Greater Yellowstone Area Critical Loads Science Workshop

April 5-6, 2011

Spring Creek Ranch
Jackson Wyoming

A workshop sponsored by the Greater Yellowstone Coordinating Committee (GYCC) to bring together a small group of state and federal agency staff, along with scientists working in the Greater Yellowstone Area (GYA) to understand the effects of air pollution on GYA ecosystems, determine if change is occurring, establish whether thresholds have been exceeded, and identify information gaps in establishing critical loads of air pollution deposition in the GYA

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Workshop Overview

Introduction

Critical loads are an emerging approach within the U.S. for quantifying the levels of air pollution deposition at which sensitive components of ecosystems are impacted. Critical loads are increasingly being used in agency planning (NEPA, Forest Plans) and regulatory processes (PSD, NO_x and SO_x draft secondary standards assessment). This two day workshop focused on the science side of critical loads development, in anticipation of future policy and management applications for critical loads in the Greater Yellowstone Area (GYA). Workshop participants from state and federal agencies, along with scientists working in the Greater Yellowstone area (National Park Service, US Geological Survey, US Forest Service, US Fish & Wildlife Service, US Environmental Protection Agency, Bureau of Land Management, State of Wyoming, State of Idaho, and the State of Montana) were invited to:

1. **Develop** a common understanding of current GYA data describing the deposition and effects of air pollutants (nitrogen and sulfur); including trends, comparison to impact thresholds for aquatic and terrestrial ecosystems, and available modeled or measured critical loads (CL);
2. **Discuss** whether we can estimate threshold exceedances and/or CL for new areas in GYA based on existing deposition and ecosystem data. Also assess where uncertainty may be too high to do so;
3. **Identify** where gaps in knowledge exist for GYA thresholds and critical loads, and prioritize information needed to develop thresholds and CL in the next 5 years;
4. **Discuss** what agency planning steps or processes may be needed in the future to make use of CL science in agency policy and decision making.

The April 5-6, 2011 Greater Yellowstone Ecosystem Critical Loads Science Workshop was initiated by participants in the Greater Yellowstone Area Clean Air Partnership, and funded through a grant from the Greater Yellowstone Area Coordinating Committee. It was held at the Spring Creek Ranch in Jackson, Wyoming.

Workshop Conclusions

The following is a summary of the group's conclusions at the end of the meeting, based on the data and information presented:

1. <u>Nitrogen deposition is increasing (statistically significant trends) in many regions of the GYA</u>:
    - Wet deposition of total inorganic nitrogen ($N\text{-}NH_4 + N\text{-}NO_3$) is increasing in most areas (6/8 NADP monitoring stations);
    - Ammonium (NH_4) concentrations in precipitation are increasing in all areas (11/11 NADP monitoring stations);
    - Nitrate (NO_3) concentrations in precipitation are increasing in some areas (3/11 NADP monitoring stations);

  - IMPROVE data trends at the Bridger site shows increasing nitrate in the winter, and at the Yellowstone site shows increasing annual trends;
  - Bulk deposition collectors at high elevation sites in the Wind River Range both show increasing trends in annual nitrogen deposition (Total N, NH_4, and NO_3);
  - CASTNet data estimating dry deposition at Yellowstone and Bridger do not show any trends.

2. Some GYA lakes show statistically significant changes in water chemistry:
   - Nitrate (at inlets) is increasing at Ross and Saddlebag lakes (Shoshone NF), and ammonium (at outlets) is increasing at Black Joe and Hobbs lakes (Bridger-Teton NF), indicating that beginning stages of lake eutrophication may be occurring in Wind River Range lakes;
   - Lakes are beginning to acidify (ANC is declining) in Ross and Saddlebag lakes (Shoshone NF) and Hobbs Lake (Bridger-Teton NF);
   - Lakes in the Beartooth and Teton ranges and Yellowstone NP can be sensitive but generally have adequate buffering to maintain stability with current low deposition levels;
   - Lake sediment cores in the Grand Teton NP all show (7/7 lakes) depletion of N^{15} which indicates increasing influence of anthropogenic sources of nitrogen to lakes.

3. Several ~~–C~~hemical or Biotic Thresholds" and critical loads exist for deposition and its effects in other similar areas, which can be used now in the GYA. These include:
   - Diatom biodiversity changes begin to occur at surface water concentrations above 0.4 ueq/l NO_3 in western high elevation lakes (Saros, 2005);
   - Ratio of Total Nitrogen to Total Phosphorus (TN:TP) in surface waters should be less than 60 (Elser et al, 2009) to constrain unnatural phytoplankton growth;
   - Ratio of Carbon to Nitrogen (C:N) in soils should be 30 or higher to avoid increases in NO_3- leaching and potential acidification of soils (Hood et al, 2003);
   - 1.5 kg/ha/yr wet deposition can be used as a critical load for nutrient enrichment (phytoplankton changes) to high elevation lakes (Baron, 2006);
   - The critical load for bulk deposition (wet + dry at high elevation sites) in the Rocky Mountains is estimated to be 3.0 kg/ha/yr for nutrient enrichment (Baron et al, 2011);
   - Sum of $SO_4 + NO_3$ = less than 10% of Base Cations (lake water) can be used as a threshold at which ANC may begin to decline (Nanus et al, 2009);
   - For alpine ecosystems in the Rocky Mountains, the CL initiating vegetation changes is 3-4 kg/ha/yr (Bowman et al, 2006);
   - For subalpine forests, CL in Northwestern Forested Mountains is 4 kg/ha/yr based on changes in foliar N, organic horizon N, base cations, net mineralization/soil transformation (Reuth and Baron, 2002).

4. There are several pressing –Research and Management Needs” which, if addressed, could greatly aid efforts to develop site specific critical loads for the GYA:
    - Each agency needs to define what represents a –significant change” in ecosystem function, so that relevant ecosystem changes can be linked to deposition loading and critical loads developed;
    - Deposition estimates should be developed for all high elevation monitoring sites of concern to NPS and FS; this can be done with existing NADP, PRISM, bulk deposition, and snowpack chemistry data; in conjunction with CMAQ dry deposition modeling;
    - The FS needs to analyze its existing 25 years of macroinvertebrate and zooplankton data from Wind River lakes at inlets and outlets to determine if change is occurring and whether any biotic changes are linked to water chemistry changes;
    - GYA partners should explore using the hindcasting modeling process used for Rocky Mountain NP by taking additional or using existing sediment cores from the Shoshone NF lakes and other areas to determine whether any diatom species shifts have occurred and estimate whether they occurred at or near critical loads developed for other areas (1.6/1.5 kg/ha/yr;
    - Lake nitrate levels currently monitored need to be compared to established thresholds to characterize potential current levels of eutrophication;
    - ANC declines in Shoshone and Bridger-Teton lakes should be compared against USFS limit of acceptable change thresholds to determine whether thresholds have been exceeded;
    - GYA partners should develop a –continuum of effects” graphic showing ecosystem changes that are occurring now and expected to increase in the future with additional N deposition;
    - GYA partners should fund/facilitate collection of the following new data because it can be compared to existing thresholds to assess whether ecosystem change/damage has already occurred:
        - TN:TP Ratios (or DIN:TP) in surface waters or sediment to determine which lakes are –N-limited” and therefore good candidates for diatom work
        - C:N Ratios in soils or sediment to gauge changes in primary production as a symptom of eutrophication
        - Establish whether the lake nitrate increases observed are contributing to excess phytoplankton productivity.

Presentation Summaries and Discussion

1. Meeting Introduction: Terry Svalberg & Tamara Blett

This workshop will address questions such as: How do we develop Critical Loads (CL)? What scale is appropriate? What indicators/monitoring methods are best? How do we use science in a meaningful way to protect ecosystems? Critical Loads are fairly new in the US, in Europe CL have been used for 20-25 years. This workshop will begin the process of synthesizing ecosystem data across administrative boundaries so that managers, air regulators and scientists can better understand the levels of deposition that may be affecting sensitive resources in the Greater Yellowstone Area.

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2. Overview of Critical Loads: Tamara Blett

***Critical load definition**:*

―The quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.”

- Critical loads can be developed for any pollutants; current focus is on sulfur and nitrogen.
- Critical loads are usually expressed as loading rates, i.e., kilograms per hectare per year (kg/ha/yr)
- Deposition below critical loads is not expected to harm sensitive ecosystems
- ―Target Loads” (TL) are the term for selection of a CL to meet a policy or management goal such as a goal for limit of acceptable change (LAC) or desired time to ecosystem recovery

In the GYA the, CL we are currently concerned with is N and S, which are important for assessing ecosystem health and providing information useful in air quality decision making processes.

What are critical loads used for?

- Land Managers- Assessing ecosystem health; communicate status to publics, air regulators, land management planning at parks, forests, wilderness areas
- Air Regulators - Assessing efficacy of emissions controls programs (e.g., Clean Air Interstate Rule, cap and trade, developing state and regional plans to improve air quality)

Some regulatory mandates are currently in place to protect resources. How can we use mandates such as the Wilderness Act, Organic Act, Clean Air Act, Clean Water Act? Can we determine cause and effect relationships with the current ecosystem and air quality data we have?

Tipping point—the addition in loading that will break the TL or CL threshold (for example: FS lake with more than 10% change in ANC may be exceeding target loads)

Two sides to CL:

1) Development (science) side—At what deposition are sensitive resources first impacted (scientists)

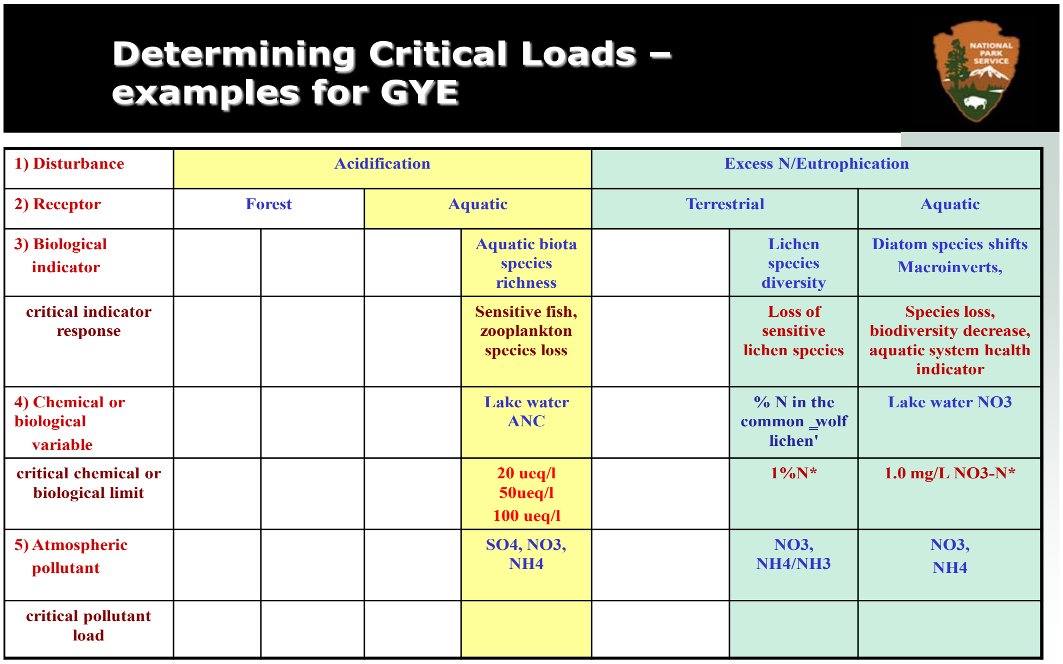
2) Implementing (policy) side—how to use critical loads (air regulators)

FS, NPS, FWS land managers are involved with both the policy and the science sides.

Limit of acceptable change—ecosystem threshold based on defining how much change is acceptable (policy + science)
Chemical or biological limit (science)—specific biological effects that occur at various chemical concentrations or amounts.

Biological indicator responses—need to define responses (i.e. chemical change that results in response from a biological indicator)

Can use a matrix to work through these problems (see below) look at disturbance, receptor, biological indicator, critical indicator response, chemical or biological variable, atmospheric pollutant, and critical pollutant load.



