Terrestrial Liming Guidebook for South Western Nova Scotia

NOVA SCOTIA

Bluenose Coastal Action Foundation

NSERC CRSNG

Hydrology Research Group
Dalhousie University

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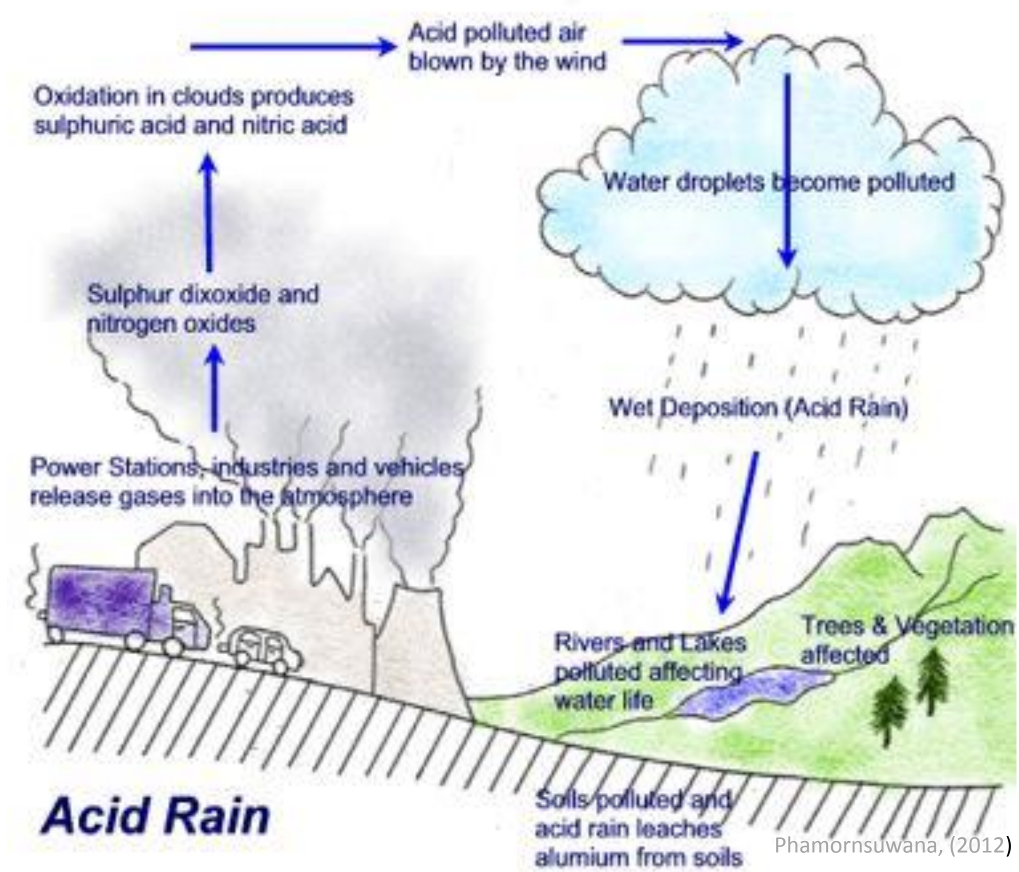
FRESHWATER ACIDIFICATION IN SWNS

Despite reductions in emissions in the early 1990's and the subsequent decrease in acid deposition, water quality has not showed a strong improvement[1,2] and is not predicted to recover naturally for 40 to 50 years[3].

Chronic freshwater acidification in SWNS is due to a combination of the following[3,5]:

1. Fossil fuel emissions from central North America causing acid deposition,
2. Poor buffering, or Acid Neutralization Capacity (ANC), of the local bedrock and soils,
3. Organic acid inputs from abundant wetlands,
4. Acidifying sea salt inputs, and
5. Acid inputs from Acid Rock Drainage (ARD) where the Halifax Formation bedrock is exposed to air or water.



Phamornsuwana, (2012)

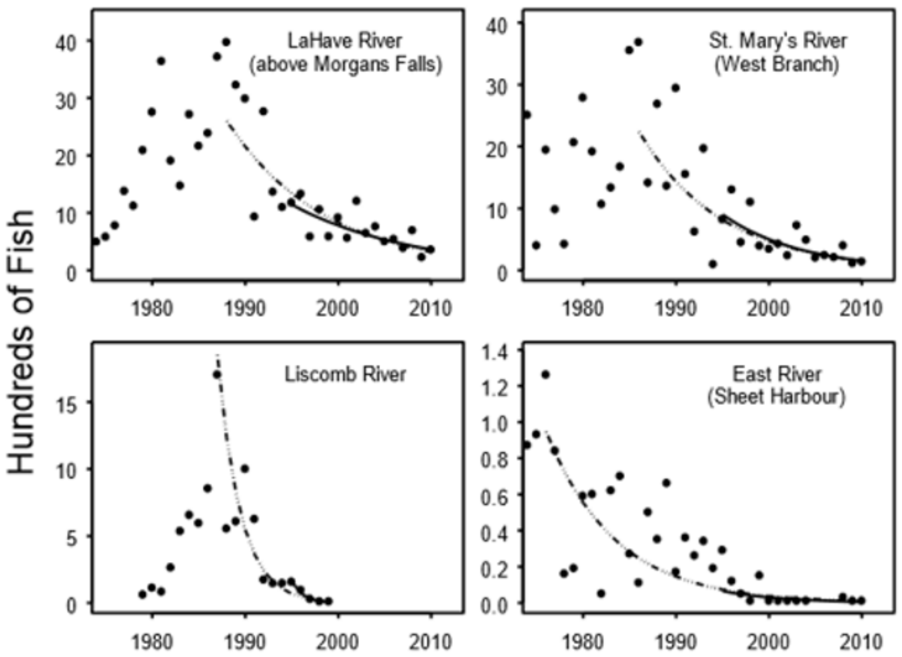
EFFECTS OF ACIDIFICATION IN SWNS

Acidification reduces aquatic and terrestrial productivity by decreasing pH and key nutrients and increasing metal mobilization.

Acidification is a major threat threat to the Southern Upland (SU) Atlantic salmon which were evaluated as “Endangered” by the Committee on the Status of Endangered Wildlife In Canada (COSEWIC) in 2010[5], and are under review to be listed under the Canadian Species at Risk Act (SARA).The SU Atlantic salmon abundance has declined from 88% to 99% since the 1980’s[4] and river specific extirpation has occurred in 13 highly acidified rivers in SWNS.

Salmon population declines will continue without improvements in water quality[3].

SU salmon declines in four indicator rivers in SWNS[4]



MITIGATING ACIDIFICATION

Liming, the addition of buffering material to soils or freshwater, is the only long term mitigation method for acidification[6, 7]. The addition of buffering material, in particular calcium, offsets the acidic inputs and improves water quality.

