Accumulation of Atmospheric Mercury in Forest Canopies

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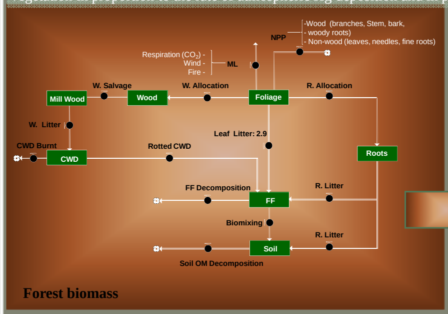
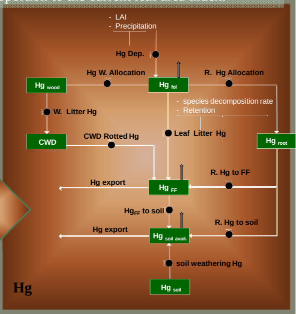
Introduction. Forests are important scavengers and sinks of atmospherically transported mercury (Hg). Much of the scavenged Hg is intially taken up by the forest canopy, through (i) adsorption to surface structures such as twigs, bark, external foliage structures, and lichens, especially *usnea* species (also known as old-man's beard , and (ii) through stomatal uptake, where Hg in gaseous and elemental form is photo-oxidized to Hg^{2+} and therefore becomes strongly attached to organic substances through organo-metal complexation. Some of the Hg so bound would then become part of the woody components of the trees; some of it would be taken up by wood and foliage consuming organisms, but most of it would fall to the ground as part of the gradually accumulating and decomposing litter layer. Harvest actions and forest fires add to this complexity by removing some of the accumulated Hg through direct exporting or through pyrolytic transformation of Hg^{2+} to volatile Hg^0.

This poster presents an overview of a model built to quantify the process of Hg sequestration, retention and release from forests as part of the overall forest biomass accumulation process before and after forest disturbances such as forest harvesting and fire. As such, the model builds on current forest inventory information, dealing with forest composition and stem volume and biomass in relation to stem diameter. The model accumulates biomass and Hg within the trees by the stand-level foliage, branch, bark, stemwood and root compartments. The model takes advantage of existing volume-to-biomass conversions and remains consistent with expected wood density values.

MODEL: Pools and Processes. A forest biomass model that can track and allocate the amount of net primary production throughout the life of a forest stand is crucial for quantifying the amount of Hg residing with within the above- and below-ground biomass and organic matter pools. Key assumptions for tracking of biomass and Hg over time with and without forest disturbances are as follows: (i) biomass is generated, allocated or lost within each pool in proportion to current of that pool size; (ii) the amount of Hg transferred into or lost from each pool is also based on the size of that pool. For example, net primary production is assumed to be proportional to current leaf biomass and leaf biomass is assumed to be proportional to the leaf area index (LAI) of the forest stand. To simplify, concentrations of Hg within each pool remain constant as a first approximation. However, this can be modified by varying Hg uptake by the forest vegetation in proportion to the rate of atmospheric Hg deposition and in proportion to the current leaf area index.

