

Multi-Year (2013-2016) PM_{2.5} Wildfire Pollution Exposure over North America Determined from Operational Air Quality Forecasts

Rodrigo Munoz-Alpizar ^{1,*}, Radenko Pavlovic ¹, Michael D. Moran ², Jack Chen ², Sylvie Gravel ², Sarah B. Henderson ³, Sylvain Ménard ¹, Jacinthe Racine ¹, Annie Duhamel ¹, Samuel Gilbert ¹, Paul-André Beaulieu ¹, Hugo Landry ¹, Didier Davignon ¹, Sophie Cousineau ¹ and Véronique Bouchet ¹

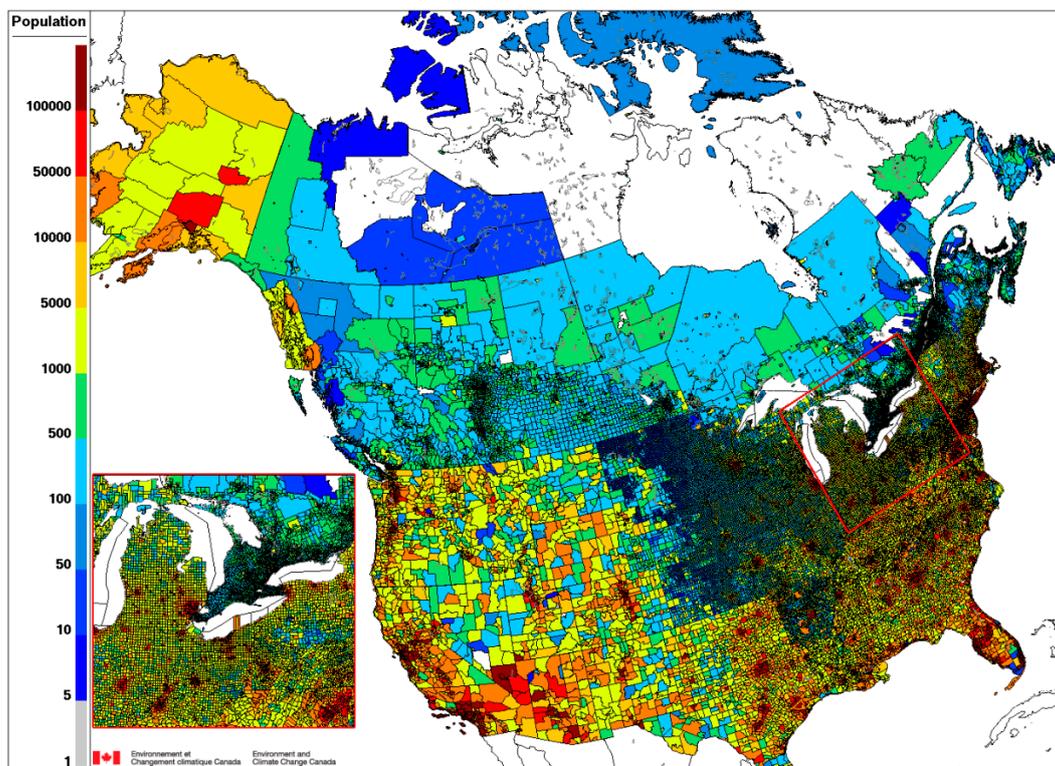


Figure S1. North American population count by census reporting geographic unit: dissemination-area level for the 2016 Canada census and census-tract level (sub-county) for the 2010 U.S. census. The red box over the four southern Great Lakes marks the location of the inset.