Two common liming methods used to improve water quality in rivers are:

1. **In-stream liming**: the addition of buffering material directly to river waters, and

2. **Terrestrial liming**: the addition of buffering material to the soils.
   1. Hand application
   2. Aerial application
   3. Ditch liming
   4. Truck application

In-stream liming using Lime doser, West River, SWNS

Lime delivery for terrestrial liming, Gold River, SWNS[4]

WATER QUALITY TARGETS

The water quality targets for terrestrial liming in SWNS, with the objective of reducing threats to Atlantic salmon, are[5]:

- **pH above 5.5, and above to 6.0 if liming efforts are focused on riparian zones or are conducted in areas where high aluminum (Al) is a concern**
- **Calcium (Ca^{2+}) levels above 2 mg L^{-1} , and**
- **Ionic Aluminum (Al_i) concentration below 15 mg·L^{-1}.**

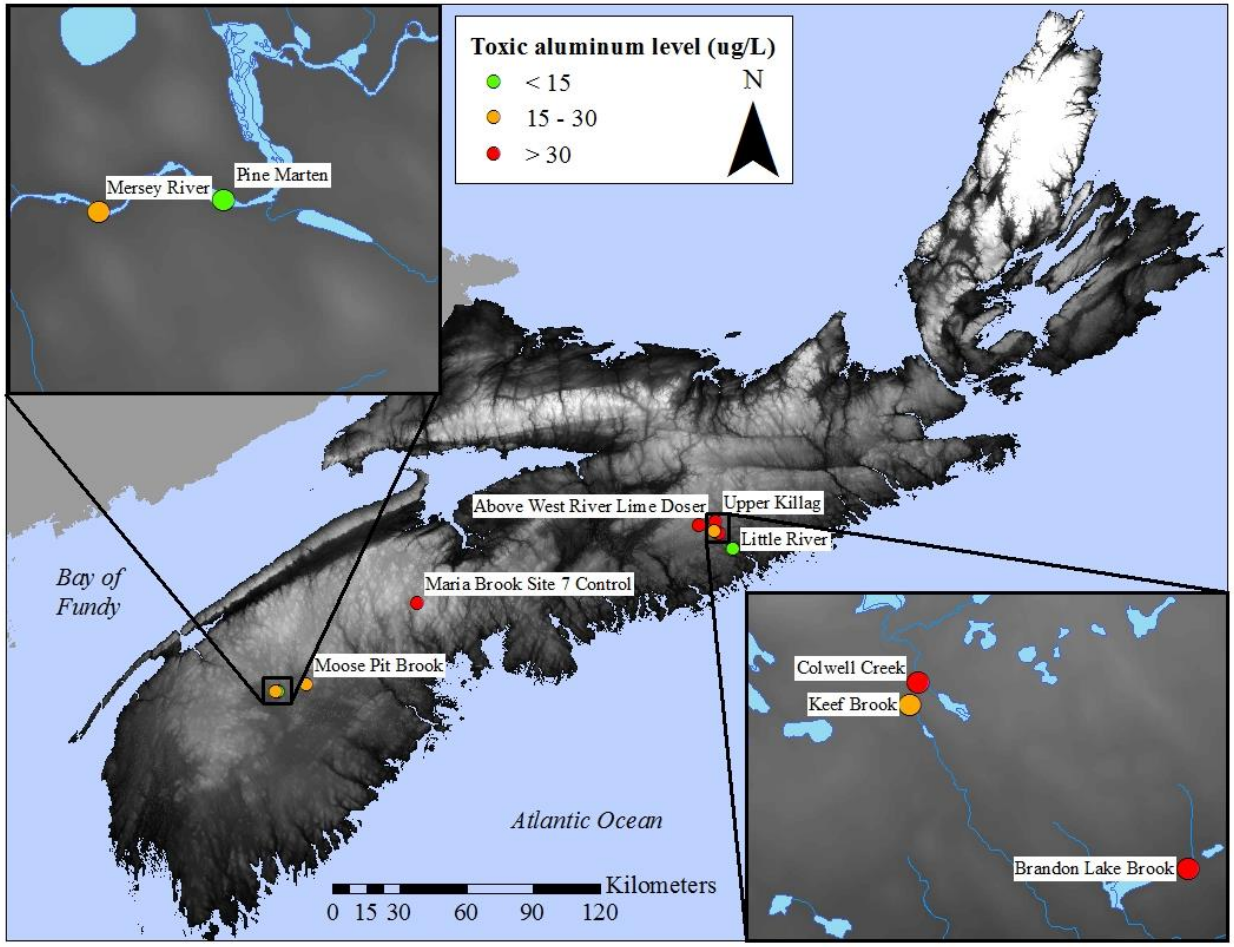
Terrestrial liming projects in SWNS should aim to meet the water quality targets[5] as it will:

- **increase aquatic productivity,**
- **improve Atlantic salmon habitat, and**
- **reduce the probability of salmon extirpation.**

Water Quality Targets:
TOXIC ALUMINUM CONCERNS

The Dalhousie Hydrology Research Group (DHRG) has conducted a water quality survey across Nova Scotia, and found that Al_i concentration was above the target level across the province.

- Average toxic aluminum (Al_i) level exceeded the maximum level of 15 $\mu g \cdot L^{-1}$ for 80% (n = 10) of the sites surveyed between April 2015 and September 2017.
- Average Al_i levels ranged from 13 $\mu g \cdot L^{-1}$ to 60 $\mu g \cdot L^{-1}$: quadruple the recommended water quality target.



TERRESTRIAL LIMING IN SWNS

Terrestrial liming in SWNS is considered more viable in the long term as:

1. It requires less maintenance compared to instream liming,
2. Water quality improvements can last decades without reapplication[8], and
3. It targets toxic metal leaching at the source within the soils.

An effective terrestrial liming project requires:

- Choosing the right location:
  - that is likely to generate the target water quality changes, and
  - that is connected to important Atlantic salmon habitat.
- Choosing the right application method:
  - that considers the physical attributes of the catchment, key water quality parameters and the budget of the project,
  - that uses the correct dose and buffering agent, and
  - that is timed to coincide with maximum likelihood of liming agent getting into the soils.