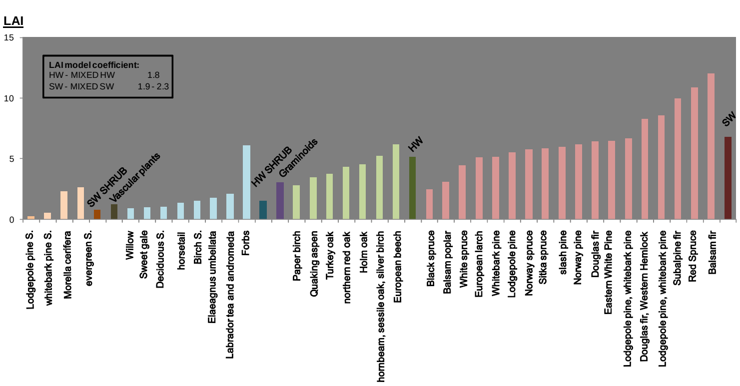


Forest biomass

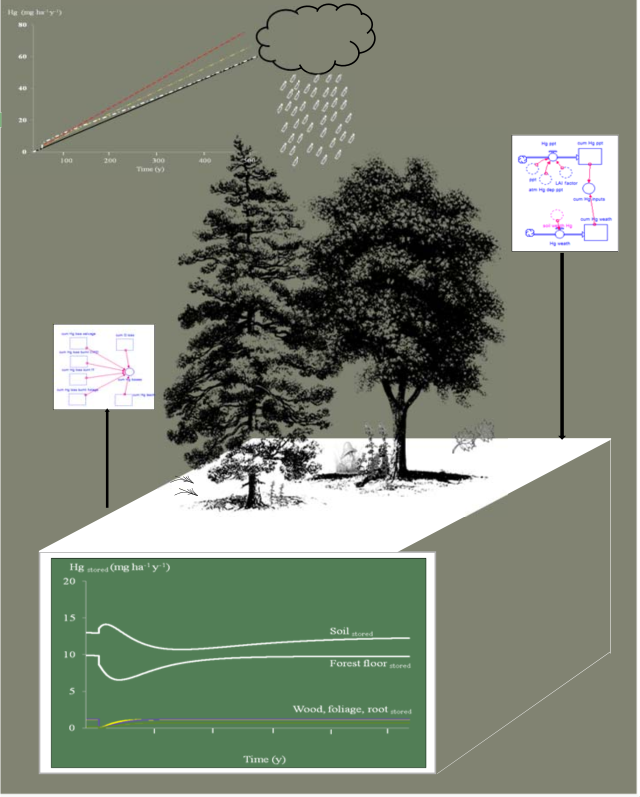


Hg

Net primary production (NPP) is in nature converted and allocated to forest biomass (foliage, wood, roots), and can be inferred from the Leaf-Area Index (LAI) as it changes in forest stands over time and with tree species. The amount of Hg sequestered by the forest canopy is also directly related to LAI the amount, as a means to represent the combined total of all the of fine surface structures within the forest canopy.



Shown below is a typical model output regarding the Hg accumulations in a forest subject to a steady influx of Hg. At first, the model is initialized to the mature condition when the forest is essentially at a steady state, so that all incoming fluxes (energy, nutrient, water, Hg) are balanced with equal amounts of losses as a result of decomposition, evapotranspiration, nutrient leaching , etc.). The data compiled in the table on the lower left are used to calibrate the biomass model to this condition. Thereafter, the model is used to simulate a forest disturbance (e.g., clear-cutting) that, for example, removes all the above biomass, but leaves the root biomass behind. The model is programmed so that the stand will recover its biomass and Hg content within the expected time towards maturity and within the well established foliage, wood and root allocation pattern.



Quantifying biomass and Hg pools and processes in forest stands. The table below presents a compilation of select literature reported values for well-studied forest stands, needed for stand-specific model initializations.

