

Wet Deposition of Mercury in Idaho

Analysis of Results from the Mercury Deposition Network
and Comparison to the REMSAD Model



**State of Idaho
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March 2013



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Executive Summary

This study examines the spatial and temporal distribution of the wet deposition of mercury in Idaho and surrounding states. Multiyear data gathered by the Mercury Deposition Network (MDN) are analyzed and compared to the results of the Regional Modeling System for Aerosols and Deposition (REMSAD). The objective is to ascertain the deposition patterns of mercury in precipitation in Idaho and to assess the suitability of using REMSAD model results in future watershed-scale analyses.

Scientists have been interested in the atmospheric deposition of mercury in Idaho since high levels of methylmercury have been found in fish tissues in a significant number of water bodies in Idaho. Forty percent of lakes surveyed in Idaho have an average methylmercury concentration in fish greater than 0.3 milligrams per kilogram, the Idaho Department of Environmental Quality (DEQ) human health criterion.

Five monitoring sites in Idaho and five in surrounding states were analyzed for wet deposition data. The ID99 site at McCall had the highest interannual average for wet deposition of mercury. ID98, at Lake Lowell, had the lowest. The Salmon Falls Creek Reservoir site had the highest 1-year average wet deposition. The examined values correspond well to those published in MDN interpolated maps. All Idaho annual average values are greater than the MDN average, which, as a network, is skewed toward wetter, lower concentration, eastern sites.

Seasonally, spring and summer have the highest deposition rates in Idaho. The winter deposition rates are significantly lower than the MDN average. These lower rates could result from instrument undercatch of snow, which is the main form of precipitation during the winter months in Idaho, as compared to the rest of the network.

The spatial distribution of mercury wet deposition in Idaho follows regional climatic, latitudinal, and terrain-based factors. No major anomalies that could be attributed to local sources are detectable. Most wet deposition in Idaho appears to come from the global pool.

The REMSAD model results, specifically the background and boundary conditions used for Tag 9, are in reasonable agreement with the MDN data. REMSAD seems to overestimate the influence of local industrial sources, like the gold mines in northern Nevada, for example. The model also appears to underestimate the wet deposition that occurs at high precipitation sites. These observations can be applied if the REMSAD data are used for watershed-scale analyses in the future.

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1 Introduction

Mercury levels in Idaho have been a concern for the Idaho Department of Environmental Quality (DEQ) since fish tissues in the state's water bodies tested higher than the DEQ human health criterion. Subsequently, multiple studies have investigated atmospheric deposition patterns, in-situ mercury methylation rates, and potential regional source areas. This study examines the existing wet deposition data gathered by the Mercury Deposition Network (MDN) in Idaho and neighboring states and by DEQ at Salmon Falls Creek Reservoir (SFCR) in Idaho.

1.1 Objectives

The objective of this investigation is to establish the temporal and spatial patterns of wet deposition in Idaho and to place these patterns in the context of regional sources and the global distribution of mercury. Furthermore, this study compares the MDN data with the results of the Regional Modeling System for Aerosols and Deposition (REMSAD) to assess the suitability of using the model results in watershed-scale analyses, like Total Maximum Daily Loads (TMDLs).

1.2 Background on Mercury in Idaho

High levels of methylmercury in fish have been found in a variety of water bodies in Idaho, prompting the issuance of fish consumption advisories for multiple lakes and reservoirs (Table 1). In 2008 surveys found that 40% of lakes in Idaho had an average methylmercury concentration in fish greater than 0.3 milligrams per kilogram, the DEQ human health criterion (DEQ 2005). The SFCR, in southernmost Idaho, has been especially intriguing to researchers because it consistently produces fish tissue with the highest levels of methylmercury concentrations in the state. The highest two results in the DEQ study were from fish collected in SFCR (DEQ 2005).

Table 1. Idaho fish consumption advisories.

Water Body	Fish Type
Statewide	Bass
American Falls Reservoir	Utah sucker
Bear River	Carp
Boise River	Catfish
Brownlee Reservoir	Carp, catfish, crappie, perch
Chesterfield Reservoir	Rainbow trout
C.J. Strike Reservoir	Bass
Glendale Reservoir	Crappie, perch, bluegill
Grasmere Reservoir	Lahontan cutthroat trout
Hell's Canyon Reservoir	Carp, catfish
Jordan Creek	Redband trout
Lake Coeur d'Alene	Kokanee, bullhead (plus others not tested)
Lake Lowell	Sucker, carp
Lake Pend Oreille	Lake trout, whitefish
Oakley Reservoir	Yellow perch, walleye
Payette Lake	Lake trout
Payette River	Sucker
Portneuf River	Cutthroat, rainbow and brown trout
Priest Lake	Lake trout
Salmon Falls Creek Reservoir	Perch, walleye, smallmouth bass, rainbow trout
Shoofly Reservoir	Lahontan cutthroat trout
South Fork Snake River	Brown trout
Weston Reservoir	Yellow perch

Note: Fish advisories apply to cohorts in differing amounts. The recommended consumption of indicated fish type will vary according to impacted group (e.g., pregnant and nursing women, children under 15 years of age, or general public not in previous groups) (IDHW 2012).

Regionally, a number of important sources of mercury exist in Idaho including soils and sediments contaminated by historical gold mining, and industrial sources. Figure 1 depicts the industrial sources within or adjacent to Idaho, including gold roasting facilities in northern Nevada and a large cement plant in eastern Oregon, among other sources. Two regional sources released more than 1,000 pounds of mercury in 2009. Re-emission of mercury stored in soils and sediments from past decades with higher deposition rates are another area source (Miller et al. 2005). The released mercury can then be dry deposited or scavenged by cloud or raindrops and redeposited.

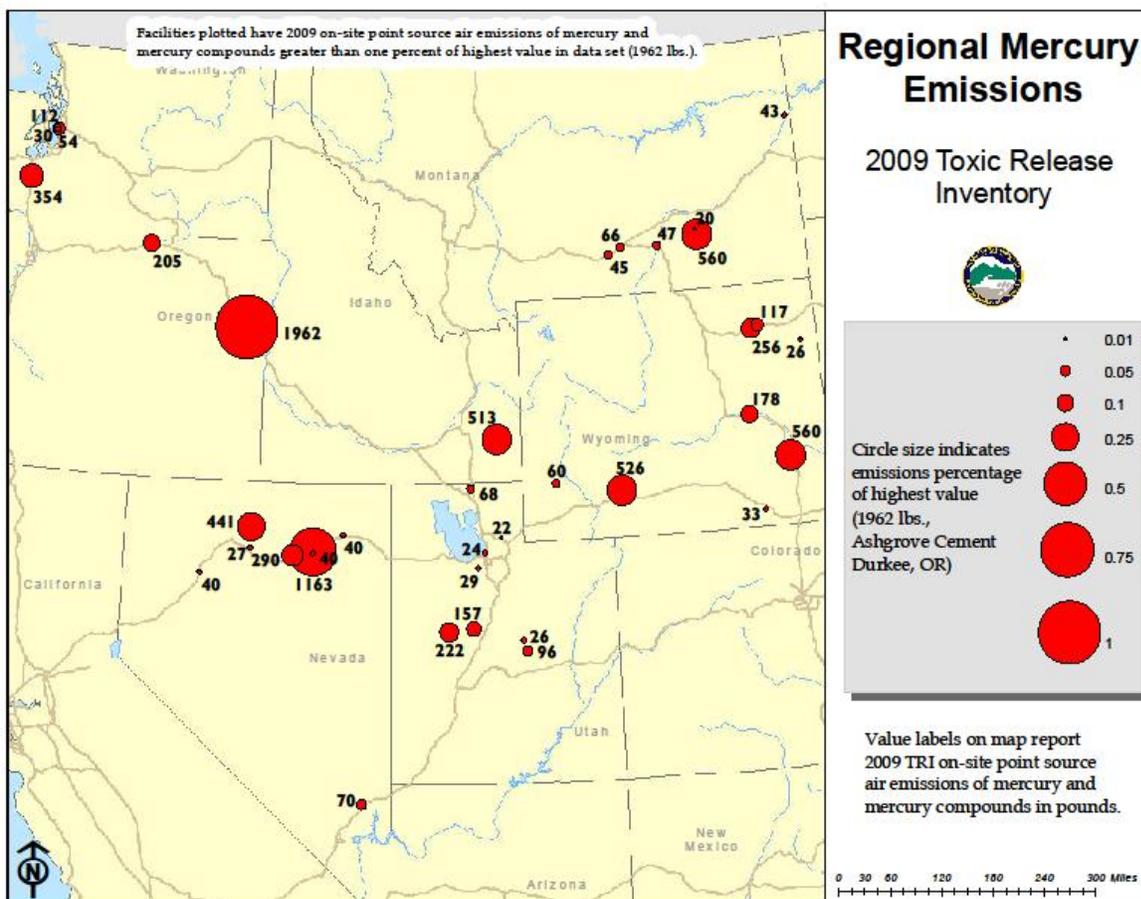


Figure 1. Regional atmospheric mercury emissions from 2009 Toxic Release Inventory.

Past studies have measured dry and wet deposition of atmospheric mercury near SFCR (Abbott and Einerson 2006; Perry et al. 2010). Soils, sediments, and snowpacks have also been measured in the area (Abbott et al. 2007; DEQ 2005, 2007a, 2007b). None found any particular enhancement in deposition or in soil/sediment concentrations in or near SFCR, compared to other parts of the state (Gray and Hines 2009). One study, by the United States Geological Survey (USGS), found that the physical characteristics (e.g., reservoir depth and geometry) of SFCR create conditions ideal for an enhanced methylation rate (Gray and Hines 2009). These conditions appear to produce methylmercury faster than other reservoirs with comparable deposition rates. Thus, the fish at SFCR have more methylmercury available to accumulate. This study may explain the SFCR outlier.

Beyond the regional signals, Idaho is affected by the global mercury pool. Selin (2009) reports a global background concentration of mercury in the northern hemisphere of 1.5–1.7 nanograms per cubic meter. Idaho's terrain, climate, latitude, and land cover determine the local oxidation and deposition rates from the global pool. Seasonal changes also affect the ambient concentration of atmospheric mercury (Lindberg et al. 2007). The multiyear MDN data are designed to provide a baseline assessment of mercury deposition, and the temporal and spatial trends are illuminating.

2 Methods

2.1 Mercury Deposition Network and Quality Assurance

The National Atmospheric Deposition Program's MDN provides a long-term, continental-scale record of atmospheric mercury concentrations and depositions. Since 1999, MDN has collected weekly data across the United States and Canada. All sites use identical collection techniques and quality assurance protocols.