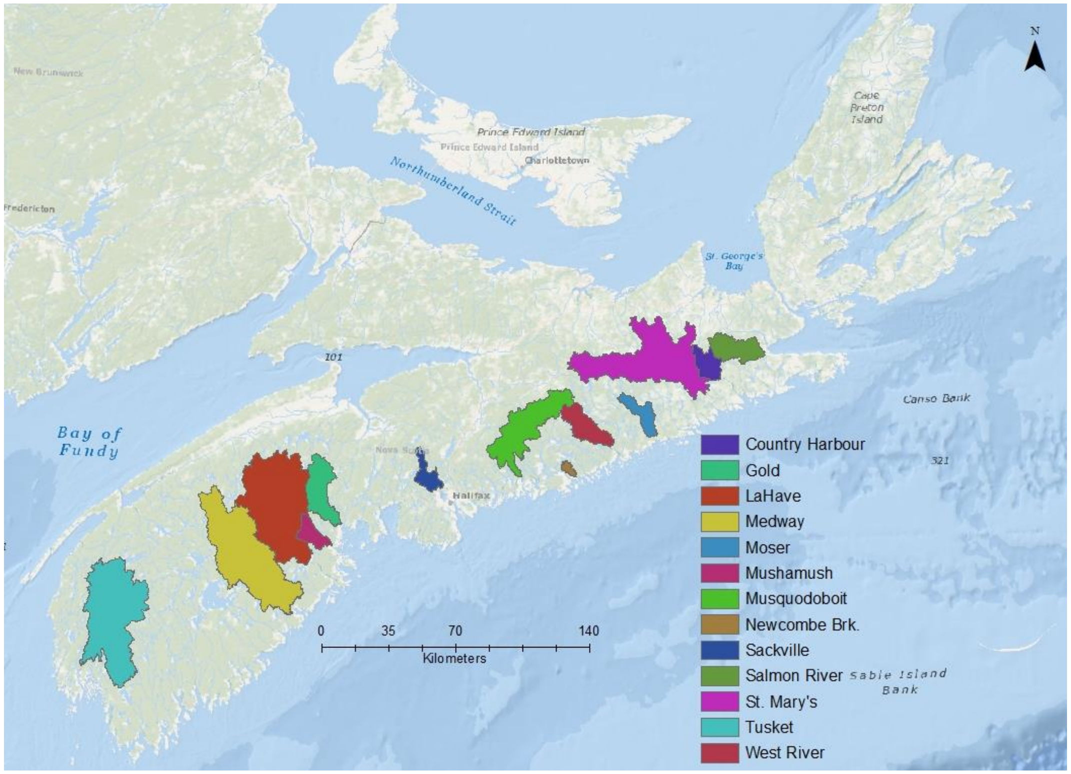
This Guidebook was developed to inform future mitigation and recovery strategies for Atlantic salmon and support effective terrestrial liming in SWNS.

CATCHMENT SELECTION:
PRIORITY SU SALMON WATERSHEDS

The Southern Upland Collaborative Projects Working Group identified 13 priority watersheds to identify areas to focus mitigation and recovery strategies for the SU salmon in SWNS[5].

The priority watersheds were selected because:

1. Salmon population consisting of a wild native strain of salmon,
2. Salmon are present in the river,
3. The river has a mean annual pH > 5.1,
4. There is an active group to promote work and collaboration, and
5. The river is relatively large with respect to rearing habitat.



CATCHMENT SELECTION:
KEY CONSIDERATIONS

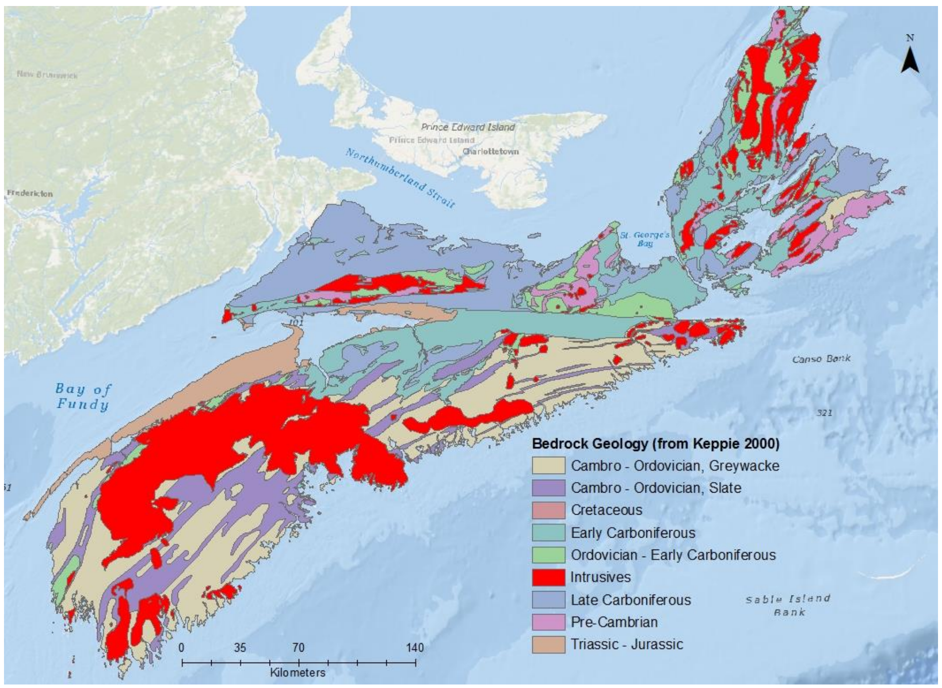
Effective terrestrial liming requires careful selection of a catchment that supports effective terrestrial liming and the target population[9]. It is important to ground truth the catchment during the planning stage to ensure that the catchment is hydrologically correct. The Catchment Selection Model should be used to assess the key parameters for effective terrestrial liming *(see next pages)*.

Consideration	Index	Description
Target population	Species range, presence	Target population must be found within catchment.
Size of catchment	Critical habitat size	Catchment should contain a large amount of critical habitat for the population.
Acidification status	pH, alkalinity, ANC	Catchment is acidified but not too acidified (pH between 4.0 and 5.5).
Geologic conditions	Bedrock and surficial geology	Bedrock type and surficial geology should support effective liming
Invasive Species	Species range, presence	Catchments with invasive species competing with target population avoided.
Permission to lime	Land ownership	Avoid catchments with multiple private landowners; preference given to crown land.
At Risk or Endangered species	Survey for At Risk or Endangered species	Avoid or alter application methods within catchments containing at risk or endangered species.

