Structure and Function of Eighteen Living Snow Fences in New York State across an Eleven Year Chronosequence

Capstone Seminar

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Project Overview

Observational study of living snow fences of various ages, species, and locations

Literature Review

Methods

Results

Discussion

Conclusion

Literature Review

Background Information

Living Snow Fences

- Rows of trees, shrubs, or combinations of multiple species
- Planted along roadways to mitigate blowing snow problems
- Same purpose and function as structural snow fences (wooden or plastic)
- Disrupt wind and cause controlled snow deposition around the fence
- Formation of snow drifts in designated areas away from the road

Economic Benefits

Reduction of snow and ice control costs

- Over $2 billion annually nationwide[1]
- Over $300 million annually in New York State[2]
  - Frequent "spot-treatments" to control blowing snow problems, often in remote areas

LSF are potentially more cost effective..

- Than structural snow fences[3]
- Other forms of passive snow control [4] (berms)
- Mechanical & chemical controls[4]

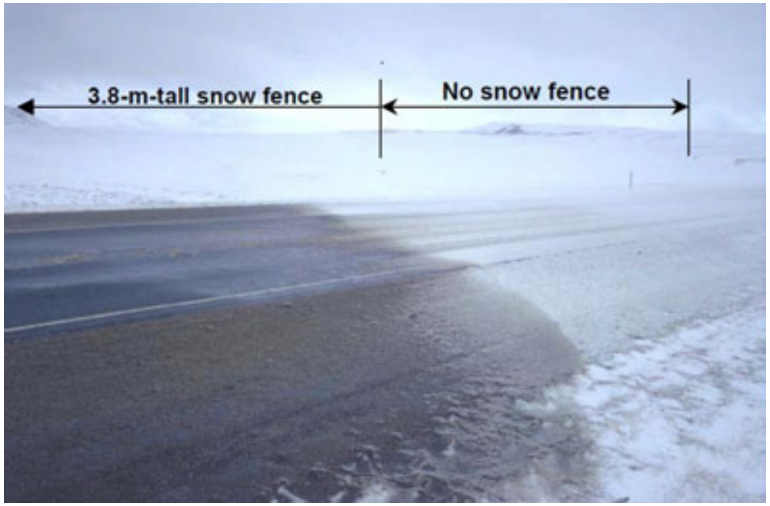
Economic performance of LSF depends on…

- Cost of installation and maintenance
- Survival of plants short and long term
- Time lag until fences become functional
- Level of snow control and other benefits

Public Benefits

Improved Highway Safety

- Road conditions and visibility
- 75% reduction in accident rates[5]
- Average cost of car accidents[6]
  - $3.5 million for each fatal accident
  - $100,000 for injury inducing crashes
  - Protecting human life and wellbeing



Value of Travel Time Savings (VTTS)

- Time is money
- Prevented road closures & reduced speeds
- Value of public and commercial travel[7]
  - $15/hr car travel
  - $25/hr truck travel

Environmental Benefits

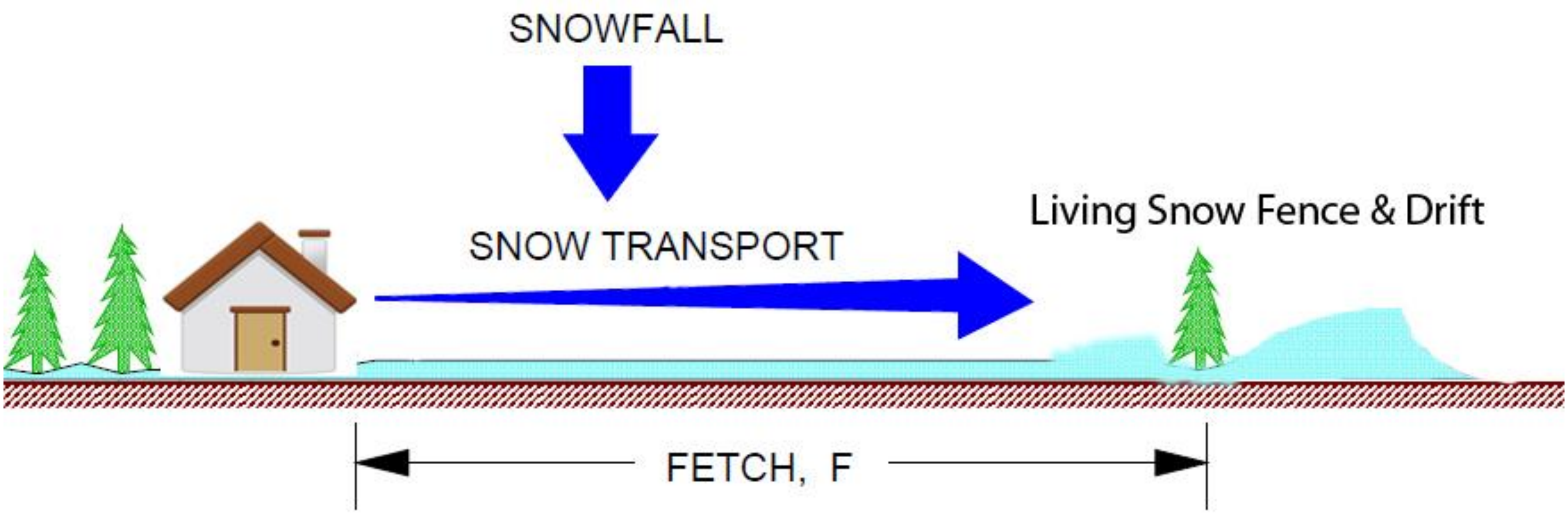
"Green" approach to snow and ice control

- Recognized as transportation best management practice[1,8]
- Highest certification in the NYSDOT "GreenLITES" program[9]
    - Ranks environmental sustainability of transportation projects

Potential for numerous auxiliary benefits[10,11,12]

- Wildlife habitat
- Carbon sequestration and offsets
- Air and water quality
- Agroforestry products
- Aesthetic value
- Phytoremediation
- Crop improvements
- And other environmental benefits

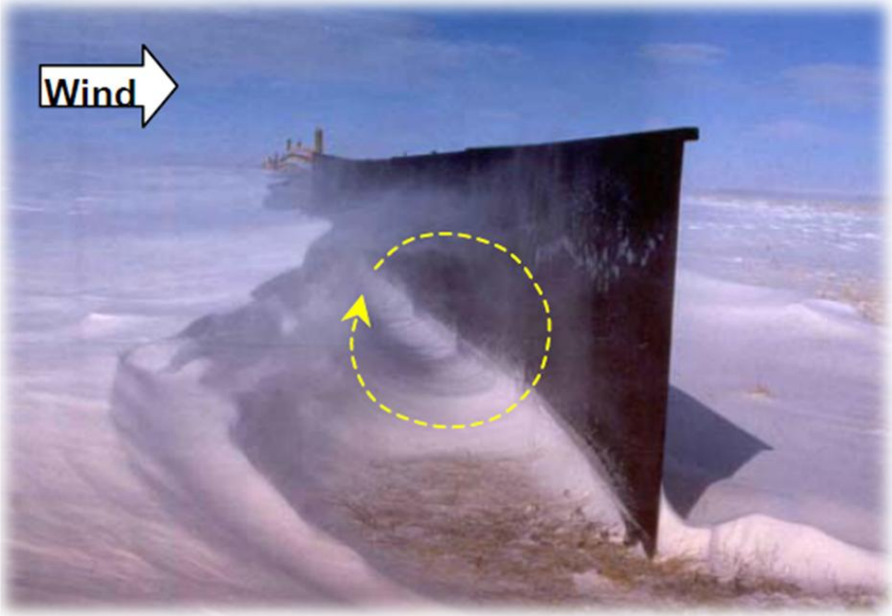
How Snow Fences Work



- Snow is picked up by the wind and transported across an open area
- Wind and blowing snow encounters a snow fence
- Snow fence disrupts wind flow and causes turbulence around fence
- Turbulence deposits snow in drifts around the fence

How Snow Fences Work

Fence causes wind turbulence & eddies



Turbulence causes snow deposition

Structural Variables that Influence Snow Trapping

(Tabler 2000[13], 2003[5])

Height

- Distance from the base of the fence vegetation to the top (m)

Optical Porosity

- Percentage of open area not occupied by vegetation (%)

Setback Distance

- Distance from the edge of road to the fence (m)

Site Characteristics

- Snowfall over the drift accumulation season
- Percentage of snow transported by the wind
- Fetch distance (open area upwind of the fence contributing to snow transport)

Vegetation Type and Planting Pattern

Models of Snow Trapping Function

(Tabler 2000[13], 2003[5])

Snow Transport Quantity

- Quantity of blowing snow at a site in an average year (t/m)
- t/m = metric tons of snow water equivalent per linear meter of fence

Snow Storage Capacity

- Quantity of snow that a fence can capture and hold in a drift (t/m)

Capacity/Transport Ratio

- Ratio of fence capacity to snow transport quantity
- Influences the shape and length of the snow drift

Predicted Drift Length

- Model of drift length that indicates the required setback distance
- Based on Height, Porosity, and the C/T Ratio

