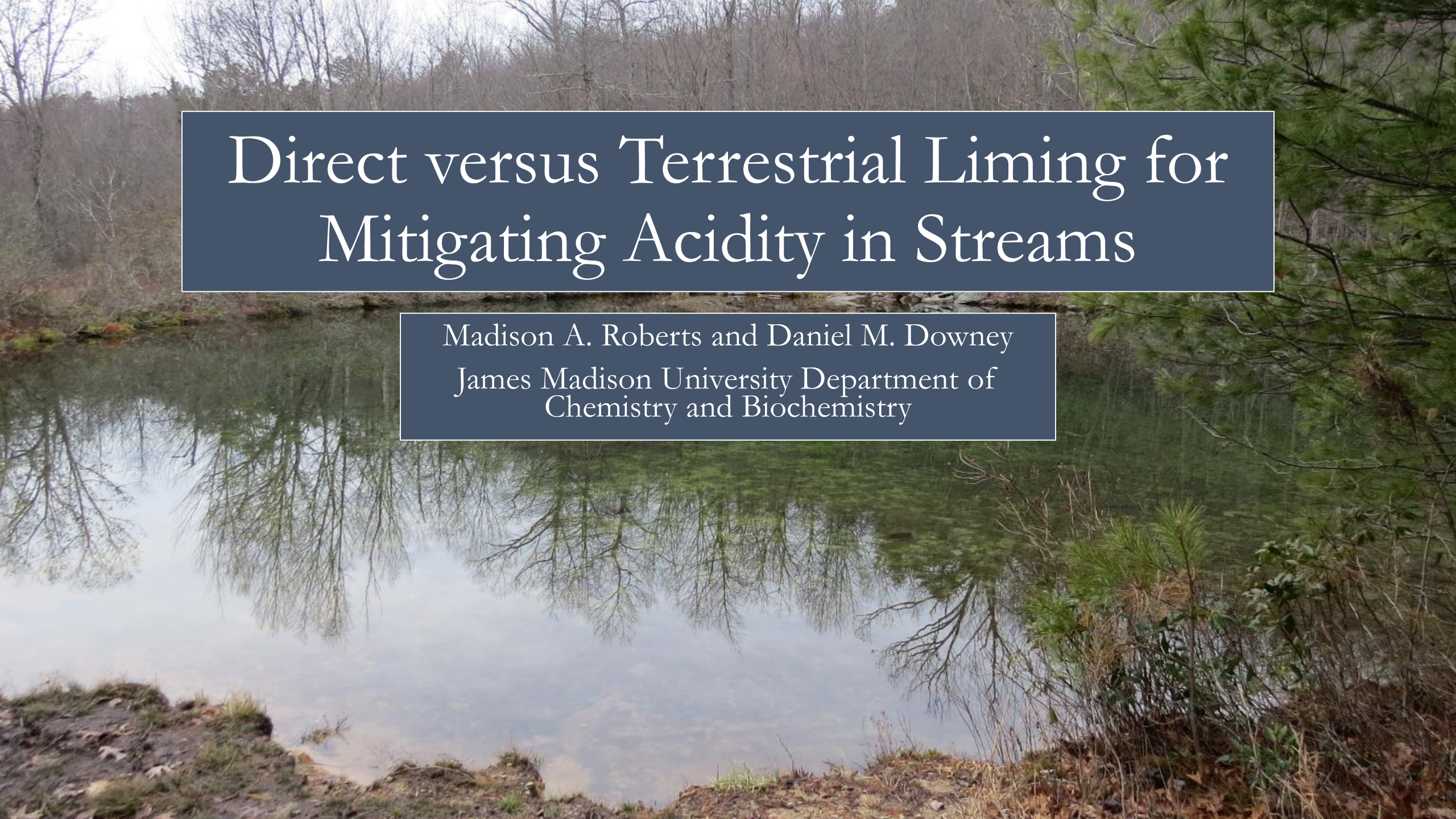

Direct versus Terrestrial Liming for Mitigating Acidity in Streams

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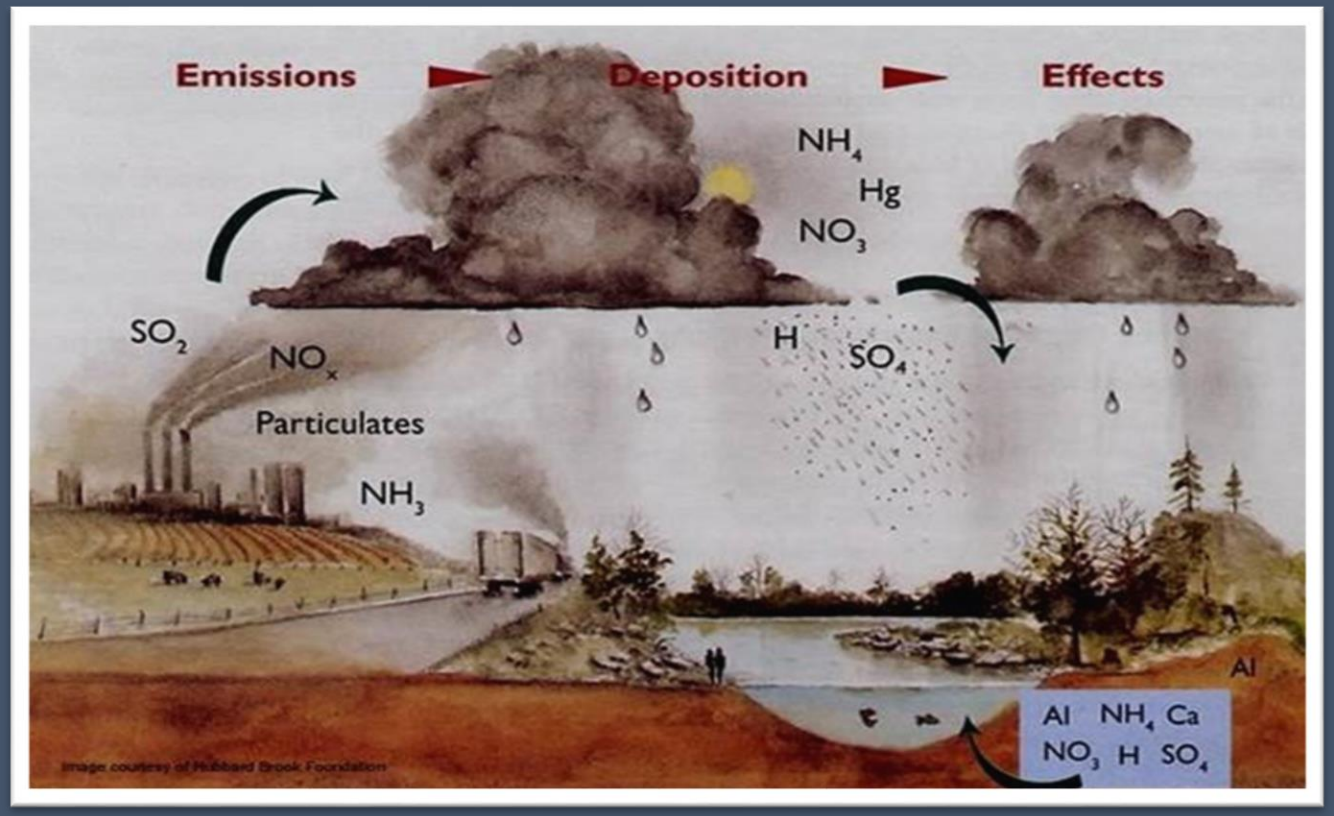
Acid Deposition

- Increased acid content in precipitation
- Caused by anthropogenic emissions of SO_2 and NO_2 gases



Chemistry of Acid Deposition

$SO_2 + \cdot OH \rightarrow \cdot SHO_3$ (alt. oxidants O_3 or NO_2)