CATCHMENT SELECTION:
PREFERRED BEDROCK

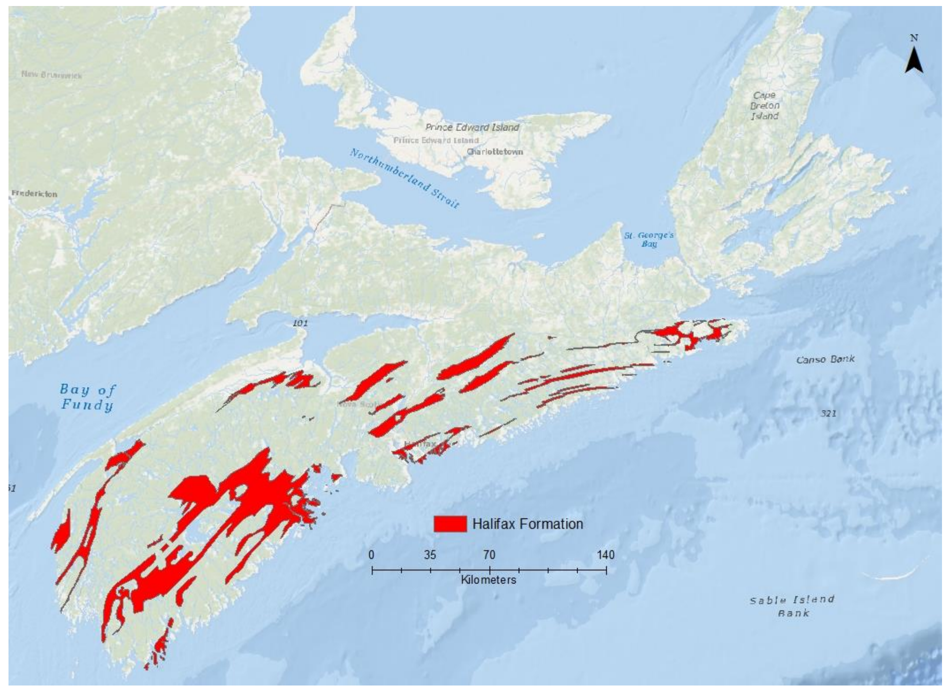
The catchment should be underlain by bedrock that supports effective liming and low environmental impact with liming. Two bedrock types should be avoided: Intrusives and the Halifax Formation.

Intrusives



Careful of high doses applied to intrusive bedrock as it may cause uranium contamination.

The Halifax Formation



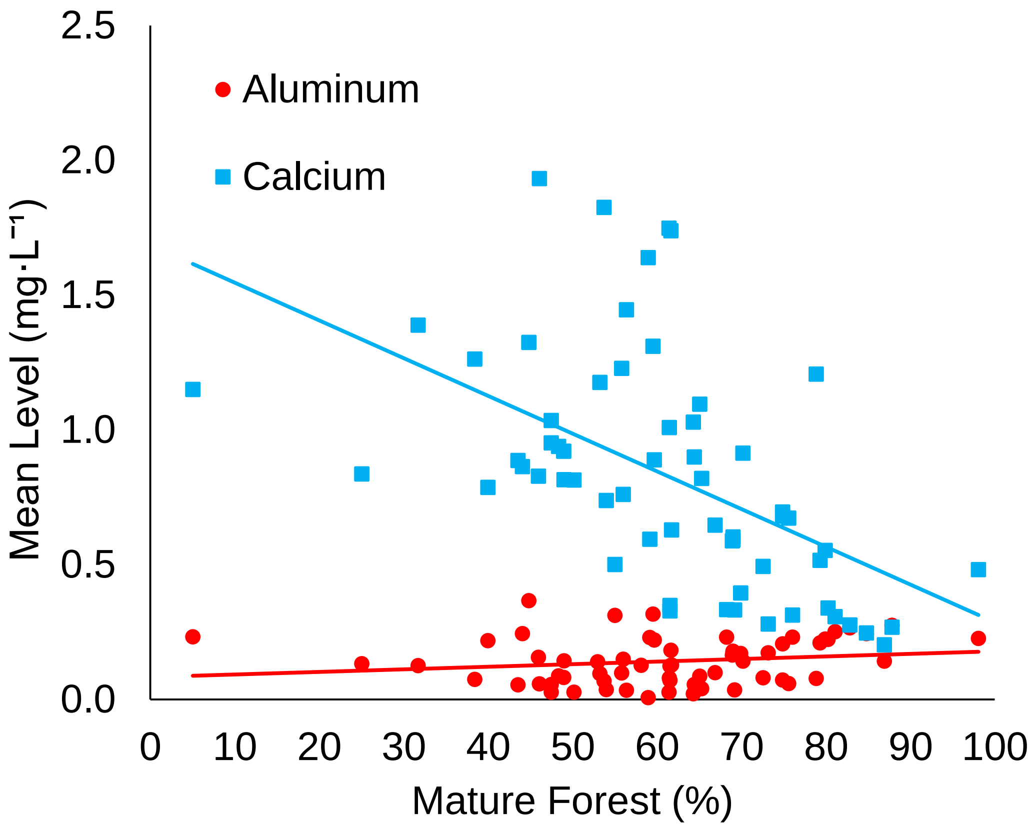
Avoid liming catchments underlain by the Halifax Formation as Acid Rock Drainage (ARD) may occur if the bedrock is exposed to air or water.

CATCHMENT SELECTION:
PREDICTING AL AND CA LEVELS

Catchment liming should be targeted toward watersheds with high aluminum-, and low calcium levels. These water quality parameters can be predicted by examining land cover, and water chemistry levels and trends.

- Higher aluminum levels tend to be found in watersheds which have:
  - A high percent area of wetlands
  - A high percent area of mature forest stands
  - A high concentration of dissolved organic carbon
  - A decreasing pH trend, and
  - An increasing aluminum trend.

- Low levels of calcium trend to be found in watersheds with:
  - A high percent area of mature forest stands
  - A decreasing pH trend, and
  - An increasing aluminum trend.



Al levels tend to increase with increased mature forest percent cover, while Ca levels tend to decrease.