For this study, all data were obtained from <http://nadp.sws.uiuc.edu/nadpdata/mdnalldata.asp>. Only samples with a Quality Rating code of A or B were retained and only wet (W) sample types were analyzed.

Figure 2 identifies the location of the sites examined in this study. Sites in the states surrounding Idaho are included to provide regional context. The SFCR site is not a part of the MDN, but all collection and analytical procedures were the same as those used at the MDN sites.

Mercury Wet Deposition Sample Sites

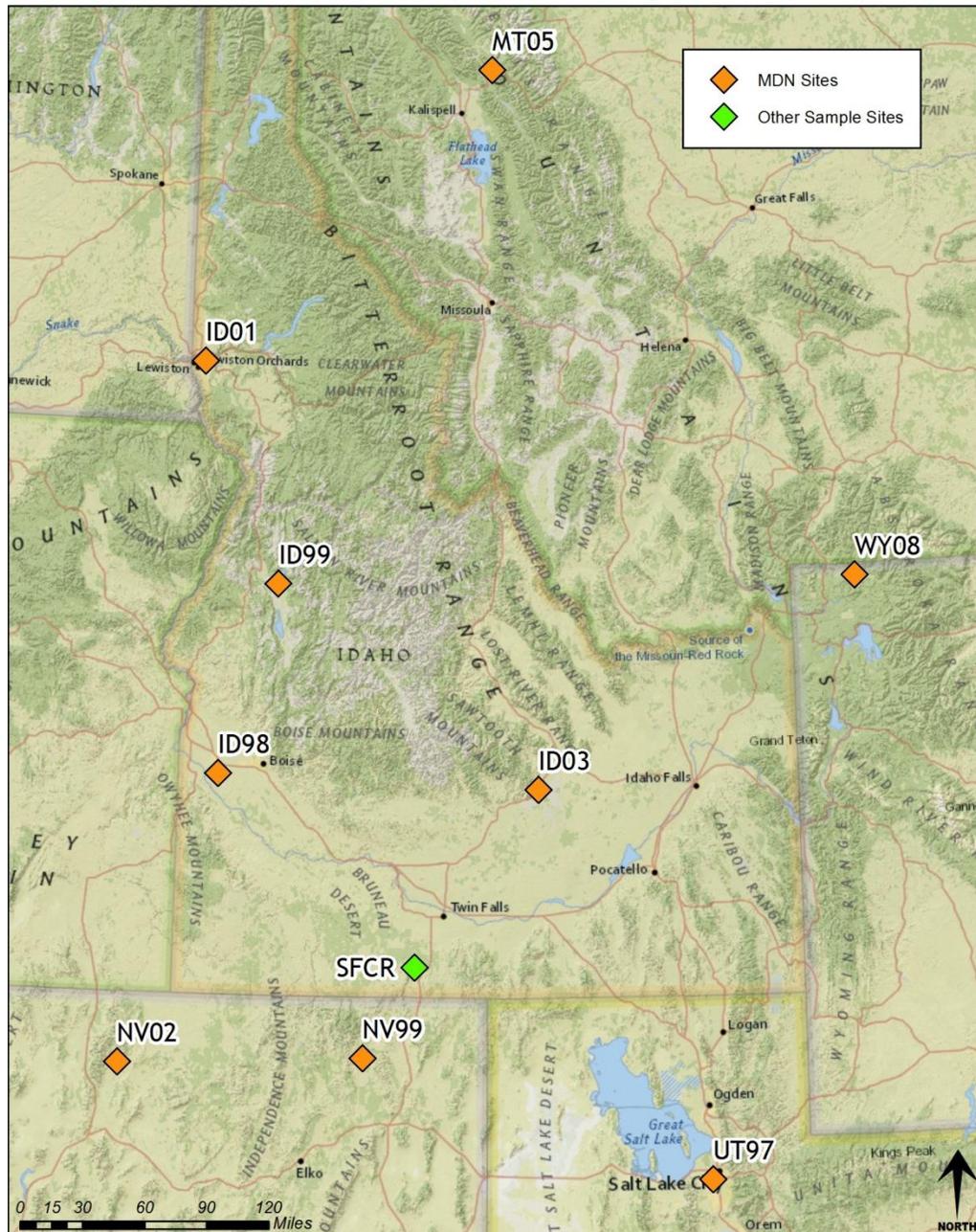


Figure 2. Location of MDN and SFCR sample sites.

Table 2 gives the location and elevation of the sites and the period of data collection. Both ID01 and SFCR sites were operated for 1 year. Other sites have data collection periods ranging from 2 years (ID98) to 7 years (MT05, NV02, and NV99).

The site locations can be classified geographically in ways pertinent to expected rates of wet deposition, given an unchanging background atmospheric concentration. Higher elevation sites like ID03, NV99, and WY08, are likely to receive greater wet deposition than lower elevation

sites, purely on the basis that higher altitudes receive more precipitation. Lower latitude sites in desert climes, like ID03, ID98, SFCR, NV02, NV99, and UT97, are expected to experience higher ambient concentrations during the summer because increased insolation results in greater oxidation rates, converting inert mercury (Hg^0) into the more highly reactive and soluble form of mercury, Hg^{2+} (Miller et al. 2005; Peterson et al. 2009). This conversion may not translate to higher levels of deposition, however, because the climate in these areas precludes much of the summer precipitation. Northern sites, like ID01 and MT05, will likely receive greater frequency of precipitation events because the climate experiences a moist maritime northwesterly flow. Finally, land cover at sites like MT05 and WY08, with their dense conifer forests, will likely enhance the capture of mercury deposition (Miller et al. 2005).

Table 2. Geographical summary of sample sites.

Site ID	Site Name	Start Date	Stop Date	County	State	Latitude	Longitude	Elevation (m)
ID01	Hatwai/Lewiston	10/26/2010	10/18/2011	Nez Perce	ID	46.4381	-116.9052	843
ID03	Craters of the Moon National Monument	10/21/2006	12/31/2010	Butte	ID	43.4605	-113.5551	1807
ID98	Deer Flats	3/18/2008	6/29/2010	Canyon	ID	43.5528	-116.6436	774
ID99	McCall	11/19/2007	6/29/2010	Valley	ID	44.8913	-116.1047	1528
MT05	Glacier National Park-Fire Weather Station	10/28/2003		Flathead	MT	48.5103	-113.9958	980
NV02	Lesperance Ranch	1/30/2003		Humboldt	NV	41.5033	-117.4989	1388
NV99	Gibb's Ranch	2/13/2003		Elko	NV	41.5713	-115.2117	1849
SFCR	Salmon Falls Creek Reservoir	2/1/2006	2/27/2007	Twin Falls	ID	42.2131	-114.7303	1541
UT97	Salt Lake City	5/16/2007		Salt Lake	UT	40.7118	-111.9609	1297
WY08	Yellowstone National Park-Tower Falls	10/21/2004		Park	WY	44.9166	-110.4203	1912

Data completeness was calculated as the quotient of valid samples to total samples collected. Table 3 gives the data completeness percentages for all sample sites. Except for MT05, all sites have values greater than 75%, a typical minimum value for inclusion in data analysis. MT05 (73%) was included in the analysis because of its long period of record.

Table 3. Data completeness for sample sites.

Site ID	Site Name	Sampling Frequency	Samples collected	Valid samples collected	Data completeness
ID01	Hatwai/Lewiston	weekly	37	35	95%
ID03	Craters of the Moon National Monument	weekly	143	117	82%
ID98	Deer Flats	weekly	82	80	98%
ID99	McCall	weekly	109	96	88%
MT05	Glacier National Park-Fire Weather Station	weekly	335	244	73%
NV02	Lesperance Ranch	weekly	224	200	89%
NV99	Gibb's Ranch	weekly	249	204	82%
SFCR	Salmon Falls Creek Reservoir	weekly	38	37	97%
UT97	Salt Lake City	weekly	144	119	83%
WY08	Yellowstone National Park-Tower Falls	weekly	285	243	85%

Figure 3, Figure 4, and Figure 5 give statistical summaries of the aggregated samples for each site, representing concentration [nanograms per liter (ng/L)], precipitation [millimeters (mm)], and wet deposition [nanograms per square meter (ng/m^2)], respectively. The box-whisker plots show values for maximum, minimum, median, mean, and quartiles for each dataset. Data are skewed low for all three metrics indicating that high values occur infrequently.

ID99 and MT05 have the lowest mean concentrations and the lowest maximums. NV02, NV99, and UT97 have the highest means, with the Nevada sites recording the highest maximum concentrations. ID03, ID98, SFCR, and WY08 fall between these extremes.

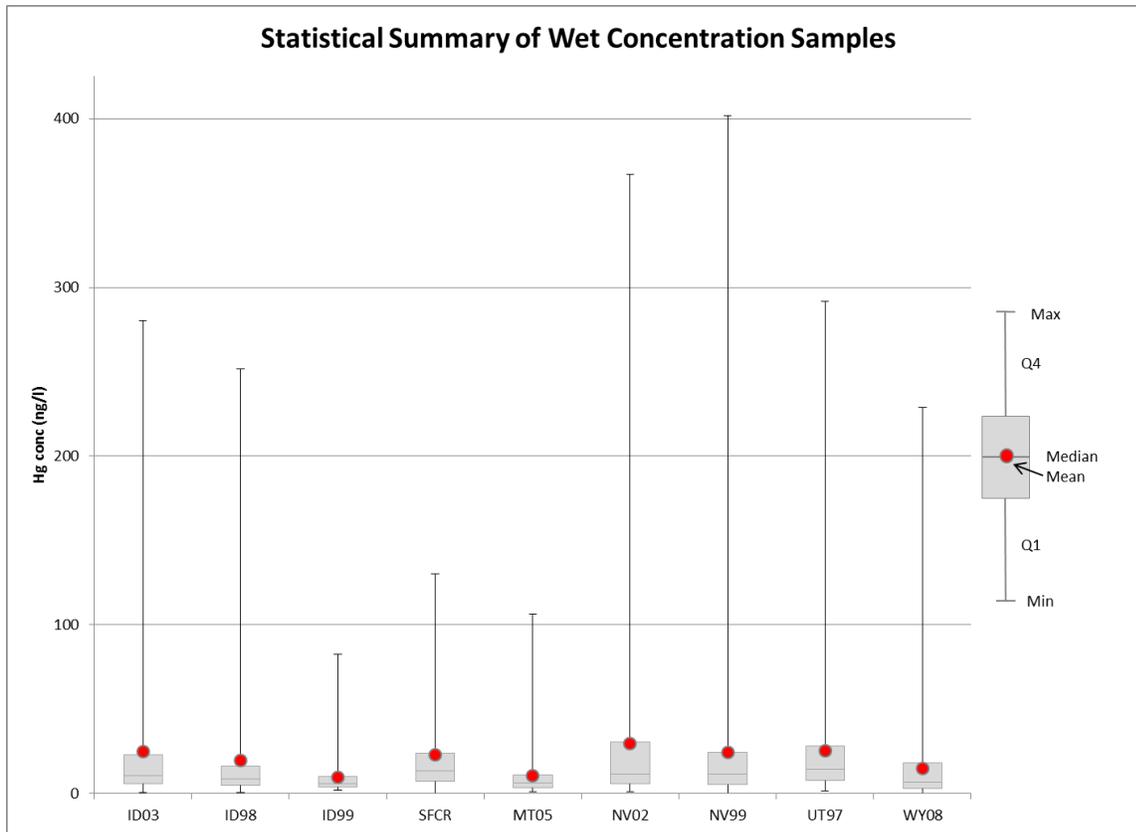


Figure 3. Statistical summary of wet concentration samples for all sites.