Site	Forest biomass production and allocation, t / ha yr					Hg concentration, ppb									
	NPP	NPP allocation, t / ha yr			Forest litter										
		Foliage	Wood	Roots		Foliage	Branches	Bark	Boles	Roots	L	F	H	Soil 0-20cm	Soil 20-40cm
Mixed Hardwoods (CH)	12,117	6,351	3,571	2,195	4,982	56.9	15	12	0.9	17	305	395	261	15	36
Pine (CP)	12,893	5,700	3,871	3,322	6,472	39	10	25	2.5	15	301	413	335		
Douglas Fir (DF)	9,849	1,050	6,800	1,999	1,780	13	1	0	0	3	34	96	172	161	133
Loblolly Pine (DL)	13,880	5,390	4,590	3,900	4,915	39	10	25	2.5	15	301	413	335		
Pacific silver fir (FL)	5,165	1,060	3,020	1,085	2,730	12	1	0	0	3	34	96	172	161	133
Slash Pine (FS)	9,733	1,869	6,402	1,462	4,453	27	20	20	2	14	32	52	NA	9	NA
Mixed Hardwoods (HF)	5,587	3,545	725	1,317	5,264	56.9	15	12	0.9	17	305	395	261	15	36
Mixed Hardwoods (HF)	5,587	3,545	725	1,317	5,264	44.7	15	12	0.9	15	305	395	261	15	36
Red Alder (RA)	12,976	3,492	6,850	2,634	4,481	48	19	20	2	18	66	195	385	151	128
Beech (SB), Plot 1	10,910	2,440	8,470		2,244	8	13	20	2	9	83	175	420	251	68
Beech (SB), Plot 2	8,582	2,120	4,720	1,742	1,828	8	13	20	2	9	83	175	420	251	68
Loblolly Pine (GL)	14,974				10,315					0					
Loblolly Pine (LP), Plot 1	8,800	2,290	6,510		2,595	8	13	20	2	9	83	175	420	251	68
Loblolly Pine (LP), Plot 2	4,015	2,850	1,165		3,500	8	13	20	2	9	83	175	420	251	68
Red Spruce (MS)					2,105	23	10	0	0	7	31	80	262	145	46
Norway Spruce (NS), PLOT R1	6,873	1,830	5,043		3,286			200	13	49					
Norway Spruce (NS), PLOT R2	5,731	1,882	3,749		2,290			200	13	49					
Red Spruce (SS)	2,823	2033	790		1,909	39	10	25	2.5	15	301	413	335		
Red Spruce (ST), Plot 1	4,530	2440	2090		1,770	39	10	25	2.5	15	301	413	335		
Red Spruce (ST), Plot 2	1,360	2160	-800		5,415	39	10	25	2.5	15	301	413	335		
Mixed Hardwoods (TL)	16,168	4176	10239	1753	3,730	8	15	6	2	6				228	
Red Spruce, Balsam Fir (WF)	7,379	2209	3640	1530	2,597	39	10		2.5	10	301	413	335		
Blue Oak, Foothill Pine, CA	5,630	4590	4590	1050	1050	27	10	0	0	7	33	56	NA	50	28
Blue Oak, Foothill Pine, CA	5,690	4130	4130	1550	1570	27	10	0	0	7	33	56	NA	50	28
Blue Oak, Foothill Pine, CA	4,350	3470	3470	880	850	27	10	0	0	7	33	56	NA	50	28

The forest biomass model has been developed to become a decision-support tool for the sustainable allocation of forest biomass resources in New Brunswick and in Nova Scotia (J. Noseworthy, MScF thesis, UNB, 2011). The Hg component is added-on to allow for province-wide tracking of atmospherically sequestered Hg through these two provinces. The same model also tracks the effects of forest harvesting and atmospheric S and N deposition on base-cation depletion on the overall sustainability of the available N, Ca, Mg, and K pools in forest soils (Nasr et al. 2010). The model also works in conjunction with the Forest Hydrology Model, primarily designed to simulate soil moisture, snow and frost conditions as well as streams discharge with small forested watersheds (Balland et al. 2005, 2006). That particular model is also instrumental in tracking upland to wetland and wetland to stream transfers of , e.g., dissolved organic carbon (DOC), nitrate nitrogen, and Hg (Jutras et al. 2011, Murphy et al. 2009). The effects of climate change on forest biomass dynamics are in part related to determining the effects of changing moisture and temperature conditions on the decomposition process of forest litter, as demonstrated by Zhang et al. (2007, 2008) and of wood, as evaluated by Smith et al. (2011) across North America. Current research at UNB expand on all of this within the context of upland-wetland–stream Hg transfer , as this varies from fairly dry basins with no wetlands to very wet basins with extensive wetland formations.

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