Institute for Catastrophic Loss Reduction
Building resilient communities

Institut de Prévention des Sinistres Catastrophiques
Bâtir des communautés résilientes

Calgary hail seeding benefit-cost analysis

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WORST
CALGARY
HAILSTORM

Hail seeding

Literature

Performance-based engineering and benefit-cost analysis (FEMA 2012)

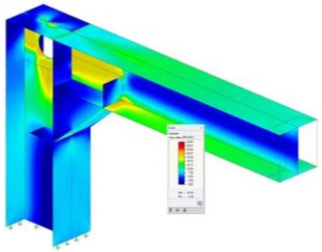
1. Define the asset

Asset analysis:
Building quantity
Roofing material

2. What nature does

Hazard analysis:
Storm frequency
Stone size distribution
Hitrate
Duration

3. Building forces, deformations



4. Damage symptoms

Damage analysis:
Shingle fragility
Damage | storm

5. Dollars, deaths, downtime, etc.

Loss analysis:
Loss | damage

6. Decision-making

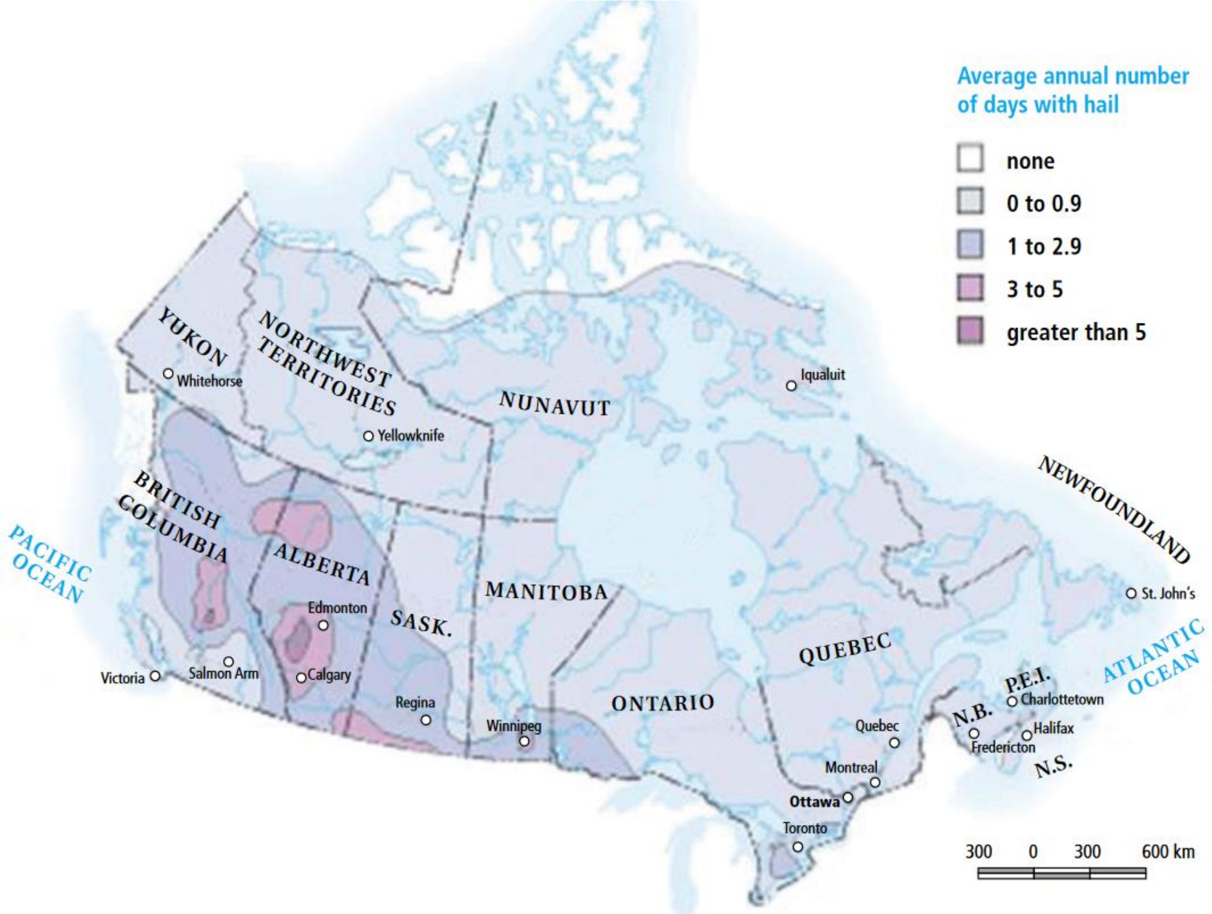
Decision analysis:
EAL as-is, what-if
Benefit
Benefit-cost ratio