Determining Critical Loads – examples for GYE

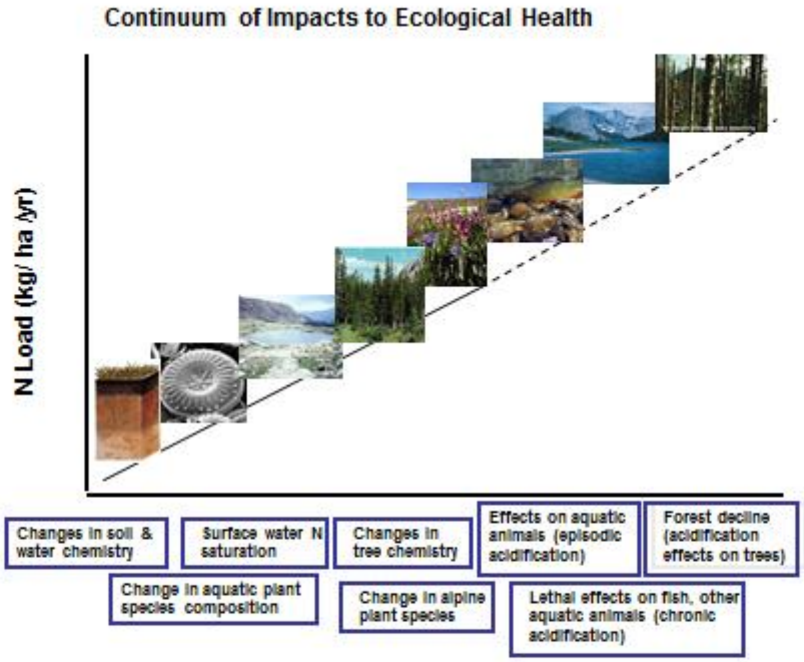
1) Disturbance	Acidification				Excess N/Eutrophication		
2) Receptor	Forest		Aquatic		Terrestrial		Aquatic
3) Biological indicator				Aquatic biota species richness		Lichen species diversity	Diatom species shifts Macroinverts,
critical indicator response				Sensitive fish, zooplankton species loss		Loss of sensitive lichen species	Species loss, biodiversity decrease, aquatic system health indicator
4) Chemical or biological variable				Lake water ANC		% N in the common ‚wolf lichen'	Lake water NO3
critical chemical or biological limit				20 ueq/l 50ueq/l 100 ueq/l		1%N*	1.0 mg/L NO3-N*
5) Atmospheric pollutant				SO4, NO3, NH4		NO3, NH4/NH3	NO3, NH4
critical pollutant load							

*= CL for areas other than GYE

Need to measure or model N deposition AT THE SITE where we are concerned (not lower elevations).

Glide paths can be used as policy to reduce deposition after CL’s are exceeded (Rocky Mountain NP is doing this).

There are different critical loads for different indicators in the GYA ecosystem (see conceptual diagram below).



Discussion/Questions:
What are the first and most sensitive parts of an ecosystem, what monitoring do we have of these indicators and can we use these indicators to establish CL in the GYA?
How much can CLs be extrapolated across regions?
Are AQ standards that protect Human Health good enough to protect ecosystem health?
Start with the small questions—if you see a change, you can immediately start working on the problem.

Resources:
CLAD is a critical loads deposition group under NADP, it meets 2 times/yr. There are a plethora of people collaborating on this issue (150 participants). Purpose is to develop strategy, synthesis of CL information: http://nadp.sws.uiuc.edu/clad/

Pardo et al. 2011 ―Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecosystems of the United States."

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3. GYA Air Quality Monitoring on the Bridger-Teton NF – Terry Svalberg

Jonah and Pinedale Anticline fields together have ~ 7000 + wells. Closest is within 7 miles of the NF within 15 miles of the Bridger Wilderness—there is a definite need to monitor.

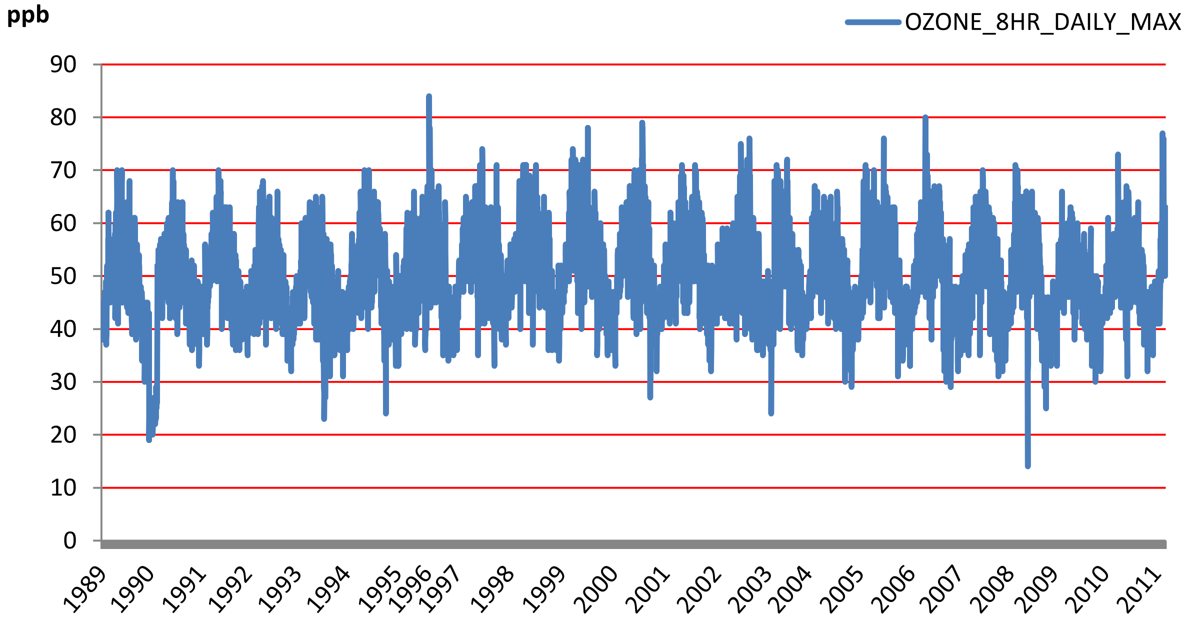
Monitoring

- Four IMPROVE sites (Yellowstone, Bridger, N. Absaroka, Boulder Lake) also a State IMPROVE site at South Pass (1 day in 3 monitoring schedule)

- Two CASTNet sites (Yellowstone and Bridger)
- Two bulk deposition monitoring sites (Hobbs and Black Joe)
- One transmissometer—takes hourly readings (Bridger)
- 5 NADP sites (Lake, Gypsum Creek, Pinedale, South Pass and Sinks Canyon)
- USGS snow sampling sites (over 50 in the central/northern Rocky Mountains)
- WY DEQ (7 Ambient air sites)
- Camera Network (One on B-T at Fortification Mtn- pictures every 15 minutes to 1 hour. State of WY also has several cameras at their ambient monitoring sites)

Summary Air Quality Trends

- BRID1: IMPROVE site shows increase in nitrate—winter *
  decrease in sulfate—annual**, summer**, fall**
- YELL1&2: IMPROVE sites shows increase in nitrate—annual*
  increase in sulfate—spring*
  decrease in sulfate—fall* (* = $p<0.1$, **= $p<0.05$, ***=$p<0.01$)
- Improved visibility (SVR—standard visual range) at all sites analyzed for best 20% , stable visibility at sites assessing the worst 20% condition
- FS-R1 IMPROVE sites had no increases in nitrate or sulfate
- BRID1 is not picking up most emissions from the oil and gas fields due to site location.
- CastNET shows that total N dry deposition is generally not changing
- The graph of daily ozone at the CASTNet Pinedale site (PND165) shows that lowering ozone standards to 65 ppb, as proposed, would make Pinedale have multiple exceedences per year.



- annual trends in bulk deposition showing an increase in N – monthly data has not yet been analyzed. S loading at the southern end is higher than the northern range. Bulk sampling is showing much more N deposition (2.35 to 2.66 kg/ha/yr at Hobbs and Black Joe) than CASTNet+NADP data from these lower elevation samplers (1.6kg/ha/yr).

Where do we go from here---need to quantify the increase and decreases we are seeing, analyze bulk deposition for seasonality. Compare IMPROVE data to other regions, look at the Boulder IMPROVE sites, and hopefully start to move towards developing CL.

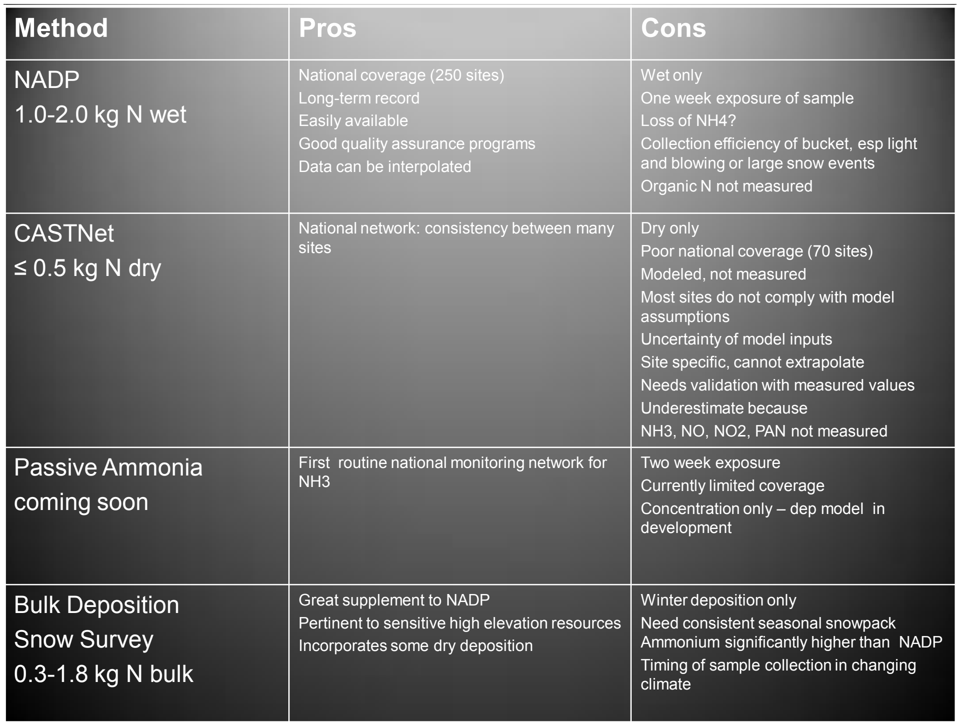
Discussion/Questions:
Maybe look at how the USGS snow data compares to monitoring sites-
bulk sites do not include organic N deposition, Jill Baron CL number for the RMNP (1.5 kg/ha/yr) is based only on inorganic wet deposition.

4. Atmospheric Deposition in the GYA- Kristi Morris

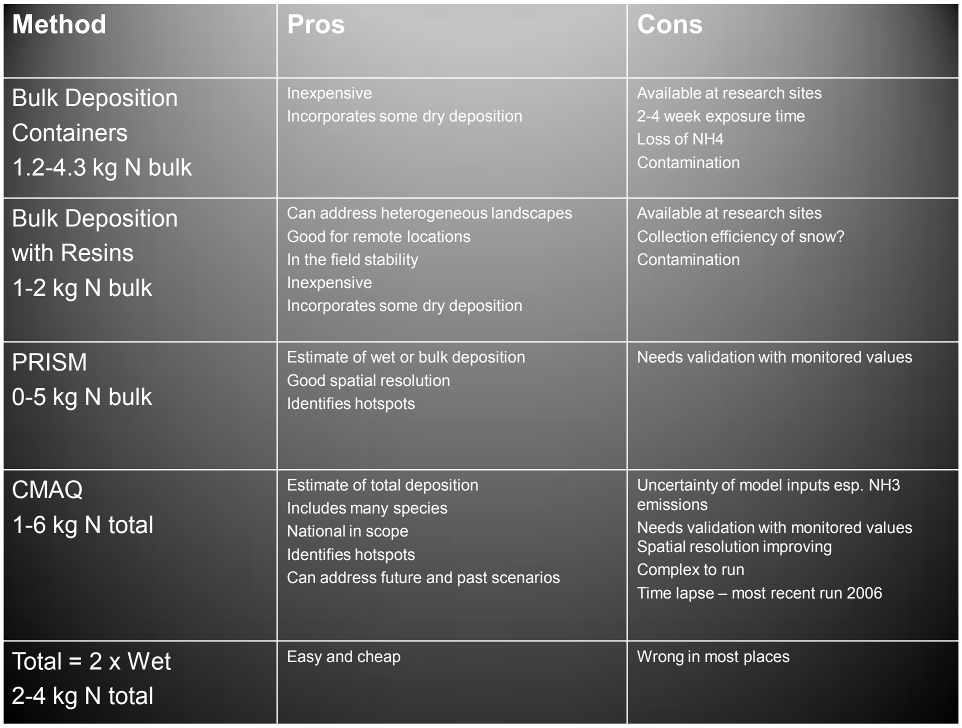
Accurate deposition estimates are needed to develop critical loads.