$\cdot SHO_3 + O_2 \rightarrow SO_3 + \cdot OOH$

$SO_3 + H_2O \rightarrow H_2SO_4$

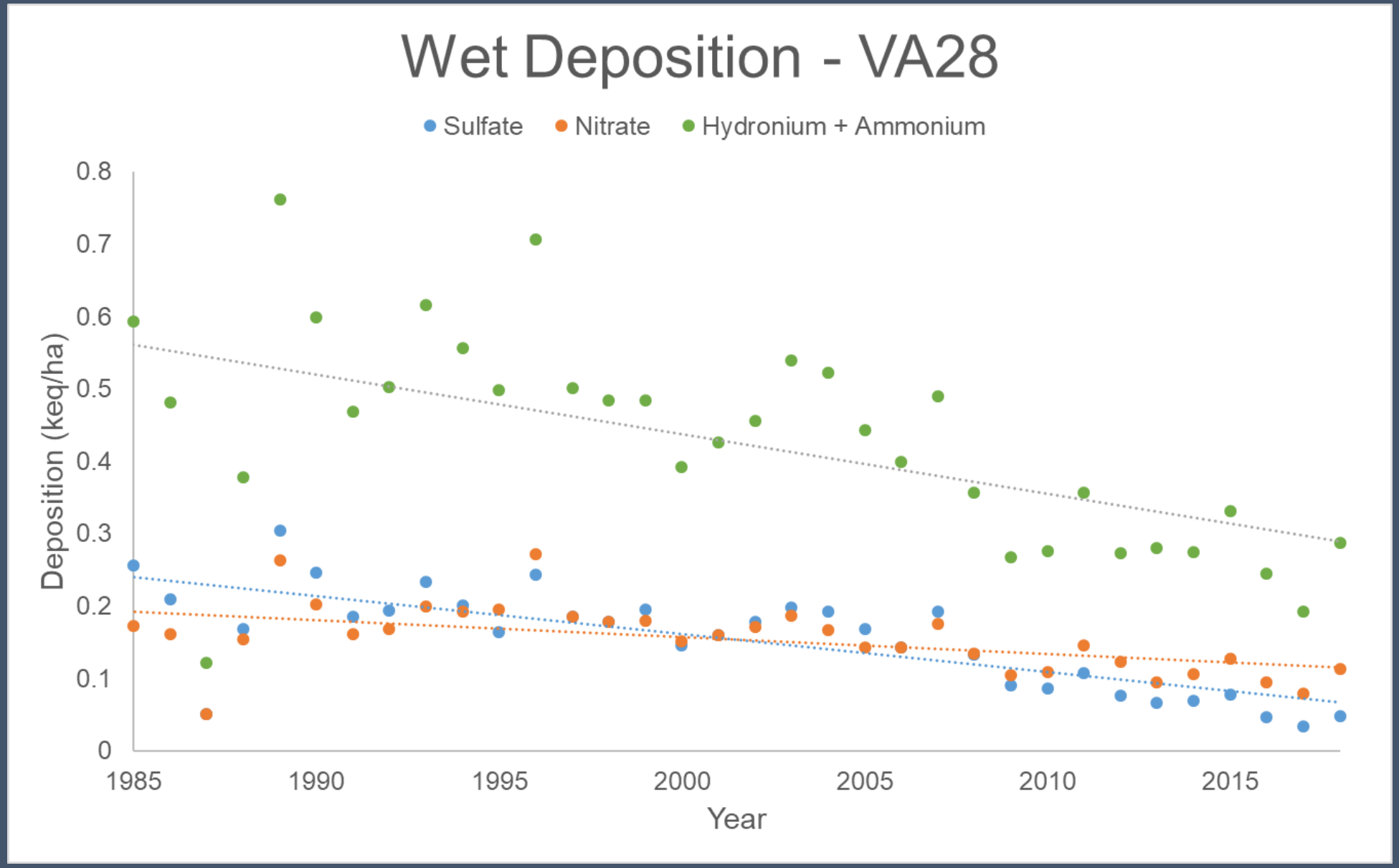
$SO_2 + H_2O \rightarrow H_2SO_3$ (aq)