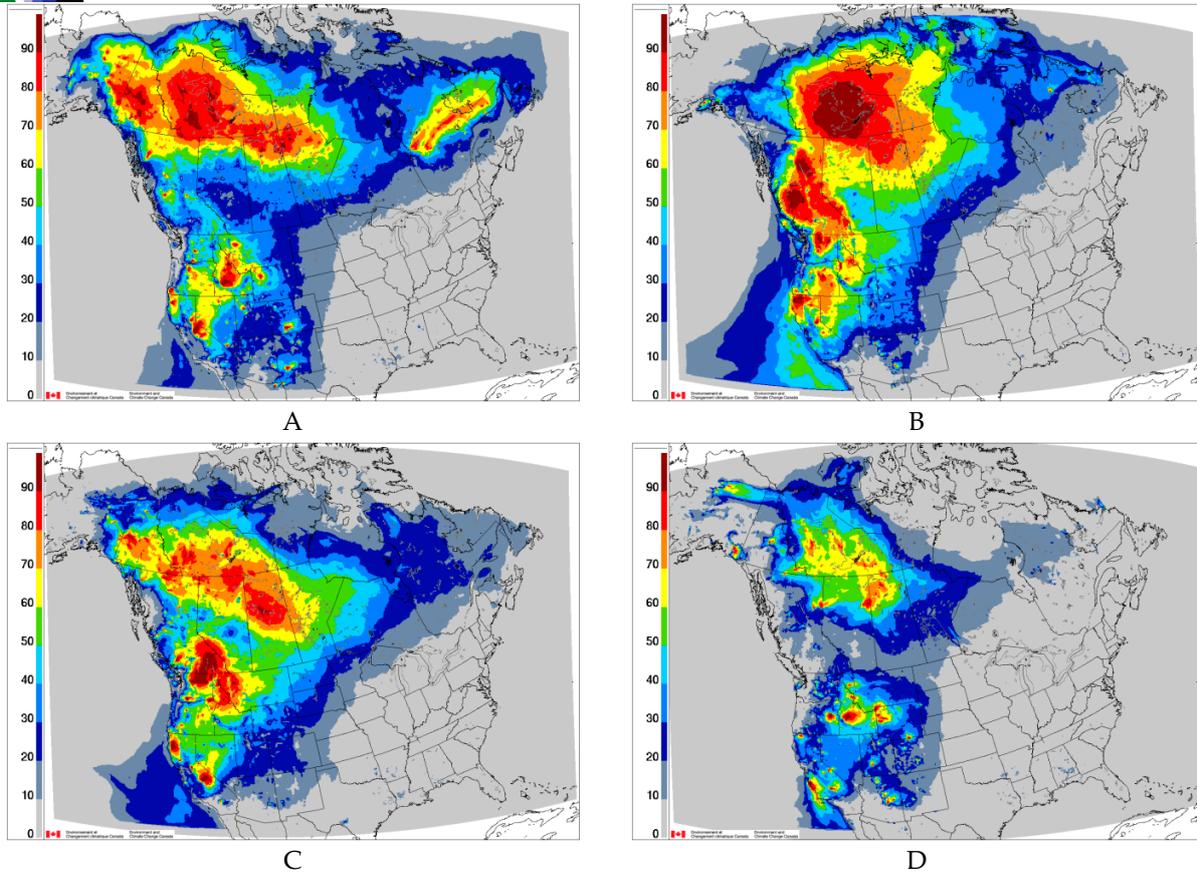


Figure S2. Average seasonal (May–Sept.) percentage of fire-PM_{2.5} contribution to average seasonal total PM_{2.5} FireWork concentrations for (A) 2013, (B) 2014, (C) 2015, and (D) 2016.

Table S1. FireWork North American seasonal (May–Sept.) biomass-burning emissions (Tg-Species season⁻¹) for 2013–2016.