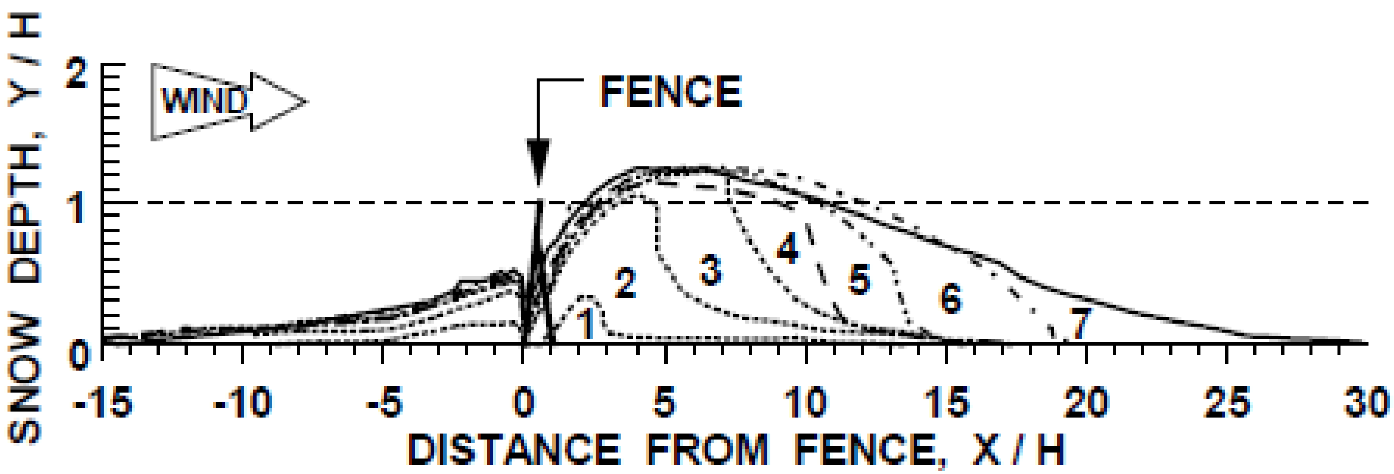
Drift Length and Setback Distance

Important topic in the analysis and design of living snow fences

- Living snow fence structure and function changes over time as plants grow
- The appropriate setback distance is based on the length of the downwind drift

Drift length depends on the stage of drift formation

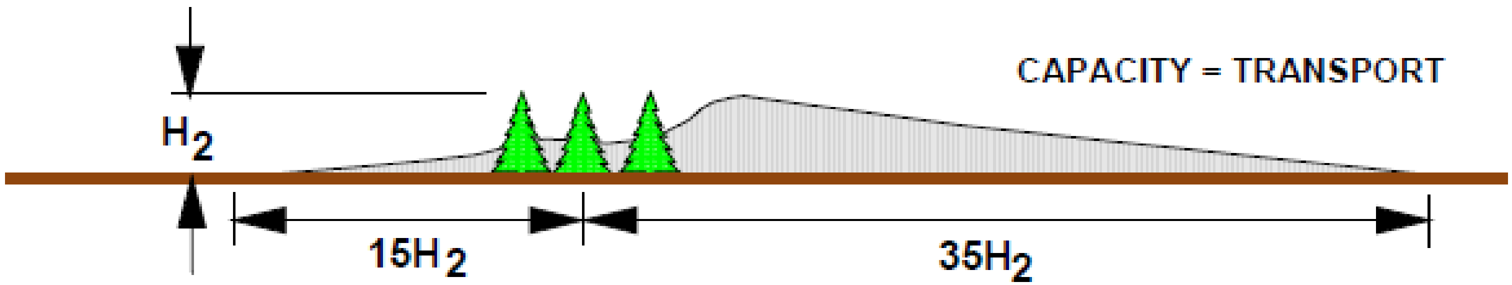
- Maximum drift length is 35 times fence height, when fence is at full capacity
- Prior to 35H, drifts form in incremental stages as snow transport increases
- Drift stage and length depends on the fence capacity, relative to snow quantity



Drift Length and Setback Distance

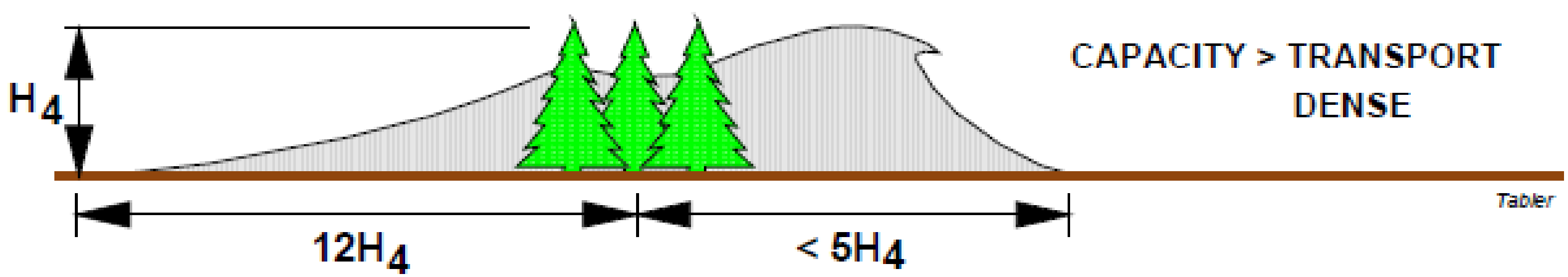
When fence capacity is less than or equal to snow transport…

- Fence fills to capacity and drift length is 35H



When fence capacity is greater than snow transport…

- Fence does not fill to capacity and drift length is less than 35H
- Setback distance can be reduced



Setback Distance in the Literature

Tabler (2003)

- Provides the most comprehensive treatment of setback for living snow fences
- Includes a drift model for LSF that accounts for the key variable of C/T ratio

Other literature on setback of living snow fences…

- Offers vague guidelines and conservative estimates of setback
- Some peer reviewed journals[14,15] – mostly fact sheets, brochures, and bulletins from...
  - Transportation, Agriculture, Forestry, and Extension Agencies [10,17,18,19, 20,21]
  - Important sources of information for resource managers when designing LSF

Summary of Literature (Outside of Tabler, 2003)

- Setback recommendation anywhere from 30 m - 180 m or more
- No mention Tabler's drift model or C/T ratio
- Complexities of setback for living snow fences have not been well understood, further researched, or incorporated into design standards

Research Objectives

1) **Identify a subset of living snow fences for study**

2) **Collect data on key structural variables at each fence**
   - Height
   - Optical porosity
   - Vegetation Type
   - Site characteristics

3) **Model structural data to determine snow trapping function**
   - Snow transport
   - Snow storage capacity
   - Capacity/transport ratio
   - Drift length and required setback

4) **Interpret and discuss results in the context of current literature on living snow fences**

Methods

Indentifying a subset of living snow fences for study

Sources of information

- List of statewide LSF provided by NYSDOT[22]
- Willow Project data archive

Initial remote sensing of Snow Fence Sites

- ArcMAP GIS with NYSDOT mile markers layer
- Most recent aerial photos from Google Earth