Assets: 409,000 single-family-equivalent dwellings

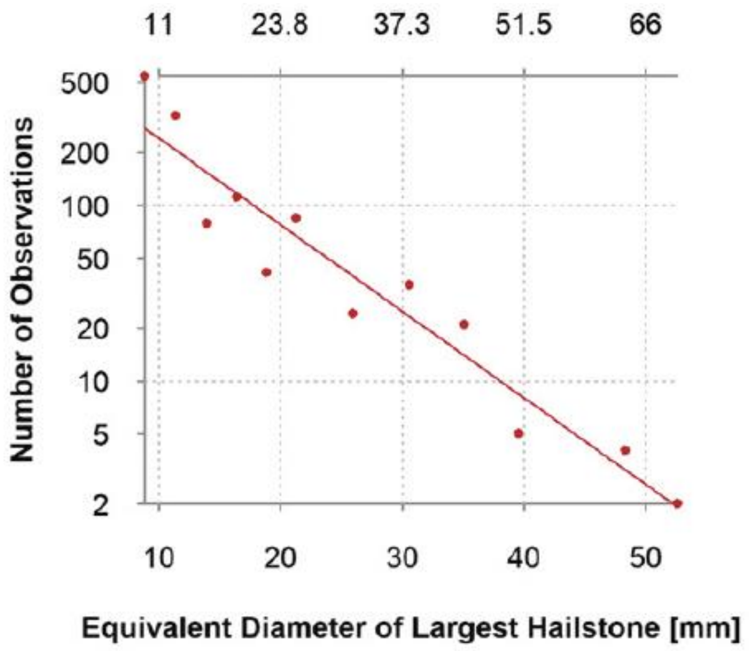
Table 1. Calgary housing statistics

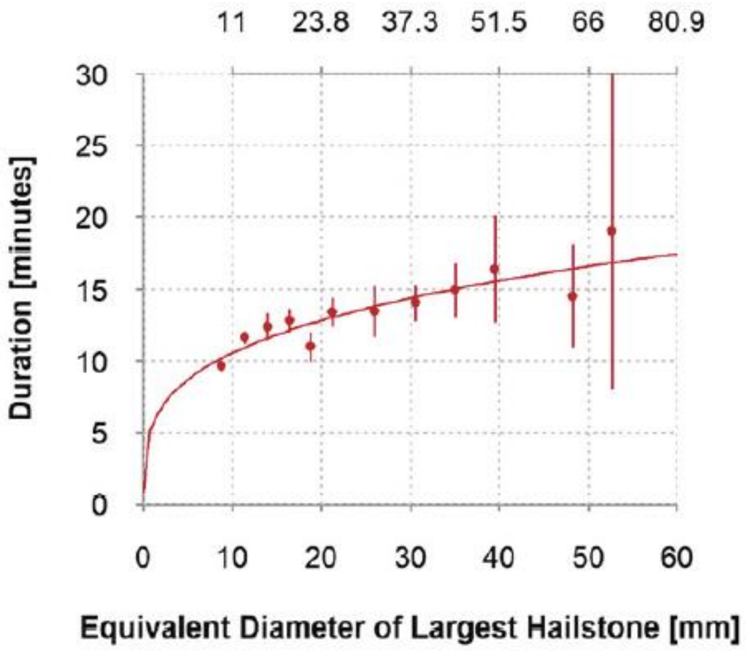
Household and dwelling characteristics	Total
Total private dwellings	531,062
Total occupied private dwellings	502,300
Single-detached house	276,050
Semi-detached house	31,660
Row house	48,860
Apartment or flat in a duplex	21,165
Apartment in a building that has fewer than five storeys	81,870
Apartment in a building that has five or more storeys	40,700
Other single-attached house	200
Movable dwelling	1,790