Monitoring
Many options exist for deposition monitoring including NADP, CASTNet, passive ammonia (AMoN), and bulk sampling (snow surveys, containers, ion exchange resins). Deposition estimates are also provided by models (PRISM precipitation to correct wet deposition for elevation; and CMAQ model).

- NADP (over 30 years, 200+ sites nationwide): 5 in GYA, new NADP site at Grand Teton NP at the end of August (will also have passive ammonia network - AMoN). Isopleth maps are online—estimates 1.25 kg of wet N/year in the GYA.
- Passive ammonia network (AMoN)-sub-network of NADP growing from 20-50 sites, no electricity required, 2 week sampling cycle, price = $2,000-$3,000 per site.
- USGS snowpack (about 20 years, over 50 sites). Estimate 0.3 and 1.8 kg of N/ha/yr (all years or the past year?), winter only deposition.
- Ice cores from upper Fremont Glacier, showed NO_x and SO_x deposition tracked the increase in emissions through time, prior to NADP monitoring (Naftz et al., 2011).



Method	Pros	Cons
NADP 1.0-2.0 kg N wet	National coverage (250 sites) Long-term record Easily available Good quality assurance programs Data can be interpolated	Wet only One week exposure of sample Loss of NH4? Collection efficiency of bucket, esp light and blowing or large snow events Organic N not measured
CASTNet ≤ 0.5 kg N dry	National network: consistency between many sites	Dry only Poor national coverage (70 sites) Modeled, not measured Most sites do not comply with model assumptions Uncertainty of model inputs Site specific, cannot extrapolate Needs validation with measured values Underestimate because NH3, NO, NO2, PAN not measured
Passive Ammonia coming soon	First routine national monitoring network for NH3	Two week exposure Currently limited coverage Concentration only – dep model in development
Bulk Deposition Snow Survey 0.3-1.8 kg N bulk	Great supplement to NADP Pertinent to sensitive high elevation resources Incorporates some dry deposition	Winter deposition only Need consistent seasonal snowpack Ammonium significantly higher than NADP Timing of sample collection in changing climate



Method	Pros	Cons
Bulk Deposition Containers 1.2-4.3 kg N bulk	Inexpensive Incorporates some dry deposition	Available at research sites 2-4 week exposure time Loss of NH4 Contamination
Bulk Deposition with Resins 1-2 kg N bulk	Can address heterogeneous landscapes Good for remote locations In the field stability Inexpensive Incorporates some dry deposition	Available at research sites Collection efficiency of snow? Contamination
PRISM 0-5 kg N bulk	Estimate of wet or bulk deposition Good spatial resolution Identifies hotspots	Needs validation with monitored values
CMAQ 1-6 kg N total	Estimate of total deposition Includes many species National in scope Identifies hotspots Can address future and past scenarios	Uncertainty of model inputs esp. NH3 emissions Needs validation with monitored values Spatial resolution improving Complex to run Time lapse – most recent run 2006
Total = 2 x Wet 2-4 kg N total	Easy and cheap	Wrong in most places

Summary:

- Estimates of N deposition in the GYA range from 0-6 kg/ha/yr (see chart above)
- Wide spread decreases in sulfate and increases in nitrate and ammonia in the West. NADP in GYA shows fairly stable nitrate, increases in ammonia, and no trends in precipitation.
- N deposition is higher in the eastern US, generally dry deposition of N is very small compared to wet…but likely because ammonia is not measured by CASTNet.

Discussion/Questions:

RMNP used Baron’s CL of 1.5 kg/ha/yr but it is based on wet deposition only. RMNP uses a glidepath and weight of evidence to determine if N loading is decreasing.

Deposition estimates should be spatially and temporally relevant to the ecological resource at risk. There are pros and cons of all monitoring methods so a weight of evidence approach should be considered.

Resources:

Van Miegroet, 2010. Assessment of N deposition, soils and alpine vegetation at GRTE-found higher N deposition in the northern part of the park ~ 2 kg/ha/yr and 1 kg/ha/yr in southern part.

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5. GrandTReND (Grand Tetons Reactive Nitrogen Deposition Study) Brett Schichtel

Grand TReND is a study to better understand the total reactive N deposition (inorganic, oxidized organic, reduced organic, and the amount that is wet or dry) in Grand Teton NP and its source (anthropogenic vs. natural).

Grand TReNDS objectives:

- measure wet and dry on both east and west side of divide
- determine where N is coming from (ID vs WY)
- determine different source types—agriculture vs fire
- assess spatial and temporal variation of area

Possible N sources—agriculture to the West, urban (Jackson, Salt Lake City), oil and gas to the SE, Fires, other natural sources.

Even if there is no issue in GRTE there will be documentation of a baseline for current N. We need to understand what we are not measuring, what are the missing components and what are the quantitative value of the missing components.

Holes in current monitoring:

1) dry deposition in ammonia (15 %)
2) dry deposition of N gases and particulates

Non-soluble N is an important component (but is harder to measure). Would like to measure total N…inorganic and organic.

The sites: Much of the monitoring will take continuous measurements.

- 2 Core sites
    - Targhee Ski Resort
    - NOAA Climate Station
    - Intensive monitoring of aerosol, gas and wet deposition data
    - Detailed N deposition budgets
- 7-8 Satellite Sites
    - Capture spatial patterns
    - Bulk measurements of inorganic nitrogen and wet deposition
- Preliminary monitoring at Driggs Idaho begins April, 2011
- Intensive monitoring: July 1 – August 31, 2011

Will apply weight of evidence approach, combine measured data with wind trajectories, and use hybrid models.

Discussion/Questions:

Will NOT be measuring VOCs except from standpoint that some will contain N.
Will have meteorological weather data at two main sites.

Maybe missing peak N activity by ONLY monitoring from May through August; may miss wintertime peaks.

Resources:
Clarisse et al 2009 presents satellite images of ammonia.

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6. Discussion on Deposition Monitoring: All

Deposition Discussion:
Need to better estimate deposition at some high elevation sites:

- Ross Lake & Lower Saddlebag Lake – Use NADP wet data from South Pass and Sinks Canyon and correct for elevation using PRISM precipitation data. Add dry deposition from CMAQ model to estimate total deposition.
- Compare calculated Ross and Saddlebag deposition with Black Joe bulk deposition rates.
- Compare bulk deposition sites with Nanus maps (2009).
- Look at USGS glacier data for long-term historic deposition trends in the ice.
- FWS may have some old lake data.

Deposition: What data is available for various sites to determine deposition?

Site	Total Inorganic	Partial Inorganic N	Other
Hobbs Black Joe Deep Upper Frozen	Bulk at 2.35 kg/ha/yr Bulk at 2.7 kg/ha/yr — —		
Lower Saddlebag	Bulk at 2.7 kg/ha/yr Nanus 2007 Total N	NADP concentrations PRISM scaled	Wind River glaciers, compare over long-term
Ross	Nanus 2007 Total N	NADP concentrations PRISM scaled &CMAQ for dry	
7 high elevation GRTE lakes	Jill Baron Ests?	Gypsum NADP @ 3.3 kg/ha/yr Snow sites Teton Pass Togatee Pass	Bug data available for Gypsum Creek
YELL high elevation lakes	?	Snow sites West Yellowstone	NEON core sites FWS lakes data
Absoroka Beartooth high elevation lakes		Yellowstone NADP, PRISM scaled and	

		CMAQ for dry. Compare with USGS snow sites.	
Wind River Reservation lake sampling		NADP concentrations, PRISM scaled and CMAQ for dry	

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7. Water Chemistry Data on the BT and Shoshone NF: Greg Bevenger and Terry Svalberg

Lake monitoring in the Wind River Mountain Range
Lakes are sampled 3x per year: right after melt off, middle of summer (prior to turn over), right before ice on.

Shoshone Long-Term Lakes

- Geology/Location
  - Precambrian granitics
  - Ross Lake in northern Winds/Fitzpatrick Wilderness (Class 1)
  - Lower Saddlebag Lake in southern Winds/Popo Agie Wilderness (Class 2)
- Size
  - Ross Lake is very large (1.5 miles long) and deep
  - Lower Saddlebag Lake is relatively small and shallow
- Elevation
  - Ross Lake at 9,675 MSL
  - Lower Saddlebag Lake at 11,262 MSL
- Lake Sampling History
  - Sampling data available for 1985-2007
  - 3 samples/yr per lake at both epilimnion and hypolimnion

Shoshone Summary:

- ANC is on a downward trend at both Shoshone lakes. There is a greater change at Ross Lake, particularly since 2000. The change is occurring at all locations. The inlet at both lakes exhibits seasonality but the outlets do not. The change at Lower Saddlebag at the outlet and hypolimnion is non-significant. At Ross it is significant.
- Nitrate is on an upward trend at the inlet of both lakes. Saddlebag exhibits seasonality while Ross does not. There is no trend at either lake at the outlet and epilimnion. The hypolimnion at Saddlebag is on an upward trend while the hypolimnion at Ross shows no trend.
- Sulfate at Lower Saddlebag does not exhibit a statistically significant change but there has been a 20% decrease (approximately). Sulfate is on a downward trend at Ross at the inlet, outlet, and hypolimnion, but not at the epilimnion. The trend at the Ross Lake inlet is non-significant, while at the outlet and hypolimnion it is significant. Lower Saddlebag does not exhibit seasonality while Ross does.

Discussion/Questions:
The Wind River Range has the largest concentration of glaciers in the lower 48 states. The glaciers have been rapidly melting. We would like to know what influence the glacial melt might have on water chemistry.

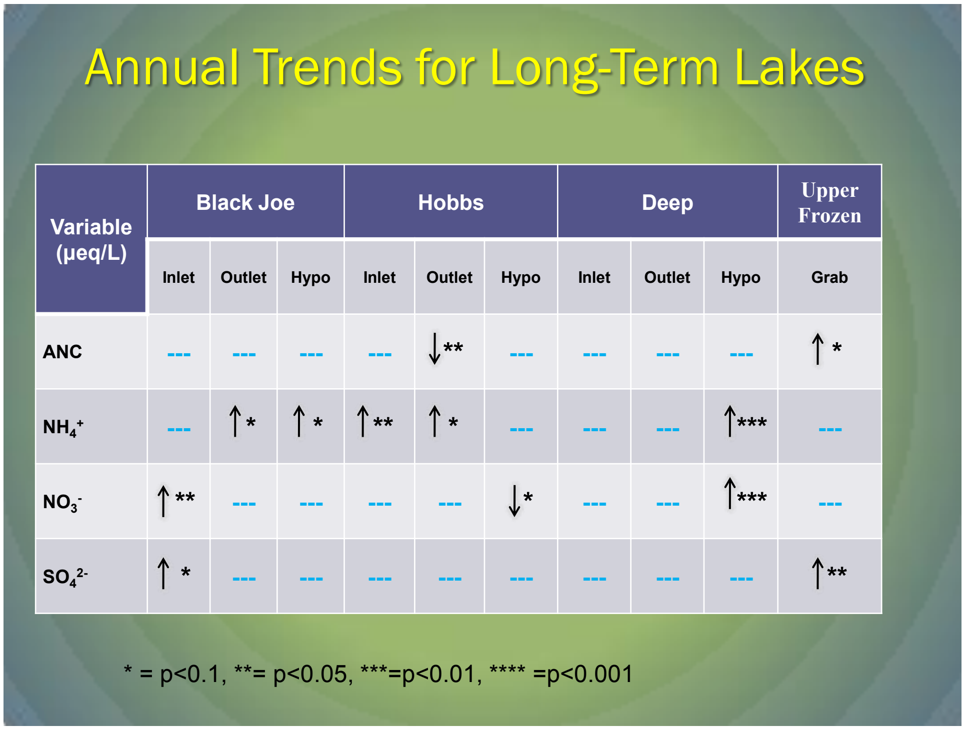
The Shoshone NF and Bridger-Teton NF have been using thresholds for ANC as no more than 10% change with ANC over 25ueq/L…..under 25 then a <1% cumulative ANC change. So the downward trends in ANC are of a concern.
Nitrate trends are different in inlet vs outlet, are lake biotic processes consuming the N? If so would this be reflected in phytoplankton increases or species shifts?

