Title: Assessment of nitrogen deposition and its possible effects on alpine vegetation in Grand Teton National Park

PMIS #: 104675

Park: Grand Teton National Park (GRTE)

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Project Summary

Introduction

Atmospheric N deposition rates show increasing N loadings since the 1980s in the western U.S. associated with increasing N emissions from industrial, urban, and agricultural sources (Fenn et al., 2003). Compared to the eastern U.S., the number of NADP/NTN (National Atmospheric Deposition Program/ National Trends Network) and CASTNet (Clean Air Status Network) monitoring sites is much more limited in the west, and they are rarely located in the highest-elevations, where ecosystems are likely to be more sensitive (Burns, 2004). Although N deposition tends to increase with elevation in this region (Williams and Tonnesen, 2000), there are considerable uncertainties about the actual N deposition levels in the Rocky Mountains. Model simulations indicate a “hotspot” of N deposition near Grand Teton National Park (GRTE) (Fenn et al., 2003; Nanus et al., 2003), but little measured data is currently available on the actual atmospheric N inputs to alpine ecosystems in GRTE, or their effect on alpine ecosystems.

Atmospheric nitrogen (N) inputs to high alpine regions mostly occur as snow. Alpine communities are considered very sensitive to changes in N deposition because a combination of short growing seasons, strong seasonal variation in moisture and temperature, shallow and poorly developed soils, steep terrain, sparse vegetation, and low rates of primary productivity generally limit the N uptake and retention capacity of the ecosystem (Baron, 1992; Fisk et al., 1998; Burns, 2004). These ecosystems are generally considered to be N-limited (Burns 2004), and increases on N availability may be reflected in changes in vegetation composition, biomass, and N content, as well as in changes in soil N status and belowground processes (Bowman et al., 1995). Because alpine ecosystems may become N saturated (i.e., lose their capacity to effectively retain N) with relatively small changes in atmospheric N deposition (Baron et al., 2000), there is great interest in identifying early indicators of ecosystem change in response changes in atmospheric N inputs.

Approximately 15,000 acres (5%) of the vegetation at Grand Teton National Park (GRTE) consists of alpine plant communities. These communities experience a range of environmental conditions from dry slopes to relatively moist toe-slopes or basins. On average, the snow free period in the alpine zone is from late July to late August, but some sites become snow free in early July due to lower snow accumulation resulting from topographic position or wind redistribution of snow, and/or earlier melt-out due to higher sun exposure in spring and early summer. Alpine sites in snow accumulation zones may retain snow until mid August. Earlier work at Niwot Ridge in the Colorado Front Range has indicated that the N cycling response to changes in N inputs is greatly influenced by soil climate, especially soil moisture and temperature (Bowman et al., 1993; Fisk and Schmidt, 1995; Fisk et al., 1998).

Project Objectives

The overall objective of this project was to assess the impact of atmospheric N deposition on the structure and function of alpine ecosystems in GRTE, based on field measurements and experimental manipulation of N loadings in alpine sites with contrasting (wet/dry) edaphic conditions and assumed N input regimes. The assessment of the N deposition effects on alpine vegetation in GRTE encompassed several facets:

- Determination of on-site (rather than modeled) N deposition, as small differences in N deposition may critically affect the ecosystem response (e.g., Rueth and Baron, 2002)
- Compilation of background information on ecosystem structure (composition) and function (biogeochemical processes) against which to evaluate future change.
- Evaluation of the interaction between N cycling and soil microclimate, by establishing study plots in locations that are expected to be microclimatically different
- Identification of processes or parameters that are sensitive to changes in N availability or can serve as early indicators of changing ecosystem function
- Initiation of N addition treatments at all locations to assess the effect of increased N loading on site characteristics, including vegetation

Pristine alpine ecosystems are typically located in remote areas (1-2 days backpacking to the sites) and access to these is often limited throughout the year due to persistence of the snowpack well into the summer. Hence, equipment installation/removal and plot measurements at GRTE had to be accomplished within a very narrow time frame (< 2 months). Consequently, we set a series of distinct year to year objectives:

2006: (1) select field sites (3 locations; 2 edaphic conditions; 3 replications= 18 plot pairs); (2) install soil microclimate and atmospheric N input collectors; (3) assess N input regime from snow survey and plot-level N input measurements using exchange resin collectors; (4) conduct floristic survey and collect soil and plant samples for laboratory analysis.