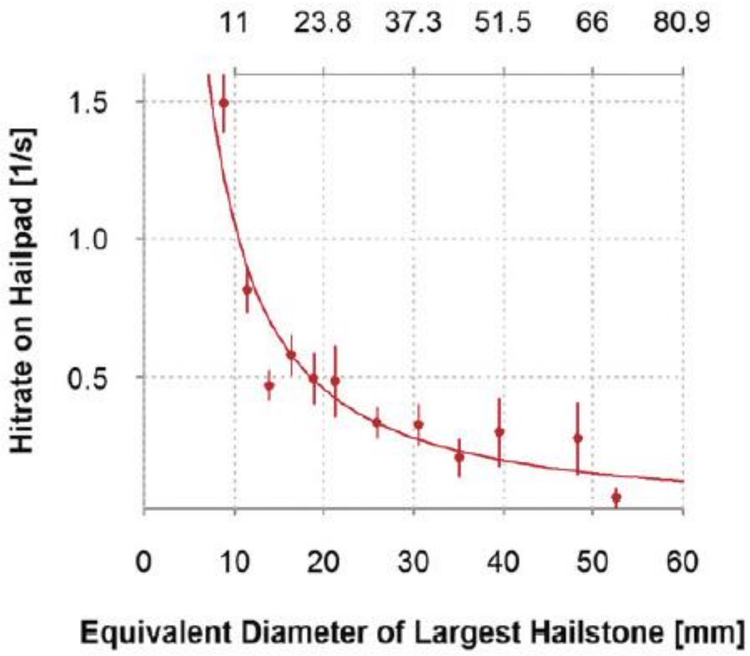
Hailstorm frequency f_h (Etkin 2018)



Largest diameter, hitrate, & duration (Grieser and Hill 2019)





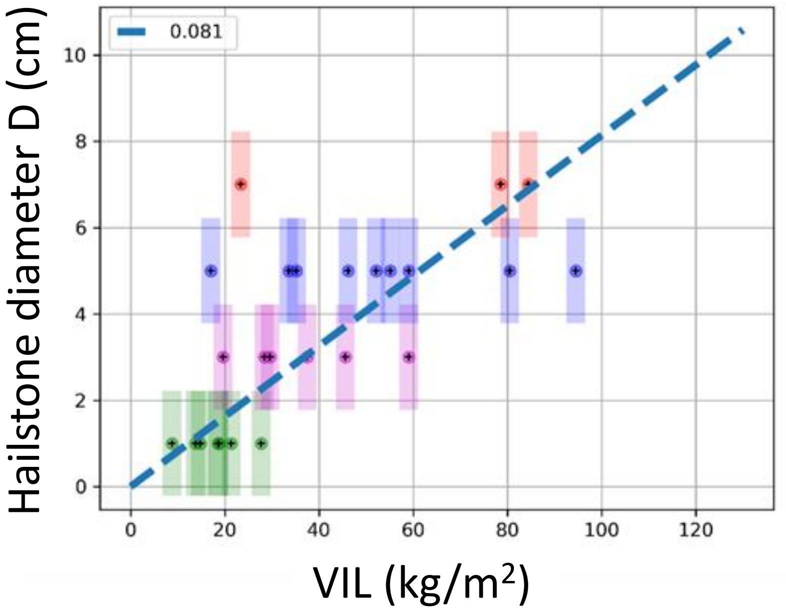


Seeding affects vertically integrated liquid (VIL); VIL affects largest diameter D_L

Pirani et al. (2023) avg effect of seeding on vertically integrated liquid (VIL) after 30 minutes

VIL percentile	Seeded – unseeded VIL
25%	+60%
50%	+24%
75%	-5%
90%	-15%
95%	-17%
99%	-18%

Joe (2023) relationship between D_L and VIL



Asphalt shingle roof fragility $P_{fL}(d)$ (Porter 2022)