Year	Higher Alkenes	Higher Alkanes	C ₃ H ₈	CO	C ₂ H ₄	NH ₃	NO	NO ₂	SO ₂	PM _{2.5}	TPM
2013	0.22	0.03	0.30	11.58	0.66	0.19	0.12	0.02	0.10	1.02	1.20
2014	0.36	0.05	0.50	19.38	1.10	0.32	0.19	0.03	0.17	1.70	2.01
2015	0.29	0.04	0.40	15.16	0.86	0.25	0.20	0.03	0.15	1.39	1.64
2016	0.17	0.02	0.23	8.85	0.50	0.15	0.10	0.02	0.08	0.79	0.93



Table S2. Mean monthly PM_{2.5} concentrations above 30 µg/m³ for U.S. Air Quality System (AQS) and Canadian National Air Pollution Surveillance (NAPS) AQ measurement stations with completeness ratios above 50%, May–September, 2013–2016, based on reports from the AIRNow and ECCC near-real-time AQ data feeds. The corresponding FireWork and RAQDPS values represent monthly PM_{2.5} concentrations forecast at those station locations by the two AQ forecast systems with and without wildfire emissions, respectively. Note that the differences between these pairs of values represent the fire-PM_{2.5} concentration values. ECCC basic quality control system for NRT AQ observations rejects as suspicious, PM_{2.5} observations with sudden spikes and/or concentration above 1,000 µg/m³. In May 2016 extreme wildfires were very close to a number of AQ stations in northern Alberta and observations above 1000 µg/m³ were frequently reported from NAPS stations 90701, 90702, 90801 and 90806. For May 2016, we recalculated concentration statistics (number in brackets), taking into account observations above the 1000 µg/m³ threshold.

State/Province	Month	AQS/NAPS Station ID	Observed Monthly PM _{2.5}	Completeness Ratio	FireWork Monthly PM _{2.5}	RAQDPS Monthly PM _{2.5}
			2013			
Oregon	August	410330011	34.4	67%	10.2	2.4
			2014			
Northwest Territories	July	129003	49.0	90%	28.5	1.1
Northwest Territories	August	129003	34.3	94%	31.1	0.8
			2015			
Saskatchewan	July	80110	31.1	86%	9.2	3.9
British Columbia	August	103502	38.7	99%	37.6	1.6
British Columbia	August	104101	39.5	79%	128.4	1.5
Idaho	August	160090010	30.2	97%	18.7	2.5
Idaho	August	160490002	33.4	91%	22.7	2.5
Idaho	August	160490003	49.9	82%	44.9	4.5
Idaho	August	160590004	36.3	95%	7.9	1.0
Idaho	August	160690012	36.4	92%	21.7	4.2
Idaho	August	160690014	34.2	96%	22.0	2.7
Montana	August	300530018	35.8	86%	33.8	2.5
Oregon	August	410290019	42.4	90%	23.5	1.8
Oregon	August	410290133	37.1	97%	14.9	4.5
Washington	August	530470009	38.6	85%	49.6	0.9
Washington	August	530470010	31.7	85%	25.2	0.8
			2016			
Alberta	May	90701	29.7 (186.1)	79% (100%)	51.6	2.3
Alberta	May	90702	30.1 (162.6)	30% (99%)	57.5	2.3
Alberta	May	90801	15.4 (61.9)	95% (100%)	10.8	2.5
Alberta	May	90806	13.9 (62.0)	95% (100%)	10.8	2.5



Table S3. Population in Canada (as number and percentage of people) affected by wildfire pollution above five PM_{2.5} concentration thresholds based on the average monthly fire-PM_{2.5} contribution to total surface PM_{2.5} concentrations and average seasonal fire-PM_{2.5} contribution to total surface PM_{2.5} concentration. The affected population is based on the 2016 Canadian census.