2007: (1) continue soil microclimate measurements (temperature and moisture) and data collection of N input (including snow survey); (2) complementary field sampling and measurements for soil and plant N characteristics; (3) first N addition (~ 4 kg N /ha as ammonium-nitrate to half (18) of the experimental plots; (4) initial data analysis

2008: (1) chemical analysis of the field samples; statistical analysis and interpretation of the data collected; (2) removal of all field equipment; (3) field addition of 4 kg N /ha as ammonium-nitrate to 18 plots; (4) documentation of location of field plots in preparation of future plot monitoring

Methods

Site selection and plot layout

Three locations in GRTE were chosen based on N deposition maps in Nanus et al. (2003). Selection criteria were: elevation above 2800 m, slope <15^{o}, and within one the following vegetation community types (Datum NAD 93, Resource Management GRTE): alpine dwarf shrubland, dry gramenoid upper elevation, herbaceous rockland slopes, herbaceous wetland meadow, tundra-dry alpine, sparsely vegetated limestone pavement, and glacier/snow. Based on field reconnaissance in summer 2005 and 2006 and evaluate potential access to the sites via the existing trail system, three candidate sites were identified: Moose Basin (High), Paintbrush Canyon /Mica Lake (Low) and Rendez-Vous Mountain (Medium/Low).

Within each of the three N deposition areas, wet/dry edaphic conditions were selected based on visual assessment of snowpack retention, local topography, and vegetation type from GRTE GIS maps. Wet and dry sites were generally plots were located within 0.50 miles from each other. Three replicates were established in summer 2006 at contrasting edaphic conditions (wet vs. dry) within the three sites. This yielded a two-factorial set-up of initial conditions (3 N deposition levels, 2 edaphic conditions) replicated three times for a total of 18 site locations for which background information on N deposition, site microclimate, vegetation, and soils was collected. Each site was georeferenced by GPS in summer 2008. At each of the 18 site locations two adjacent 2.5m by 2.5m plots were delineated separated by a 1-m buffer zone, and assigned as either control or +N treatment (2007 and 2008 treatment)

N deposition measurements

In early spring 2006, at maximum snow accumulation, snow surveys were conducted at Moose Basin and Rendez-Vous Mountain in collaboration with the USGS. Snow depth, snow water equivalent and chemical composition were determined by USU crew at Moose Basin in 2006, and by USGS personnel at Rendez-Vous Mountain in 2006 and 2007. Due to logistical constraints, no snow surveys were done at Mica Lake. Furthermore, the USU crew was unable to repeat the snow survey in 2007 or 2008 due to early melt of the snow pack and avalanche hazard that prohibited access to the sites.

N input during the snow free period (summer 2006 and 2007) was measured at each of the 18 plot pairs, using ion exchange resin funnels left in the field for ~ 2 months (Fenn and Poth, 2004). Resins were retrieved at the end of each summer field season, extracted with 2N KCl, and the extractant analyzed for NH_4-N and NO_3-N.

To capture the combined N input from snowmelt and wet+dry deposition during the snow free period, PVC tubes with ion exchange resins (Susfalk and Johnson, 2003) were placed closed to the ground in early summer 2006, retrieved in summer 2007 and extracted as described above.

Vegetation Characteristics

Vegetation composition, species richness, aboveground biomass and N content were determined by floristic surveys and destructive sampling in all 36 plots. Vegetation composition and species richness was determined by identifying plant species and accounting for percent cover of each plant within a 1m x 1m subplot located within the 2.5

m x 2.5 m plot. Total percent cover for the entire 1m x 1m plot was then assessed including percent bare ground and percent rock. Aboveground plant biomass was determined by clipping vegetation within two 25 cm by 25 cm frames, drying the materials at 65°C and weighing it. Subsamples were ground and analyzed for N and C using LECO combustion. Belowground biomass and N content was determined from soil cores (0-15 cm depth; 1 per plot), by manually separating roots and analyzing ground biomass for N as described above.