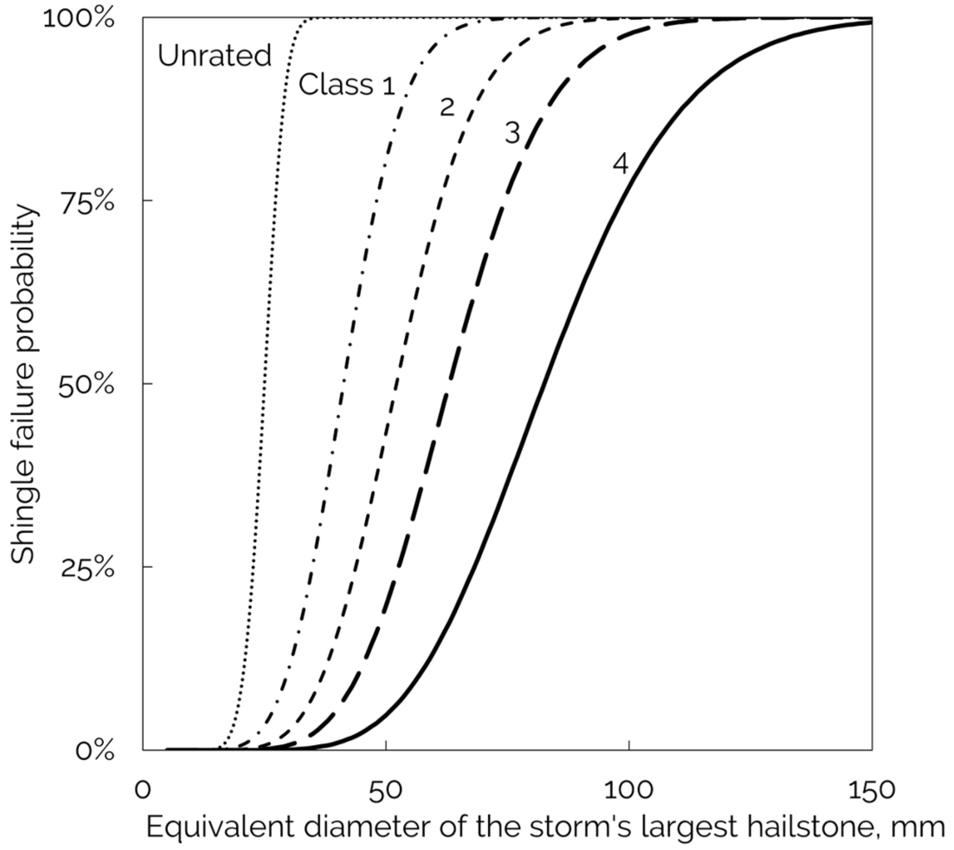
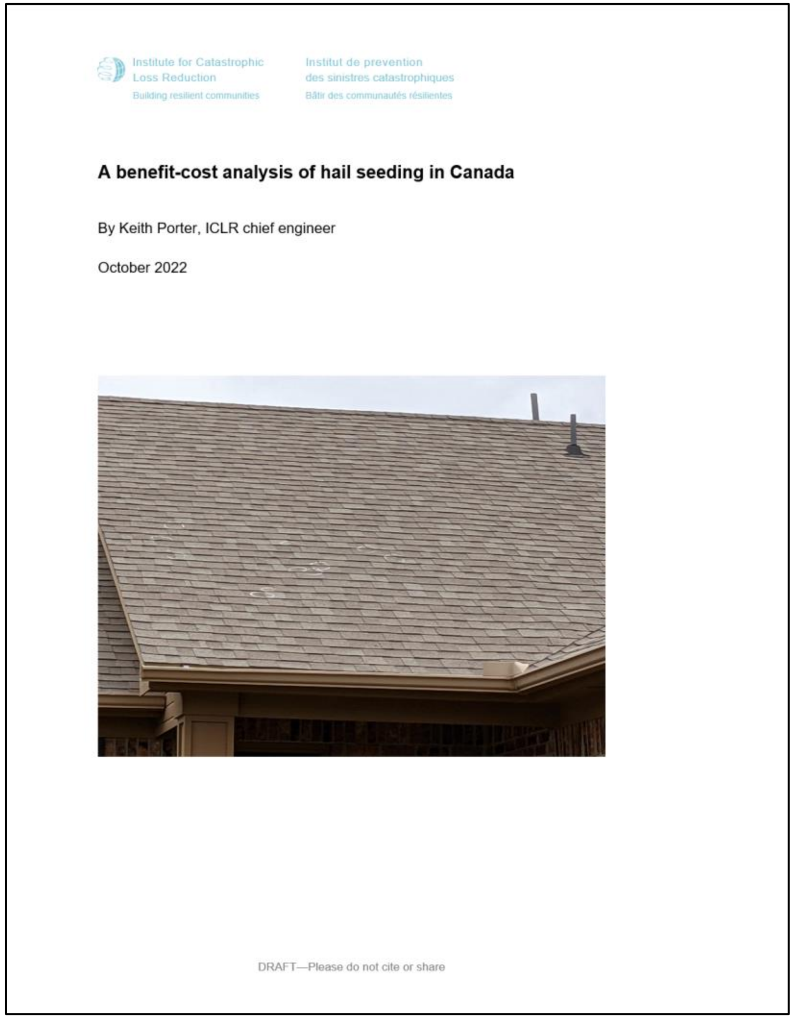