H_2SO_3 (aq) + H_2O_2 (aq) $\rightarrow H_2SO_4 + H_2O$

$N_2 + O_2 + \text{heat} \rightarrow 2NO$

$NO + O_3 \rightarrow NO_2 + O_2$

$NO_2 + \cdot OH \rightarrow HNO_3$

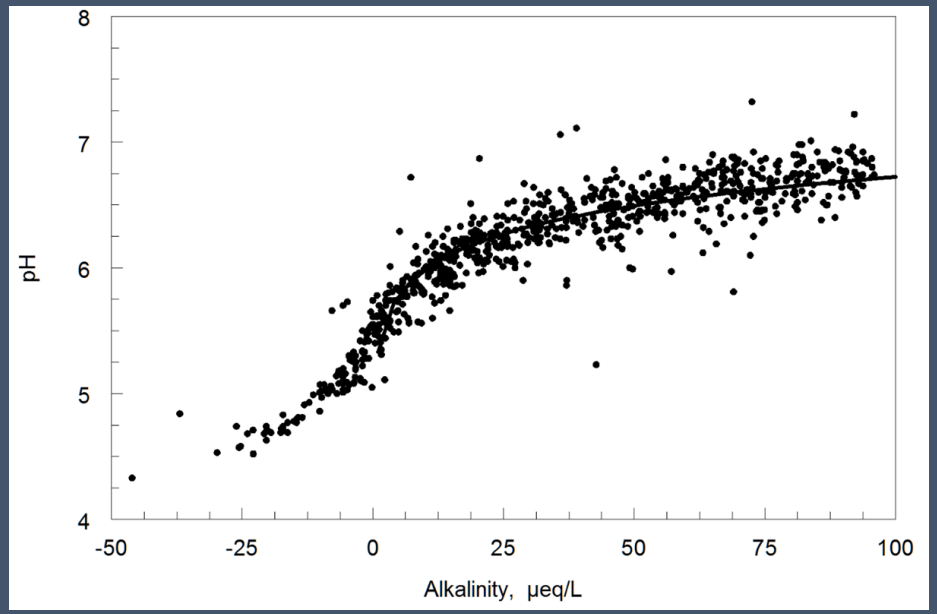

Wet Deposition - VA28
Sulfate
Nitrate
Hydronium + Ammonium
Deposition (keq/ha)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1985
1990
1995
2000
2005
2010
2015
Year