Soil characteristics

Several cores (0-15 cm length, 5 cm diameter) were taken in each plot (summer 2006 and 2007) to determine bulk density, root biomass, soil moisture content, total and extractable inorganic N, and soil nitrification potential. Inorganic soil N content in the upper soil was determined by extracting homogenized soil samples with 2N KCl in the field (Van Miegroet, 1995) and analyzing extractant for NH_4-N and NO_3-N. All concentrations are expressed on a dry weight basis using gravimetric soil moisture content measurements on subsamples with rock and debris removed and dried at 105 °C. Total N content of the soils was determined though LECO combustion,

Nitrification potential was determined by incubating 8g of fresh soil soils 50 ml plastic test tubes placed in a constant-temperature incubator (~ 25 °C) for 60 days, extracting subsamples after 30 (t_1) and 60 days (t_2) with 2 N KCl , and analyzing extractant for NO_3-N as described above. Changes in NO_3-N concentration relative to in-field extraction (t_0), expressed on a soil dry weight basis, were used as a relative index of nitrification potential. In addition, N availability was assessed using plant root simulator probes (PRS-probes) (Western Ag Innovations Inc., Saskatoon, Canada), which are cation and four anion exchange strips, that were deployed during summer 2006 and winter 2006-2007, extracted and analyzed for a suite of cations and anions, including inorganic N.

Soil Microclimate

Soil temperature will be measured continuously at each of the 18 locations using miniature data loggers (StowAway Tidbits - Onset Computer Corp), installed within the 1-m buffer zone between 5-15 cm depth, programmed to record temperature at 1 to 2-hour interval, and downloaded at the beginning and end of the snow free period. Due to equipment malfunction, soil temperature data record is incomplete. Soil moisture regime was determined using 10-cm long soil moisture probes (Decagon ECH_2O probes) installed vertically under the soil surface in the 1-m buffer zone. Periodic measurements were taking in summer 2006 and 2007 using a portable readout device. At selected field sites dataloggers were hooked up to the ECH_2O probes, but several of the dataloggers malfunctioned (likely due to snow immersion) and limited continuous soil moisture data could be obtained.

Except for the snow surveys at the Rendez-Vous site, which were done by USGS personnel, all measurements associated with the project were conducted by personnel and students from Utah State University.

Results: what was accomplished, what worked and what were the challenges?

Long-term monitoring plots

Positive outcomes: Within the time frame of this project, we were able to obtain most of the site data we set out to collect with use of field equipment and through field sampling. While all measurement equipment has now been removed from all sites, plot locations have been carefully marked and documented for future use as long-term vegetation monitoring plots. This will allow us or NPS personnel to return to the sites in the future to record changes in site characteristics over time in the control and treatment plots.

N deposition inputs

Positive outcomes: The findings thus far suggest that atmospheric N into the alpine system primarily occurs in winter as snow (Figure 1). Results from the 2006 snow survey at Moose Basin and Rendez-Vous confirm the modeled N deposition gradient (Nanus et al., 2003) with higher atmospheric N inputs to the north of the Park (Moose Basin; 1.7 kg N ha^{-1}) and lower levels to the south (Rendez-Vous; 0.95 kg N ha^{-1}), with a slightly greater proportion entering as NH_4-N (not shown). Summer N inputs as determined with resin tube collectors deployed in summer 2006 and 2007, so-called "Fenn collectors" (Fenn and Poth, 2004), show additional N inputs <0.5 kg N ha^{-1} that do not appear to differ among locations.

Challenges and failures: our study only has limited information on N deposition via snow, even though that seems to be the major pathway of N input to these systems. The main challenge is to find and deploy trained personnel in a timely matter to conduct the snow surveys at locations that are readily and safely accessible (avalanche danger) at critical measurement times (i.e., peak snow accumulation). We had hoped that the use of resin cores that were left to overwinter, the so-called "Johnson collectors" (Susfalk and Johnson, 2003), would be able to circumvent some of these logistical problems by capturing the inorganic N released during snowmelt. We found however, that the "annual" N input values obtained from these resins cores seemed to greatly overestimate N input fluxes, possibly due to resin breakdown during long-term exposure (~ 1 year) (Mamo et al., 2004). Consequently these data need to be interpreted with caution.

Vegetation Characteristics

Positive outcomes: The graduate student at USU was able to successfully complete the vegetation survey at all sites, including information to the species level; vegetation covers by vegetation types; and to collect quantitative samples for biomass and N content measurements. Laboratory processing and chemical analysis of these samples has been completed, but statistical analysis and interpretation of the results is currently in progress. Preliminary analysis does suggest that more N is stored in aboveground biomass at the high N (MB) site compared to the lower deposition sites. This plot-level vegetation survey data represents valuable background information against which to compare changes in the future.