Followed by site investigations

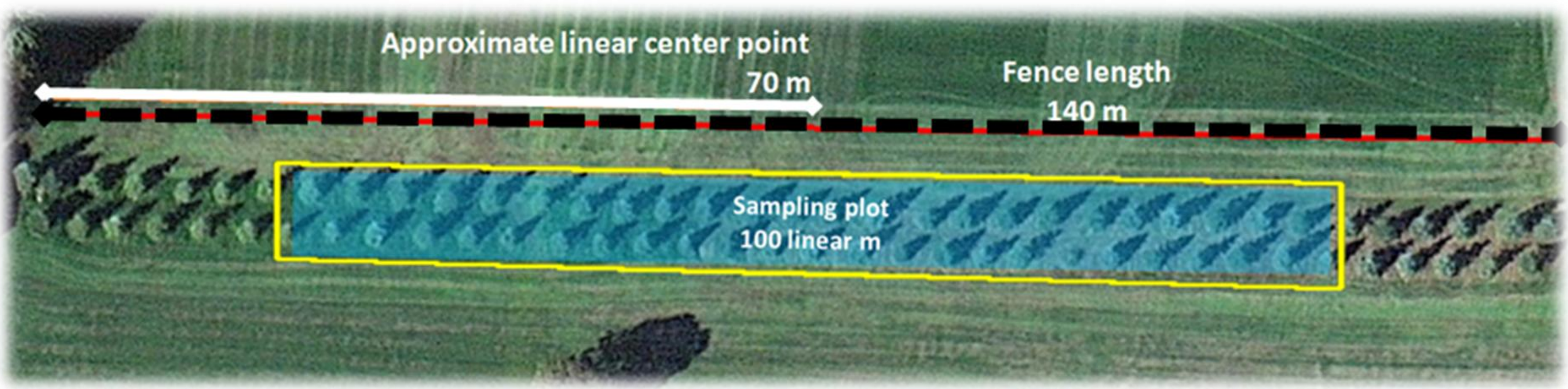
- Fall 2011 through Fall 2012

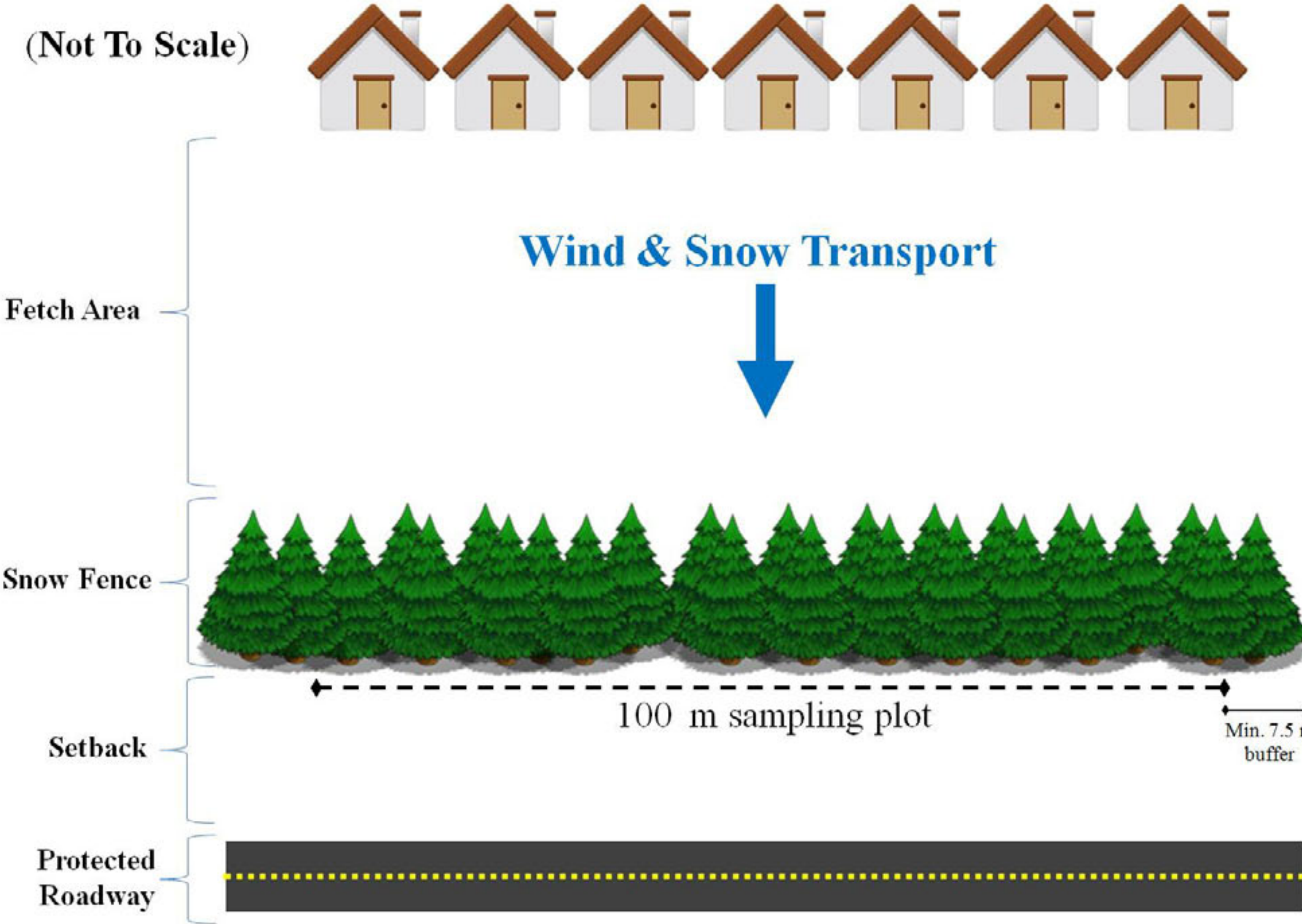
Stratified sample of state-wide fences based on…

- Ability to identify fence remotely and in the field
- Site accessibility and safety considerations
- Select a range of ages and vegetation types for study
- Age defined as years since installation

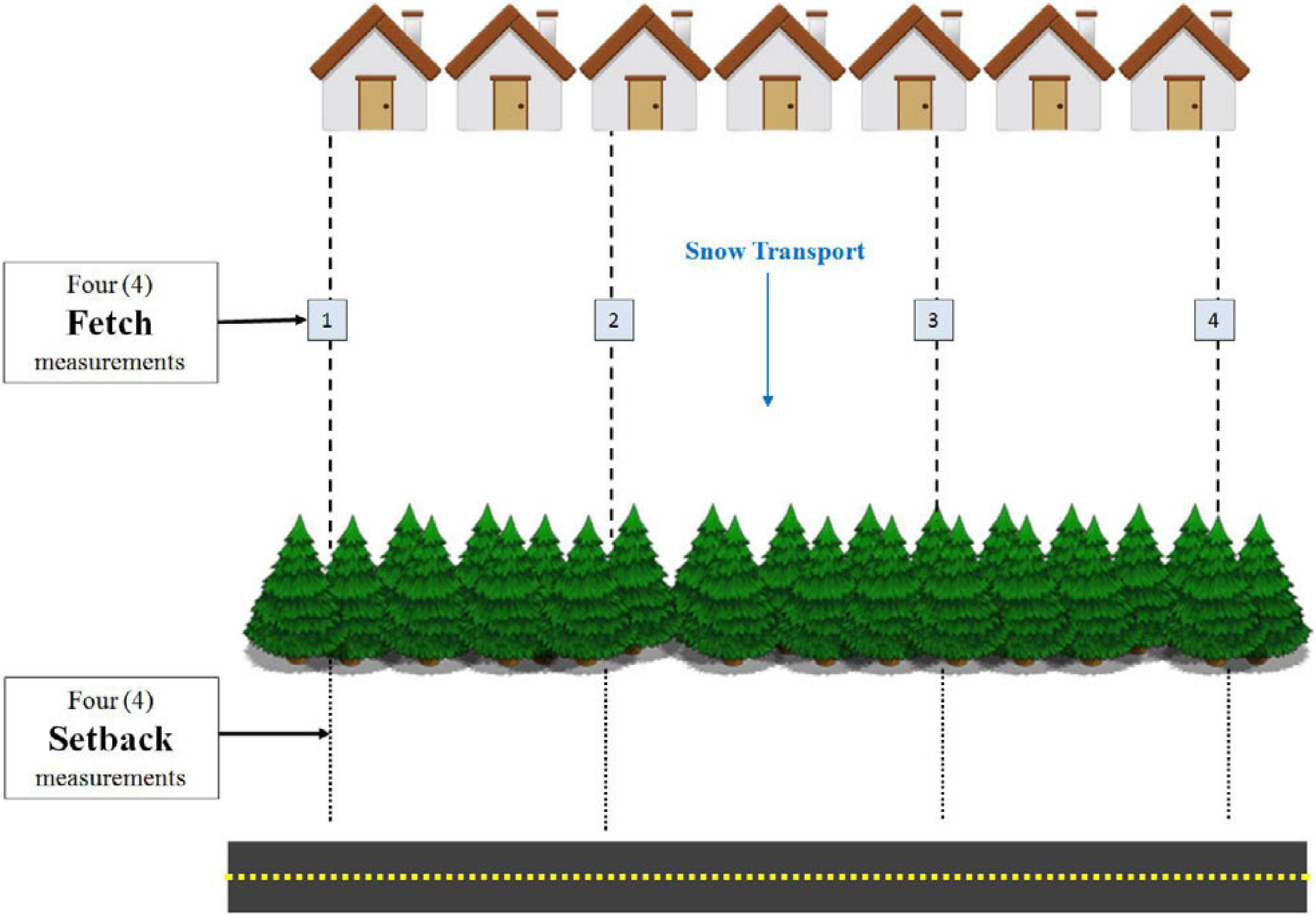
Sampling Plots and Measurements

- Sampling unit reported on = one living snow fence
- 100 m sampling plot established across linear center of each fence
- Remote measurements of setback and fetch distance
- Field measurements of fence height and porosity