CATCHMENT SELECTION:
MODEL TO SUPPORT INFORMED SELECTION

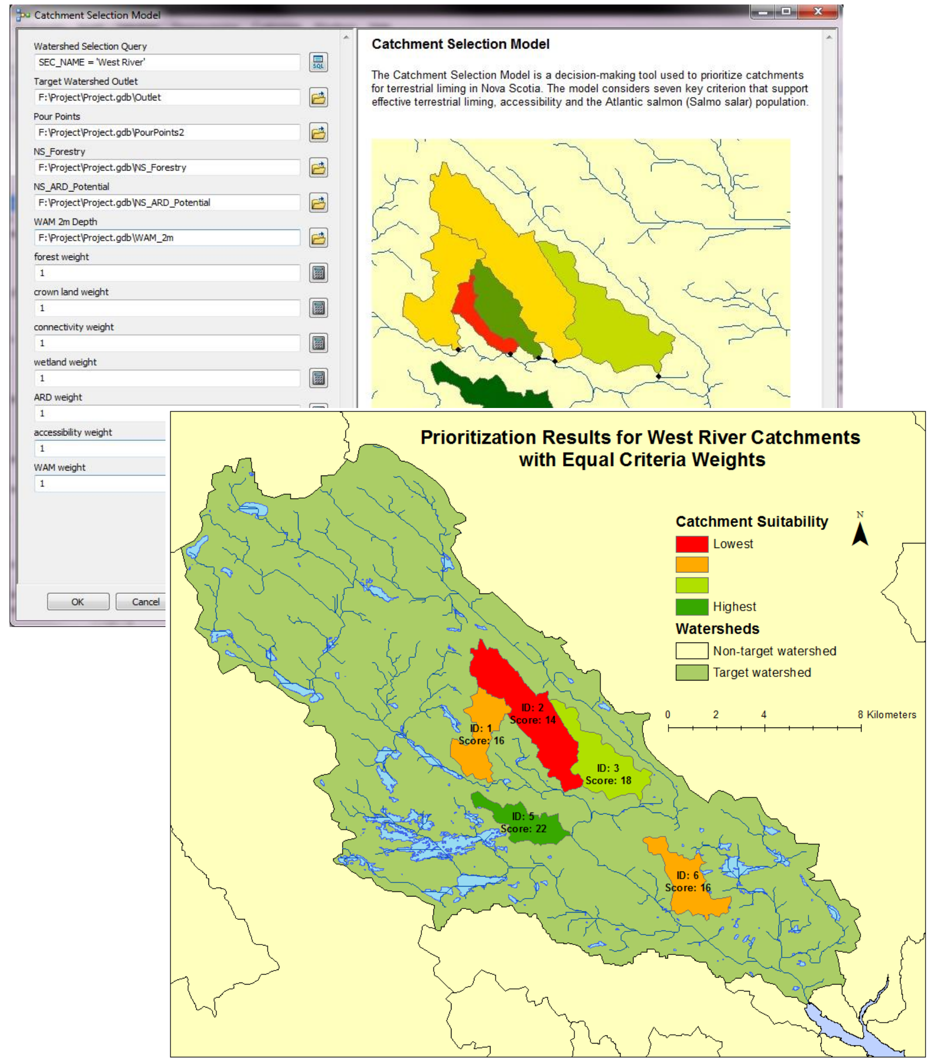
The Catchment Selection Model prioritizes catchments for terrestrial liming that best support:

- effective terrestrial liming,
- Atlantic salmon populations, and
- accessibility for monitoring.

The model is available through the Coastal Action and is simple to use and can be easily modified with additional or more up-to-date information.

ArcMap 10.2.2 (or higher) with ArcGIS Spatial Analyst Extension is required.

Included with the model is a geodatabase containing all datasets required to run the model and a comprehensive user-guide.



APPLICATION METHODS:
AERIAL VS GROUND

There are two main application methods used for terrestrial liming: aerial application, the application of buffering material by helicopter or plane, and ground application, the hand dispersal of buffering material.

COMPARISON OF AERIAL AND GROUND APPLICATION METHODS		
AERIAL	Advantage	Disadvantage
	Requires little manual labor	Expensive
	Easy access to remote areas	Problems with drift
	Faster with less risk of clumping	
GROUND	Advantage	Disadvantage
	Less expensive	Hard manual labor; involves heavy lifting and may involve the creation of trail system
	Ability to accurately apply material to designated areas	Requires accessibility throughout the catchment; greater negative impact on forest ecosystem
		Hand application is difficult to spread evenly; buffering material can clump and solidify.

Aerial application within the West River Sheet Harbour watershed, Nova Scotia.

Ground application within the Gold River, SWNS[4]

APPLICATION METHODS:
WETLAND VS. WHOLE

There are two terrestrial liming application methods: wetland liming, mega-dosing the wetland area of a catchment, and whole catchment liming, applying buffering material to the entire catchment area. The table below summarizes the advantages and disadvantages of both methods.

COMPARISON OF WETLAND AND WHOLE CATCHMENT LIMING APPLICATION METHODS		
WETLAND LIMING*	Advantage	Disadvantage
	Inexpensive and easier application	Mega-dosing wetlands may cause adverse effect on sensitive wetland flora species
	More immediate improvements	Does not target aluminium toxicity at the source within the soils
WHOLE CATCHMENT LIMING	Advantage	Disadvantage
	Longer lasting water quality improvements	Expensive or work intensive application using helicopter or hand dispersal methods, respectively.
	Targets aluminium toxicity at the source within the soils	Avoids mega-dosing wetlands, better preserving sensitive species

**We suggest using a Wet Area Mapping (WAM) of <2m or <5m to delineate wetlands where surface water is more likely to be in contact with the buffering agent for a longer period of time.*

MATERIAL AND DOSE:
EQUIVALENTS TABLE

The type of material and buffering capacity used to terrestrial lime impacts the effectiveness of the liming. For SWNS powdered limestone is suggested as it is readily available and less costly then other products.

Buffering equivalent table from Olem (1991)

Common name	Formula	Theoretical buffering equivalent (%)
Limestone	$CaCO_3$	100
Wollastonite*	$CaSiO_3$	n/a
Dolomite	CaCO3-MgCO3	109
Sodium carbonate	Na_2CO_3	94
Sodium bicarbonate	$NaHCO_3$	119
Calcined lime	CaO	179
Calcined dolomite	CaO-MgO	207
Hydrated lime	$Ca(OH)_2$	135
Dolomitic hydrate	$Ca(OH)_2$-MgO	175
Pressure dolomitic hydrate	$Ca(OH)_2$-$Mg(OH)_2$	151
Caustic soda	NaOH	125

**has a CO_2 capturing effect*[15]

MATERIAL AND DOSE:
GRAIN SIZE

The grain size of the buffering material effects the activation time, the duration of improvements and the equipment used for application. Most liming projects in NS have used fine powdered limestone, however there has been an issue with clumping during hand application. If hand application is being used to apply powdered limestone, we suggest applying during dry weather to avoid excessive clumping. A coarse gravel grain size of 2.5mm is required for ditch liming methods.

COMPARISON OF GRAIN SIZE		
FINE (e.g. powdered)	Advantage	Disadvantage
	Quick the activation with more immediate improvements	High probability of clumping during hand application.
	Does not require advanced equipment for application	The duration of improvements may be shorter
COARSE (e.g. pellets)	Can be tailored to site needs	Requires more advanced equipment for application
	The duration of improvements may be longer	Slower activation with less immediate improvements

MATERIAL AND DOSE:
APPLICATION RATE

The greater the whole application rate and percent of catchment limed, the greater the probability of effective terrestrial liming

Updated graph from Brown (1988)