Nitrate concentrations have only increased in absolute numbers a small amount, but since nitrate concentrations are low the percentage increase is large.

Bridger Wilderness Long-Term Lakes:

Lake	Elevation(m)	Depth(m)	Area of lake (acres)
Black Joe	**3,121**	**28.9**	**80.4**
Deep	**3,218**	**27.0**	**60.5**
Hobbs	**3,083**	**18.3**	**17.3**
Upper Frozen	**3,487**	**42.9**	**23.5**

- Hypolimnion and epilimnion are only sampled during mid-season.
- Macro-inverts (inlet and outlet) and zooplankton (hypolimnion) are also sampled.
- 153 synoptic lake samples were collected on the B-T; 8 lakes were less than 25 ueq/L ANC. 33 lakes were sampled on the Shoshone NF.



Annual Trends for Long-Term Lakes

Variable (µeq/L)	Black Joe			Hobbs			Deep			Upper Frozen
	Inlet	Outlet	Hypo	Inlet	Outlet	Hypo	Inlet	Outlet	Hypo	Grab
ANC	---	---	---	---	↓**	---	---	---	---	↑ *
NH_4^+	---	↑ *	↑ *	↑**	↑ *	---	---	---	↑***	---
NO_3^-	↑**	---	---	---	---	↓*	---	---	↑***	---
SO_4^{2-}	↑ *	---	---	---	---	---	---	---	---	↑**

* = $p<0.1$, **= $p<0.05$, ***=$p<0.01$, **** =$p<0.001$

Thoughts:

- Increases in hypolimnion NH_4 means there may be some eutrophication;
- Increase ANC (increase in cations and sulfate) at Upper Frozen lake—maybe due to rapidly melting snow fields;
- In recent years, inlets have been drying up. Nitrate is elevated in Black Joe
- N and S are much higher at inlets than outlets;
- High ANC fluctuation at inlets vs outlets….represents fluctuation in snow melt;
- An N spike in inlet vs outlet meets the definition of eutrophication and represents a build-up in N entering the lakes.

Bridger-Teton Summary:

- Sulfate has been increasing (hypolimnion) since the late 90's;
- Increase in ammonium in lakes (agrees with the general increase in NH_4 deposition occurring across the western US);
- Increase in nitrate during season 3 lake sampling for Black Joe and Deep inlets;
- Overall increase in Na^+,Ca^{2+}, Mg^{2+}, and K^+ concentrations (melting of snow fields and drought);
- A decrease in Cl^- was found, most notably in the hypolimnion and outlet samples of Black Joe and Deep;
- Hobbs Lake appears to be the lake most impacted by additions of N;
- Deep Lake appears to be using additions of N (increasing in the hypolimnion).
- Both Black Joe and Hobbs lakes are showing increases in NH_4 at the outlets which may contribute to changes downstream;
- Increases in nearby oil and gas development may increase N loading;

- Sulfate and nitrogen loading are higher in lakes on the south end of the Wind River Range.

Future:

- Need to look at seasonal graphs of all hypolimnion samples to determine potential stages of saturation.
- Need to better understand what is happening to nitrates and sulfates between the inlet and outlet (what is changing?)
- Determine if ANC concern thresholds have been exceeded and work towards developing critical loads for ANC and Nitrogen for these lakes.

Resources:

Lake and Bulk Sampling Chemistry, NADP, and IMPROVE Air Quality Data Analysis on the Bridger-Teton National Forest (USFS Region 4)—(Grenon et al. 2010).

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8. Water Chemistry Data—Gallatin NF and Forest Service R1: Mark Story

In USFS Region 1 (Montana, Idaho, North Dakota) stationary source emissions are lower than the southern areas of the GYA. In USFS R1 oil and gas development is low. The largest stationary sources are in the Billings, Laurel, and Coalstrip areas but these are downwind of all USFS R1 Wilderness areas. Most of the industrial air pollution in USFS R1 consists of small local industrial and mining sources, transportation emissions, and regional transport from sources west and south west of USFS R1. USFS R1 has 13 Wilderness Areas: (7 Class I and 6 Class II) with about 2,000 lakes in these Wilderness Areas.

USFS R1 monitoring consists of 7 primary types:

- particulate matter
- visibility (IMPROVE)
- NADP
- long-term lakes (sampled once annually 1993-present) and synoptic lakes (sampled once)
- lichens
- snow
- precipitation

USGS snowpack data shows nitrate and ammonia elevated around Targhee Pass which may potentially related to Snake River Plain emissions sources (dust and agriculture).
The strong increase in ammonia at all NADP wet deposition sites doesn't show up in R1 lake sampling (but the lakes are only sampled once/year, so trends difficult to establish).

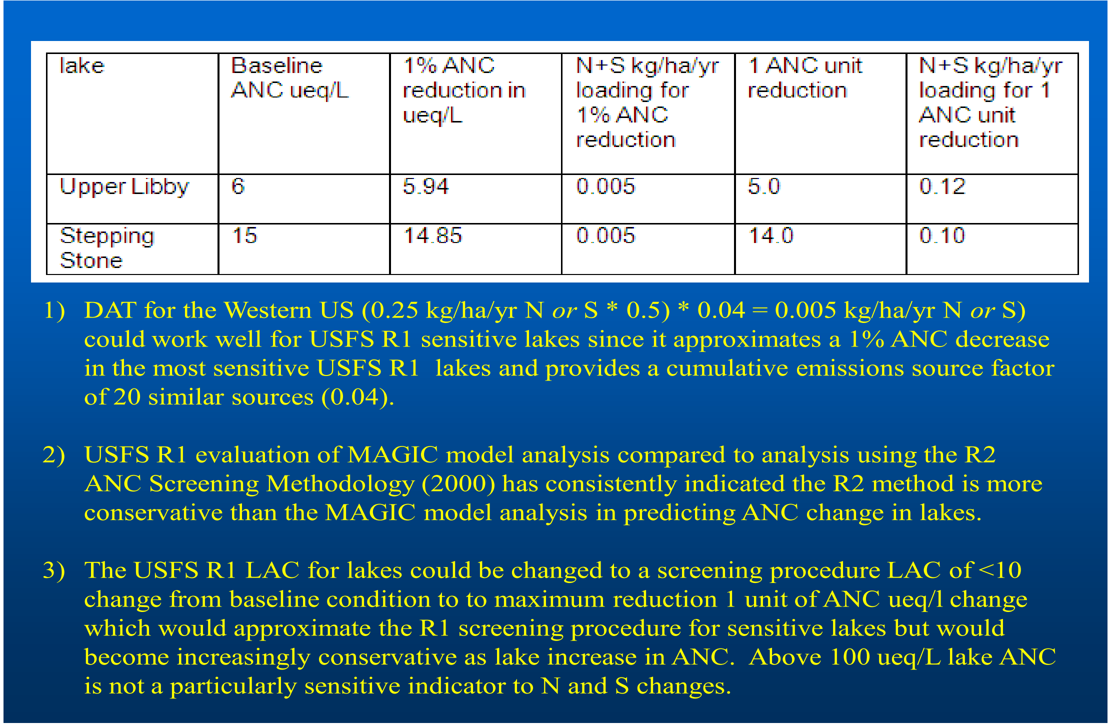
Summary:

- Trend interpretation, particularly cause/effect, is difficult and complex.
- Stepping Stone Lake in the Beartooth range showed a slight decrease in ANC (only lake that shows this) but in the past 3 years, ANC has increased in other lakes.

- Two lakes have shown an increase in pH and many lakes showed changes in cations and anions; explanation of changes has yet to be determined.
- Consistent NH_4 increase trend at all of the NADP sites. This may be partially due to increased agriculture emissions such as feedlots in E. Oregon and E. Washington
- Most nitrate levels in lakes were very low to non-detectable.
- Consistent decrease sulfate at NADP sites is consistent with US trends the last 2 decades with reduced industrial sulfate emissions.
- Consistent improvement in visibility at all of the IMPROVE sites as expressed in increased SVR, decreased deciviews, and reduced extinction. Lower visibility years correlate with high wildfire activity.

Organic levels of S and N were much lower than inorganic measured levels of S and N.

R2 ANC Screening Method is more sensitive than the MAGIC Model for allowable change.



lake	Baseline ANC ueq/L	1% ANC reduction in ueq/L	N+S kg/ha/yr loading for 1% ANC reduction	1 ANC unit reduction	N+S kg/ha/yr loading for 1 ANC unit reduction
Upper Libby	6	5.94	0.005	5.0	0.12
Stepping Stone	15	14.85	0.005	14.0	0.10

1) DAT for the Western US (0.25 kg/ha/yr N *or* S * 0.5) * 0.04 = 0.005 kg/ha/yr N *or* S) could work well for USFS R1 sensitive lakes since it approximates a 1% ANC decrease in the most sensitive USFS R1 lakes and provides a cumulative emissions source factor of 20 similar sources (0.04).

2) USFS R1 evaluation of MAGIC model analysis compared to analysis using the R2 ANC Screening Methodology (2000) has consistently indicated the R2 method is more conservative than the MAGIC model analysis in predicting ANC change in lakes.

3) The USFS R1 LAC for lakes could be changed to a screening procedure LAC of <10 change from baseline condition to to maximum reduction 1 unit of ANC ueq/l change which would approximate the R1 screening procedure for sensitive lakes but would become increasingly conservative as lake increase in ANC. Above 100 ueq/L lake ANC is not a particularly sensitive indicator to N and S changes.

The table shows the extent to which current N and S deposition would need to be reduced to meet the Forest Service's limit of acceptable change for ANC in two sensitive lakes.

Resources:

U.S. Forest Service Region 1 Lake Chemistry, NADP, and IMPROVE Air Quality Data Analysis (Grenon and Story 2009).

USDA Forest Service Rocky Mountain Region. 2000. Screening Methodology for Calculating ANC Change to High Elevation Lakes– User's Guide.

9. Lake Sensitivity to Acidic Deposition in the Rocky Mountains: GYA National Parks: Leora Nanus

Research Study - Part I:
Two key study objectives were to:

1) Develop a remote approach to identify lakes sensitive to acidic deposition; by estimating ANC using 151 lake sites in Glacier, Yellowstone, Grand Teton, and Rocky Mountain, and Great Sand Dunes:

- looked primarily at lake ANC and nitrate
- used landscape attributes from GIS
- used precipitation-scaled deposition estimates from PRISM maps
- conducted site visits to ground-truth model predictions

2) Evaluate controls on spatial distribution of nitrate more specifically the spatial distribution of isotopes of nitrogen ($\delta^{18}O(NO_3)$ and $\delta\ ^{15}N(NO_{3)})$ in lake water across the region compared to 7 co-located NADP/NTN sites.

Isotopes can help determine the source of pollutants to ecosystems. For example, $\delta^{15}N$ values are higher in power plant emissions than vehicle emissions.

Data used: GIS data--Geochemical rank map that shows buffering capacity of bedrock, topography, vegetation, soils, and nitrogen deposition (DIN), and water-quality data.

A sensitive lake is defined as a lake with an ANC <100 ueq/L. Built a model (based on above data) to predict the probability of a lake being sensitive and then did ground-truthing (with 58 lakes). For the validation data set the r-squared value is 0.93 (Nanus et al., 2009).

Summary:

- Remote approach identified sensitive lakes ANC and NO_3 (positive outcome for the model).
- Elevation had the greatest influence, also bedrock type, steep slopes, deposition.
- Areas with the highest proportion of sensitive lakes (ANC<50) are in Southern Rockies (Rocky Mountain, Great Sand Dunes and Grand Teton NPs). A lower proportion of sensitive lakes were found in Glacier and Yellowstone NPs.
- Lake NO_3 increases with increasing elevation.
- The isotopic signature of $\delta^{15}N$ of lake NO_3 correlated with higher lake $NO_{3.}$
- $\delta^{15}N$ of lake NO_3 correlated with pollutants in wetfall.
- $\delta^{15}N(NO_3)$ in precipitation and lakes increases with elevation.
- $\delta^{15}N(NO_3)$ in precipitation correlated with emissions.
- $d^{18}O(NO_3)$ data doesn't point to direct atmospheric source of N.