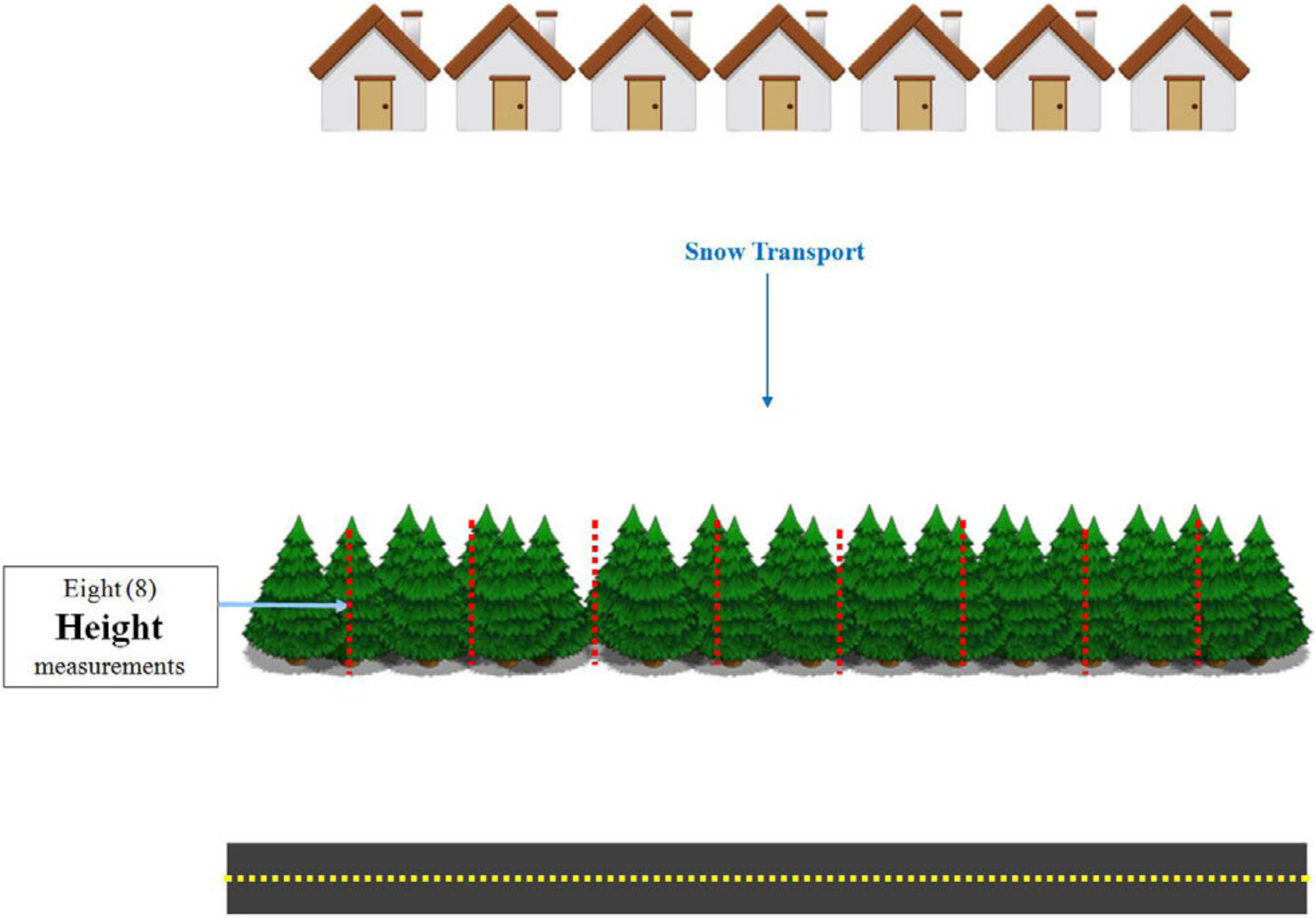




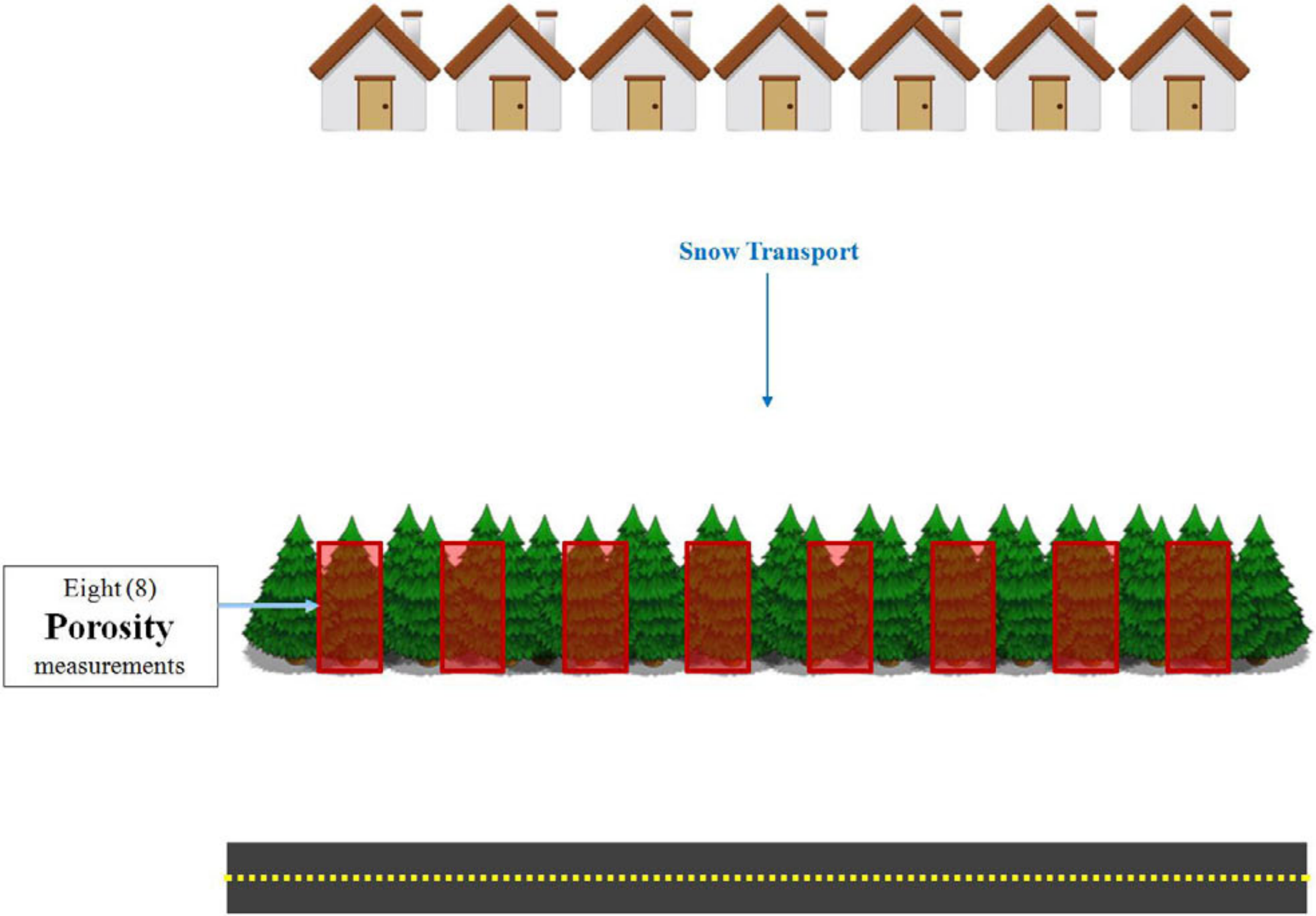
(Not To Scale)
Fetch Area
Wind & Snow Transport
Snow Fence
100 m sampling plot
Min. 7.5 m buffer
Setback
Protected Roadway



Four (4)
Fetch
measurements
Snow Transport
1
2
3
4
Four (4)
Setback
measurements



Snow Transport
Eight (8)
Height
measurements


Snow Transport
Eight (8)
Porosity
measurements

Optical Porosity Sampling

- Chroma-key backdrop (willow)
- High-contrast photos (conifers)
- Functionally equivalent result
- Photos analyzed in Adobe Photoshop
- Quantify open space vs. vegetation

Models of Snow Trapping Function

Tabler (2003)

- Synthesis of 40 year career in snow fence engineering

Tabler (2000)

- Climate variables specific to the function of snow fences in NY

Snow Transport $\mathbf{Q} = 1500(\mathbf{C_r})(\mathbf{S_{we}})(1\text{-}0.14^{\mathbf{F}/3000})$

Fence Capacity $\mathbf{Q_c} = (3 + 4\mathbf{P} + 44\mathbf{P}^2 - 60\mathbf{P}^3)\ \mathbf{H}^{2.2}$

Capacity/Transport Ratio $(\mathbf{Q_c}/\mathbf{Q})$

Drift Length $\mathbf{L} = \{[10.5 + 6.6(\mathbf{Q}/\mathbf{Q_c}) + 17.2(\mathbf{Q}/\mathbf{Q_c})^2]/34.3\}(12 + 49\mathbf{P} + 7\mathbf{P}^2 - 37\mathbf{P}^3)(\mathbf{H_{req}})$