Soil characteristics

Positive outcomes: It was hypothesized that soil N status, as expressed by various indicators such total and extractable N, soil C:N, N captured by exchange resins, and N nitrification potential, would be higher in high deposition sites (i.e. Moose Basin) compared to low N deposition sites (i.e. Rendezvous Mountain). All samples have been collected and analyzed in the lab as planned, and the graduate student is currently conducting the statistical analysis of the results. Results so far show that some (but not all) soil parameters reflect the N input regime. Total N concentration is higher at MB compared to the lower N deposition sites, while extractable inorganic N appears to be a good indicator of moisture regime (higher extractable N at the wetter sites) but not of N input regime. The analysis of available N (i.e., PRS® probes) for the three sites (Figure 2) for summer 2006 and winter 2006/2007 shows that there is a significant correlation between N deposition gradient and soil N status with Moose Basin, the high deposition site, having significantly more available N ($p = 0.004$) than the other two sites. There is also a significant difference between wet and dry sites ($p = 0.01$) for available N. The C/N ratio of soils taken in summer 2006 and 2007 is significantly different among locations along the N deposition gradient (p-value = 0.03 in 2006; p-value = 0.008 in 2007) with the C/N higher (indicative of lower N availability) at the RDV, characterized by lower N input (Figure 3). The average C/N ratio of the soils across sampling dates and edaphic conditions for was 9.8, 17.4, and 10.4 for MB, PB, and RDV respectively; which is generally lower than most lowland forest sites. We are still in the process of interpreting the nitrification potential, which is indicative of the size and activity of the nitrifier population, and expect this to be a sensitive indicator of soil N status and N deposition regime.

This study will yield a broad suite of soil indicators of N status that are expected to be more or less sensitive to changes in N deposition. Thus, at the end of our analysis we are confident that some will emerge for potential use as early indicators of change. Also, the current plot-level soils data represents valuable background information against which to evaluate responses to N additions or changes in the future at these sites.

Soil Microclimate

Positive outcomes: Despite the failure of some of our data loggers, we were able to collect sufficient soil temperature and summer soil moisture data to distinguish differences in soil microclimate at each site. Since this data set was largely complementary to the other measurements (i.e., deposition, soil, vegetation), we consider we have achieved that objective.

Challenges and failures: The greatest challenge working at remote sites that can only periodically be visited and experience extreme weather conditions is to have equipment that operates reliably while unattended, yet is affordable. The data loggers for the soil moisture probes we used in this project (Em5b by Decagon) were unable to function properly under our extreme site conditions (especially snow cover), and we have conveyed this information to the manufacturers. In hindsight, we should have opted for newer (more expensive) data loggers in a fewer locations.

Soil N addition treatments

Positive outcomes: In the second year of the project (summer 2007) we started increasing the N load to a subset of the plots at each location by adding the equivalent of 4 kg N ha^{-1} in a single dose to the soil in dissolved NH_4NO_3 form. The time frame of current project was too short to be able to see any treatment effects, nor was evaluating treatment effects an explicit goal of this study. However, the establishment of long-term monitoring plots, half of which receiving annual N additions, should prove a valuable resource to the ecosystem monitoring and assessment efforts by the NPS. We hope to be able to continue these annual treatments in the future with cooperation from NPS and GTRE.

Conclusions and future directions

Our preliminary data indicate that (1) N deposition inputs to the alpine zone of the Grand Teton National Park are generally low; (2) there is indeed an N deposition gradient; and (3) that there are detectable differences in N dynamics among N input sites that are further modified by local edaphic conditions. While static soil parameters (e.g., extractable inorganic N) reflect differences in edaphic conditions (wet-dry), they do not appear to be good indicators changes in N deposition. More dynamic soil parameters on the other hand, seem more sensitive indicators of changes in soil function due to a combination of N deposition and soil moisture regime. This study indicates that even small differences in N input (<1 kg N ha^{-1} yr^{-1}) can result in detectable differences in soil characteristics.

The project has yielded important data that will further our understanding of how these alpine ecosystems function and respond to increases in atmospheric N inputs. The data set will be the basis for a MS thesis of one graduate student (projected defense in spring 2009), and possibly several papers in the scientific literature. Some results have already been presented at a national conference in fall 2007.