$\mu\text{g}/\text{m}^3$	>0.2		>1		>5		>10		>28	
2013										
May	642,932	(1.8%)	18,326	(0.1%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
June	25,703,385	(73.1%)	137,098	(0.4%)	13,170	(0.0%)	1,306	(0.0%)	2	(0.0%)
July	33,101,990	(94.2%)	13,982,625	(39.8%)	25,265	(0.1%)	3,051	(0.0%)	29	(0.0%)
August	34,686,331	(98.7%)	24,566,761	(69.9%)	45,658	(0.1%)	7,771	(0.0%)	881	(0.0%)
September	14,506,471	(41.3%)	3,281,702	(9.3%)	805	(0.0%)	148	(0.0%)	26	(0.0%)
2014										
May	789,748	(2.2%)	5689	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
June	1,226,604	(3.5%)	127,592	(0.4%)	1007	(0.0%)	41	(0.0%)	8	(0.0%)
July	34,429,961	(98.0%)	7,550,339	(21.5%)	534,846	(1.5%)	47,472	(0.1%)	3318	(0.0%)
August	32,841,741	(93.4%)	11,746,035	(33.4%)	5,206,866	(14.8%)	867,789	(2.5%)	27,160	(0.1%)
September	32,017,304	(91.1%)	9,083,676	(25.8%)	17,925	(0.1%)	1,104	(0.0%)	186	(0.0%)
2015										
May	6,827,721	(19.4%)	75,421	(0.2%)	147	(0.0%)	8	(0.0%)	0	(0.0%)
June	9,091,940	(25.9%)	2,549,094	(7.3%)	84,180	(0.2%)	7592	(0.0%)	10	(0.0%)
July	34,584,325	(98.4%)	11,000,104	(31.3%)	1,306,565	(3.7%)	212,670	(0.6%)	11,412	(0.0%)
August	34,008,429	(96.8%)	7,524,084	(21.4%)	3,693,197	(10.5%)	2,718,506	(7.7%)	417,171	(1.2%)
September	28,735,636	(81.8%)	12,678,392	(36.1%)	7884	(0.0%)	1540	(0.0%)	0	(0.0%)
2016										
May	5,792,812	(16.5%)	1,006,543	(2.9%)	82,734	(0.2%)	75,627	(0.2%)	69,909	(0.2%)
June	344,367	(1.0%)	604	(0.0%)	6	(0.0%)	1	(0.0%)	0	(0.0%)
July	4,861,438	(13.8%)	2,025,218	(5.8%)	531	(0.0%)	13	(0.0%)	1	(0.0%)
August	7,612,530	(21.7%)	1,465,695	(4.2%)	4	(0.0%)	1	(0.0%)	0	(0.0%)
September	4,890,111	(13.9%)	27,860	(0.1%)	116	(0.0%)	0	(0.0%)	0	(0.0%)
Seasonal Exceedances (Population)										
2013	34,475,250	(98.1%)	851,888	(2.4%)	4058	(0.0%)	620	(0.0%)	0	(0.0%)
2014	32,582,255	(92.7%)	9,266,563	(26.4%)	166,858	(0.5%)	28,984	(0.1%)	272	(0.0%)
2015	33,609,887	(95.6%)	7,216,956	(20.5%)	1,330,196	(3.8%)	118,152	(0.3%)	5,656	(0.0%)
2016	6,639,152	(18.9%)	150,902	(0.4%)	70,226	(0.2%)	65,458	(0.2%)	0	(0.0%)



Table S4. Population in the U.S. (as number and percentage of people) affected by wildfire pollution above five PM_{2.5} concentration thresholds based on the average monthly fire-PM_{2.5} contribution to total surface PM_{2.5} concentrations and average seasonal fire-PM_{2.5} contribution to total surface PM_{2.5} concentration. The affected population is based on the 2010 U.S. census.

