023	2.610	0.052
Time_step*Greed	5	0.033	0.007	0.760	0.590
Samples*Greed	1	0.004	0.004	0.430	0.519
3-Way Interactions	5	0.012	0.002	0.270	0.925
Time_step*Samples*Greed	5	0.012	0.002	0.270	0.925
Error	23	0.203	0.009		
Total	47	1.642			