Results

Summary of Fences

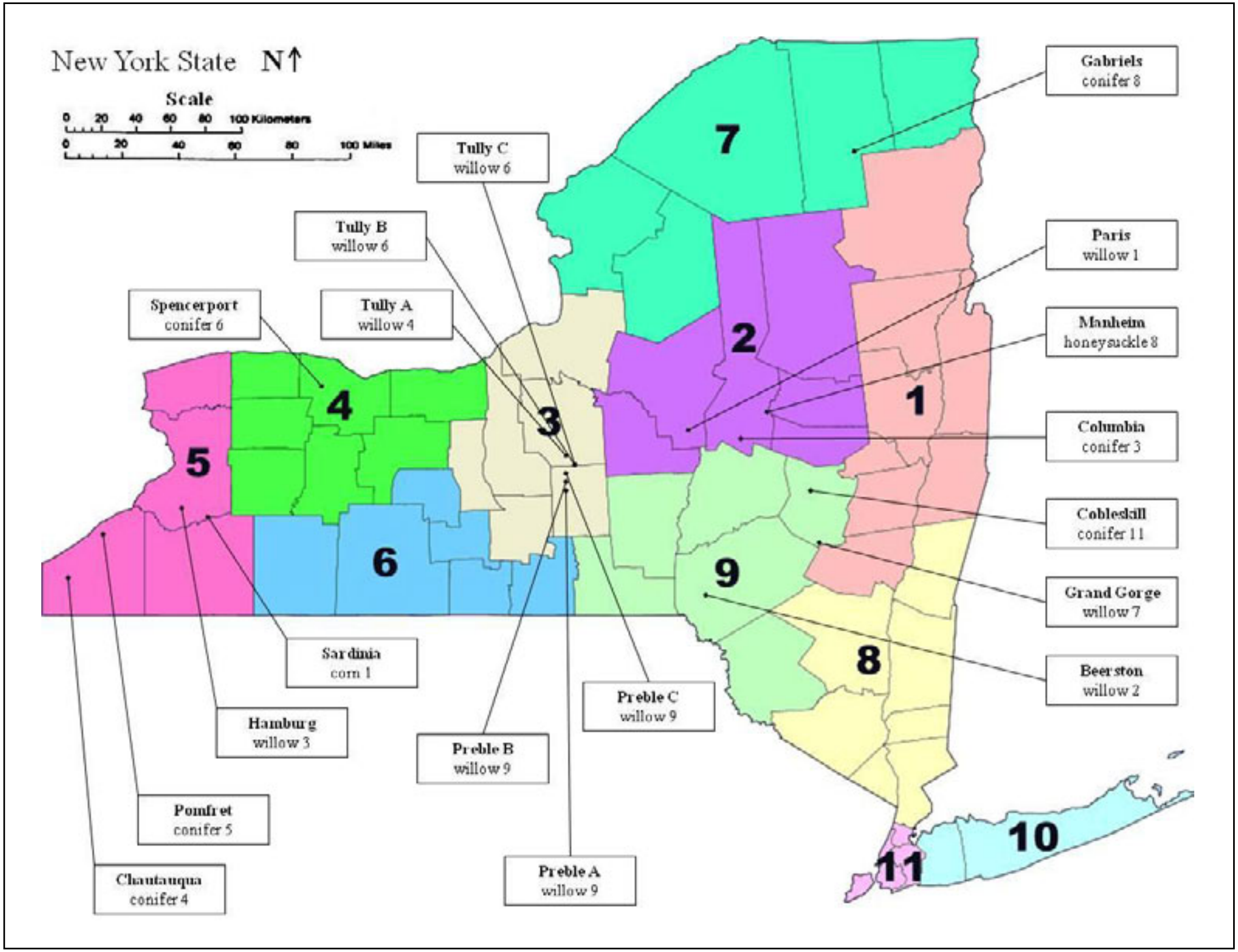
- 18 fences identified and studied
- 10 counties & 6 NYSDOT regions
- Fence age ranged from 1 – 11 years

Four General Vegetation Types…

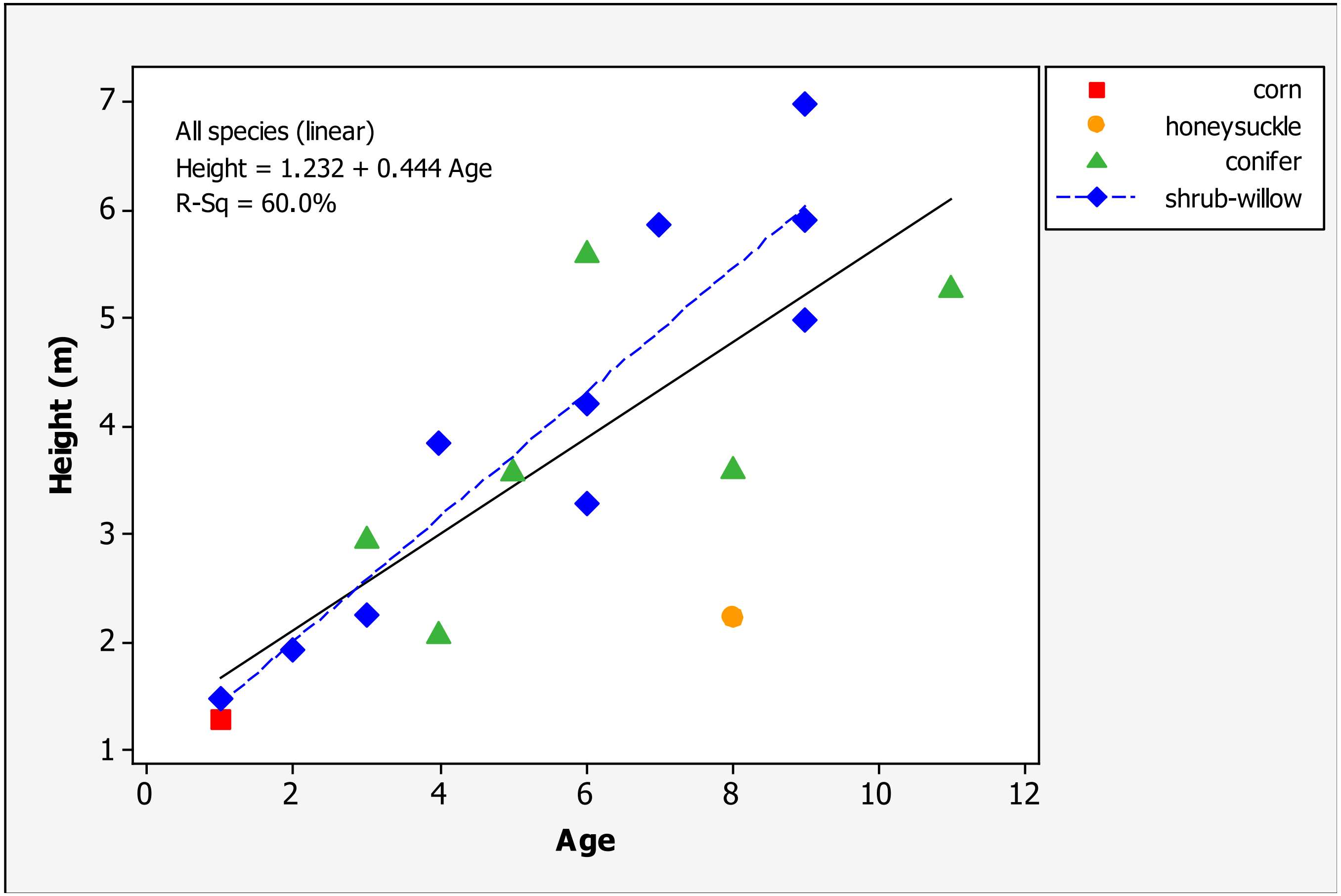
- **Shrub-willow** (10 fences)
- **Conifer** (6 fences)
- **Honeysuckle** (1 fence)
- **Standing corn** (1 fence)

- One, two, or three rows. Corn = 8
- Various plant and row spacings

Map of Fence Locations

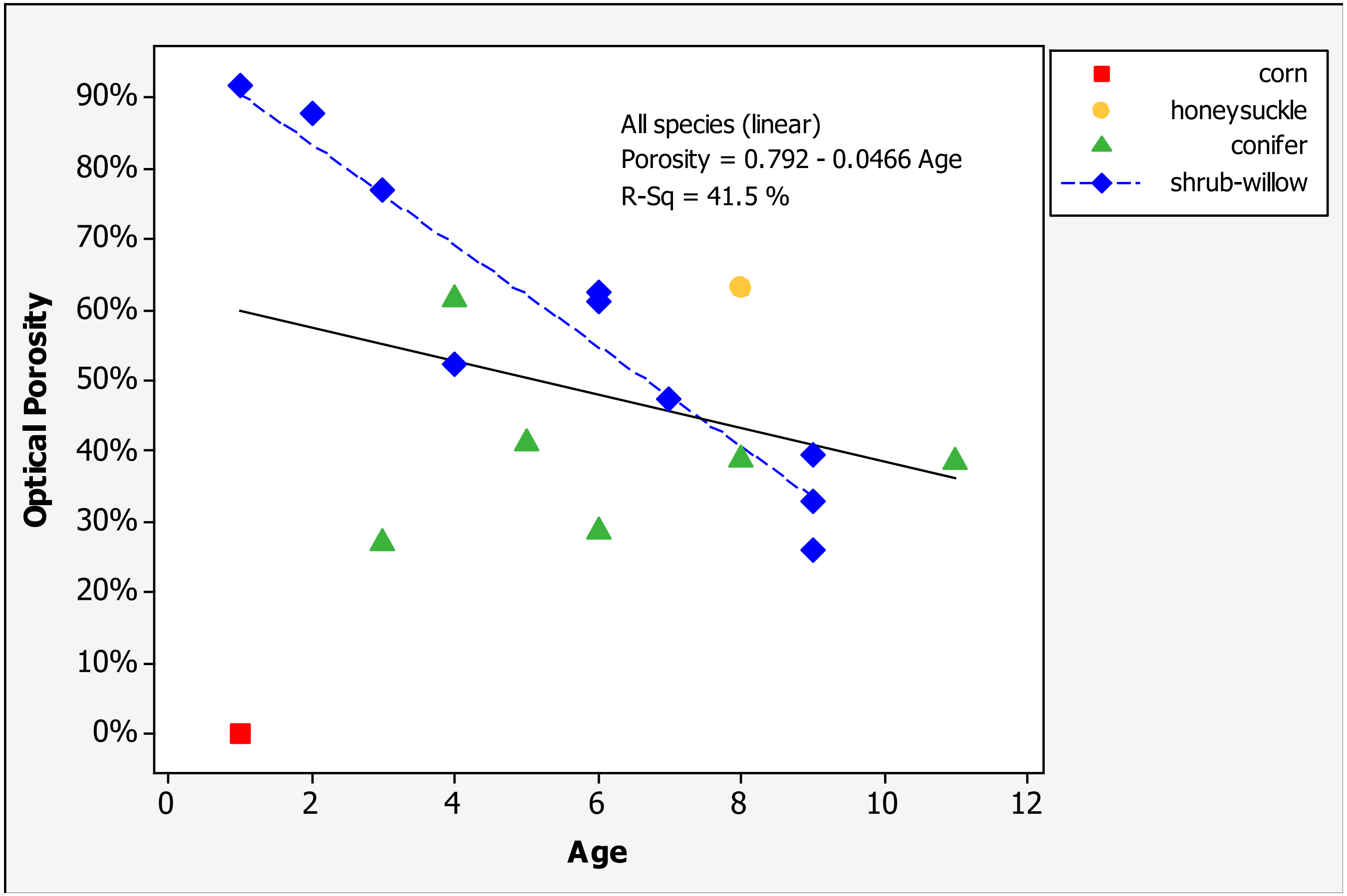


Age versus Height



- Fence height ranged from ~1 – 7 m
- Height increased linearly over time (P < 0.001)
- Shrub-willow increased at slightly faster rate than all fences