The precipitation summary chart (Figure 4) shows greater variety in measurements. ID99 and MT05 have the highest maximums, means, and largest interquartile ranges. ID98 and SFCR receive the least amount of precipitation of all sites and have the smallest range of measurements.

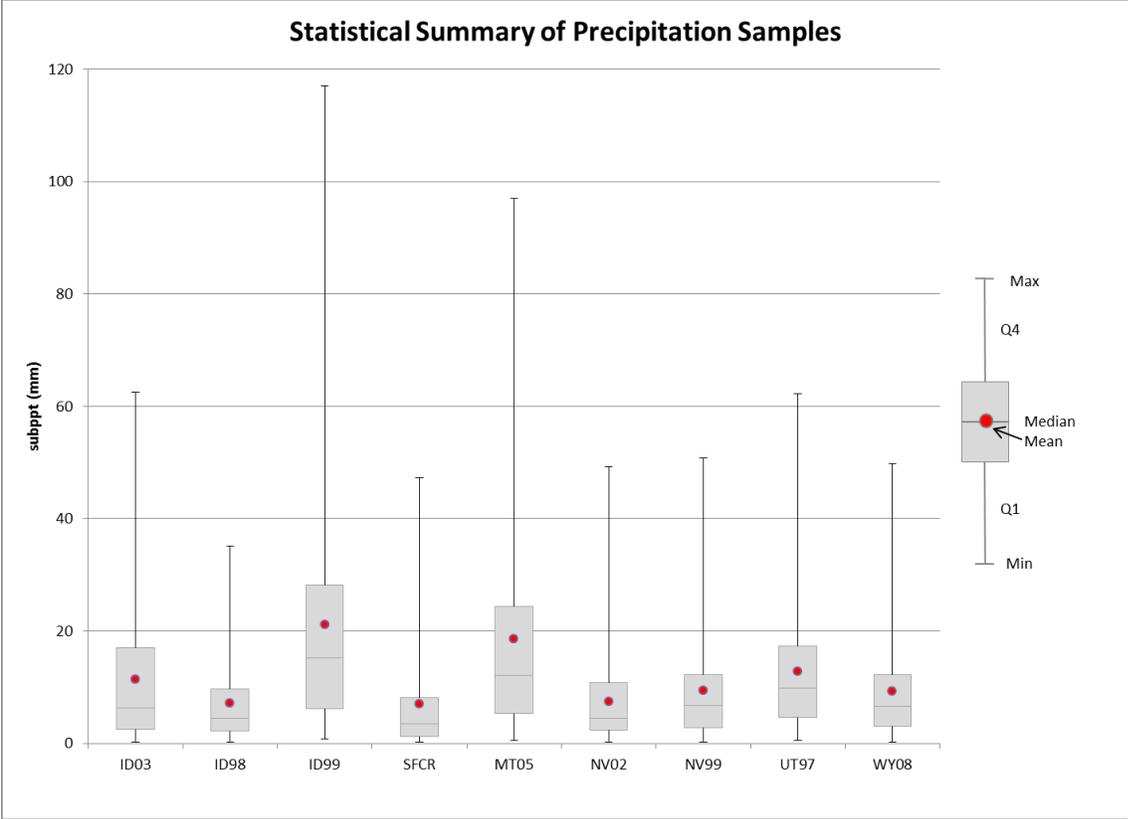


Figure 4. Statistical summary of precipitation samples for all sites.

The wet deposition summary chart (Figure 5) shows that on an aggregated basis, ID99 and UT97 receive the highest mean weekly wet deposition during the periods of record. The maximum recorded weekly accumulation was nearly 2,000 ng/m² of mercury at NV02. ID98 received the least deposition.

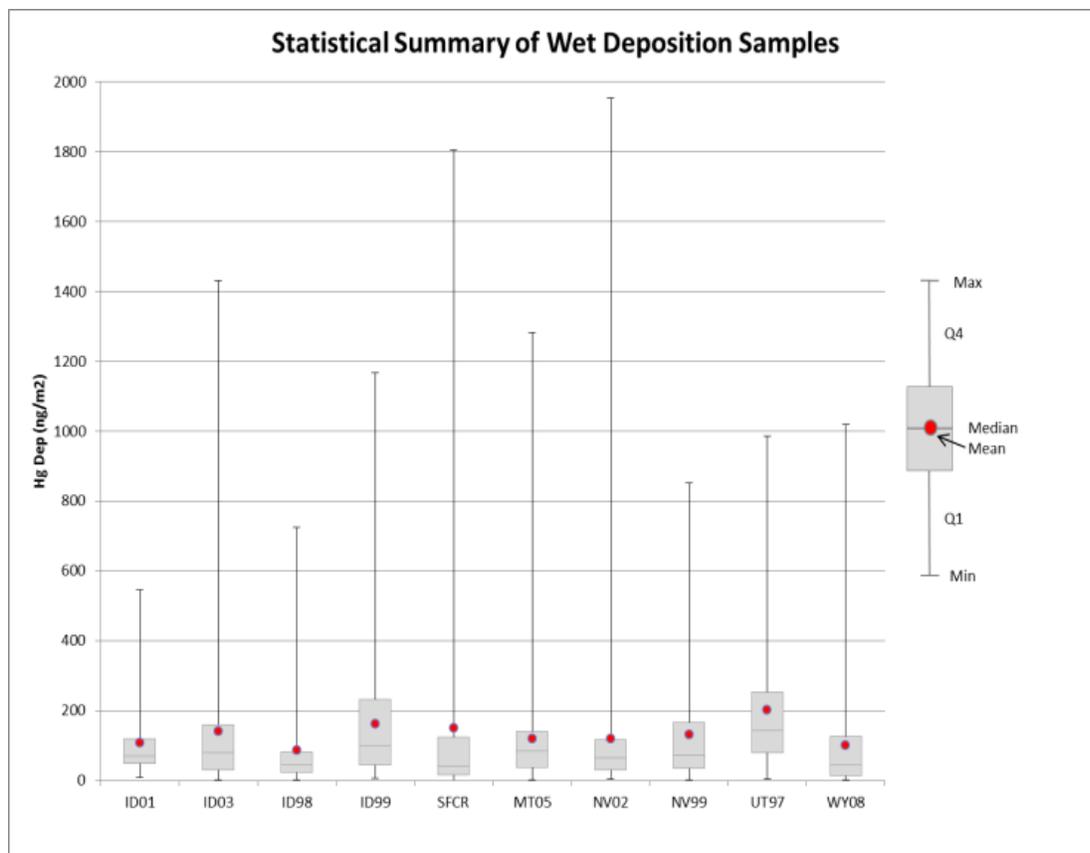


Figure 5. Statistical summary of wet deposition samples for all sites.

3 Results and Discussion

Valid data for all sites were split out by year and checked for seasonal completeness. Only those years with at least 2 months per 3-month season represented were used to calculate the interannual averages, so that the results would not be biased.

3.1 Interannual Averages

Average annual concentration (Figure 6) was calculated by finding the average concentration of all valid samples for each year, then averaging the means across the years. Figure 6 shows the resulting mean concentrations as red circles accompanied by whiskers that represent the standard deviation between the annual averages. For SFCR and ID01, both sites had only 1 year of complete data, so the means represent that 1 year, and the whiskers are the intrayear standard deviation. The gray-outlined boxes correspond to the secondary y-axis, giving a total sample count. The black-dashed line indicates the mean concentration calculated for the MDN in 2008 by Prestbo and Gay (2009).

Of the Idaho sites, ID03 and SFCR have the highest average concentrations (25 ng/L and 31 ng/L, respectively), whereas ID01 and ID99 have the lowest (13 ng/L and 10 ng/L, respectively). The greatest variability between years occurs at ID03 (the long whiskers at ID01

and SFCR are for values within 1 year). The Nevada and Utah sites (NV02, NV99, and UT97) have significantly higher annual average concentrations than ID99 and MT05.

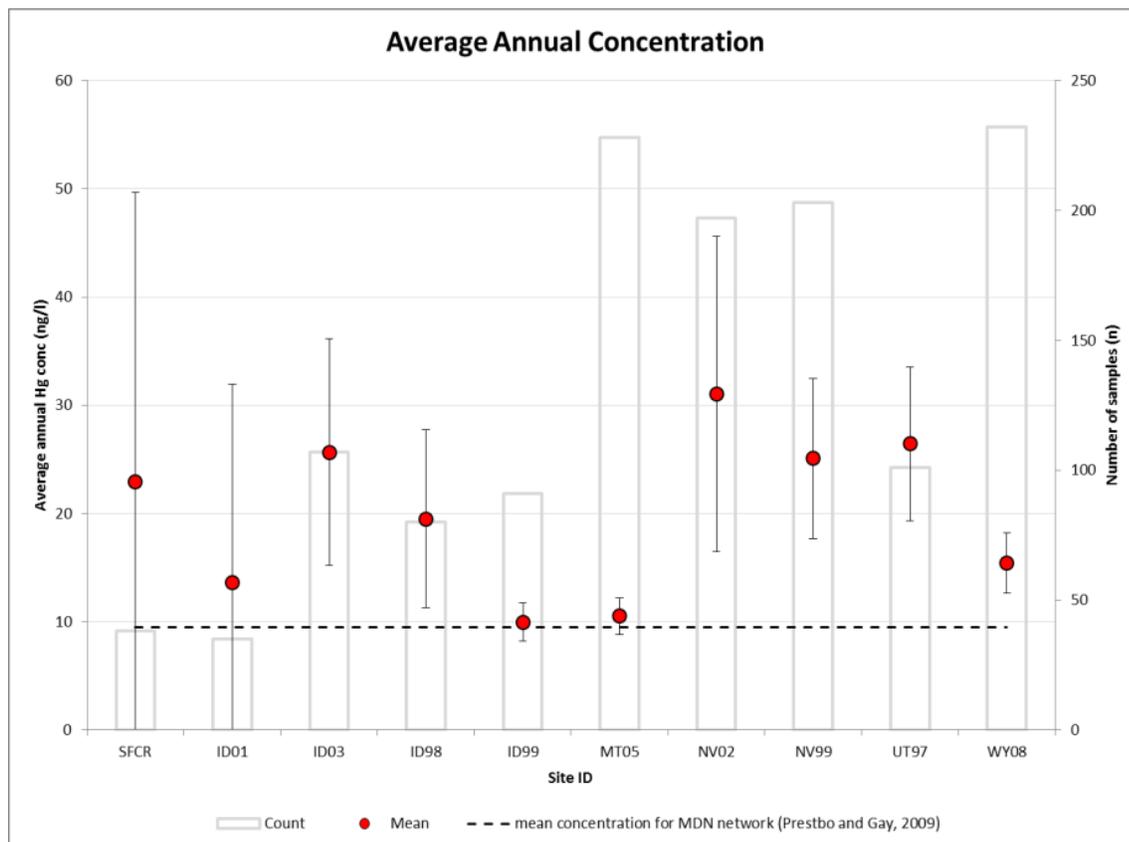


Figure 6. Average annual concentration for all sample sites.