This study provides a framework for future monitoring activities in the alpine zone of GRTE, by establishing a series of monitoring plots and documenting their location, gathering baseline soil and vegetation data against which to compare future data sets, and by implementing a low-level N addition experiment by which (if continued) long-term ecosystem changes could be observed.

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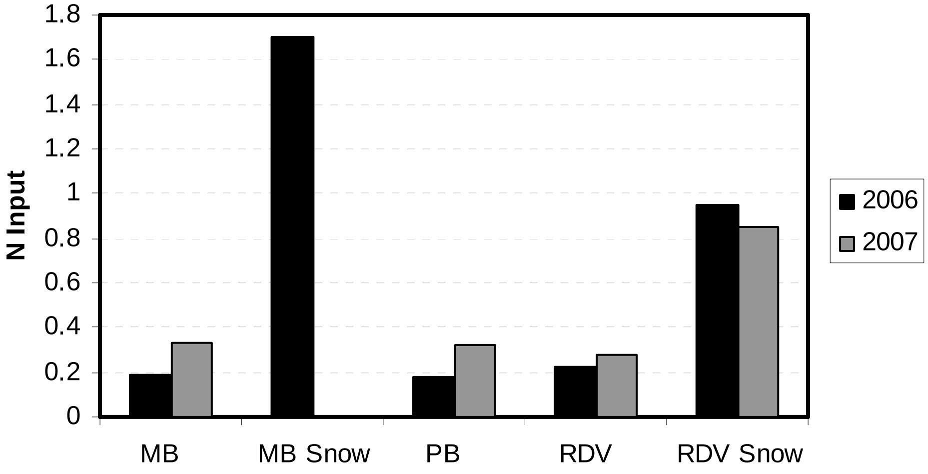

Figure 1 Summer (Fenn collectors) inorganic N input for 2006 and 2007 (kg N ha^{-1} 90^{-1} days) compared to winter (snow pack survey) inorganic N input (kg N ha^{-1} yr^{-1}).

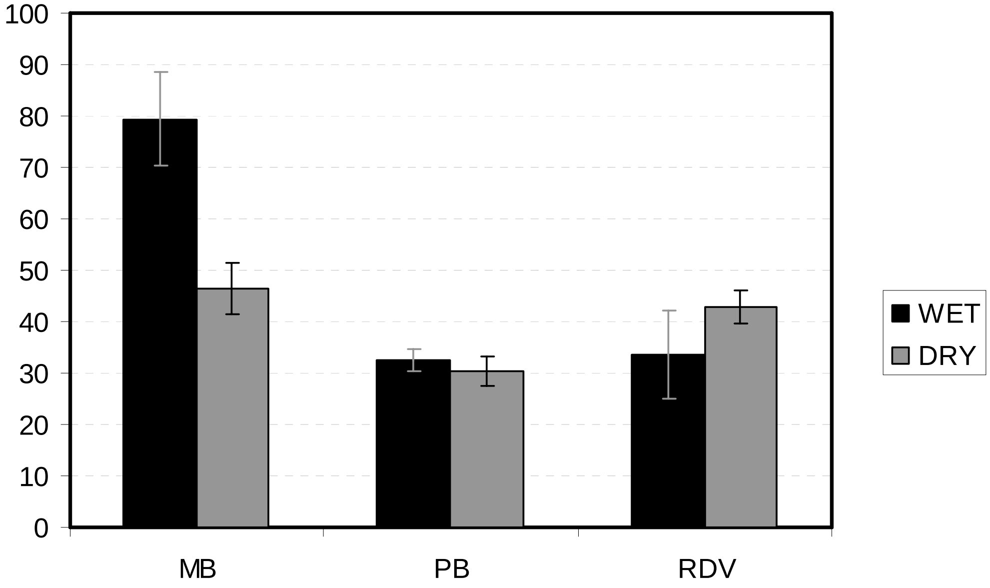

Figure 2 Soil available N (µg/10cm^2/180 days) for the three sites for summer of 2006, and winter of 2006/2007. P-value for gradient = 0.004; P-value for wet/dry = 0.01.