Age versus Porosity



- Porosity was between ~90% and 25%   corn was 0% (non-porous)
- Porosity decreased linearly time (P = 0.005)
- Shrub-willow decreased at a faster rate than all fences

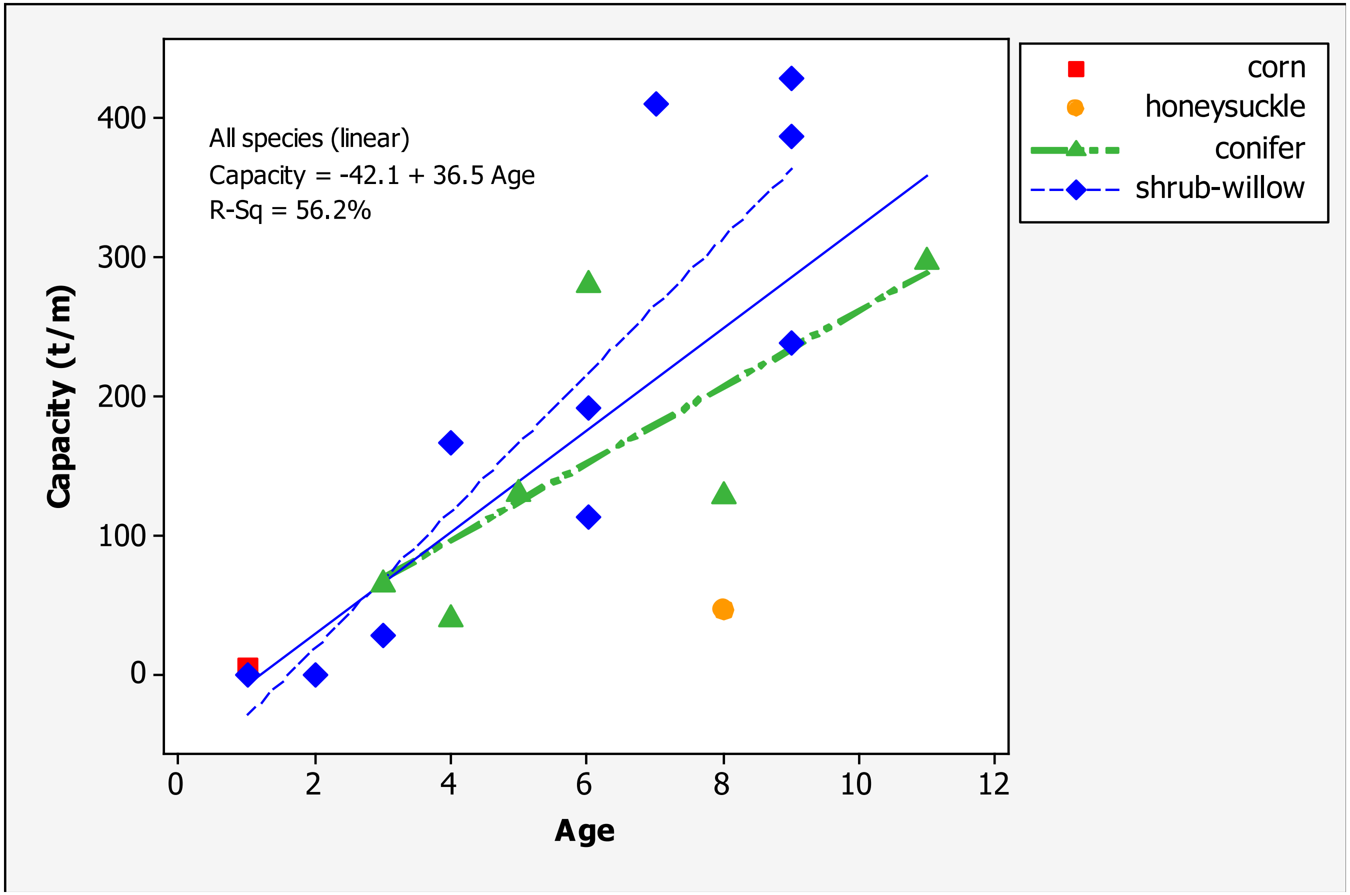
Snow Transport Model

- Snow transport ranged from 4 – 19 t/m
- Mean snow transport was 9 t/m
- Severity of blowing snow conditions [4]
  - Classified as “Very light” to “Light” across all sites

Snow Severity Classifications[4]

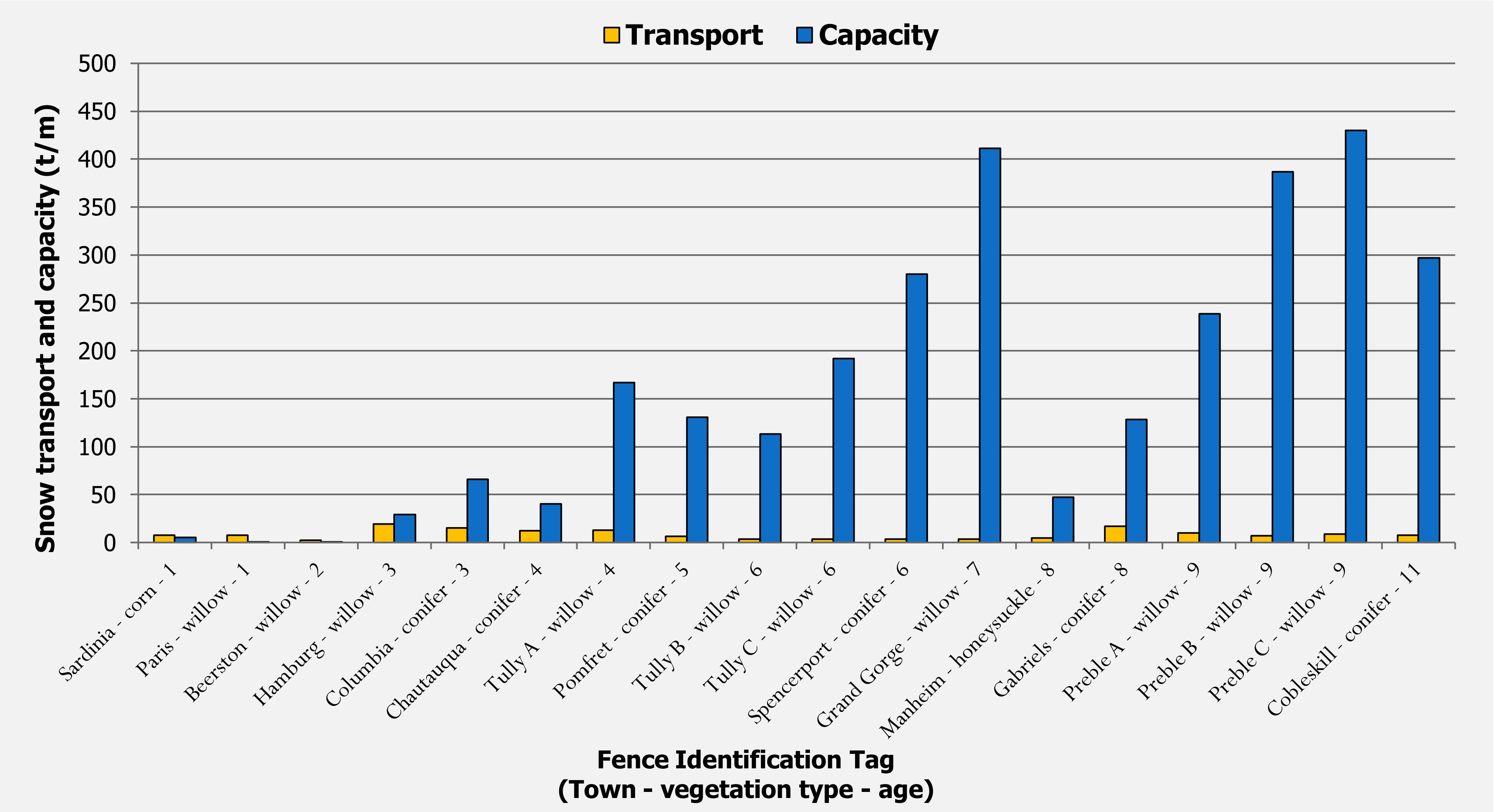
Class	Snow Transport (t/m)	Description
1	<10	Very light
2	10 – 20	Light
3	20 – 40	Light-to-moderate
4	40 – 80	Moderate
5	80 – 160	Moderately severe
6	160 – 320	Severe
7	>320	Extreme