All the sites in this study have average concentrations higher than the MDN mean, which is expected because most MDN sites are in the eastern United States, and these sites tend to have lower overall concentrations, as demonstrated by the MDN interpolation in Figure 7.

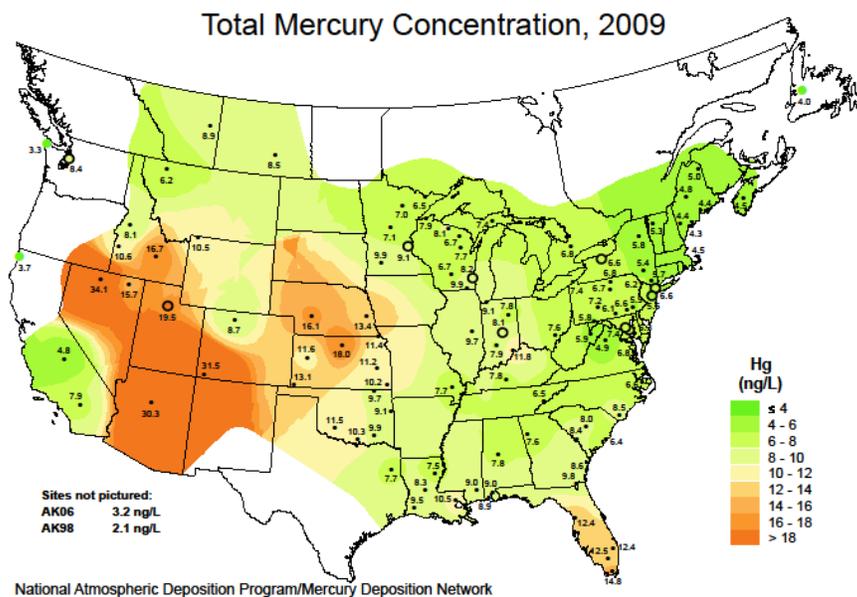


Figure 7. Nationwide MDN total mercury concentration, 2009.

Average total annual precipitation (Figure 8) was calculated by summing the precipitation by year, then averaging the sums together. ID99 and MT05 receive the highest amounts of precipitation, between 600 and 700 mm on average. ID98 and NV02 receive the least, just under 200 mm. ID99 has the greatest interannual range, and ID98 the smallest interannual range.

To validate the precipitation totals, the annual averages were compared to 100-year (1895–1997) averages at each each monitoring site, produced by the PRISM Climate Group (2013). The PRISM values for the Idaho monitoring sites are denoted by yellow triangles in Figure 8. All the PRISM precipitation values are greater than those collected at the MDN and SFCR sites. The values at SFCR and ID01 are very similar, and the PRISM values at ID03 and ID99 are both within the interannual standard deviation. The exception is at site ID98, where the PRISM annual average is greater than the interannual standard deviation.

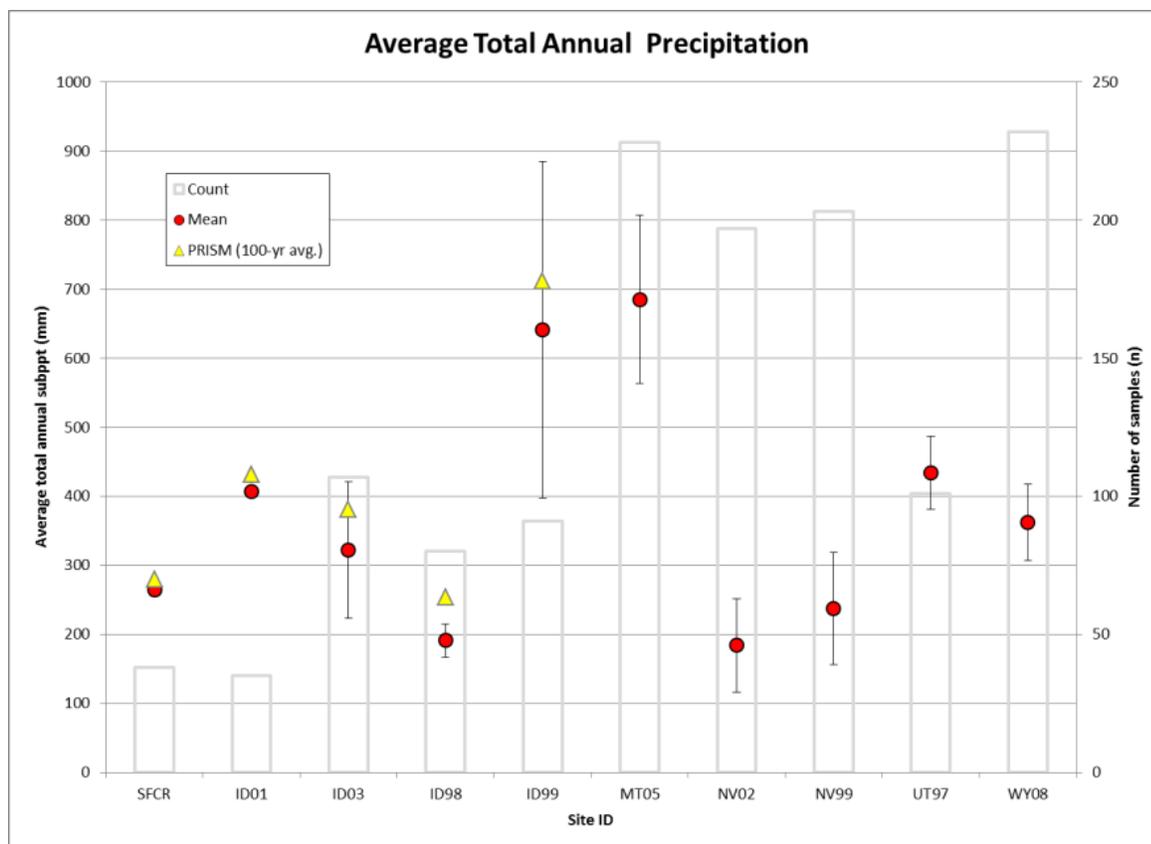


Figure 8. Average total annual precipitation for all sample sites.

Average total annual wet deposition (Figure 9) was calculated by summing the wet deposition by year, then averaging the sums together. SFCR and UT97 have the highest accumulations of mercury, averaging $5,600 \text{ ng/m}^2$ and $6,900 \text{ ng/m}^2$, respectively. ID98 collected the least mercury accumulations. These values correspond well with the published annual interpolation from 2009 in Figure 10.

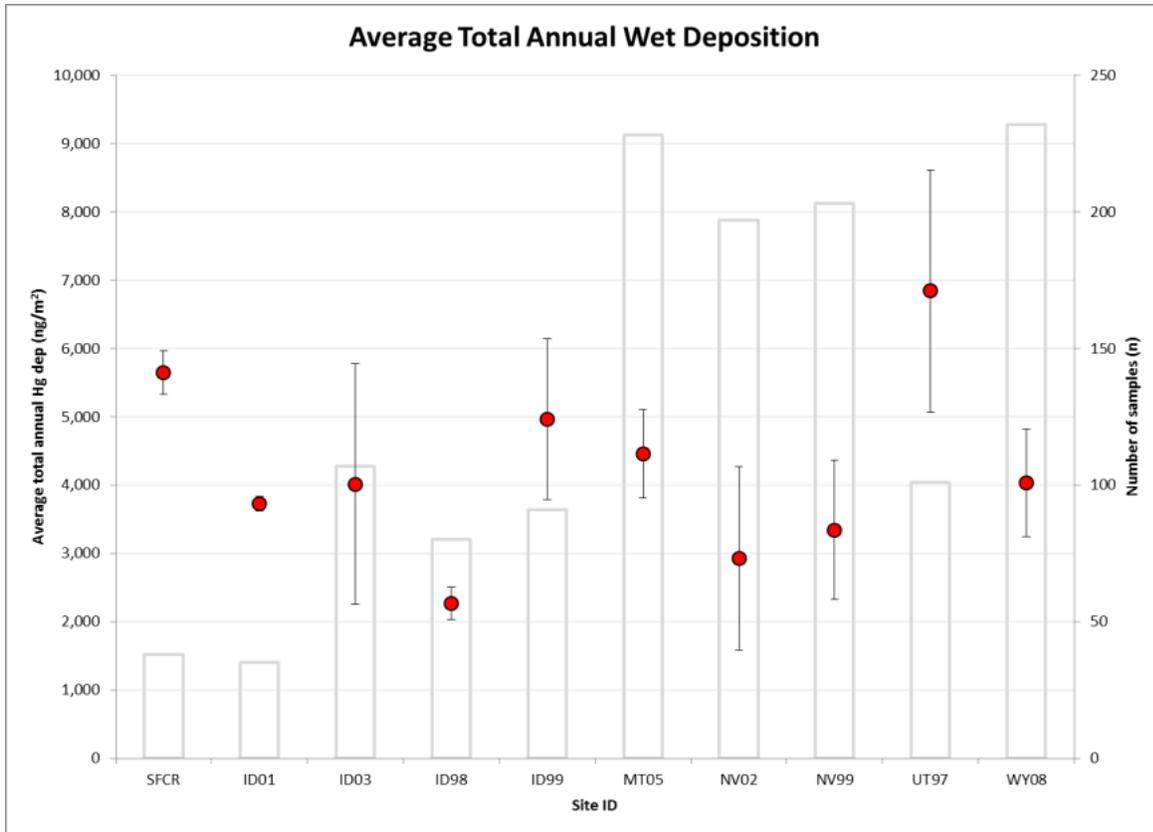


Figure 9. Average total annual wet deposition for all sample sites.