$\mu\text{g}/\text{m}^3$	>0.2		>1		>5		>10		>28	
2013										
May	6,369,855	(2.1%)	198,586	(0.1%)	4813	(0.0%)	326	(0.0%)	0	(0.0%)
June	197,044,345	(64.4%)	15,192,358	(5.0%)	797,344	(0.3%)	248,193	(0.1%)	57,186	(0.0%)
July	218,319,685	(71.4%)	42,832,356	(14.0%)	2,279,485	(0.7%)	771,072	(0.3%)	29,122	(0.0%)
August	288,283,960	(94.3%)	96,744,807	(31.6%)	5,243,763	(1.7%)	1,914,121	(0.6%)	301,617	(0.1%)
September	203,256,658	(66.5%)	31,730,054	(10.4%)	1,382,830	(0.5%)	480,466	(0.2%)	62,077	(0.0%)
2014										
May	57,553,087	(18.8%)	1,324,240	(0.4%)	28,277	(0.0%)	7210	(0.0%)	1031	(0.0%)
June	18,276,881	(6.0%)	314,624	(0.1%)	5310	(0.0%)	2176	(0.0%)	228	(0.0%)
July	201,766,374	(66.0%)	14,044,215	(4.6%)	499,710	(0.2%)	139,979	(0.0%)	36,489	(0.0%)
August	287,394,732	(94.0%)	64,578,196	(21.1%)	7,836,148	(2.6%)	764,217	(0.2%)	97,036	(0.0%)
September	252,734,010	(82.7%)	60,364,536	(19.7%)	16,100,001	(5.3%)	2,671,458	(0.9%)	248,975	(0.1%)
2015										
May	4,490,883	(1.5%)	74,724	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
June	134,546,945	(44.0%)	4,176,000	(1.4%)	459,683	(0.2%)	142,071	(0.0%)	3540	(0.0%)
July	236,814,300	(77.5%)	15,810,821	(5.2%)	77,063	(0.0%)	9983	(0.0%)	176	(0.0%)
August	269,206,672	(88.0%)	61,998,284	(20.3%)	6,070,142	(2.0%)	2,698,188	(0.9%)	277,029	(0.1%)
September	267,691,338	(87.6%)	51,286,713	(16.8%)	1,722,668	(0.6%)	953,907	(0.3%)	390,504	(0.1%)
2016										
May	10,427,628	(3.4%)	600,746	(0.2%)	29,852	(0.0%)	8457	(0.0%)	1221	(0.0%)
June	37,920,470	(12.4%)	4,344,490	(1.4%)	150,327	(0.0%)	67,638	(0.0%)	11,484	(0.0%)
July	55,219,480	(18.1%)	35,628,602	(11.7%)	4,314,219	(1.4%)	1,551,592	(0.5%)	291,674	(0.1%)
August	64,447,567	(21.1%)	49,600,688	(16.2%)	7,332,800	(2.4%)	1,042,200	(0.3%)	91,643	(0.0%)
September	91,482,431	(29.9%)	46,808,579	(15.3%)	4,772,423	(1.6%)	1,926,979	(0.6%)	369,326	(0.1%)
Seasonal Exceedances (Population)										
2013	268,654,774	(87.9%)	24,794,215	(8.1%)	1,197,192	(0.4%)	257,899	(0.1%)	54,677	(0.0%)
2014	231,384,067	(75.7%)	45,016,698	(14.7%)	876,429	(0.3%)	179,841	(0.1%)	32,549	(0.0%)
2015	275,424,035	(90.1%)	16,234,259	(5.3%)	1,457,392	(0.5%)	354,050	(0.1%)	56,442	(0.0%)
2016	63,133,239	(20.6%)	37,210,716	(12.2%)	2,314,608	(0.8%)	339,295	(0.1%)	40,703	(0.0%)



Table S5. Canadian population size in numbers and percentages (rounded to the nearest decimal place) affected by wildfire pollution based on percentage of days with 24-h moving average fire-PM_{2.5} above five PM_{2.5} concentration thresholds between May-September for four individual years (2013–2016). The affected population is based on the 2016 Canadian census. The lowest percentage used is 1% and the 1-day frequency corresponds to 0.65% in a 5-month period.