Figure 12. *Shingle failure probability as a function of the storm's largest hailstone*



Repair cost/square

Table 7. *Contributors to repair cost per roofing square.*

Cost parameter	Unrated	Class 4	Comment
Underlayment demo + replace material	$6.69	$6.69	Unit cost roof underlayment, demolish & replace 15# felt, from RSMeans (2020) pg. 73
Underlayment demo + replace labour	$22.20	$22.20	Ditto
Shingle demo & install labour	$125.73	$125.73	Labour unit cost demolish & install 30-year comp shingles RSMeans (2020, pg. 73)
Shingle material low	$85.00	$167.00	Marquis Weathermax (Home Depot Calgary); Mystique (RONA); TruDefinition Duration (Menards, Home Depot)
Shingle material moderate	$96.00	$260.00	Dakota (RONA.ca); Manoir (RONA.ca); TruDefinition Weathguard HP (Hanscomb Ltd 2020)
Shingle material high	$99.00	$340.00	Everest (RONA.ca); Vista AR (Hanscomb Ltd 2020); Stormfighter IR (Hanscomb Ltd 2020)
Total cost/sq low	$239.62	$321.62	
Total cost/sq moderate	$250.62	$414.62	
Total cost/sq high	$253.62	$494.62	
Marginal cost/sq low	$0.00	$82.00	
Marginal cost/sq moderate	$0.00	$164.00	

Method

Roof repair cost given max hailstone diameter *L*(*d*)

P_{FL}(d) = fraction of shingles to be replaced if $D_L = d$

U = unit repair cost

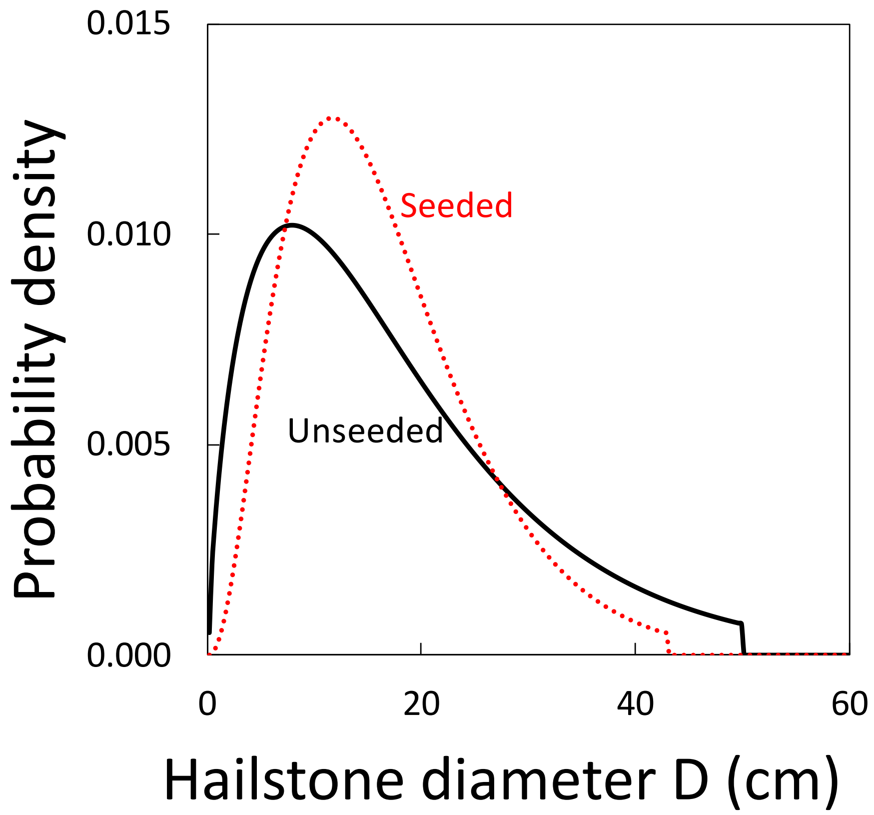
A = roof area

R = repair difficulty factor

E = threshold for replacement

$$
\begin{aligned}
L(d) &= P_{f_L}(d) \cdot U \cdot A \cdot R \\
&= P_{f_L}(d) \cdot V & \quad P_{f_L}(d) < E \\
&= V & \quad P_{f_L}(d) \geq E
\end{aligned}
$$