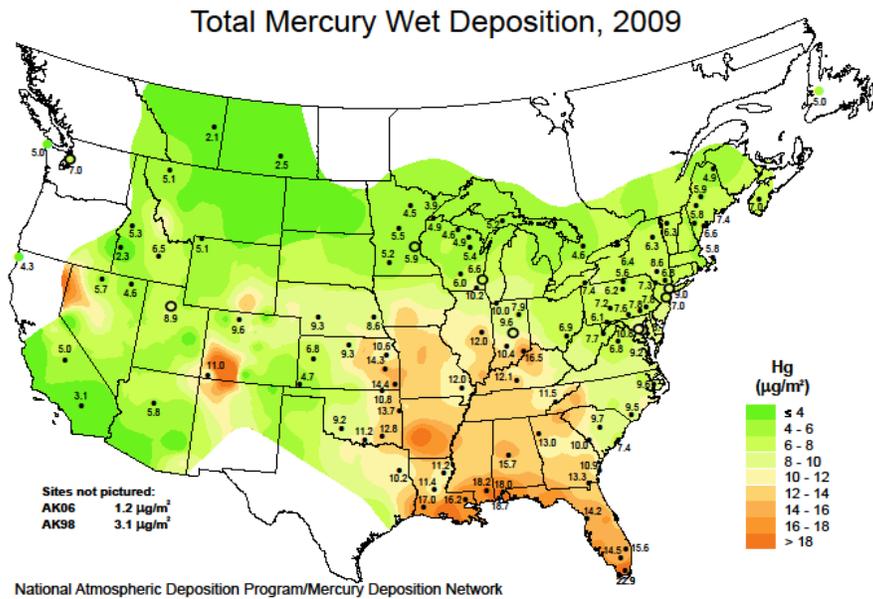


Figure 10. Nationwide MDN total mercury wet deposition, 2009.

3.2 Seasonal Trends

It is known that atmospheric mercury concentration has a strong seasonal component (Lyman et al. 2007; Peterson et al. 2009; Prestbo and Gay 2009; Selin and Jacob 2008). Concentration levels tend to be highest during spring and summer because atmospheric oxidant levels are higher as a result of increased insolation. The greater amounts of solar radiation allow the conversion of elemental mercury to the more reactive, soluble form of Hg^{2+} (Miller et al. 2005).

This study, therefore, examines the data for seasonal trends. Data completeness quality assurance protocols were followed as with the annual analysis. Seasons were designated as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and fall (September, October, and November). A season's data were included only if at least 2 months of each season contained events.

Figure 11 looks at the frequency of events by season. Since wet deposition at a particular site is controlled by a complex interplay between land cover (e.g., receptor surfaces), atmospheric composition (e.g., mercury concentration and oxidant levels), and climate (e.g., relative humidity, precipitation frequency, sky cover, and insolation rate) (Miller et al. 2005), event frequency might highlight purely climatic differences between sites. As shown in Figure 11, regionally, summer is the driest season. All sites record the lowest frequency of events during summer, except for MT05 and WY08. The Wyoming site (WY08) is the highest of the sites and probably receives orographically enhanced precipitation. The Montana site (MT05) sits to the windward of the high Glacier National Park peaks and may benefit from this geographical configuration in the form of enhanced precipitation.

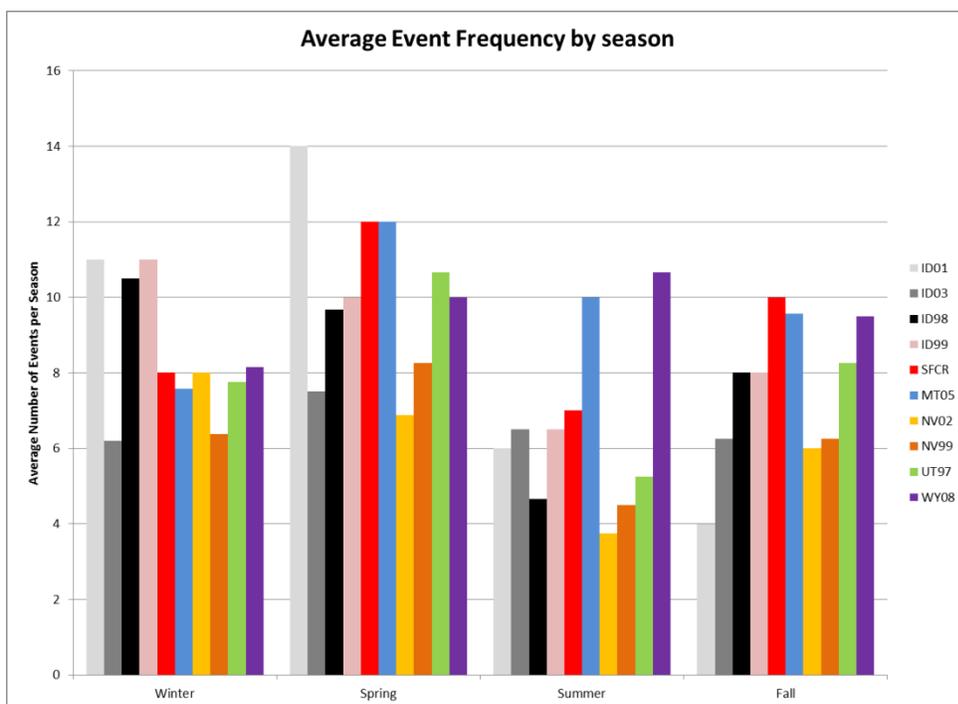


Figure 11. Average event frequency by season.

Figure 12 presents the average seasonal concentration. These values were calculated by averaging the concentration for each season, then averaging the means for each season. Figure 12 clearly shows that concentration peaks during the summer. ID03, ID98, SFCR, NV02, and NV99 are the highest. UT97 has one of the higher averages as well. This pattern makes sense since the solar radiation-latitude relationship has been recognized previously (Selin and Jacob 2008), and these sites are the most southerly. The exception, ID01, only represents 1 year of data, so it is difficult to know what a long-term trend would look like at this site. Winter has by far the lowest concentrations at all sites, while fall shows the three most southerly sites (NV02, NV99, and UT97) contrasting with the other sites.

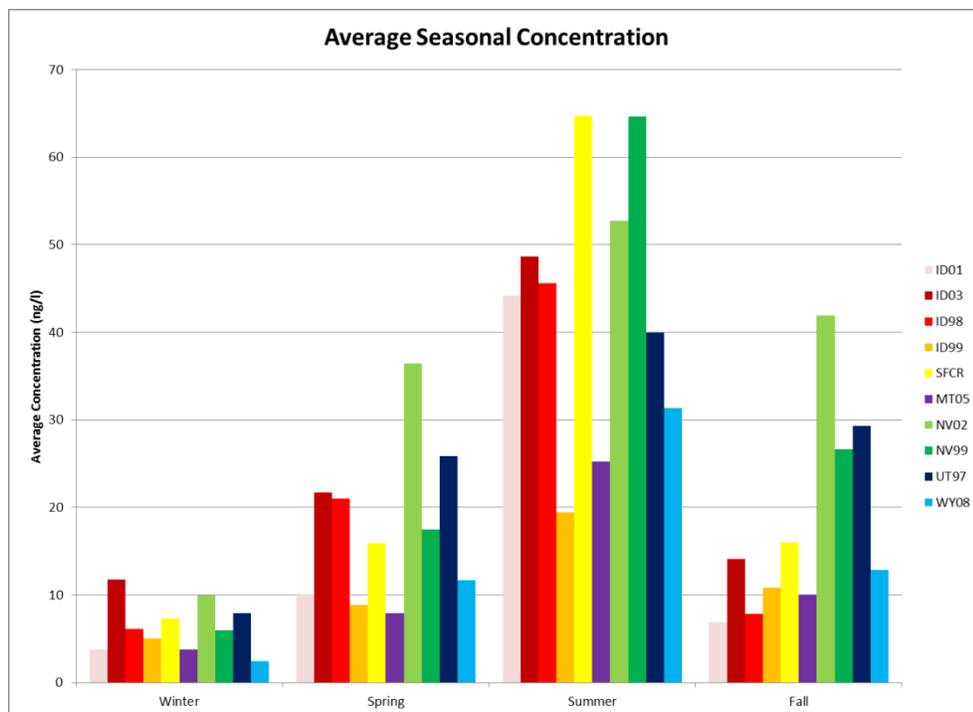


Figure 12. Average seasonal concentration.

Figure 13 is another way of looking at event frequency shown in Figure 11. Average seasonal precipitation suggests the climate patterns at the sites. The values in this chart were calculated by summing the total precipitation by season, then averaging the sums to obtain average seasonal precipitation. Just like in the frequency chart, all sites except MT05 and WY08 receive the lowest amount of annual precipitation during the summer. ID01, ID98, and ID99 accumulate more precipitation in winter and spring than summer and fall, with ID99 amassing the most of all sites in winter and spring. SFCR collected more precipitation in spring and summer than the other seasons.

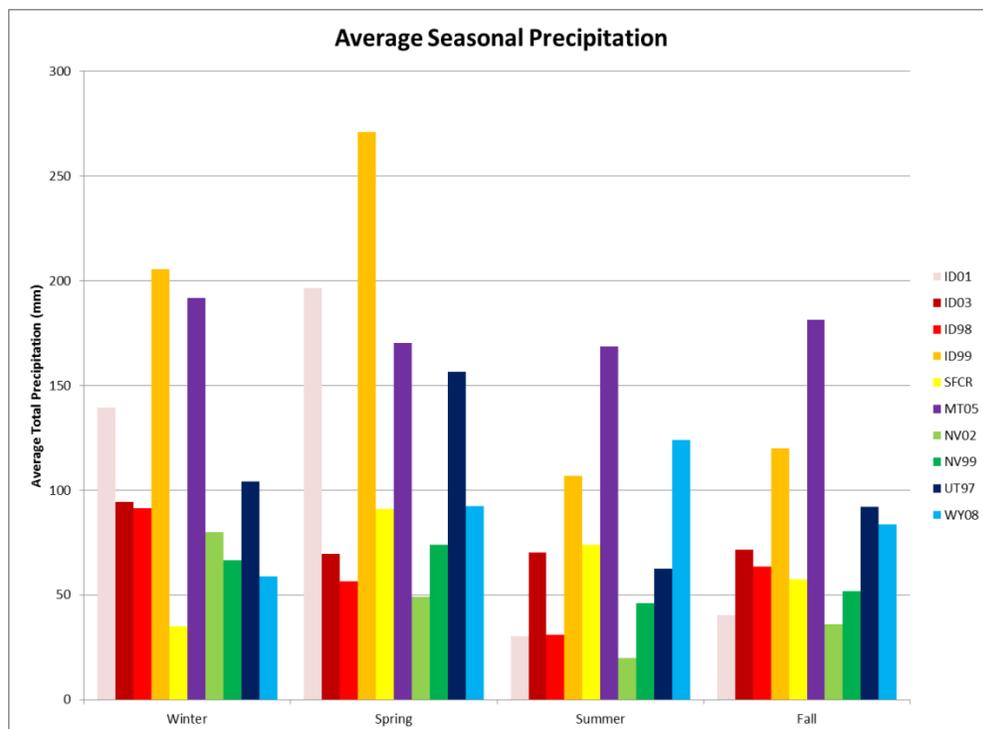


Figure 13. Average seasonal precipitation.