Effects of Acid Rain on Stream Chemistry

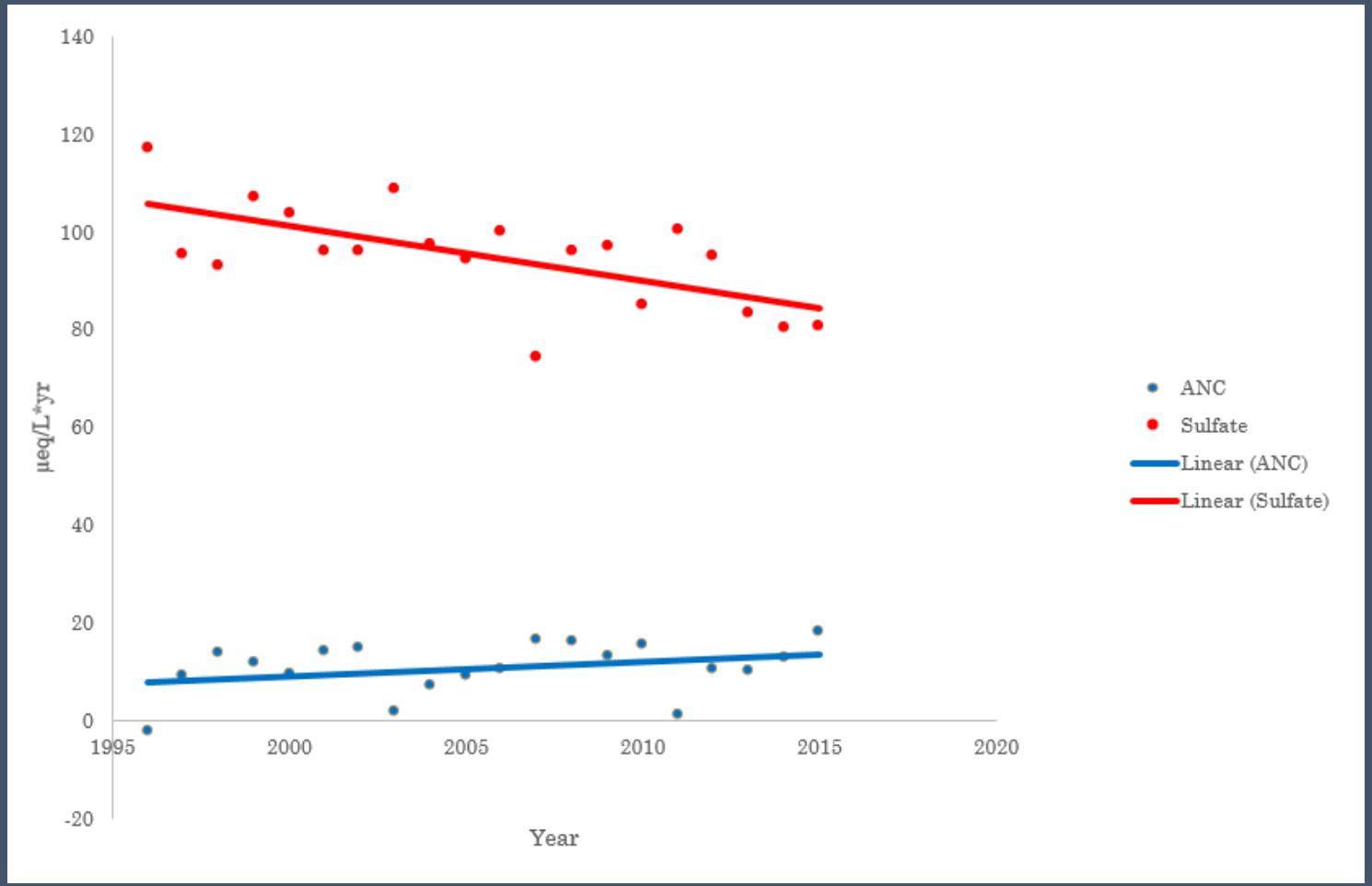
- Weathering of bedrock is the main contribution to ionic composition of stream water
- Charge balance:

$[H^+]+2[Ca^{2+}]+2[Mg^{2+}]+[K^+]+[Na^+]=[OH^-]+[Cl^-]+[NO_3^-]+2[SO_4^{2-}]+[HCO_3^-]$