% of days	>1 µg/m ³		>5 µg/m ³		>10 µg/m ³		>28 µg/m ³	
Seasonal Exceedances (population) 2013								
[0–1]	6,749	(0.0%)	2,106,685	(6.0%)	25,993,759	(74.0%)	34,871,358	(99.2%)
[1–10]	1,234,459	(3.5%)	32,632,296	(92.8%)	9,132,418	(26.0)	276,328	(0.8%)
[10–20]	12,500,102	(35.6%)	383,367	(1.1%)	21,564	(0.1)	826	(0.0%)
[20–30]	16,676,160	(47.4%)	25,121	(0.1%)	770	(0.0)	0	(0.0%)
[30–40]	4,573,235	(13.0%)	1,042	(0.0%)	0	(0.0)	0	(0.0%)
[40–50]	155,087	(0.4%)	0	(0.0%)	0	(0.0)	0	(0.0%)
[50–60]	2720	(0.0%)	0	(0.0%)	0	(0.0)	0	(0.0%)
[60–70]	0	(0.0%)	0	(0.0%)	0	(0.0)	0	(0.0%)
[70–80]	0	(0.0%)	0	(0.0%)	0	(0.0)	0	(0.0%)
[80–90]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
Seasonal Exceedances (population) 2014								
[0–1]	36,939	(0.1%)	20,857,052	(59.3%)	24,775,798	(70.5%)	30,682,463	(87.3%)
[1–10]	4,795,491	(13.6%)	6,011,662	(17.1%)	6,189,533	(17.6%)	4,390,848	(12.5%)
[10–20]	18,969,140	(54.0%)	3,281,520	(9.3%)	4,085,339	(11.6%)	71,206	(0.2%)
[20–30]	3,905,019	(11.1%)	4,852,005	(13.8%)	69,526	(0.2%)	3828	(0.0%)
[30–40]	4,203,031	(12.0%)	141,643	(0.4%)	28,317	(0.1%)	166	(0.0%)
[40–50]	3,102,960	(8.8%)	4630	(0.0%)	0	(0.0%)	0	(0.0%)
[50–60]	132,479	(0.4%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[60–70]	3453	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[70–80]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[80–90]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
Seasonal Exceedances (population) 2015								
[0–1]	40,447	(0.1%)	2,002,167	(5.7%)	20,650,180	(58.8%)	28,079,097	(79.9%)
[1–10]	2,714,861	(7.7%)	26,134,354	(74.4%)	13,108,503	(37.3%)	7,027,047	(20.0%)
[10–20]	20,250,115	(57.6%)	6,480,795	(18.4%)	1,373,668	(3.9%)	42,368	(0.1%)
[20–30]	5,250,745	(14.9%)	531,195	(1.5%)	16,161	(0.0%)	0	(0.0%)
[30–40]	5,898,553	(16.8%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[40–50]	993,791	(2.8%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[50–60]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[60–70]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[70–80]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[80–90]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
Seasonal Exceedances (population) 2016								
[0–1]	18,951,956	(53.9%)	28,959,306	(82.4%)	32,113,839	(91.4%)	34,984,009	(99.5%)
[1–10]	9,749,579	(27.7%)	6,082,138	(17.3%)	2,965,671	(8.4%)	97,898	(0.3%)
[10–20]	4,058,078	(11.5%)	108,365	(0.3%)	70,381	(0.2%)	67,985	(0.2%)
[20–30]	2,207,083	(6.3%)	82	(0.0%)	0	(0.0%)	0	(0.0%)
[30–40]	104,489	(0.3%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[40–50]	78,708	(0.2%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[50–60]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[60–70]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[70–80]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[80–90]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)



Table S6. U.S. population size in numbers and percentages (rounded to the nearest decimal place) of people affected by wildfire pollution based on percentage of days with 24-hour moving average fire-PM_{2.5} above five PM_{2.5} concentration thresholds between May-September for four individual years (2013-2016). The lowest percentage used is 1% and the 1-day frequency corresponds to 0.65% in a 5-month period.