Since wet deposition is the product of concentration and precipitation, the balance of these two factors determine the resulting wet deposition rate. Areas with high atmospheric concentrations may see low total deposition because they receive only small amounts of precipitation. For example, Figure 7 shows that the southwestern United States has the highest levels of concentration in the nation, while Figure 10 makes clear that the southwest receives some of the lowest total deposition amounts. Conversely, sites with high precipitation frequency and total accumulation may not receive high levels of deposition because of washout. Prestbo and Gay (2009) examined this phenomenon and found that observed concentration decreased rapidly with increasing rainfall amounts, up to about 1 liter of precipitation.

Figure 14 depicts the results of the seasonal wet deposition calculations. These totals were determined by summing the deposition for each season, then averaging the sums for multiple years. The deposition provided in the downloaded MDN data is the product of the rain gauge precipitation amount and the total mercury concentration reported by the laboratory. Overall, spring and summer see the highest total average deposition for most sites; fall and winter record the least. The highest average depositions were recorded at ID01, SFCR (both single-year totals), ID99, UT97, and WY08. The total range, from the lowest (142 ng/m^2 at WY08 in winter) to the highest ($3,555 \text{ ng/m}^2$ at SFCR in summer), is smaller than the range reported in the analysis of 48 MDN sites across the United States in Prestbo and Gay (2009). In that study, the lowest average deposition was found during the winter in the midwest region at approximately 500 ng/m^2 . The highest was found to be around $6,500 \text{ ng/m}^2$ during the summer in the southeast region of the United States. Prestbo and Gay (2009) averaged all sites seasonally and found a high/low, summer/winter range to be $\sim 3,800 \text{ ng/m}^2$ to $\sim 1,000 \text{ ng/m}^2$. The Idaho data fit comfortably within this range for all seasons except winter, where the averages tend to be lower by half than the Prestbo and Gay (2009) minimum. This result could be caused by instrument

undercatch, when precipitation gauges are not properly wind-shielded and fail to fully catch precipitation during snow events. Compared to the rest of the MDN, most of the winter precipitation in Idaho falls in the form of snow.

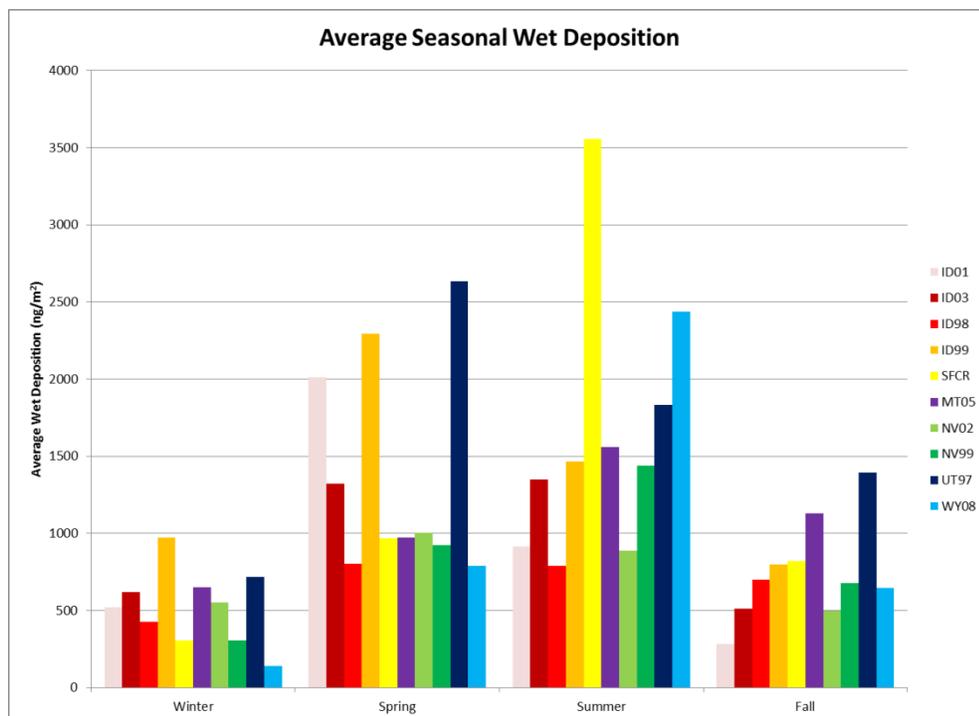


Figure 14. Average seasonal wet deposition.

3.3 Spatial Distribution

The spatial distribution of the annual average concentration, precipitation, and wet deposition at Idaho MDN sites is presented in Figure 15, Figure 16, and Figure 17. The maps were made by applying a simple inverse distance-weighted interpolation, which honors true values at the observation sites and assumes that the closer an area is to a measured value, the more likely that area is to have a similar value.

Annual average concentrations in Figure 15 show a strong latitudinal pattern, with values increasing with decreasing latitude. This is a known pattern (Bullock Jr. et al. 2008; Prestbo and Gay 2009; Selin and Jacob 2008), supporting the correlation found to exist between Hg^{2+} concentrations and solar radiation (Perry et al. 2010). The pattern produced in Figure 15 is similar to that in the MDN mapping (Figure 7). Southern Idaho forms the northern tier of the high concentration zone of the southwestern United States, where observed concentrations at MDN sites in New Mexico and southwestern Colorado are typically the highest of all US sites annually (Prestbo and Gay 2009).

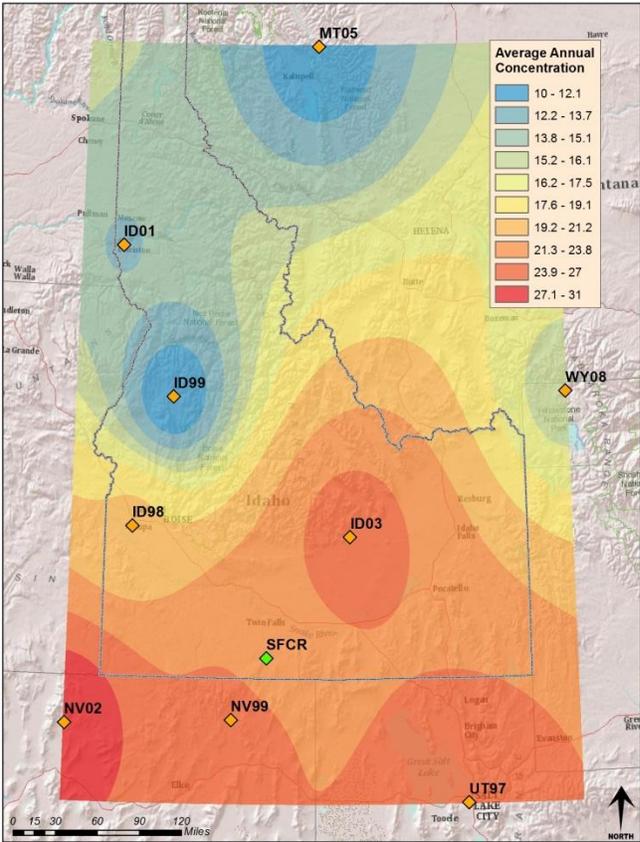


Figure 15. Inverse distance-weighted interpolation of average annual concentrations (in ng/L).

The pattern of annual average precipitation shown in Figure 16 illustrates the concept of orographic enhancement of precipitation. The areas with the highest annual amounts (ID99 stretching northeast to MT05 and UT97) occupy mountainous high ground or are windward of the Rocky Mountains and Wasatch Range. The other sites, with lower annual precipitation, like ID98 to ID03 and south to SFCR and Nevada, are located in the lowlands of the Snake River Plain and upper Columbia Basin.

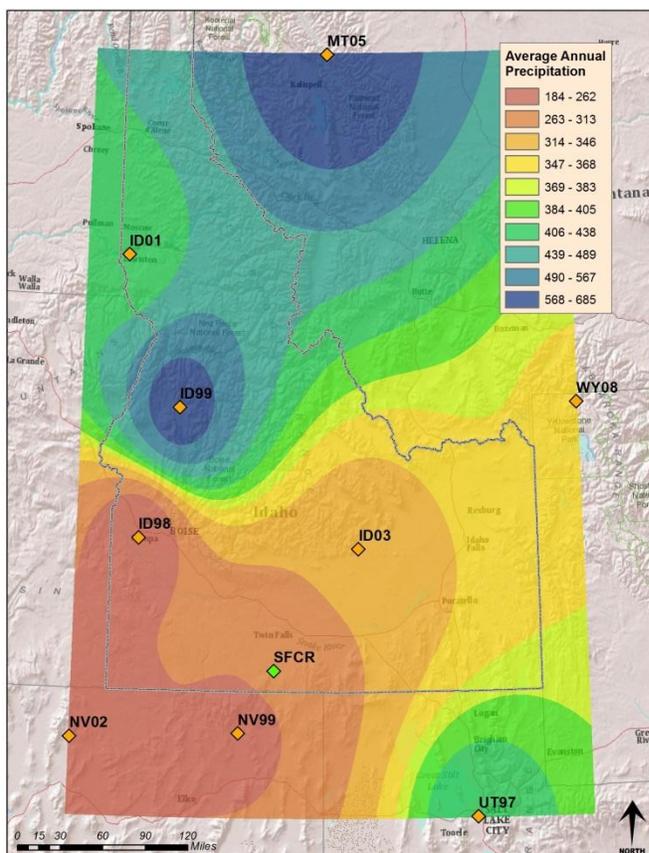


Figure 16. Inverse distance-weighted interpolation of average annual precipitation (in mm).

Figure 17 displays the interpolation of the average annual total mercury deposition at the MDN sites in Idaho and surrounding states. UT97, SFCR, and ID99 collect the highest amounts of mercury annually by wet deposition processes, and ID98 receives the least.