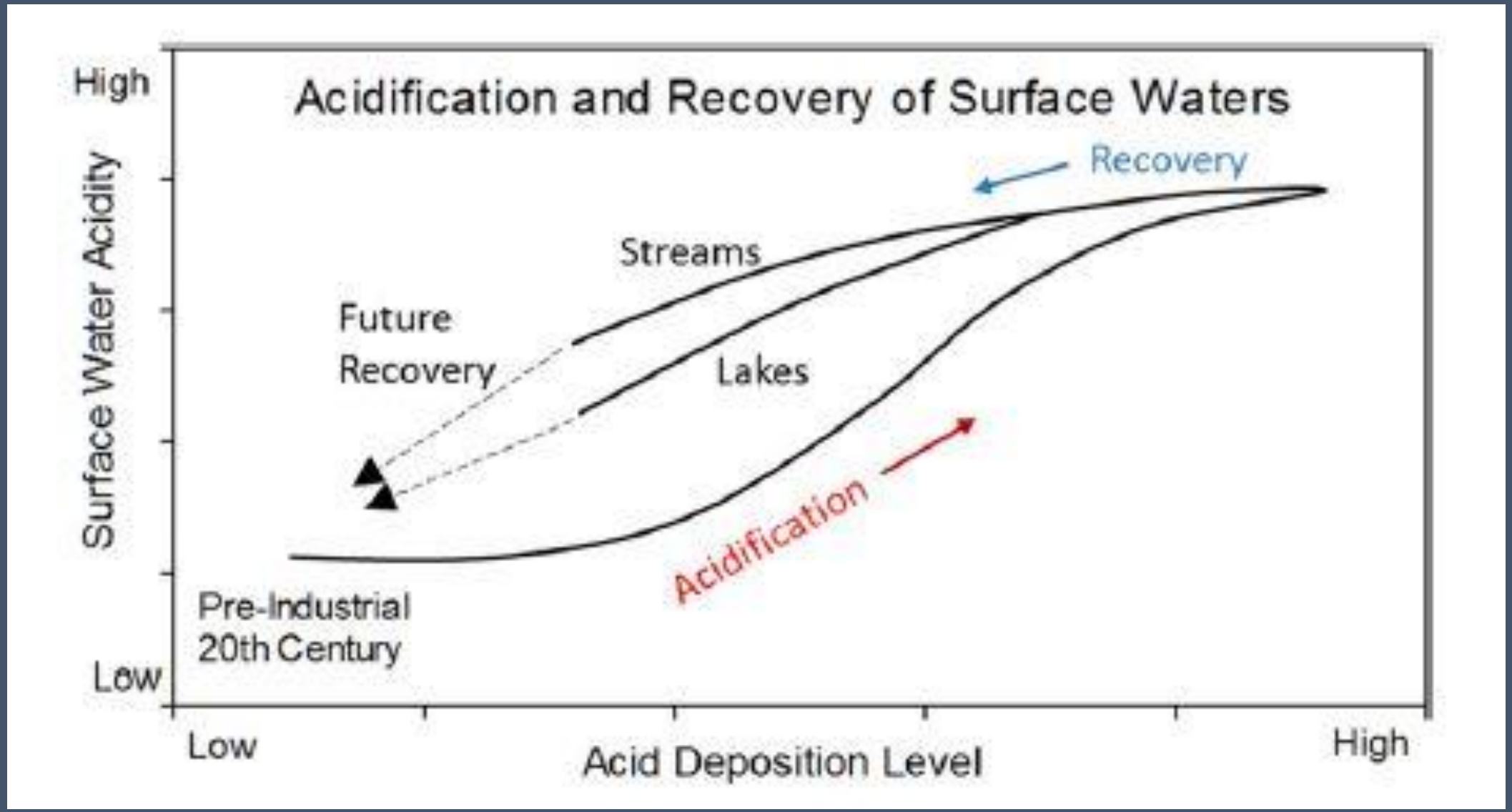
- Acid neutralizing capacity (ANC)
  - a.k.a. alkalinity or $[HCO_3^-]$
- 800 USFS stream samples: pH versus observed alkalinity