The $d^{18}O(NO_3)$ result doesn't correspond to other atmospheric deposition data, possible explanations for the result could be:

- Enhanced N cycling may occur because of increased N deposition;

- More N deposition may be present at higher elevations;
- Less vegetation may exist at higher elevation;
- Less dissolved inorganic nitrogen (DIN) assimilation may occur at higher elevation;
- All these factors increase net nitrification

The study tested the probability that each of the 151 lakes would have <5ueq/L NO_3 concentrations. A lake threshold of <5 ueq/L NO_3 was used –not too many biotic effects have been documented in other studies at this level.

Research Study Part II: Mapping Critical Loads in the Rocky Mountains (includes Wilderness areas)

Approach used:

- Inorganic Nitrogen (IN) deposition mapping.
- Modeling (Empirical): Predicted surface water nitrate concentrations at coarse (Rocky Mountain region) and fine (Rocky Mountain National Park) scales (used basin characteristics and N deposition).
- Identify threshold nitrate.
    1- For surface water.
    2- By relating nitrate to lake diatom community structure and identifying the concentrations at which diatom species shifted.
- Mapping critical loads of N and exceedances.

530 surface water sites, northern New Mexico to Canadian border.
Used snowpack, NADP, and PRISM data to create IN deposition map (Kriged data).

Predicted surface water nitrate is <3 ueq/L in over 95% of region but some areas had predicted nitrate > 10 ueq/L. Important explanatory variables were Inorganic N deposition, % catchment barren, and mean slope.

Used two approaches to define CL from diatoms:
Results:
Tested four different nitrate thresholds to estimate CLs and exceedances (0.4 ug/L; 1ug/L; 1.6 ug/L; 2ug/L).

Predicting historical lake water NO_3 from diatoms in lake sediments does not look promising for the Rockies, due to switch from N to P limitation in lakes and its effect on diatom communities.

Summary: Lowest N CL occurs at high elevations and the highest critical loads exceedance values occur at high elevations.

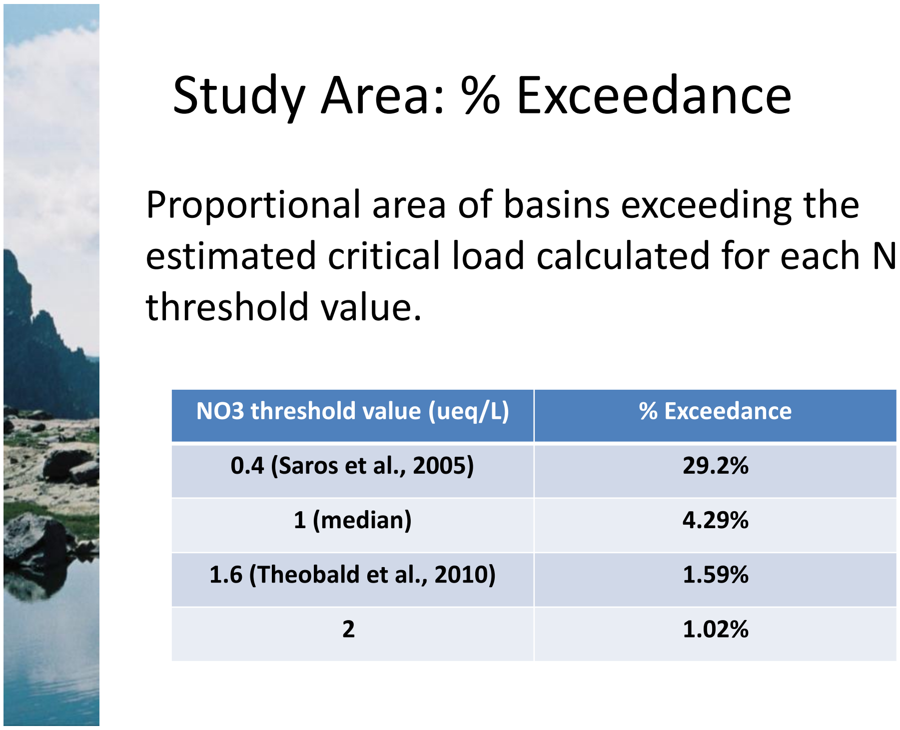
Limitations:

- Critical loads and exceedance estimate are very sensitive to:
    (1) Variability in basin characteristics
    (2) Different NO_3 threshold value at which ecological effects are thought to occur (see slide below)

- Uncertainty in NO_3 threshold value propagates directly to critical loads estimate;
- Uncertainty in inorganic N deposition value affects the critical loads estimate;
- Coarse scale analysis does not capture fine scale landscape features;

% Exceedance = the proportional area of basins exceeding the estimated critical load calculated for each NO_3 threshold value in the Southern, Central and Northern Rocky Mountain Study Area.

Preliminary estimates are shown in the table below:



Study Area: % Exceedance

Proportional area of basins exceeding the estimated critical load calculated for each NO_3 threshold value.

NO3 threshold value (ueq/L)	% Exceedance
0.4 (Saros et al., 2005)	**29.2%**
1 (median)	**4.29%**
1.6 (Theobald et al., 2010)	**1.59%**
2	**1.02%**

Recommended Future Directions:

- Develop critical loads and exceedance maps of N for the GYA at finer spatial and temporal resolution;
- Evaluate seasonal variability in lake sensitivity;
- Evaluate influences of climate change on hydrologic and biogeochemical processes;
- Continue long-term monitoring;
- Initiate wet and dry deposition monitoring in Grand Teton National Park;
- Determine nitrate sources-direct (deposition) and indirect processes;
- Develop deposition maps of additional pollutants and at finer spatial and temporal resolution.

Discussion/Questions

Can you jump from water threshold to catchment threshold which includes terrestrial? So maybe elevation effect is more of a function of flora density?

Resources:

- Nanus, L., Williams, M.W., Campbell, D.H., Tonnessen, K.A., Blett, T., Clow, D.W., [2009]. Assessment of Lake Sensitivity to Acidic Deposition in National Parks of the Rocky Mountains, *Ecological Application*s 19, 4, 961-973.
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- Nanus L., Campbell, D.H., Williams, M.W., [2005]. Sensitivity of Alpine and Subalpine Lakes to Acidification from Atmospheric Deposition in Grand Teton and Yellowstone National Parks, Wyoming, *USGS Scientific Investigations Report 2005-5023.*
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- Nanus, L., Clow, D.W., Stephens, V.C., Saros, J., [2010]. Mapping Critical Loads of Atmospheric Nitrogen in the Rocky Mountains, USA, *Eos Trans. AGU, Fall Meet. Suppl., Abstract B43C-0475.*
- Clow, D.W., Nanus, L., Huggett, B., [2010]. Use of Regression-Based Models to Map Sensitivity of Aquatic Resources to Atmospheric Deposition in Yosemite National Park, *Water Resources Research, 46, W09529,* doi: 10.1029/2009WR008316.
- Nanus, L., and Clow, D.W., [2004]. Sensitivity of Lakes in Wilderness Areas in Oregon and Washington to Atmospheric Deposition, *U.S. Department of Agriculture Forest Service, Region 6, Administrative Report.*
- Saros, J.E., Michel, T.J., Interlandi, S.J., Wolfe, A.P., 2005. Resource requirements of *Asterionella formosa* and *Fragilaria crotonensis* in oligotrophic alpine lakes: implications for recent phytoplankton community reorganizations. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 1681-1689.
- Theobald, D.M., Baron, J.S., Newman, P., Noon, B., Norman, J.B., Leinwand, I., Linn, Sophia E., Sherer, R., Williams, K.E., Hartman, M., 2010. A natural resource condition assessment for Rocky Mountain National Park, Natural Resource Report NPS/NRPC/WRD/NRR – 2010/228, National Park Service, Fort Collins, Colorado.

10. USFS Watershed Condition Framework and CLs: Ann Mebane

The 2006 Budget review said that the FS lacked a nationally consistent approach to prioritizing watershed improvement, so FS implemented a mandatory watershed condition framework.

The Framework is based on HUC (Hydrologic Unit Code) for every 6th level (12 digit) watershed that contains FS lands.

Two aquatic indicators used related to deposition were: ANC and NO_3-N. Dissolved organics is a big factor in lake chemistry in some regions and ecosystems, so used DOC as a screen in ANC (DOC of 5% or greater may mean lake is naturally acidic).

class I: good (ANC >= 50)
class II: moderate (ANC between 20-50)
class III: poor (ANC <20 ueq/L)

Water Quality Indicator for N: If NO_3-N <= 2 µeq/L (west) or <= 4 µeq/L (east) – Condition Class = 1 (Good). If NO_3-N >2 µeq/L and <20 µeq/L (west) or >4 µeq/L and <20 µeq/L (east) – Condition Class = 2 (Fair). If NO_3-N >20 µeq/L and not naturally nitrified due to spp. like alder - Condition Class = 3 (Poor)

Lakes were rated for ANC and rated for nitrate based on numbers above and then the lower rating was used to rate the HUC overall.

If we had good local CL than we could use a percent change in the HUC as a measure of condition class. For example (using different classes):

- Good >10% above critical load
- Fair between CL and 10% above CL
- Poor below CL

Forests are directed to use site-specific CLs if they have them.

FS and USGS data were available for about 1/3 of HUCs nationwide—used minimum ANC values measured in each HUC and used max N from nitrate regardless of season. Note that these two measures only affect 5% of the overall HUC watershed condition score.

Incorporating Air Pollution Impacts into the Watershed Assessment Process (PART) using Deviation from the Critical Load to determine condition of the Air Quality Indicator *.

*Other measures could be used until Critical Loads are developed for all areas.

FS Watershed Condition & Critical Loads – Where we want to end up…

WATERSHED ASSESSMENT PROCESS
DEVIATION from CRITICAL LOAD determines condition of the WATER QUALITY INDICATOR

CRITICAL LOADS DEVELOPED (AND REFINED)

Acidification or Nitrogen enrichment

CALCULATE DEVIATION from CRITICAL LOAD

Use current or projected future deposition.

July 2, 2009

Limitations:

- Limited number of sites and samples in each HUC – 10,000-40,000 acres is BIG!

- Very conservative approach of using lowest ANC/highest NO_3-N, but, some thresholds may be too high for some areas.
- Sampling seasons and years varied – spring vs fall - may be major difference, particularly in NO_3-N measurements.
- Same set of thresholds for lake vs. stream chemistry.

Discussion/Questions:
Is 50 ANC too low? Should we use 75 or 100….many of the waters tested have naturally low ANC.

Flow chart (above) will be updated in the future, it was an initial thought process.

11. Atmospheric Deposition of Reactive Nitrogen (Nr) on Diatom Community Composition in the Alpine Lakes in the Grand Teton National Park: Megan Otu

Nr = reactive N (inorganic N such as ammonium and nitrate)
non-reactive N (fixed N2 gas)

The annual diatom biomass in alpine lakes is typically highest during spring snowmelt because the majority of diatom growth occurs during spring in temperate lakes.

Why diatoms

- represent a type of algae found in almost all aquatic ecosystems,
- short life-span
- diverse ecology
- highly responsive (changes in community composition can be documented)
- cell walls are preserved in sediments
- respond strongly to Nr deposition as recorded in sediment cores.

N, P, and Silica are key nutrient to diatoms, so species compositions change with competition for resource of available N and P.

There are weedy diatom species (*Asterionella formosa and Fragilaria crotonensis*) that can take over and outcompete other species when excess nitrogen is present.

Over time diatom communities change with climate naturally, but changes in community can be induced or sped up with increases in anthropogenic pollution. Thresholds of 5% of relative abundance for these ―weedy" species have been used by researchers to assess change in diatom species composition that can be used to develop critical loads.

Naturally, the element N occurs with variability in the # of neutrons (^{15}N & ^{14}N). This makes the element have two different potential atomic weights, and each form of the element will react slightly differently in the environment. The ratio of ^{15}N to ^{14}N naturally occurring in the atmosphere is known, while anthropogenic processes (e.g. manufacturing of fertilizer, coal burning) changes the ratio.