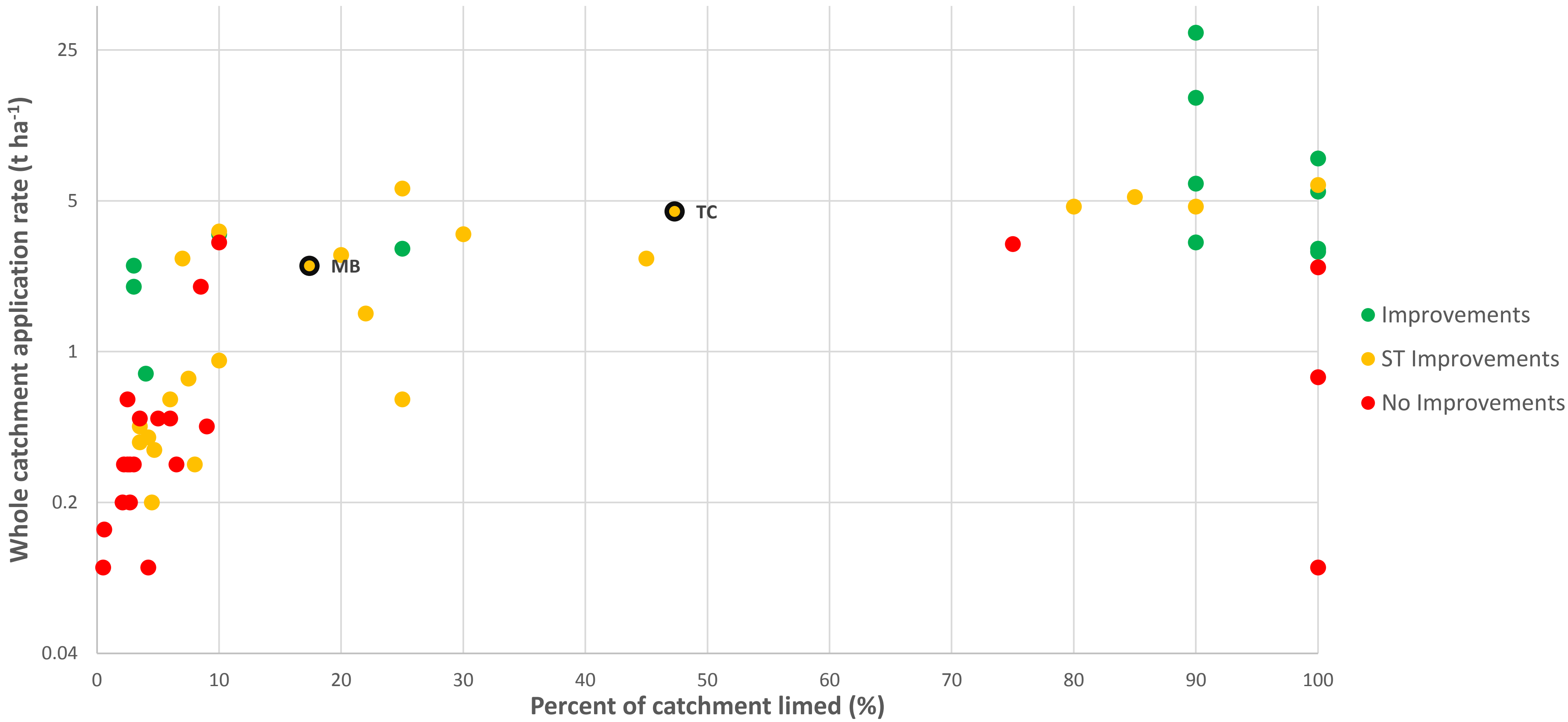


Figure 1. Whole catchment application rate, percent of catchment limed and status of water quality improvements of terrestrial liming studies across the world. Includes results of the Maria Brook (MB) and Ted Creek (TC) experimental liming projects in the Gold River Watershed, SWNS

MATERIAL AND DOSE:
APPLICATION RATE

The greater the local application rate and percent of catchment limed, the greater the probability of effective terrestrial liming

Updated graph from Brown (1988)

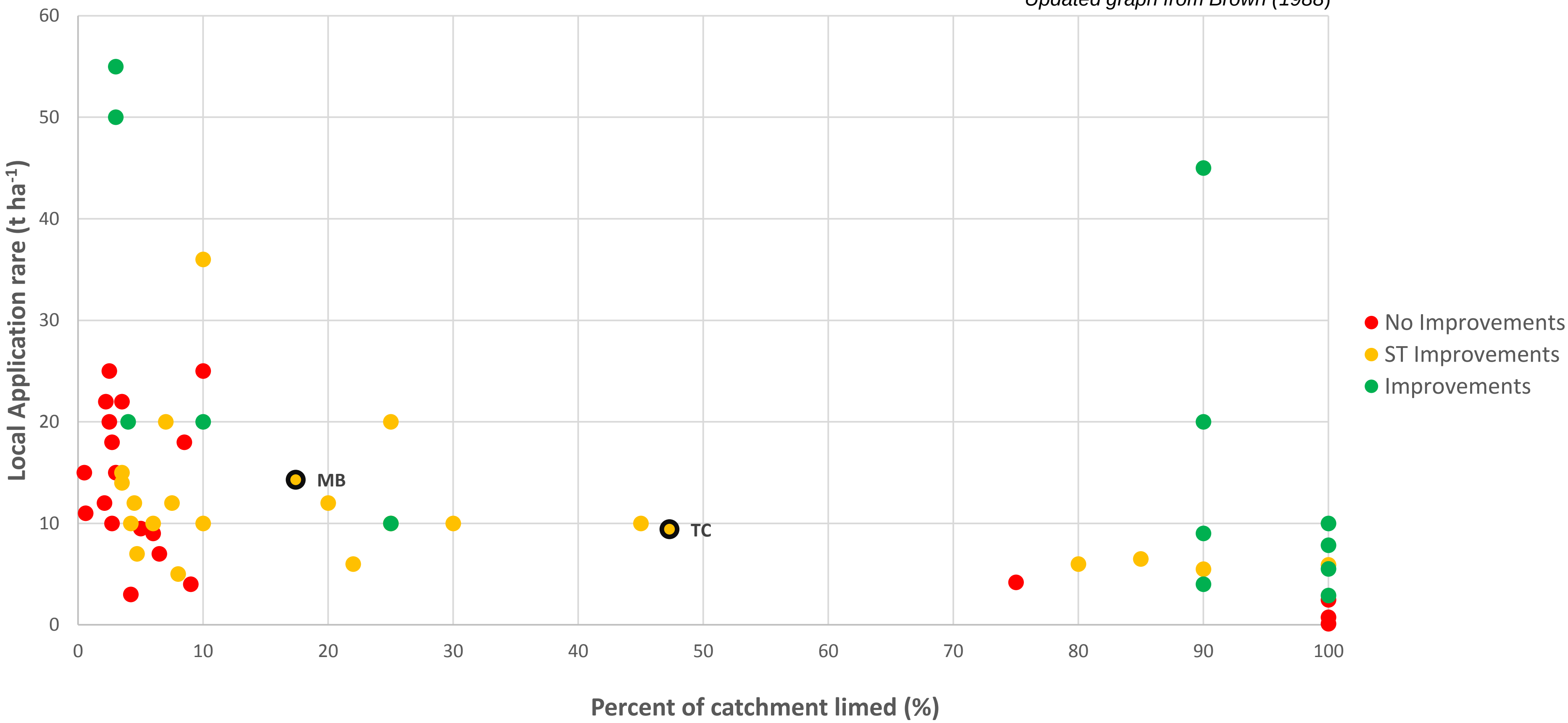


Figure 2. Local application rate, percent of catchment limed and status of water quality improvements of terrestrial liming studies across the world. Includes results of the Maria Brook (MB) and Ted Creek (TC) experimental liming projects in the Gold River Watershed, SWNS

MATERIAL AND DOSE:
APPLICATION SUGGESTION

Application rates are uncertain given the range of results and the uniqueness of each catchment. We recommend a trail application on a small test area with monitoring to adjust for local conditions.