Little Stony Creek: Annual Average ANC and SO_4^{2-} Concentration Values



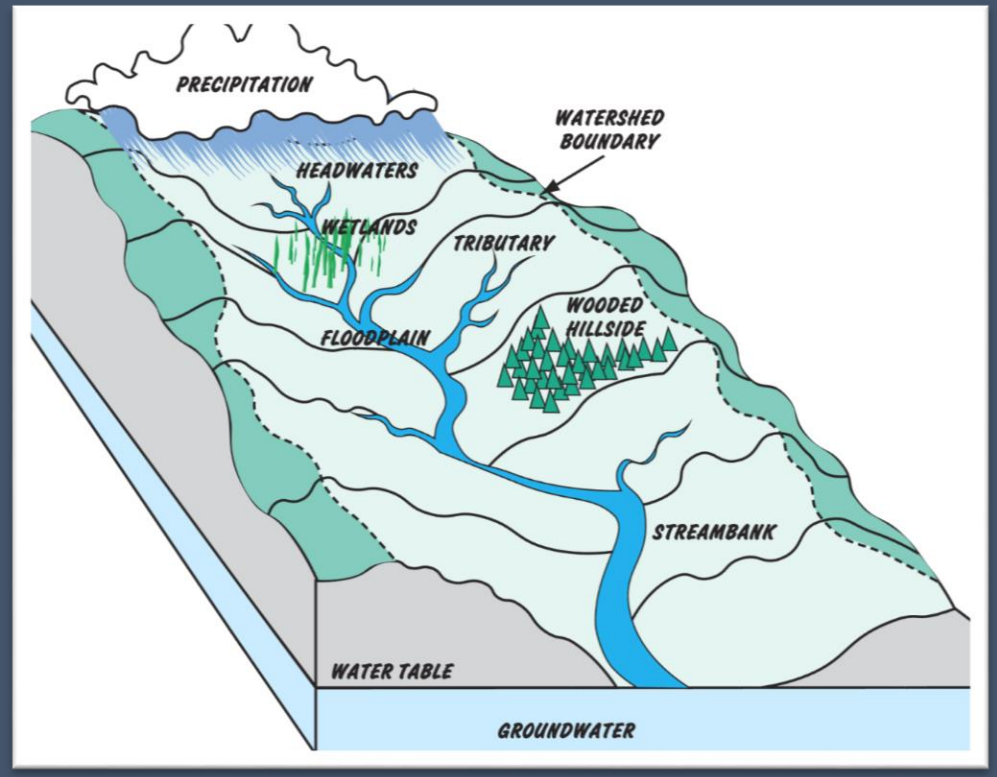
Pyszka, 2017



Lawrence et. al., 2016

Mitigation Strategies: Liming

- Stream liming
  - Direct introduction of lime material to stream water
  - Targets aquatic system
  - Application method: dump truck, front-end loader or helicopter
- Terrestrial (watershed) liming
  - Application of lime material over a specific area of land
  - Indirect introduction to stream water
  - Targets aquatic and terrestrial systems
  - Application method: helicopter or fixed-wing aircraft



https://www.awapa.org/marketingpromotion

Stream Liming

- Benefits
  - Immediate effects on water chemistry
  - Point application
  - Tailored to stream flow and chemistry
  - Predictable
  - Low relative cost
  - Single treatment within days
- Limitations
  - Does not mitigate the effects of acid rain on soils and terrestrial vegetation
  - Limited treatment duration
  - Treatment occurs downstream of liming site
  - Requires road access
  - Higher cost for helicopter