Age versus Capacity



- Snow storage capacity ranged from 0 - 430 t/m mean 185 t/m
- Capacity increased linearly over time ($P < 0.001$)
- Shrub-willow again increased at a slightly faster rate than all fences

Capacity/Transport Ratio

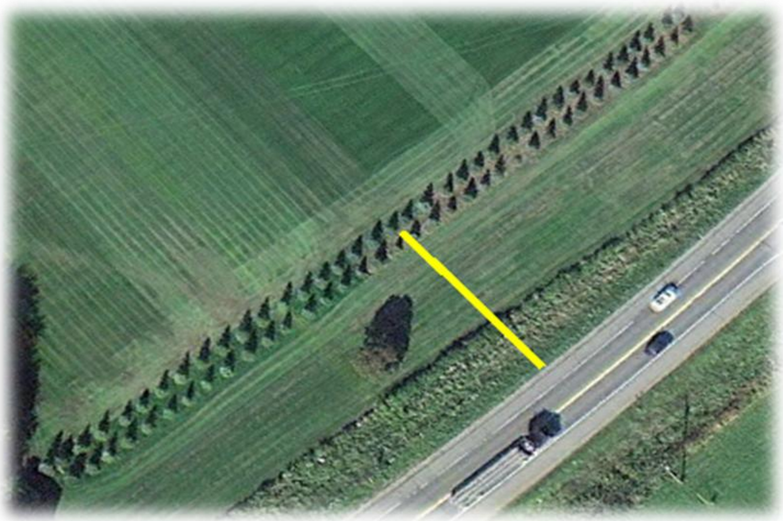


- Mean C/T ratio amongst all fences was 27:1
- All fences were fully functional (capacity>transport) by age 3
- C/T ratio between ~10:1 and 100:1 for all fences age 5 and older

Observed Setback Distance

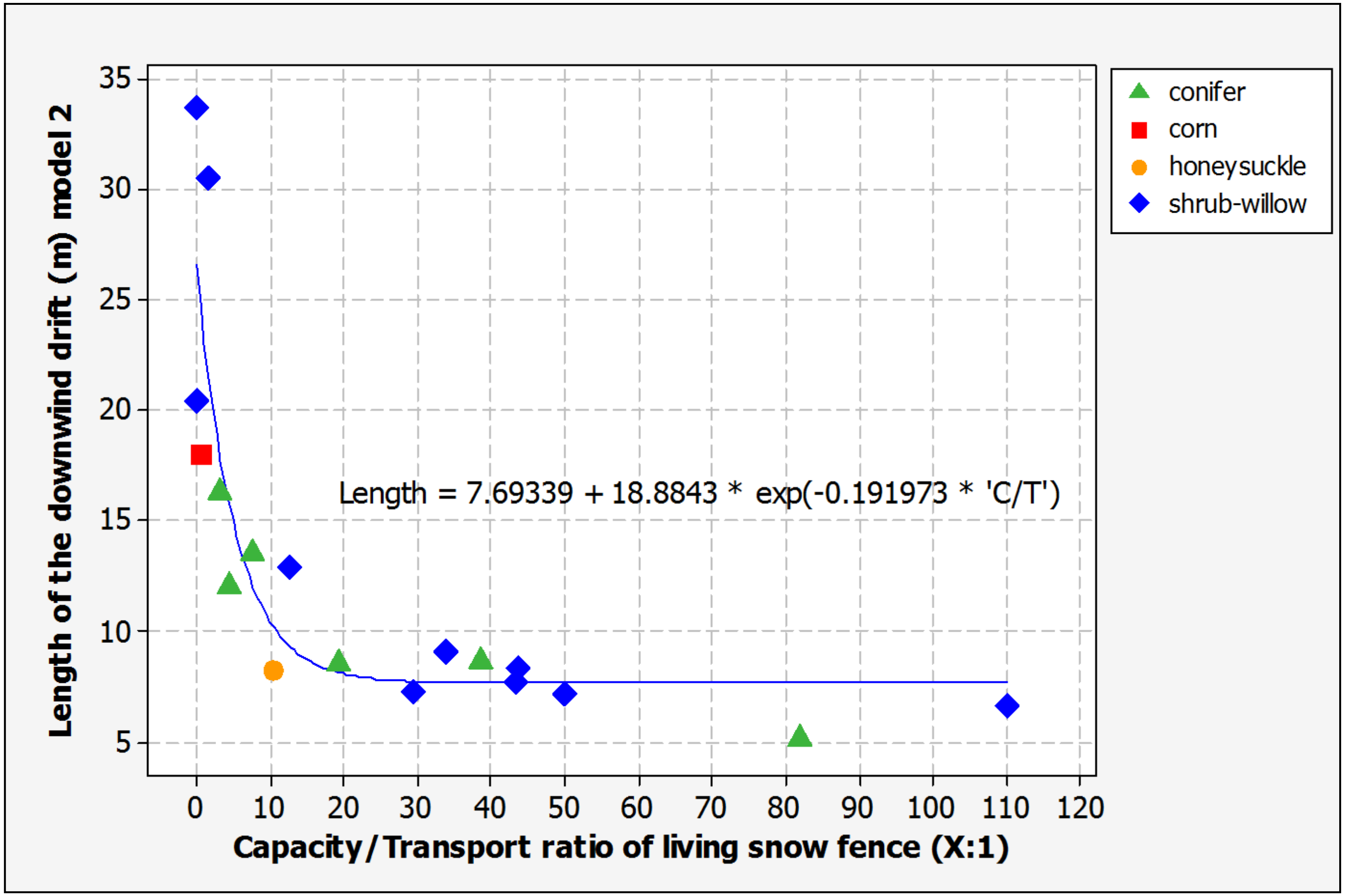
- Observed setback distance ranged from ~ 10 – 100 m mean 35 ±25 m
  - High maximum, large range, and large standard deviation in setback distances
- No significant relationship between setback and C/T ratio, nor any other predictor variables that would influence the *choice* of setback ($P > 0.417$)
- Likely influenced by site limitations, but also reflects literature which provides no standard or precise guidelines for selecting setback distance for LSF

Blue spruce setback 60 m



Blue spruce setback 30 m

Drift Model



- Significant negative relationship (P = 0.006) between C/T ratio and drift length
- Best fit to an asymptomatic curve (S = 4.037)
- Drift length rapidly decreases from 35 m - 8 m, when C/T ratio is between 0 and 15:1
- When C/T ratio exceeds 15:1, drift length is consistently less than 10 m

Discussion

Full Functionality at Early Ages

- Results of this study showed *fully functional* snow fences by age three (3)
  - (capacity was greater than the average annual transport)
- Literature states 5 - 20 years or longer for full functionality of LSF[16,24]
- Some studies indicate shrub-willows can be functional earlier[22,23] but…
  - Based on growth rates in biomass plantings, not quantified in context of LSF
- Factors contributing to the observed early functionality in current study…
  - Light transport conditions across all sites
  - <u>Shrub-willows</u>: fast growth rate and porosity exclusion
  - <u>Conifers</u>: use of large planting stock (not seedlings), multiple rows, high planting densities

Full Functionality at Early Ages

Implications of early functionality

- Less lag time for benefits, better life cycle economic performance
- Dependent on the use of best management practices for LSF[4,10,25]
  - Site preparation, plant selection, planting techniques, and weed control

Three year old Norway spruce living snow fence fully functional

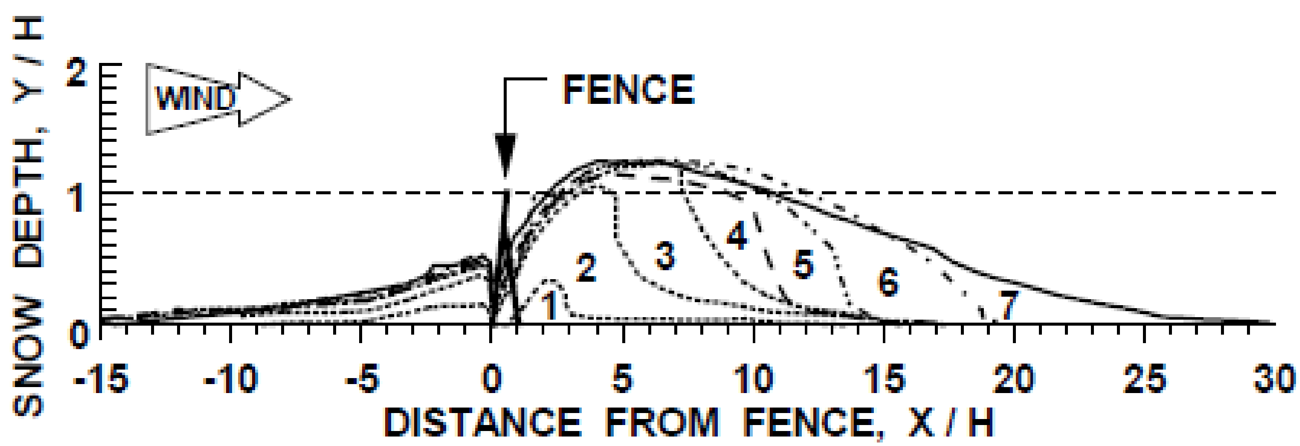
Capacity/Transport Ratio

Results showed large amounts of excess capacity at early ages

- C/T ratio between 10:1 and 100:1 for all fences age 5 and older
- Fences to add even more capacity in future years based on the observed linear growth trends, further increasing C/T ratios