Nitrogen isotope ratios (the ratio of ^{15}N to ^{14}N is expressed as ―δ^{15}N”) can be assessed in environmental samples such as sediments to help determine where the N came from:

- In RMNP, δ^{15}N values reflect anthropogenic N from sources that are frequently depleted in δ^{15}N relative to natural sources
- δ^{15}N of fossil fuel NOx is highly variable (−7 to +12‰)
- δ^{15}N of NH_3 from coal combustion (−10 to 0‰)
- δ^{15}N of nitrate and ammonium fertilizers (−3 to +3‰)
- δ^{15}N of ammonia volatilized from confined animal feeding operations is substantially more depleted (−15 to −9‰)

The Grand Teton NP (GRTE) study:

- This study has been going on for about 9 months.
- It spans 3 alpine watersheds in GRTE NP (east-side lakes include: Grizzly, Holly, Whitebark Mtn, Ramshead, Lake of the Crags, Delta, Amphitheater, and Surprise lakes)—all waterbodies have low conductivity, ANC <100, are circumneutral, have elevations around 2,800m, and identified as Nr deposition sensitive.
- There are a lot of different N species and a range of N budgets in the lakes that make up the total N—ammonia is very poorly measured because of uptake.

Can summarize sediment cores by *Fragilaria crotonensis* concentration presence---look for eutrophication trend over time, and exceedance of the 5% threshold. Look at C and N burial when species increase as a sign of eutrophication.

Look at total N to total P ratios (TN:TP) and compare nutrient ratios in order to assess whether lakes are N or P limited. When lakes are exposed to long term anthropogenic inputs of N, they can shift from N limitation to P limitation (Elser et al 2009). If lakes are no longer N limited (N saturated), then diatom work to assess changes due to N may not work.
P is now becoming limited at some high alpine lakes which is surprising. P is generated by weathering. P limitation is likely driven by increase in N deposition (Elser et al 2009).

Summary:

- All the lakes in GRTE show δ^{15}N depletion (a decrease in the ratio of ^{15}N to ^{14}N)
- As nitrogen deposition to sediment increases, the depletion of δ^{15}N in lake sediment records of 4 GRTE lakes also increases (Holly, Amphitheater, Ramshead and Grizzly), indicating that anthropogenic inputs are occurring.
- Each of the seven lakes have different watershed characteristics, and the biotic response to anthropogenic N varies in response to these characteristics.
- Increased primary production (↓ C:N), a symptom of eutrophication from nutrient inputs that sustain greater algal biomass (↑[C], [N]) (but benthic algae are prevalent throughout GRTE, so they may not be good indicators here).
- Inputs of anthropogenic emissions (↓δ^{15}N) to these lakes with greater TIN (NH_4) deposition at the Wyoming NADP sites.

- Holly lake is one of the 7 lakes that appears to be N limited based on N:P ratio. Data for Holly lake also shows an increase in *Asterionella formosa* since 1989, this may be an early warning of nutrient enhancement effects in the lake (same response as lakes in Rocky Mountain NP).
- All lake sediment cores show a shift in δ^{15}N since 1970 and all sediment cores show trend of increasing N.

Future and thoughts:

Future research could involve creating diversity index = benthic : planktonic ratios (indicator doesn't have to be the dominant species). Still need to measure P so that you get an N:P ratio. Conduct trace metal analyses and tree ring analyses.

Resources:
Elser et al 2009
Saros et al 2010
Wolfe et al 2003

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12. GYA Macroinvertebrates: Response of Benthic Communities to Changes in their Environment: Brett Marshall

Benthic macroinvertebrates (the most diverse assemblage in the world)

Why macroinvertebrates?

- High diversity (800,000+ species)
- High abundance / density (can remove without decimating a population)
- Very important ecological roles
- Many aspects of ecosystem function represented.
- Real-world consequences
- Very short generation time (most annual 10 days to 5 yrs)

Cons:

- Down-side is that the species taxonomy can be confusing, how do you sort out change in species/community, what changes are a red flag and what is not?
- They are soft and sometimes they get beat up in collection and can't be id'ed to species (just family)…also can't id when really mature.

To assess change and impacts to macroinvertebrates, recommend categorizing species into roles:

1) collector-gatherers
2) collector-filterers
3) scrapers
4) shredder-detritivores
5) shredder-herbivores
6) macrophyte piercers
7) predator-engulfers
8) predator-piercers

Can use food web to piece together how one would expect these communities to change over time, or change with additions of excess N.

Would expect a net increase as food (nitrogen or species that consume it) increases, but may hit a net threshold where may get problems.

Lakes are nutrient sinks so when lakes start reaching saturation then outlets show concentrations of nutrient particles increase and changes occur in presence of different inverts role groups. For example, as N loads increase, green algae increases, and benthic community changes can occur.

B-T long-term lakes:

- The specimens were collected at the inlet and outlet of the lakes (zooplankton has also been collected).
- Lake ecosystems are different from streams in that most of the biological production is planktonic.
- Export of plankton to river outlets (or from impoundments) contains plankton concentrations proportional to the concentration of plankton in the lake.
- Collector-filterers often become more dominant in streams receiving significant flow from lentic sources.
- As nitrate loads increase filamentous green algae become more prevalent.
- Macroinvertebrates that eat green algae becomes prevalent over scrapers.
- Collectors (both gatherers and filterers) may dwell in the physical habitat provided by tufts of filamentous green algae.
- Macroinverts from B-T long-term lakes (2009) are almost all –collector-gathers” at both inlets and outlets.
- May need to key samples to species instead of to sub-family to adequately assess the samples taken and characterize them into appropriate role groups.
- No predatory midges present in B-T 2009 samples.

Net abundances of role group may be important way to assess the existing data sets.

In Green River—variation in macroinvertebrates have been decreasing 4 years in a row 2000-2004…but could be due to natural variation and response…was it drought, was it velocity change? Can’t say much about this data on a short time scale.

So many variables affect macroinvertebrate communities—(e.g. if stream velocity changes then you are going to see a change in community). So need to do a careful job of teasing out the impacts that may be related to atmospheric deposition.

Recommendations—

- Since macroinvertebrate species/role groups sensitive to low ANC and high NO_3 are known, existing data should be assessed to look at patterns in these species/role groups and check for correlations with stream chemistry data.
- Collect covariates, finer taxonomic ID, scale of other measurements.

13. Discussion- Aquatic Biota Threshold and Critical Loads: All

Developing CL for aquatic eutrophication:
Agencies in the GYA will need to look at lake chemistry data from the B-T and Shoshone and compare it to existing NO_3 thresholds (see Nanus talk). If thresholds are exceeded then just need to establish deposition loading currently (or in the past, if thresholds exceeded some time ago) at the site. Be sure to convert mg/l to ueq/l so working in same units --16.13 x mg/l NO_3 = ueq/l.

GYA lakes appear to be well over NO3 thresholds for all except the Beartooths. (> .4, 1.0, 1.6 and 2ueq/l used in Nanus research).

The rate of lake chemistry change in ANC and NO_3 in Wind River Range lakes is fast (significant trends have occurred over the past 20 years).

GYA Lake Chemistry Data Summary Compared to Existing ANC and NO_3 Thresholds:

Site	**ANC Sensitivity**	**<ANC**	**NO_3 & NH_4 Trend**	**NO_3 concentration***
Hobbs	60-80 mg/l, >50 ueq/l	<	> NH_4 (0&i)	.35 mg/l, 4.2 ueq/l
Black Joe	70-100 mg/l, >50 ueq/l	-	> NH_4 (o&h)	2.24 ueq/l
Deep	70-90 mg/l, >50 ueq/l	-	> NH_4 &NO_3(h)	.25 mg/l
Upper Frozen	10-20 mg/l, <20 ueq/l	-	-	4.6 ueq/l
Lower Saddlebag	60 mg/l, > 50 ueq/l	< (e,h,i,o)**	>NO_3 (i)	.7 mg/l
Ross	50 mg/l, >50 ueq/l	< (e,h,i,o)	>NO_3 (i)	.4 mg/l
7 GRTE lakes	Avg = 100 meq/l 3/7 = < 50 ueq/l 5 lakes < 50 ueq/l 28% of lakes < 100 ueq/l	?	?	Avg = 5 ueq/l and .4 ueq/l
YELL Lakes	Avg = 200 meq/l	?	?	Avg = .2 meq/l
Absaroka Beartooth lakes	37 lakes, avg = 83 mg/l 6 < 50 ueq/l 2 < 25 ueq/l Stepping Stone lake	< at Stepping Stone lake	NH_4 & NO_3- no trends	0-25 ueq/L Avg=0.2ueq/L
Regional GYA	>50% = < 100ueq/l	?	?	.03-.18 mg/l .55-2.55 ueq/l
Wind River Reservation lakes	?	?	?	?

*Compare to NO3 thresholds of 0.4, 1.0, 1.6, & 2 ug/L used and published by Nanus in her research

** e= epilimnion, h= hypolimnion, i=inlet, o=outlet

Aquatic Biota Gaps and Needs:

1. Need additional data to **develop GYA-specific diatom thresholds related to N** deposition:
   - GRTE – sediment cores/diatoms are being collected as part of Spaulding/Otu research project, so more data should be available soon at GRTE.
   - YELL – lots of existing cores that could be reanalyzed for diatoms (Whitlock) (Low NO_3 and fire may confound this analysis).
   - B-T – Existing sediment cores could be reanalyzed for diatom species shifts (USGS & Nigel).
   - Shoshone – some sediment cores may exist.
   - Absaroka Beartooth cores were previously collected and assessed for diatoms and published- Saros, 2005).

Comments:

- Consider adding $^{15}N + ^{13}C + C + N$ analyses ($8.00/sample at UC Davis) if cores are reanalyzed for diatoms.
- Need to know how thinly the sediment is sliced...how many years of atmospheric deposition does it represent?

2. Could **use additional chemical indicators for assessing effects of deposition** on aquatic biota:
   - C:N (Carbon to Nitrogen ratio, measured as particulates in sediment).
   - N:P (Ratio of Total N to Total P). Threshold is > 60 (units) seasonally. Ratios greater than this number mean that waters are no longer N limited (and therefore would not be as useful for diatom studies assessing response to N).
     - Do have TN and TP data for GRTE lakes (Leora)
     - Don’t have TN and TP data for FS lakes
     - –One time” samples would be okay to determine TN:TP status.
     - Could look at TN:TP for EPA’s Western Lake Survey 1985 samples.
   - Lake benthic grab samples for biota (Mast/Saros) This would show current biota to relate to water NO_3 samples. Look for eutrophication with changes in autotrophs becoming planktonic.

3. **Macroinvertebrates – Gaps &Recommendations:**

   B-T and Shoshone have 25 years of macroinvertebrate data that has not been adequately interpreted. We need to:
   - Get taxonomic data from early years@ B-T and Shoshone (Fred Magnum’s data) assess data quality.
   - Assess 25 years of data and interpret it (macroinvertebrates and plankton). Define baseline and changes over time and assess relationships to water chem. data.
   - Add extra replicate samples where current monitoring is occurring so you can do a variability analysis (5 reps/site is recommended).
   - Ask the Bug Lab to re-examine samples of midge heads to determine the genus.

4. **Discussion – Next steps needed:**

- Analyze sediment cores that are available for diatom species shifts in N limited lakes (USGS, Nigel, 1980’s Maine study);
- Check with Kathy Whitlock for Yellowstone cores (MSU). N is low in Yellowstone, so it may not show anything. Old cores are likely already dated, and diatom change work is relatively fast;
- Collect more sediment cores in N limited lakes and assess diatom changes;
- Obtain expertise to assess existing macroinvert data for Shoshone & BT and recommend any programmatic changes needed:
  - Replication of samples/covariant analysis.
  - Review old data.
  - Look at archived data (midge heads) to better characterize species.
  - B-T data should be reviewed to develop a baseline and show changes.