Considering the uncertainty, the application rate suggestion for terrestrial liming in SWNS based on figures 1 and 2 are:

Local application of 10 $t \cdot ha^{-1}$ at a minimum 25% of catchment with aerial application and more if hand application is used.

The majority of studies used aerial liming application methods.

Experienced gained in Maria Brook and Ted Creek suggests that clumping of powdered limestone on the ground was unavoidable during hand application and led to a reduction in the effectiveness of liming.

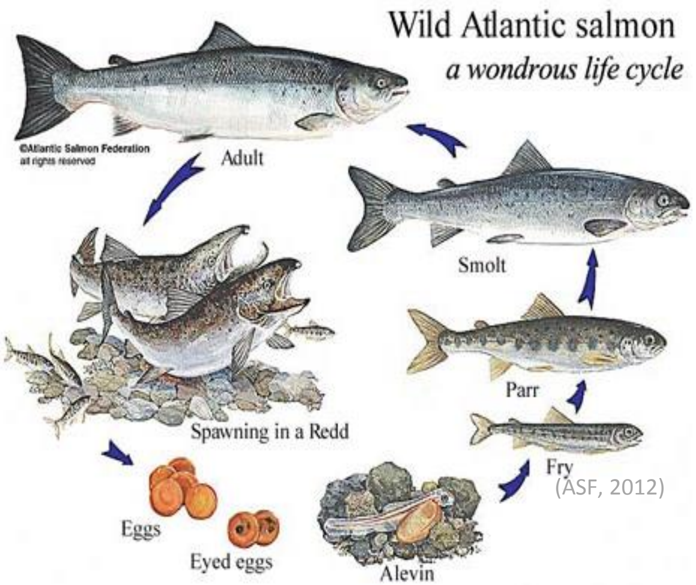
(MTRI, 2014)

APPLICATION TIME:
CRITICAL TIMING

It is important to time the liming application in that it best supports integration of buffering agent into the soils.

Key considerations when determining the right time to lime:

1. Not during winter months or early spring run-off when soils are frozen and/or snow on the ground.
2. The suggested season to lime is late summer or early fall.
3. Consider the effects of season leaf fall for example helicopter liming may be easier once the leaves have fallen from the trees for improved visibility.



(ASF, 2012)

CASE STUDY FOR SWNS:
TERRESTRIAL LIMING IN THE GOLD RIVER WATERSHED

Two terrestrial liming experiments were conducted in the Gold River watershed.

Maria Brook Project

Application	Date of Application	Amount of Limestone in tonnes (t)	Local application rate	Equivalent Whole catchment rate
1	June 2012	27 t	13.1 t/ha for 2.08 ha or 4.4 % of catchment	0.58 t/ha
2	June 2013	60 t	16.13 t/ha for 3.72 ha or 7.9% of catchment	1.28 t/ha
3	June 2014	30 t	12.79 t/ha for 2.36 ha or 5% of catchment	0.64 t/ha
TOTAL	2012 to 2014	117 t	14.3 t/ha for 8.16 ha or 17.4% of catchment	2.5 t/ha

Ted Creek Project

Application	Date of Application	Amount of Limestone in tonnes (t)	Local application rate	Equivalent Whole catchment rate
1	June 2012	27 t	13.1 t/ha for 2.08 ha or 4.4 % of catchment	0.58 t/ha

Short term improvements in water quality were observed at both sites with increased pH, calcium and decreased levels of aluminium. However the improvements are unclear as the trends were not consistent and did not persist long term; the data continues to be analyzed. The likely cause of the reduced effectiveness is the extensive clumping of powdered limestone on the surface. In October 2016 helicopter application methods will be used at a new experimental terrestrial liming project in West River Sheet Harbour and is hoped to adhere more positive results.

MONITORING

Monitoring before, during and after liming is important to understand the effect of terrestrial liming on water quality. Monitoring can help indicate when reapplication of buffering material is needed.

Grab samples are samples taken directly from the water and should be filtered in the field, kept at 4 °C and analyzed within 48 hours. In-situ measurements are measured directly in the field without further lab analysis.

Measurement	Method	Pre-	During	Post-	Notes
pH	in-situ	√	√	√	Measure of acidification. Requires temperature measurement as well. Target pH level of 6.0 for aquatic health[5]
Metals	Grab	√	√	√	Measure of metal ions (e.g. aluminum and iron). Target is to decrease metal ion concentrations.
Major ions	Grab*	√	√	√	Measure of major ions (e.g. Calcium and Potassium). Target is to increase major ion concentrations; indicator of aquatic health.
Dissolved organic Carbon (DOC)	Grab and/or in-situ	√	√	√	Measure of the amount of organics in the water. Influences amount of metals in water; indicator of aquatic health.
Ionic aluminum (Ali)*	Grab, with speciation in-situ	√	√*	√*	Measure of toxic form of aluminum (Ali). Target is to decrease Ali concentrations below 15 ug/L[12]. If the pre-liming analysis does not show toxic levels of Ali, then continue sampling at lower frequency. Contact Coastal Action for freshwater aluminum sampling information sheet.
Aquatic biota sampling	In-situ	√		√	The biodiversity and abundance of aquatic invertebrates are indicators of aquatic health. Canadian Aquatic Biomonitoring Network (CABIN) protocol is suggested.

**conductivity can be used as a proxy to measure Ca^{2+} concentrations[14]*

ADDITIONAL SUGGESTIONS

- Careful catchment selection and ground truthing during planning stages. Use the Catchment Selection Model and consider the key selection factors discussed within the Guidebook.
- Develop a good understanding of the current water quality and catchment hydrology and morphology.
- Habitat survey to (1) ensure catchment contains the minimum area required to support the target population and (2) assess the risk to sensitive species within the catchment.
- Ionic aluminum sampling prior to liming. Whole catchment liming is suggested if ionic aluminum is above 15 $\mu g \cdot L^{-1}$ threshold.
- Effective application rates will vary depending on a variety of parameters; we suggest a high application rate and the liming of a large percentage of the catchment.
- Monitoring is key during all stages of the project.

DIRECTION:
CURRENT EFFORTS AND FUTURE WORK

Current terrestrial liming efforts and research in the Nova Scotia Southern Uplands include:

- The West River Sheet Harbour lime doser
- Experimental helicopter liming in West River Sheet Harbour
- Analysis of liming in the Gold River
- Aluminium toxicity in NS

Future terrestrial liming research should focus on:

- Characterizing an effective liming dose/response relationship for SWNS.
- Identifying the critical source area for aluminum within catchments in SWNS.