Implication

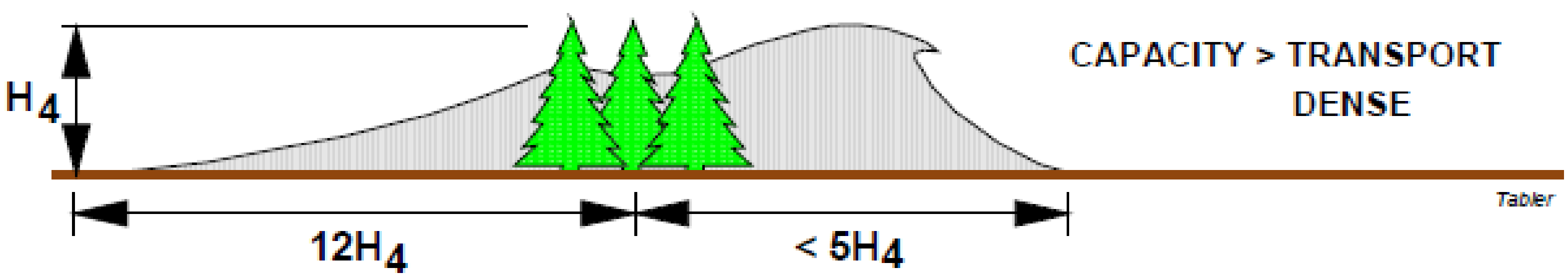
- High C/T ratios will reduce drift lengths from the maximum of 35H, and reduce the required setback distance



Drift Length Model

Drift Model Results

- Showed the expected negative response of drift length to C/T ratio
- As C/T ratio increases, drift length decreases
- Drift length is less than 10 m when C/T ratio is >15:1
- Predicted drift length was also less than the observed setback distance for 16 of the 18 fences in this study



Drift Length and Setback

Implications of shorter drift lengths

- For the conditions and fences investigated, setback distance can be *much less* than the 30 - 180 m or 35H commonly prescribed in the literature

Reduced setback distances have the potential to…

- Reduce the cost of living snow fences
- Eliminate "near snow" problems
- Allow LSF installations where ROW space is limited

If validated in future research, this finding…

- Provides a clear methodology for calculating the most appropriate setback distance for living snow fences
- Clarifies the hodgepodge of vague recommendations found in the current literature

Snow Fences by Vegetation Type

Standing Corn Fences

- Limited height growth limits functionality
- Snow load & herbaceous form also reduce height
- Annual recurring costs to purchase corn
- Likely less economically efficient than other vegetation types

Honeysuckle Fences

- Lacks some of the key plant traits for LSF
- Capacity was lower than the trend of all fences
- Bottom gap was observed in single row fence
- Likely less economically efficient than other vegetation types

Shrub-willow Fences

Benefits

- Fastest height growth and capacity increase
- Likely more cost effective than structural fences and other vegetation types[24,26]

Drawbacks

- High intensity maintenance for several years
- Long term survival may be limited by…
  - Susceptibility to pests and diseases
  - Other traits associated with pioneer species
    - Coppice potential may be a means of regeneration that can extend the life cycle of fences

A large four year old willow fence

Conifer Fences

Benefits

- More widely researched and demonstrated as living fences (shelterbelts)
- More climax species traits with longer natural lifecycles
- Rapid functionality by installing large trees and multiple rows (landscape effect)

Drawbacks

- Higher costs associated with large planting stock
- Long term space requirements of large trees may limit feasibility
- Large stem diameters are not allowed in close proximity to some roadways

Failed Snow Fences

- Fences in this study were limited to a maximum age of 11 due to a lack of older fences identified in the landscape
- Fences may have been…
  - Planted less frequently in previous years
  - Intentionally or accidentally removed over time
  - Grown together with natural vegetation
  - Poor growth and survival rates due to
    - Site conditions and/or management practices
- Some younger fences (or sections) also failed to thrive
- At least 18 healthy living snow fences in NYS, but an equal or greater number that have struggled or failed
- Biological systems in nature prone to natural and human disturbances and competition
- Success is never guaranteed…but best management practices improve the chances

Limitations and Future Research

Limitations of This Study

- Bias for fences that had best management practices and highest success
- Assumptions of snow transport quantity (relocation coefficient and fetch size)

Future Research

- Continued research and development of BMPs for living snow fences
- Repeat the methods of this study using…
  - More fences, more species, and fences older than age 11
  - Collect snow data to verify predicted values and drift lengths

Small snow drifts formed around honeysuckle living snow fence

Conclusion

Conclusion

- Indentified and investigated 18 living snow fences in the landscape across New York State
- Collected data on key structural variables at each fence
- Modeled structural data to estimate snow trapping function
- Discussed results in the context of current literature on LSF

Conclusion

- Fence capacity (via height and porosity) increased faster than previously reported
- Fences were fully functional by age three, much younger than generally reported
- Large C/T ratios create shorter drifts lengths
- Fences can likely be installed much closer to the roadway than the setback distances observed in the field, and what is commonly recommended in the literature

References

1 - Lashmet (2013) Snow and ice control in New York State. Presentation from Lake George Park Commission Forum, April, 2013. New York State Department of Transportation, Office of Transportation Maintenance, Albany

2 - NCHRP National Cooperative Highway Research Program (2005) NCHRP Synthesis 344 Winter Highway Operations. Transportation Research Board, Washington D.C.

3 - Daigneault W, Betters, DR (2000) A comparison of the economic efficiency of living and artificial snow fence designs for road protection. West J of App For 15:70-74

4 - Tabler RD (2003) Controlling blowing and drifting snow with snow fences and road design. National Cooperative Highway Research Program Project 20-7(147). Tabler and Associates, Niwot

5- Tabler RD and Meena JA (2006) Effects of snow fences on crashes and road closures: a 34-year study on Wyoming interstate-80. Cold Regions Engineering 2006: 1-10

6 - NYSDOT New York State Department of Transportation (2010a) Average accident costs/severity distribution state highways 2010. New York State Department of Transportation, Safety Information Management System, Albany

7 - USDOT U.S. Department of Transportation (2003) Revised Departmental Guidance: Valuation of Travel Time in Economic Analysis. U.S. Department of Transportation, Office of the Secretary of Transportation, Washington D.C.

8 - Goodwin LC (2003) Best practices for road weather management. Mitretek Systems Inc, Falls Church

9 - Heavey JP and Volk TA (2013a) Cost-Benefit Model for Living Snow Fences in New York State. State University of New York College of Environmental Science and Forestry, Syracuse

10 - Gullickson D, Josiah SJ, Flynn P (1999) Catching the snow with living snow fences. University of Minnesota Extension Service, St. Paul

11 - NRCS Natural Resources Conservation Service (2012) Working Trees Fact Sheet Series. Natural Resources Conservation Service, USDA National Agroforestry Center, Lincoln

12 - Streed E and Walton J (2001) Producing marketable products from living snow fences. University of Minnesota Extension, St. Paul

13 - Tabler RD (2000) Climatalogic analysis for snow mitigation in New York State: final report. Tabler and Associates, Niwot

14 - Shaw DL (1988) The design and use of living snow fences in North America. Ag, Ecoyst, and Env 22/23: 351-362

15 - Blanken PD (2009) Designing a Living Snow Fence for Snow Drift Control. Arctic, Antarctic, and Alpine Research 41:418-425

16 - USDA United State Department of Agriculture (2011) Living snow fence: an agroforestry practice. USDA National Agroforestry Center, Lincoln

17 - Cornell Cooperative Extension (2011) Home grown facts: living snow fences. Cornell Cooperative Extension, Oneida County

18 - Colorado State University Extension (2013) Small acreage management: windbreaks and living snow fences. Colorado State University Extension, Fort Collins

19 - NYSDOT New York State Department of Transportation (2012) Living snow fences: design basics. New York State Department of Transportation, Albany

20 – South Dakota Department of Agriculture (2004) The living snow fence program in South Dakota. South Dakota Department of Ag, Prince

21- Bratton TL (2006) Living snow fences in Kansas. Kansas Forest Service, Manhatten

22 - Volk TA, Abrahamson LP, Nowak CA, Smart LB, Tharakan PJ, and White EH (2006) The development of short-rotation willow in the northeastern United States for bionergy and biproducts, agroforestry and phytoremediation. Biomass and Bioenergy 30:715:727

23 - Kusovkina YA and Volk TA (2009) The characterization of willow (*Salix L.*) varieties for use in ecological engineering applications: Co-ordination of structure, function and autecology. Eco Eng 35:1178–1189

24 - Powell KC, Reed L, Lanning D, and Perko (1992) The use of trees and shrubs for control of blowing snow in select locations along Wyoming highways. Federal Highway Administration Report No. FHWA-92-WY- 001.

25 - Heavey JP and Volk TA (2013b) Living Snow Fence Fact Sheet Series. State University of New York College of Environmental Science and Forestry, Syracuse

26 - Heavey JP and Volk TA (2013a) Cost-Benefit Model for Living Snow Fences in New York State. State University of New York College of Environmental Science and Forestry, Syracuse

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Willow Project at SUNY ESF: 4, 7b

New York State Department of Transportation 6b, 7a

Tabler (2003): 6a, 10, 11, 31, 40, 41, 42

Google Earth:15, 34a, 34b,

Questions