Probability density function of hailstone size, $f_{DL}(d)$



Average roof repair cost per hailstorm per house, $E[L]$

$f_{DL}(d)$ = probability density function of D_L

$$E[L] = \int_{d=5}^{\infty} L(d) \cdot f_{D_L}(d) \cdot dd$$

No. of roofs in a community, in single-family-equivalent dwellings, N_{SFED}

i = house type

N_i = number of houses of type i

F_{5i} = roof area of type i as fraction of a single-family dwelling

$$N_{SFED} = \sum_i N_i \cdot F_{5i}$$

Average annualized loss in a community, *EAL*

f_h = hailstorm frequency

$$EAL = f_h \cdot N_{SFED} \cdot E[L]$$

Annual benefit of mitigation *B*, benefit-cost ratio *BCR*

EAL = as-is

EAL' = with seeding

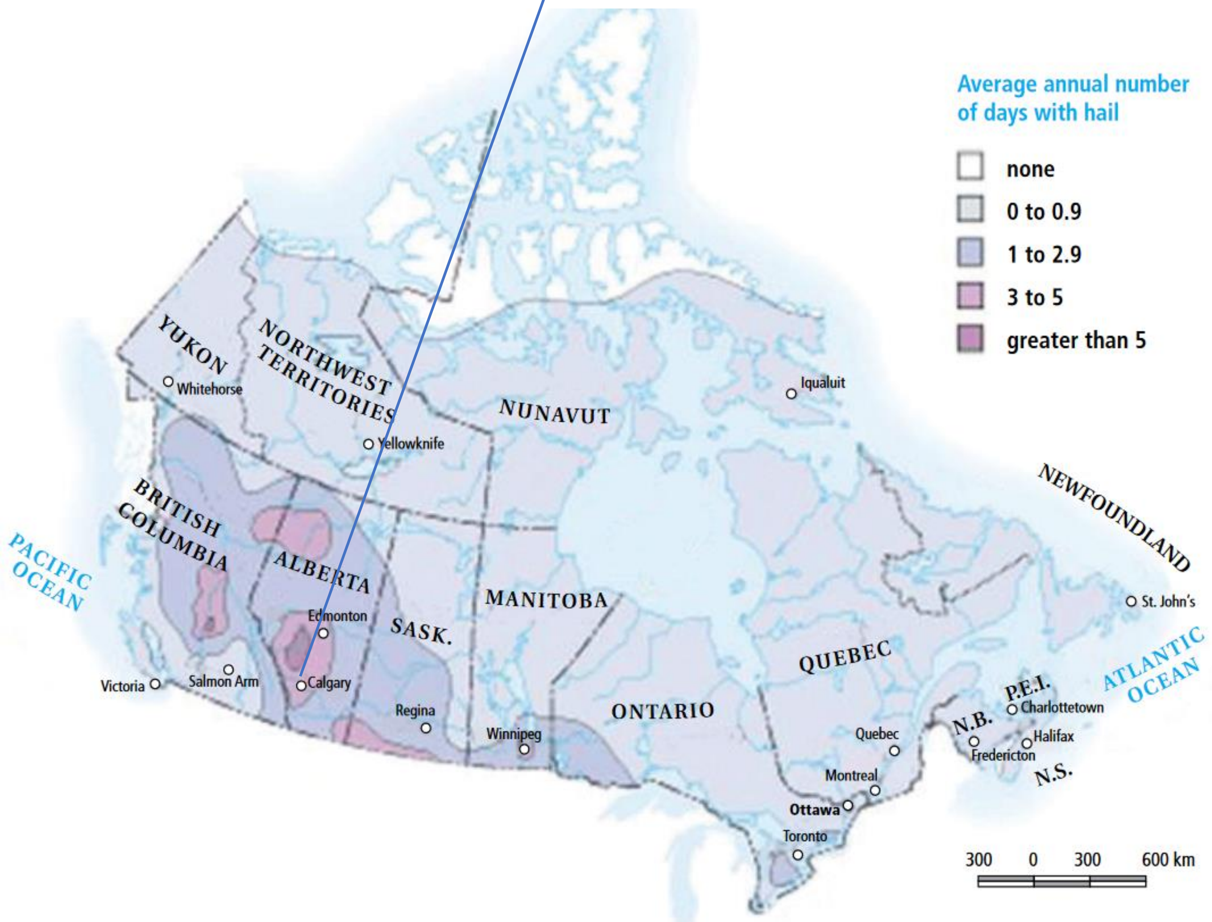
C = annual cost of seeding

$$B = EAL - EAL'$$

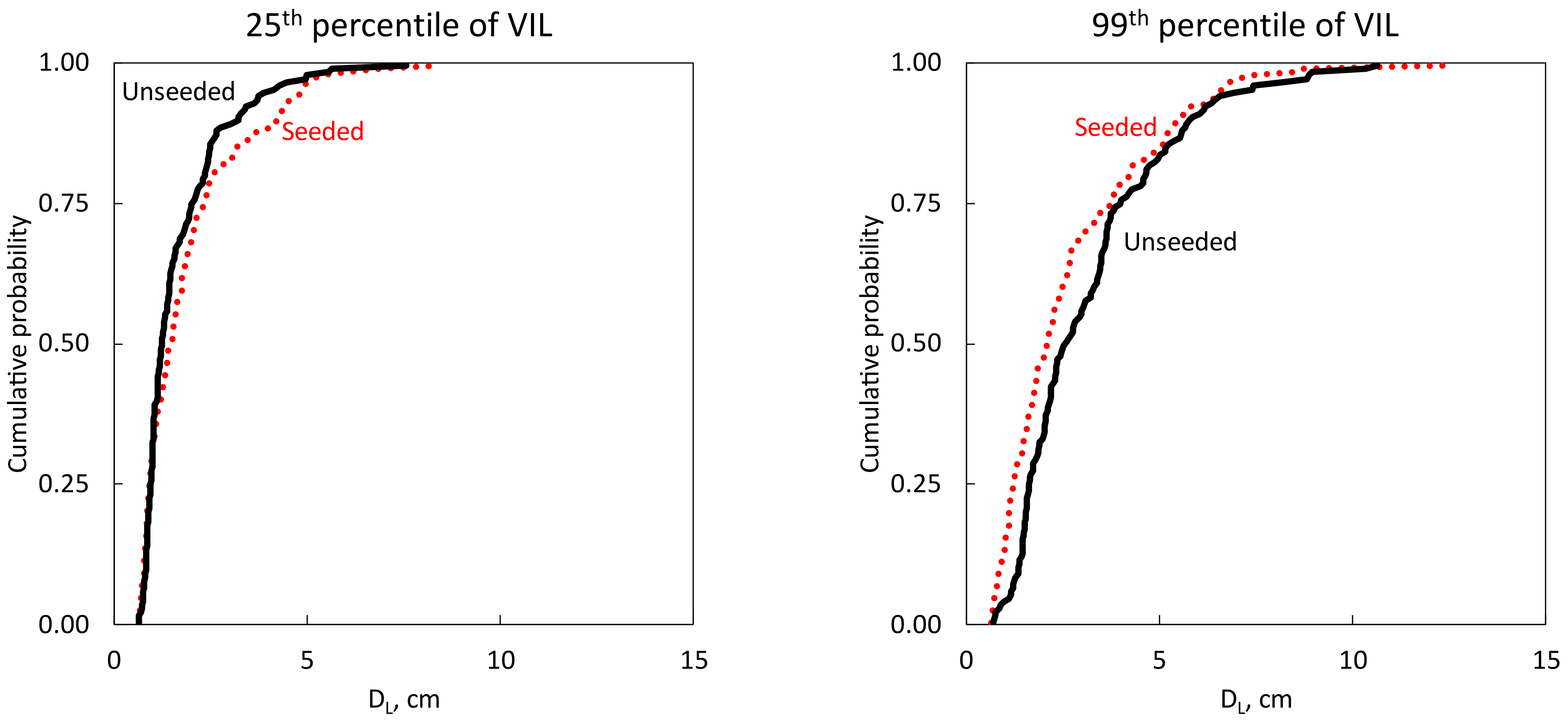
$$BCR = \frac{B}{C}$$

Application

Calgary hailstorm frequency: f_h = 2.35 per year (Etkin 2018)