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14. Terrestrial Critical Loads Using Lichens: Linda Geiser & Jill Grenon

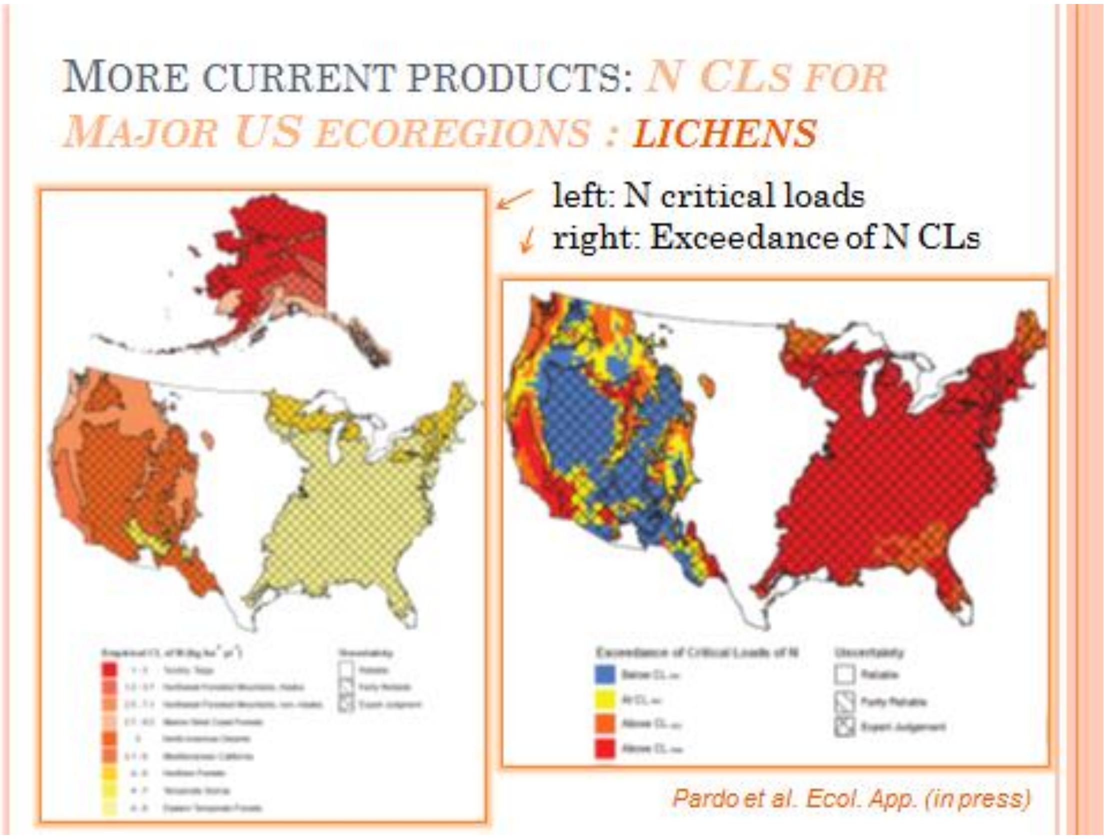
Lichen from low nitrogen sites (oligotrophs) tend to be foliose, pendant types of lichen. Eutrophic (high nitrogen) species tend to be crustose types of lichens.

Lichen are important in ecosystems because they support ecological linkages to wildlife (e.g. the flying squirrel relies on one species of oligotrophic lichen for 50% of its food needs; and the spotted owl feeds on the flying squirrel). Lichen are also used for dyes, art, food, and have microbial properties.

Excess nitrogen can change the proportion of oligotrophic and eutrophic species in ecosystems. These changes can be linked back to air pollutants by using ―air scores” which rely on a variety of existing air quality data sources and models.
Good regressions exist between CMAQ, NADP, IMPROVE and lichen response (.35, .64, .93 respectively). Throughfall monitoring provides the best correlations with lichen response, but they can be labor intensive and expensive. The air scores provide a method to identify a critical level beyond which N deposition becomes a concern, and lichen species begin to shift.

A new study is about to be published (Sarah Jovan) which shows stronger correlation with lichen response and oxidized forms of N (e.g. NO_3) than reduced forms (e.g. NH_4).

A critical load of 3 has been used in the western US as the point at which lichen begin to respond to N excess. 5 kg/ha/yr is the threshold marking a general shift from oligotrophic species to eutrophic species, and 10 kg/ha/yr is the thresholds for extirpation of oligotrophic species.



MORE CURRENT PRODUCTS: *N CLS FOR MAJOR US ECOREGIONS* : *LICHENS*

left: N critical loads
right: Exceedance of N CLs

Pardo et al. Ecol. App. (in press)

These critical load values suggest that much of the GYA may be within 1kg/ha/yr of being at a critical load concern. Grenon's MS thesis will provide useful information for CL determination specific to the GYA.

15. Terrestrial Critical Loads using Alpine Plants: Bill Bowman

Monitoring of alpine plants is a good option for assessing N deposition increases and establishing critical loads, e.g., changes in species abundance. These changes are related to eutrophication rather than acidification. Different species of grasses and sedges respond differently to nitrogen additions. Carex rupestris seems to be highly responsive species to N in the Rockies.

Research in the Colorado Rockies suggests a critical load of 3-4kg/ha/yr (based on research at Niwot Ridge and Rocky Mountain NP) may be a good choice for initial alpine plant species responses to excess N. Responses to nitrogen at the plant community level tend to occur around 10 kg/ha/yr (based on the same research). Soil nitrate leaching critical load may be more like 15-20 kg/ha/yr. Colorado Front Range alpine plant CLs (3, 10 and 15kg/ha/yr, depending on which ecosystem response is being assessed) are probably reasonable for GYA acid sensitive bedrock areas.

Acidification is also a concern in the Colorado Front Range. Some episodic acidification (temporary depression of ANC below zero) has been documented at some high elevation site at

Niwot Ridge, where deposition is high (6-8 kg/ha/yr). Currently seeing signs of soil acidification at Niwot Ridge (soil pH is decreasing) and mobilization of Al from soils (Al is increasing). These are signs that acidification is beginning to occur at Niwot. However acidification has not been documented at Rocky Mountain NP, where current deposition is around 4 kg/ha/yr.

Estimates of N critical loads in the alpine:

Amount: (kg ha^{-1} yr^{-1})	Source:	Basis:
4-10	Bowman et al. 2006	vegetation change (NWT)
3	Bowman et al. in prep	vegetation change (ROMO)
15-20	Bowman et al. 2006	soil NO_3^- leaching
4 *	Williams & Tonnessen (2000)	surface water chemistry
1.5*	Baron (2006)	hindcasting analysis
3-4	Baron et al. (1994)	CENTURY model (N leaching)
10-15	Bobbink et al. (2002)	vegetation change

*wet deposition only

Recommendations for GYA:
Monitoring soil pH may be an option for monitoring N deposition susceptibility. Perhaps magnesium too. Soil chemical metrics (base cations, C:N ratios, etc) should be pursued.

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16. Discussion- Terrestrial Biota Threshold and Critical Loads: All

Lichen CL increases with elevation while plant CL decreases. So may want to develop a gradient CL. Bottom line is 3-6 kg/ha/yr appears to be the magic number when N response occurs.

Terrestrial Biota Gaps and Needs:

- We can apply existing critical loads for lichen and alpine plants in the GYA now (and refine it later).
- Pardo's critical loads GTR and monograph has a list of variables that can be used now to fine tune critical loads for new areas (e.g. soils).
- Need to have a critical loads for a variety of indicators in the GYA.

Refining terrestrial critical loads in the GYA:

- Lichen work is ongoing (Grenon/Geiser) in much of the GYA. (gradients, FIA, Bridger), so nothing needed other than continue to support this work.
- Alpine plant responses in the GYA could use more analysis:
    - Verify GYA critical loads (Helga VanMegroet). Is there a north to south gradient? Explore further to keep climate change separate.
    - Collect grab samples of soils and plants along the north to south gradient.
    - Explore deposition gradient in the Wind River Range (Expect to see higher N on south end of the Range).
    - Explore connections to other projects.
        - Alpine plots. (e.g. Gloria-Ashton's work)
        - Idaho State – Alpine plant monitoring in YELL.

Terrestrial Thresholds and Critical Loads- What is Needed Next:

- Look at soil sensitivity.
- Look at C:N, N:Mg, and N:Ca in plants and compare to known thresholds.
- Jill Grenon's lichen model for GYA should be helpful when project is complete.
- Look at Helga VM's gradient for N deposition. Limited data shows lower deposition and N loading in plants and soils in south GRTE and higher in the north GRTE (but need confirmation, since only a few sites were used).
- In developing an N deposition gradient try to keep the variables as constant as possible (except for deposition).
- We need better N deposition monitoring and validation of CMAQ modeled deposition for high elevation sites in GYA where impacts are beginning to occur.

Breakout Groups – Day 2

Objectives

Two breakout groups (1) Aquatic chemistry and biotic effects and (2) Deposition and terrestrial ecosystem effects; were formed to discuss seven questions (below) and provide answers to the extent possible from the existing data.

Group 1- Aquatic Chemistry and Biotic Effects

The aquatic chemistry and biotic effects discussion was led by Mark Story. Group participants were Ann Mebane, Brett Marshal, Megan Otu, Greg Bevenger, Leora Nanus, Ted Porwoll, Debbie Miller, Sue O'Ney, and Jill Webster.

Overall conclusions the group felt that could be made from the aquatic information presented in the workshop are that:

- Lakes in the Wind River Range are currently being affected by air pollutants;
- The Snake River flood plain area may be producing pollutants (NH_3) impacting lakes in the Grand Teton NP;
- A single critical loads number doesn't work, a range of CL linked to elevation will be needed for the GYA;
- Macroinvertebrate data from the Bridger-Teton NF is not currently well-understood, existing data needs additional analysis;
- Nitrogen critical load is more important than ANC critical load (eutrophication will impact aquatic biota first).

Group 2- Deposition and Terrestrial Ecosystem Effects

The Deposition and Terrestrial ecosystem effects discussion was lead by Terry Svalberg. Group participants were Bill Bowman, Linda Geiser, Kristi Morris, Jill Grenon, Roy Renkin, and Cara Keslar.

Overall conclusions that could be made from the deposition and terrestrial information presented in the workshop are that:

- Data shows much of the GYA is already impacted or on the verge of impacts from atmospheric deposition;
- There are lots of data on deposition and sensitive ecosystems in the GYA;
- Evidence suggests ecosystem effects are already occurring, so the next step is to link the deposition data to the ecosystem data to develop good critical loads estimates.

Workshop Questions: What can we conclude about thresholds and critical loads in the Greater Yellowstone Area?

1. What can we conclude overall from the GYA data presented here?

- Surprising how much combined data there is between all the agencies; spanning deposition as well as impacts to aquatic and terrestrial ecosystems.

- Data suggests that critical loads across much of the GYA is ―on theverge of being exceeded, ecosystems may be threatened or already impacted."
- Majority of CMAQ modeling indicates most GYA sites are currently at 1.5 to 3.0 kg/ha/yr N (where critical loads have been established in other ecosystems) Other deposition data supports this.
- Regardless of actual trajectory, having good CL estimates is key since evidence suggests impacts.

2. Are there existing thresholds which we can apply now to the GYA data?

- Yes and need better deposition values based on on-going monitoring not just CMAQ.
- Need to prioritize areas of focus based on ―suspected impacts" (hot spots).
- Yes, and can initiate this process by making a map using projected critical loads and thresholds from Pardo's General Technical Report, regional lake data, bulk deposition data, NADP data and CMAQ (wet). Other resources to use are:
    - CMAQ database (and IER/Throughfall collectors)
    - HUC Lichens (Weight of evidence)
    - Diatoms (actual and regional) (NADP, BULK, CMAQ wet)
    - Alpine plants data
    - Other indicators as described in Pardo's GTR.
- Identify sensitive lakes (ANC) and use to prioritize use of IGR (deposition collection) tubes.

3. Can critical loads be developed easily for any existing data sets?

- Lichens (easy)
- Alpine plants (maybe) (use Helga Van Miegroet's data?)
    - Add 1 experimental site for alpine plant N fertilization (see Q5)
- Soil chemistry data (Bridger-Teton NF – maybe)
- Geology maps
- Plant classification (EUI)

4: Is there existing data that can be extrapolated or critical loads that can be calculated for new areas based on what we know now?

- YES (refer to questions 2 and 3)
    - Extrapolated data reliability is somewhat lower.

5: Where are there key gaps in GYE aquatic or terrestrial ecosystem data for which critical loads should be developed?

- (1st priority) Lichens
- (1st priority) Data integration
- (2nd priority) Deposition at sites (include clean and polluted as identified from map in Q 2)
- (2nd priority) Experimental plots for plant response
- (3rd priority) If we can, identify gradients in:
    - Subalpine forests (soils and trees)
    - Foliar N
    - Organic horizon N (Thickness of O horizon and C:N ratio of soils)

    - Base cations
    - Net mineralization/soil transformation
- (3rd priority) Ectomycorrizal community structure
- (3rd priority) Other forests (Montane)

6: What are the highest priorities for filling gaps in the next 3-5 years?