The Utah site achieves the highest deposition by having both high concentration levels and high precipitation. The presence of the Great Salt Lake likely increases the oxidation rates of elemental mercury (Hg^0) to reactive gaseous mercury (Hg^{2+}) by providing halides to the local atmosphere (Miller et al. 2005).

The results for SFCR are interesting because total deposition is higher than expected when compared to adjacent regional sites like ID03 and NV99. For 2006, the period during which the SFCR data were collected, the results are similar. SFCR had an annual wet deposition of $5,649 \text{ ng/m}^2$, compared to $4,214 \text{ ng/m}^2$ at NV99 and $2,035 \text{ ng/m}^2$ at NV02. However, the results should not be given great weight, since they only represent 1 year of data for comparison with SFCR.

ID99's relatively high deposition rate is clearly controlled by its high precipitation rate. Miller et al. (2005) notes that areas of relatively low mercury concentration frequently experience relatively high rates of wet deposition driven by high precipitation rates. In this case, the precipitation rate controls the outcome of the wet deposition rate.

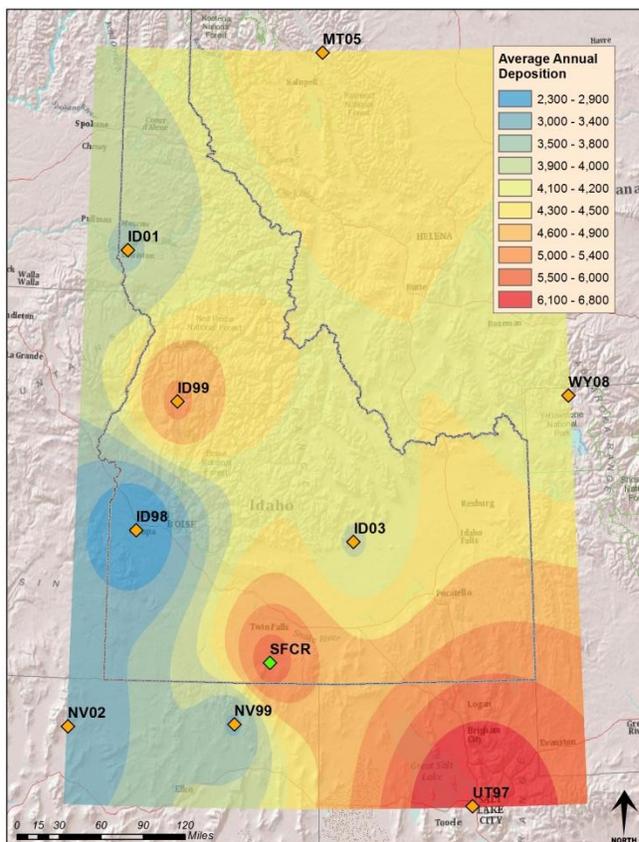


Figure 17. Inverse distance-weighted interpolation of average annual deposition (in ng/m^2).

Overall, the spatial distribution of mercury wet deposition in Idaho seems to follow regional climatic, latitudinal, and terrain-based factors. No major anomalies that could be attributed to local sources are detectable. The Idaho deposition rates fall in the lower range of all US MDN sites: <3 micrograms per square meter per year ($\mu\text{g}/\text{m}^2/\text{yr}$) in northern California to >25 $\mu\text{g}/\text{m}^2/\text{yr}$ in south Florida (Prestbo and Gay 2009). The MDN is designed to capture regional patterns of mercury wet deposition and it seems, in the case of Idaho, to be successful. Given the global pool of background atmospheric mercury, the variable deposition rates at Idaho sites are controlled by local terrain, climate, and latitudinal factors. If a local source had an outsize effect on a particular site, then the deposition rate would be expected to reflect this. However, this effect does not seem to be the case in Idaho. Selin and Jacob (2008) support this assertion by stating that on a regional scale most of the mercury deposition in the United States originates from the global pool.

4 Comparison to REMSAD Model

The final objective of the present study is to compare the observed MDN data with the modeled wet deposition data for Idaho provided by REMSAD. The comparison will allow for an assessment of the utility of using the REMSAD results for TMDLs.

4.1 Description of Model

The REMSAD model was commissioned by the United States Environmental Protection Agency (EPA) Office of Water to provide state and local air and water quality agencies with information regarding the sources and mechanisms of mercury deposition (wet and dry). Furthermore, the REMSAD undertaking provided data to support TMDL analyses in affected areas (Myers et al. 2006).

REMSAD is a three-dimensional grid model that calculates mercury concentration averages and deposition totals for any time during the simulation period and at any location within the domain. The modeling period is 2003, and the domain covers the entire United States and parts of Mexico and Canada with a 12 kilometer (km) grid. In addition, REMSAD includes a Particle and Precursor Tagging Methodology (PPTM) that tracks source emissions and quantifies their contributions to mercury concentration and wet deposition. A selected source of emissions or group of sources is called a *tag* (Myers et al. 2006). Greater detail on the design of the REMSAD model is found in Myers et al. (2006).

4.2 Comparison with Mercury Deposition Network Data

To begin the comparison, REMSAD annual wet deposition totals were extracted from each 12-km grid cell that contained an MDN or SFCR observation site. Different results are given for model runs using varying combinations of background models and boundary conditions. All options were compared to the interannual wet deposition averaged observations. Table 4 lists the ratios for modeled to monitored values for each site and each tag number. Table 5 gives the emissions sources and background models included in each tag. Of the nine tags, Tag 9, which uses all North American emissions with the REMSAD modeled Global/Regional Atmospheric Heavy Metals (GRAHM) background, returns the smallest ratios overall. EPA (2009) recommends model-to-monitor comparisons within a factor of two to be within the acceptable limits of a good comparison.

Table 4. Ratio of REMSAD model to MDN monitor annual wet deposition values for REMSAD model cells containing MDN and SFCR observation sites for nine REMSAD tags.

Site ID	Tag 1	Tag 2	Tag 3	Tag 4	Tag 5	Tag 6	Tag 7	Tag 8	Tag 9
ID01	1	4	1	4	2	3	1	1	1
ID03	1	4	1	5	1	3	1	1	1
ID98	3	7	2	8	4	6	2	2	1
ID99	1	3	1	4	1	3	1	1	1
MT05	1	3	0.5	4	2	3	1	1	0.4
NV02	2	7	2	7	3	5	2	2	1
NV99	3	7	3	8	4	6	3	3	3
SFCR	2	4	1	4	2	3	1	1	1
WY08	1	5	1	6	2	4	1	1	1

Table 5. Relevant REMSAD tag number definitions.

Tag No.	Emissions Sources and Background Models
1	All US, Canada, and Mexico emissions plus average of CMAQ and REMSAD CTM, GRAHM, and GEOS-Chem background
2	All US, Canada, and Mexico emissions plus average of CMAQ CTM, GRAHM, and GEOS-Chem background
3	All US, Canada, and Mexico emissions plus average of REMSAD CTM, GRAHM, and GEOS-Chem background
4	All US, Canada, and Mexico emissions plus CMAQ CTM background
5	All US, Canada, and Mexico emissions plus CMAQ GEOS-Chem background
6	All US, Canada, and Mexico emissions plus CMAQ GRAHM background
7	All US, Canada, and Mexico emissions plus REMSAD CTM background
8	All US, Canada, and Mexico emissions plus REMSAD GEOS-Chem background
9	All US, Canada, and Mexico emissions plus REMSAD GRAHM background

Notes: Community Multiscale Air Quality (CMAQ), Regional Modeling System for Aerosols and Deposition Chemical Transport Model (REMSAD CTM), Global/Regional Atmospheric Heavy Metals (GRAHM), Goddard Earth Observing System (GEOS-Chem)

The ratios from Tag 9 are charted in Figure 18. The red box outlines the values within a factor of two. Only the ratios at the NV99 and MT05 sites fall outside the box; all Idaho sites are in reasonable agreement.

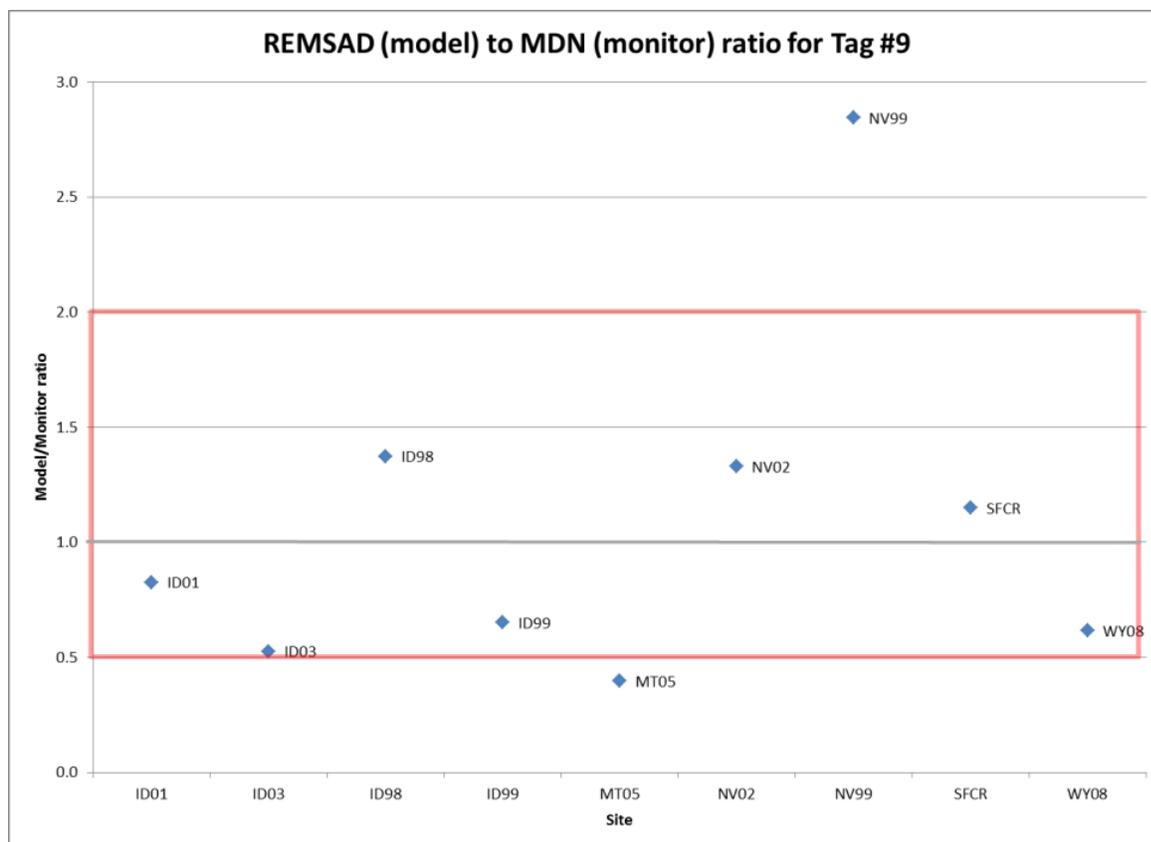


Figure 18. Chart of model-to-monitor ratio for Tag 9. Red box designates values that fall within a factor of two.