Pirani et al. (2023) + Joe (2023): more small hailstones, fewer big ones



Hazard analysis: 18% reduction in D_L, 5% reduction in storm area

Pirani et al. (2023) seeding & VIL

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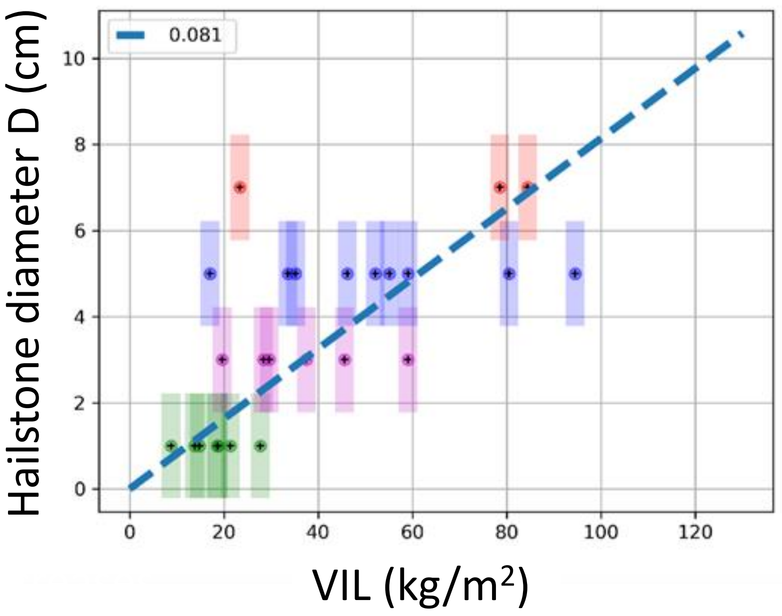
Joe (2023) VIL & D_L



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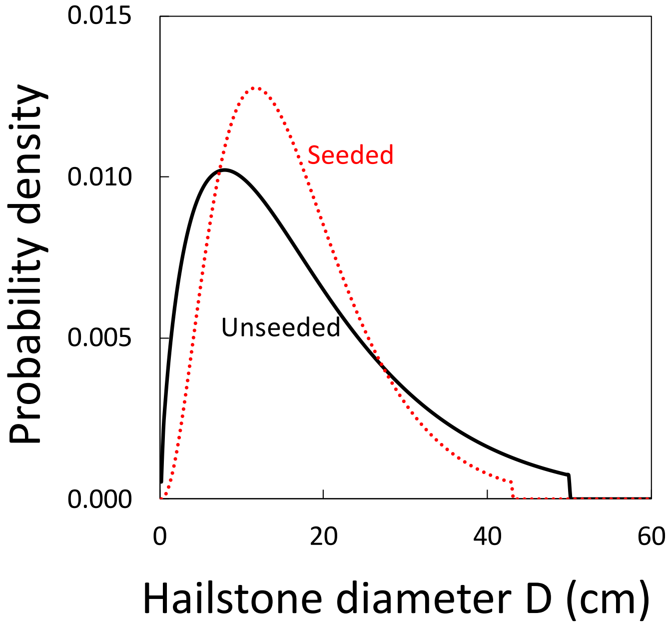

Decision-making: benefit and BCR

	No seeding	With seeding
A. Avg roof repair cost per hailstorm per house, $E[L]$	$293	$155
B. Single-family-equivalent dwellings, N_{SFED}	409,000	409,000
C. Calgary hailstorms per year, f_h	2.35	2.35
D. Hailstorm footprint area relative to unseeded	1.0	0.95
E. Annual roof repair cost = A × B × C × D	$282 million	$142 million
F. Reduced annual roof repair cost = $E_{\text{no seed}} - E_{\text{with seed}}$		$140 million
G. Reduced annual auto repair cost (by proportion)		$90 million
H. Benefit per year = F + G		$230 million
I. Seeding cost per year (Tait 2022)		$5 million
BCR = benefit (H) ÷ cost (I)		45:1

Limitations

- Vehicle damage assumed proportional to roof damage, rather than modeled more directly
- Expressing hazard in terms of vertically integrated liquid to estimate hailstone diameter adds uncertainty and potential error to the model
- Analysis imputes causation to correlation between seeding and ΔVIL, and between ΔVIL and ΔD_L
- One can imagine double-blind testing like Kerr (1982)

Summary

1. Hail seeding may reduce Calgary loss by ~\$200M/year (not eliminated)
2. Several limitations, so maybe actual reduction is less. \$100 M/year?
3. Even so, \$100 million/\$5 million = 20:1 is very good

Alberta Severe Weather Management Society

Q&A