- See ratings for emphasis in response to question 5.
- Depends on resources and availability of willing hands/experts.

7: What GYA agency actions, planning steps or processes are needed in the next 3-5 years to make use of critical load science in future policy and decision making?

- Figure out how to integrate information to present to management.
- Budgeting up front and communicating issues is important.
- Continue monitoring
- Continue developing critical loads
- Convince Agency (FLM...GYACAP, GYCC, GYA) there is a problem and action should be taken (meet bi-weekly for discussions?)
- Then with FLM on board, go to others (DEQ, EPA....) and educate to get on board with concerns.
- Communication is a gradual process. Plan on participating in meetings (FLF, GYCC, GYA, GYACAP....)
- Website /marketing of –Critical Loads” (private and public access?)

How to move forward from today?

1. Task group to get together to identify information (local and extrapolated) to present to FLM leadership.
    a. Emphasize negative consequences/urgency while being site specific.
2. Goal of first item is to get support from upper level management to fund additional monitoring and critical load development.

Attachment 1: Participant List and Contact Information

Greater Yellowstone Ecosystem Atmospheric Deposition and Effects Workshop - Participants List

April 5-6, 2011

Jackson, WY

First	Last	affiliation	role	email
Greg	Bevenger	Shoshone NF, Wyoming	Shoshone AQRVs and LT monitoring	gbevenger@fs.fed.us
Tamara	Blett	National Park Service Air Res. Div.	National critical loads & CLAD	tamara_blett@nps.gov
Bill	Bowman	Univiersity of Colorado Boulder	Alpine plant critical loads in the Rocky Mountains	william.bowman@colorado.edu
Linda	Geiser	Siuslaw NF, Oregon	Lichen critical loads national expert	lgeiser @fs.fed.us
Jill	Grenon	Bridger Teton NF, Wyoming	Bridger Teton lichens	jgrenon@fs.fed.us
Cara	Keslar	State of Wyoming	Air Quality monitoring	ckesla@wyo.gov
Ann	Mebane	USDA Forest Service	FS Watershed Condition Assessment Thresholds & CL	amebane@fs.fed.us
Debra	Miller	USFS R2	FS Region 2 overview	dcmiller@fs.fed.us
Brett	Marshal	River Continuum Concepts	Macroinverts	brett@rivercontinuum.org
Kristi	Morris	National Park Service Air Res. Div.	Deposition monitoring and NADP	kristi_morris@nps.gov
Leora	Nanus	San Francisco State Univ (formerly USGS)	Rocky Mountain aquatic ecosystem sensitivity to atm dep	lnanus@sfsu.edu
Sue	O'Ney	Grand Teton NP	Grand Teton Natural resource program manager	susan_o'ney@nps.gov
Megan	O-Tu	University of Colorado- Boulder	Post-doc Grand Teton NP lake/diatom project	megan.otu@gmail.com
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Bret	Schichtel	National Park Service Air Res. Div.	Atmospheric Transport Assessment Study in GRTE	schichtel@cira.colostate.edu
Mark	Story	Gallatin NF, Montana	Gallatin AQRVs, modeled CL for water	mstory@fs.fed.us
Terry	Svalberg	Bridger Teton NF, Wyoming	Bridger Teton AQRV prog manager	tsvalberg@fs.fed.us

Attachment 2: Final Workshop Agenda

Greater Yellowstone Ecosystem Critical Loads Science Workshop
April 5-6, 2011
Spring Creek Ranch
1800 N Spirit Dance Road
Jackson, WY

FINAL AGENDA (as of 3-30-11)

Objectives:

Critical loads are an emerging approach within the U.S. for quantifying the levels of air pollution deposition at which sensitive components of ecosystems are impacted. Critical loads are increasingly being used in agency planning (NEPA, Forest Plans) and regulatory processes (PSD, NOx and SOx draft secondary standards). This two day workshop will focus on the science side of critical loads development, in anticipation of future policy and management applications for critical loads in the Greater Yellowstone Ecosystem (GYE). It will bring together a small group of state and federal agency staff, along with scientists working in the Greater Yellowstone area (National Park Service, US Geological Survey, US Forest Service, US Fish & Wildlife Service, US Environmental Protection Agency, Bureau of Land Management, State of Wyoming, State of Idaho, State of Montana) to:

5. **Develop** a common understanding of current GYE data describing the deposition and effects of air pollutants (nitrogen and sulfur); including trends, comparison to impact thresholds for aquatic and terrestrial ecosystems, and available modeled or measured critical loads (CL);
6. **Discuss** whether we can estimate threshold exceedances and/or CL for new areas in GYE based on existing deposition and ecosystem data. Also assess where uncertainty may be too high to do so;
7. **Identify** where gaps in knowledge exist for GYE thresholds and critical loads, and prioritize information needed to develop thresholds and CL in the next 5 years;
8. **Discuss** what agency planning steps or processes may be needed in the future to make use of CL science in agency policy and decision making.

Tuesday April 5, 2011
(each presenter covers objectives 1 & 2: current data, trends, thresholds and spatial extrapolation-with time for participant questions and discussion)

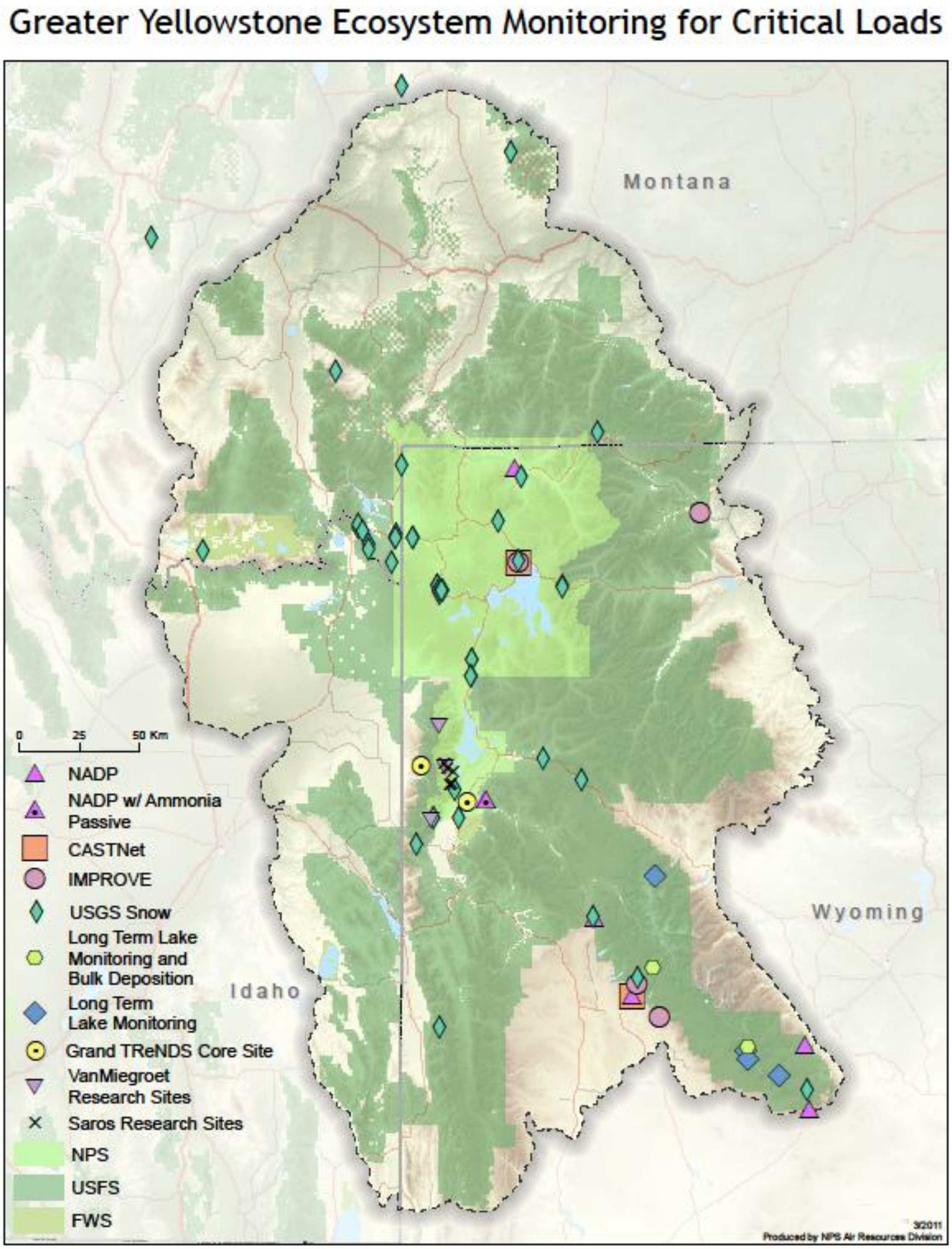
	Topic	**Presenter/Discussion Leader**
8:00am	**Welcome**	Blett/Svalberg
8:15-8:45	**Critical Loads Conceptual Overview** (definitions; thresholds; acidification vs. nutrient N; effects continuum; empirical vs modeled critical loads; CLAD)	Blett
8:45-9:15	**GYE Air Quality Monitoring Data and Trends** (IMPROVE, CASTNet, Wind River Bulk Deposition)	Svalberg
9:15-9:45	**GYE Deposition** (NADP, USGS Divide-wide snow, GRTE-Resin collectors, Nanus PRISM estimates),	Morris

	ROMO trends interpretation,	
9:45-10:00	**GrandTRENDS-** GYE N deposition, speciation and transport study overview (sites and N species)	Schichtel
10:00-10:30	Break	
10:30-11:15	**Discussion- Deposition Tracking for CL Development**	All
11:15-11:45	**Water chem. data-BT and Shoshone NFs** - long term chem trends, episodic acidification; synoptic data for ANC (BT and Shoshone)	Svalberg/Bevenger
11:45-12:00	**Water chem. data-Gallatin NF** lake chem trends & Synoptic ANC data?	Story
12:00-1:15	Lunch – on your own	
1:15-1:45	**Water chemistry acid sensitivity (YELL and GRTE)** & **Rocky Mountains water chem. NO3 & diatom thresholds**	Nanus
1:45-2:15	**FS watershed condition classification: ANC and NO3 thresholds**	Mebane
2:15-3	**Discussion – Aquatic Critical Loads development:** Use of GYE **water chemistry data** in development of acidification (ANC) & nutrient NO3) thresholds and CL	All
3-3:15	Break	
3:15-3:45	**Nitrogen influences on diatoms (species shift thresholds) for sediment cores** in GRTE	Otu
3:45-4:15	**Macroinvertebrates as a GYE long-term indicator species of acidification or eutrophication;** Does the data show change over time? Have threshold species shifts occurred?	Marshall
4:15-5:00	**Discussion- Aquatic Critical Loads development** Use of GYE **biotic data** in development of acidification & nutrient thresholds and CL	All
5:00	ADJOURN for Day 1	

Wednesday April 6, 2011
(presenters cover objectives 1,2 before the morning break; objectives 3 & 4 - priorities and actions following the break)

	Topic	**Presenter/Discussion Leader**
8:00	Overview of Day 2	Blett/Svalberg
8:15-8:45	**Terrestrial critical loads using lichens**	Geiser/Grenon
8:45-9:15	**Terrestrial critical loads using alpine plants** (ROMO example and extrapolation to GYE?)	Bowman
9:15-10:15	Discussion – Use of terrestrial data in development of nutrient CL	All
10:15-10:30	Break	
10:30-3:00 (With a 1:15 lunch break when convenient)	Whole group or Breakout groups (Aquatic and Terrestrial?) to address questions: 1. What can we conclude overall from the GYE ecosystem data presented? 2. Are there existing thresholds which we can apply now to the GYE data? 3. Can critical loads be developed easily for any existing data sets? 4. Is there existing data that can be extrapolated or CLs calculated for new areas based on what we know now? 5. Where are there key gaps in GYE aquatic or terrestrial ecosystem data for which CL should be developed? 6. What are the highest priorities for filling gaps in the next 3-5 years? 7. What GYE agency actions, planning steps or processes are needed in the next 3-5 years to make use of CL science in future policy and decision making?	All
3:00-4:00	Groups discuss action items/next steps to implement	All
4:00	Wrap up/adjourn	Svalberg/Blett

Attachment 3: Map of GYA ecosystem monitoring and air quality networks



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