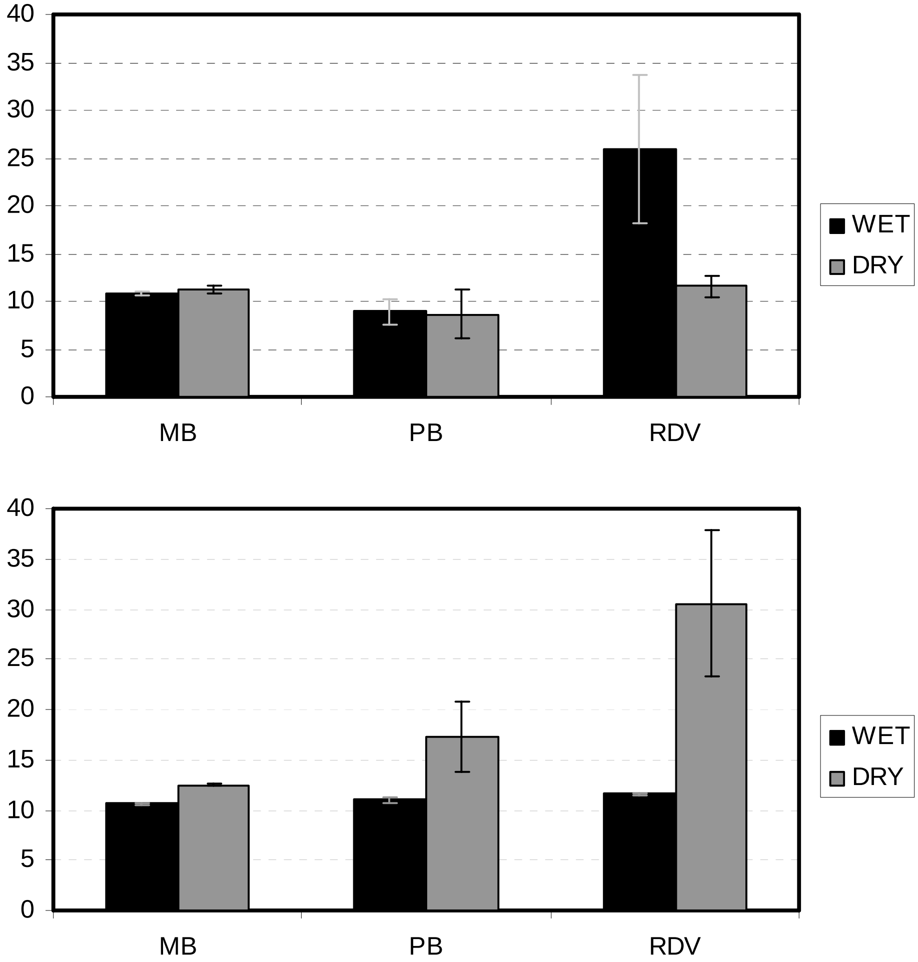

Figure 3 C:N ratio in the soil for the three field sites in 2006 (top graph) and 2007 (bottom graph). 2006: p-value for gradient = 0.03, p-value for wet/dry differences = 0.12 (ns); 2007: p-value for gradient = 0.008, p-value for wet/dry differences = 0.009, p-value = 0.017 for interaction between edpahic condition and N deposition gradient.

Summary of Project Budget and Expenditure

HELGA VAN MIEGROET

	YEAR 1	BUDGET A14594	YEAR 2	BUDGET A16406		
	NPS 2006-2007		NPS FY 2007-08			
	END DATE MARCH 31, 2008		END DATE MARCH 31, 2009			
	BUDGET	**TOTAL EXPENSES**	**BUDGET**	**YEAR TO DATE EXPENSES**	**OPEN COMMITMENTS**	**BALANCE AVAILABLE**
SALARIES	$15,000.00	$9,000.00	$20,082.00	$14,625.00	$0.00	$5,457.00
WAGES	7,200.00	12,998.95	9,000.00	9,364.22	0.00	-364.22
BENEFITS	2,433.00	760.71	4,443.00	650.20	0.00	3,792.80
TRAVEL	3,000.00	4,103.13	2,000.00	2,799.95	114.00	-913.95
OTHER	15,000.00	15,770.43	6,950.00	10,625.05	30.00	-3,705.05
SUBCONTRACTS	0.00	0.00	0.00	0.00	0.00	0.00
EQUIPMENT	0.00	0.00				
INDIRECT COSTS	7,461.00	7,460.78	7,433.00	6,661.33	771.67	0.00
TOTALS	$50,094.00	$50,094.00	$49,908.00	$44,725.75	$915.67	$4,266.58