The actual wet deposition values for model and monitor are given in Figure 19. The REMSAD model underestimates the observed wet deposition at three Idaho sites (ID01, ID03, and ID99) and overestimates at two sites (ID98 and SFCR). The model overestimates by half at NV99. If the MDN data for NV02 and NV99 are compared with the model data for the year the model represents (2003), the same relationship exists. NV02 had an annual wet deposition of $2,955 \text{ ng/m}^2$ in 2003, very similar to the site's annual average. NV99 had an annual wet deposition of $4,338 \text{ ng/m}^2$ in 2003, about $1,000 \text{ ng/m}^2$ higher than its annual average. However, the model predicts at least 50% more wet deposition at that site.

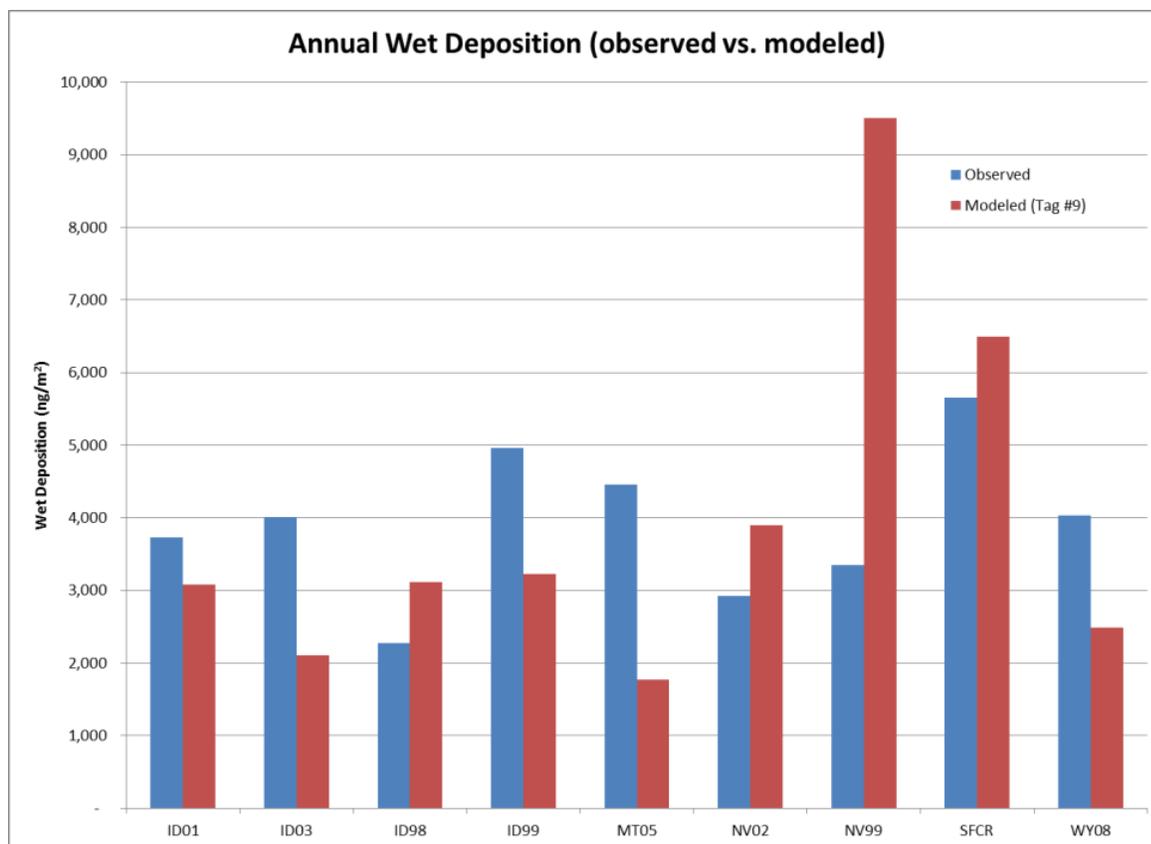


Figure 19. Observed average annual wet deposition at monitoring sites and modeled annual wet deposition from REMSAD (in ng/m²).

Figure 20 is an inverse distance-weighted interpolation of the REMSAD wet deposition, comparable to that developed for the observed data in Figure 17. The main spatial differences between the two interpolations (besides the loss of UT97 in Figure 20, the REMSAD data obtained did not extend to the Utah site) are the higher values apportioned to the sites in the southwestern corner of the domain. NV02, NV99, and ID98 are all greater in the model than the observations. Otherwise, the simulation is satisfactory.

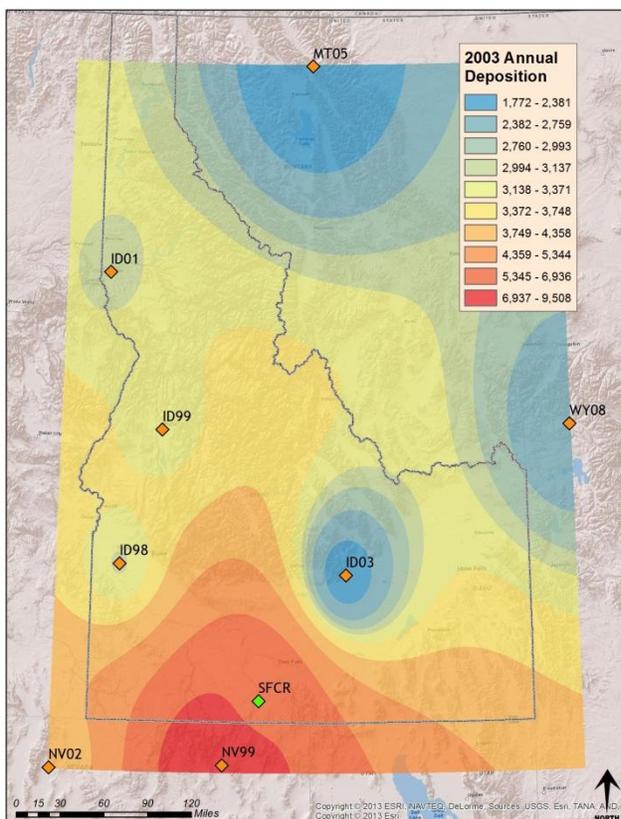


Figure 20. Inverse distance-weighted interpolation of 2003 annual deposition (in ng/m²) for REMSAD grid cells containing MDN and SFCR observation sites.

Figure 21 presents a possible explanation for the overestimation by the model for sites like NV99 and ID98. The figure gives the proportion of emissions associated with either background (the global pool) or US sources. NV99, the most grossly overestimated site, attributes nearly half its emissions to US sources (specifically, local Nevada gold roasting operations). All other sites attribute less than one-quarter of their emissions to US sources. Most emissions come from the global pool. NV99, SFCR, NV02, and ID98 are the closest monitor sites to significant regional emissions sources (Figure 1). It appears that the REMSAD model is overestimating the influence of local sources at these sites.

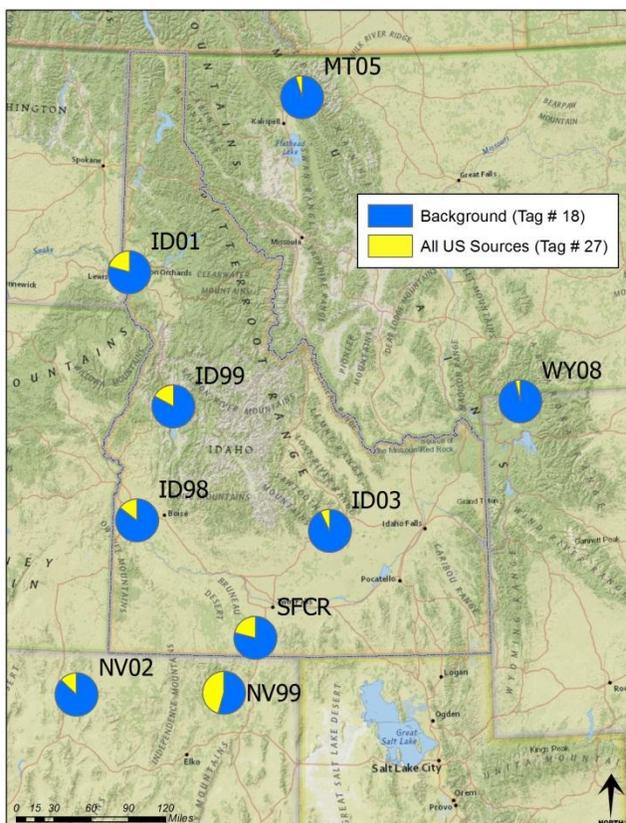


Figure 21. REMSAD wet deposition sources at MDN observation sites.

Interestingly, REMSAD underestimates the three sites (ID99, ID01, and MT05) with the highest average annual precipitation. Perhaps the model meteorology incorrectly quantifies the expected rainfall in these regions. Bullock Jr. et al. (2009) compared MDN and REMSAD results for mostly eastern US sites and found that the model had difficulties simulating during spring and summer, stating that “precipitation in the warm seasons over North America is largely convective in nature and this presents special difficulties for the meteorological simulation on which air quality models rely to estimate wet deposition.” This point can be applied to watershed-scale analyses using REMSAD data; precipitation biases will be higher in the uplands.

The following observations, (1) sites closely adjacent to major local sources have their contributions from local sources overestimated by REMSAD and (2) sites with orographically enhanced precipitation may have their total precipitation underestimated by REMSAD, may help inform future use of the REMSAD data in preparing Idaho TMDLs. Generally, the REMSAD model, using results from Tag 9, seems appropriate for use in watershed-scale mercury analyses.

5 Conclusions and Recommendations

This study examined the MDN data available for Idaho and placed it within the context of the MDN. Idaho's rates and spatial patterns of mercury wet deposition are not unusual from a climatic, seasonal, or geographical point of view. The sites with the highest deposition tend to have the most precipitation. The warm months tend to have the highest rates of deposition and the southerly sites tend to have the highest concentrations. Comparisons with the REMSAD model are reasonable, and the results can be used for watershed-scale analyses with the following caveats in mind: REMSAD overestimates the influence of significant industrial sources and underestimates the deposition at high precipitation sites.

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