The West River Sheet Harbour Lime doser, in operation since 2015.

EXPERTISE AND ADVICE:
CONTACT COASTAL ACTION

If you are interested in Terrestrial Liming in SWNS, please contact Coastal Action for expertise on:

- selecting where to lime by providing access to/and or running the catchment selection model,
- terrestrial liming methods, and
- contracts to perform water quality monitoring and CABIN analysis.

CONTACT INFORMATION

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Coastal Action
Foundation

FURTHER READING

Subject	Reference
Freshwater acidification in SWNS	Clair, T. A., Dennis, I. F., Amiro, P. G. and Cosby, B.J. (2004). Past and future chemistry changes in acidified Nova Scotian Atlantic salmon (Salmo salar) rivers: A dynamic modeling approach. *Canadian Journal of Fisheries and Aquatic Sciences, 61*(10), 1965-1975.
	Clair, T. A., Dennis, I. F., and Vet, R. (2011). Water chemistry and dissolved organic carbon trends in lakes from Canada's Atlantic Provinces: no recovery from acidification measured after 25 years of lake monitoring. *Canadian Journal of Fisheries and Aquatic Sciences*, 68, 663-674.
	Clair, T. A., Ehrman, J. M., Ouellet, A. J., Brun, G., Lockerbie, D., and Ro, C.-U. (2002). Changes in freshwater acidification trends in Canada's Atlantic Provinces: 1983-1997. *Water, Air, and Soil Pollution*, 135, 335-354
Aluminum in SWNS	Dennis I.F., and Clair, T. (2012). The distribution of dissolved aluminum in Atlantic salmon (Salmo salar) rivers of Atlantic Canada and its potential effect on aquatic populations. *Canadian Journal of Fisheries and Aquatic Sciences, 69*(7), 1174-1183.
	MacLeod, S. and Sterling, S. (2015). TITLE. *In Writing.*
	Howells, G., Dalziel, T., Reader, J., & Solbe, J. (1990). EIFAC water quality criteria for European freshwater fish: Report on aluminum. Chemistry and Ecology, 4(3), 117-173
Terrestrial liming	Sterling, S., Angelidis, C., Armstrong, M., Biagi, K., Clair, T., Jackson, N., and Breen, A. (2014). Terrestrial liming to promote Atlantic salmon recovery in Nova Scotia–approaches needed and knowledge gained after a trial application. *Hydrology and Earth System Sciences Discussions, 11*(9), 10117-10156.
	Clair, T.A. and Hindar, A. (2005). Liming for the mitigation of acid rain effects in freshwaters: A review of recent results. *Environmental Reviews,* 13, 91-128.
	Brown, D. (1988). The Loch Fleet and other catchment programs. *Water, Air and Soil Pollution,* 41(1), 409-415.
	Geddes M. and Sterling, S. (2015). A New Method for Prioritizing Catchments for Terrestrial Liming: a Case Study in Nova Scotia. *In Writing.*
	Jenkins, A., Waters, A. and Donald, A. (1991). An Assessment of Terrestrial Liming Strategies in Upland Wales. *Journal of Hydrology*, 124(3-4), 243-261.

REFERENCES

1. Anderson, Kenneth II. (2015). Acid Rain Recovery via Alkali Road Runoff Channels. *9th International Conference on Acid Deposition.* 71. Retrieved from: http://acidrain2015.org/Documents/AcidRain2015_Proceedings.pdf

2. Brown, D. (1988). The Loch Fleet and other catchment programs. *Water, Air and Soil Pollution,* 41(1), 409-415.

3. Clair, T. A. and Dennis, I. F. (2011). Water chemistry and dissolved organic carbon trends in lakes from Canada's Atlantic Provinces: no recovery from acidification measured after 25 years of lake monitoring. *Can. J. Fish. Aquat. Sci*., 68, 663-674

4. Clair, T. A., Dennis, I. F., Amiro, P. G. and Cosby, B.J. (2004). Past and future chemistry changes in acidified Nova Scotian Atlantic salmon (Salmo salar) rivers: A dynamic modeling approach. *Canadian Journal of Fisheries and Aquatic Sciences, 61*(10), 1965-1975.

5. Committee on the Status of Endangered Wildlife in Canada. (2010). Assessment and status report on the Atlantic salmon. Ottawa: Environment Canada.

6. Clair, T.A. and Hindar, A. (2005). Liming for the mitigation of acid rain effects in freshwaters: A review of recent results. *Environmental Reviews,* 13, 91-128.

7. Department of Fisheries and Oceans Canada (DFO): Recovery potential assessment for Southern Upland Atlantic Salmon, DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/009, Canadian Science Advisory Secretariat, Ottawa, ON, Canada, p. 60, 2013.

8. Geddes M. and Sterling, S. (2015). A New Method for Prioritizing Catchments for Terrestrial Liming: a Case Study in Nova Scotia. *In Writing.*

9. Hindar, A., Wright, R. F., Nilsen, P., Larssen, T., and Hogberget, R. (2003). Effects on stream water chemistry and forest vitality after whole-catchment application of dolomite to a forest ecosystem in Southern Norway. *Forest Ecology and Management, 180*(1-3), 509-525.

10. Howells, G., Dalziel, T. R. K., Reader, J. P and Solbe, J.F. (1990). EIFAC water quality criteria for European freshwater fish: Report on aluminium. *Chemistry and Ecology Chemistry and Ecology, 4*(3), 117-173.

11. MacLeod, S. and Sterling, S. (2016). Increasing Aluminum Levels in Lakes and Rivers in Recovering from Acidification. *In Writing.*

12. Moore, Jean-David., Ouimet, Rock., Long, Robert., Bukaveckas, Paul. (2015). Ecological benefits and risks arising from liming sugar maple dominated forests in northern North America. *Environmental Reviews, 23(1):66-77.*

13. Olem, H. (1991). Liming acidic surface waters. Chelsea, Mich.: Lewis Publishers.

14. Sterling, S., Angelidis, C., Armstrong, M., Biagi, K., Clair, T., Jackson, N., and Breen, A. (2014). Terrestrial liming to promote Atlantic salmon recovery in Nova Scotia–approaches needed and knowledge gained after a trial application. *Hydrology and Earth System Sciences Discussions, 11*(9), 10117-10156.

15. Stoddard, J. L., Jeffries, D. S., Lukewille, A., Clair, T. A., Dillon, P. J., Driscoll, C. T., . . . van Dam, H. (1999). Regional trends in aquatic recovery from acidification in North America and europe. *Nature, 401*(6753), 575.

16. Taylor, Lyla l., Quirk, Joe., . . . Beerling, David J. (2016). Enhanced weathering strategies for stabilizing climate and averting ocean acidification. *Nature Climate Change 6, 402-406.*