Dosage Calculations—Little Stony Creek

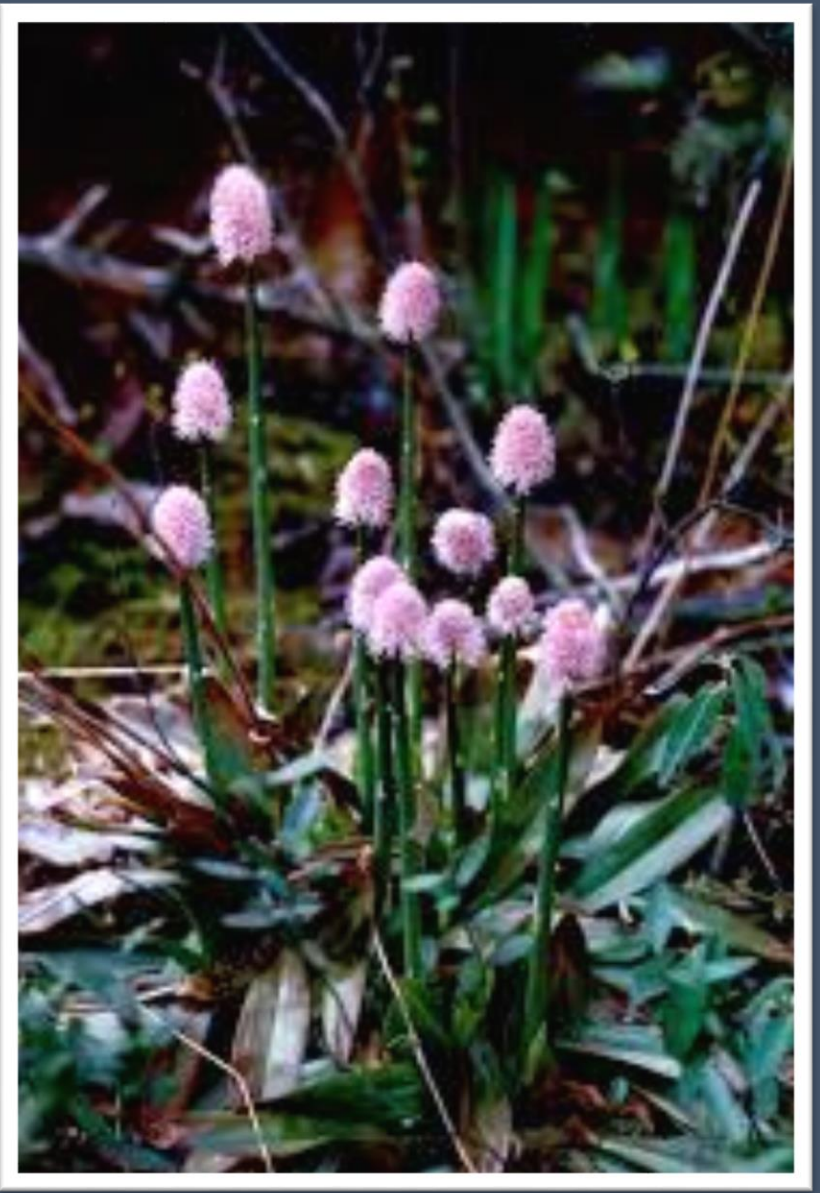
Model	Limestone Dose (tonnes/yr)	
	1996	2015
Deposition	13.50	5.01
"Lost" ANC	6.95	6.32
Sulfate equivalence	20.1	15.0
Target ANC/pH	4.05	2.73

- "Deposition" Model – to offset input of H^+ and NH_4^+
- "Lost" ANC model – based on late 1980s data
- "Sulfate" Model – the amount equal to sulfate input minus the natural amount present in stream water
- "Target" Model – to achieve pH 6.5 and 25 μeq/L ANC

Pyszka, 2017

Watershed Liming

- Benefits
  - Could supply Ca^{2+} to soils that are base cation-depleted
  - Long-term treatment
  - Can treat entire stream reach
  - Whole ecosystem treatment
- Limitations
  - Relative high cost
  - Does not replace all depleted base cations
  - Difficult to predict mass of limestone needed for treatment
  - Takes time to manifest in stream water chemistry
  - Could be detrimental to plants/animals that prefer acidic habitats (Ex: Swamp Pink)
  - Significant logistical considerations



https://foldedpetal.wordpress.com/2015/02/06/get-to-know-an-endangered-plant-swamp-pink/

Comparison of Direct Stream Liming and Watershed Liming for St. Mary's Wilderness for a 50-year Treatment Period

Parameter	Stream Liming	Watershed Liming
Dosage	25.9 tonnes/yr	6.89 tonnes/ha
Treatment	182 tonnes	27,900 tonnes
Total Limestone	1,274 tonnes	27,900 tonnes
Treatment Time	1 day (7 days)	155 days
Duration per Treatment	7 years	50 years
Miles treated	10 mi	15 mi
Soils	No	Yes
Vegetation	Aquatic only	Yes
Flora/Fauna Risk	No	Potential
Cost/Labor	High	Very high
Predictable Outcome	Yes	Unproven

Driscoll et. al., 1996

Acknowledgements

- Valerie Nelson and Dawson Bowles
- Dawn Kirk, Fisheries Biologist, USFS
- United States Forest Service –George Washington and Jefferson National Forests
- Virginia Department of Game and Inland Fisheries
- James Madison University Chemistry Department
- NSF-REU Grant No. CHE-1757874

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