% of days	>1 µg/m ³		>5 µg/m ³		>10 µg/m ³		>28 µg/m ³	
Seasonal Exceedances (population) 2013								
[0–1]	7,916,845	(2.6%)	195,134,634	(63.8%)	253,260,524	(82.8%)	287,939,405	(94.2%)
[1–10]	46,704,662	(15.3%)	100,587,839	(32.9%)	49,567,388	(16.2%)	17,168,723	(5.6%)
[10–20]	105,226,072	(34.4%)	7,382,717	(2.4%)	2,805,174	(0.9%)	623,775	(0.2%)
[20–30]	102,908,407	(33.7%)	2,593,554	(0.8%)	110,866	(0.0%)	12,381	(0.0%)
[30–40]	36,617,230	(12.0%)	44,107	(0.0%)	0	(0.0%)	0	(0.0%)
[40–50]	6,172,874	(2.0%)	1101	(0.0%)	333	(0.0%)	0	(0.0%)
[50–60]	196,345	(0.1%)	333	(0.0%)	0	(0.0%)	0	(0.0%)
[60–70]	1517	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[70–80]	333	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[80–90]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
Seasonal Exceedances (population) 2014								
[0–1]	1,912,326	(0.6%)	222,926,096	(72.9%)	245,709,853	(80.4%)	285,097,403	(93.2%)
[1–10]	123,611,407	(40.4%)	51,800,339	(16.9%)	50,233,796	(16.4%)	20,311,201	(6.6%)
[10–20]	100,944,641	(33.0%)	24,866,259	(8.1%)	9,475,378	(3.1%)	311,914	(0.1%)
[20–30]	38,554,325	(12.6%)	5,661,490	(1.9%)	307,357	(0.1%)	21,216	(0.0%)
[30–40]	33,905,817	(11.1%)	489,435	(0.2%)	17,900	(0.0%)	2551	(0.0%)
[40–50]	5,369,938	(1.8%)	333	(0.0%)	0	(0.0%)	0	(0.0%)
[50–60]	1,443,725	(0.5%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[60–70]	1157	(0.0%)	333	(0.0%)	0	(0.0%)	0	(0.0%)
[70–80]	616	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[80–90]	333	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
Seasonal Exceedances (population) 2015								
[0–1]	6,902,989	(2.3%)	123,377,072	(40.4%)	231,511,051	(75.7%)	291,556,926	(95.4%)
[1–10]	111,965,261	(36.6%)	172,907,954	(56.6%)	70,991,662	(23.2%)	13,366,344	(4.4%)
[10–20]	139,767,952	(45.7%)	7,861,300	(2.6%)	3,005,440	(1.0%)	805,549	(0.3%)
[20–30]	37,264,427	(12.2%)	1,573,918	(0.5%)	235,494	(0.1%)	15,465	(0.0%)
[30–40]	8,774,610	(2.9%)	24,041	(0.0%)	638	(0.0%)	0	(0.0%)
[40–50]	1,068,548	(0.3%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[50–60]	498	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[60–70]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[70–80]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[80–90]	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
Seasonal Exceedances (population) 2016								
[0–1]	64,648,068	(21.1%)	219,895,549	(71.9%)	250,698,389	(82.0%)	279,283,510	(91.3%)
[1–10]	173,636,706	(56.8%)	52,869,611	(17.3%)	44,113,851	(14.4%)	26,521,513	(8.7%)
[10–20]	16,433,623	(5.4%)	24,970,053	(8.2%)	10,584,771	(3.5%)	230,187	(0.1%)
[20–30]	12,077,764	(4.0%)	7,873,251	(2.6%)	625,393	(0.2%)	46,823	(0.0%)
[30–40]	23,255,827	(7.6%)	460,857	(0.2%)	67,423	(0.0%)	8609	(0.0%)
[40–50]	15,966,674	(5.2%)	20,655	(0.0%)	814	(0.0%)	0	(0.0%)
[50–60]	67,996	(0.0%)	333	(0.0%)	0	(0.0%)	0	(0.0%)
[60–70]	1927	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
[70–80]	878	(0.0%)	333	(0.0%)	0	(0.0%)	0	(0.0%)
[80–90]	1178	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)