Proposal to Measure Atmospheric Deposition in Utah Lake

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Prepared for the Utah Lake Science Panel
April, 2019
Revised August, 2019

Introduction

The National Atmospheric Deposition Program (NADP; http://nadp.slh.wisc.edu/NADP/) was organized in 1977 and sites in the NADP precipitation chemistry network began operations in 1978. The goal was to provide data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation. Notably, although measuring nutrients was listed as a primary goal, only nitrate was originally measured and ammonia measurement didn't begin until 2009. While efforts to develop dry deposition sampling protocols are apparently underway and similarly, efforts to add phosphorus to the list of analytes has been mentioned; there are currently no dry deposition or phosphorus data listed on the NADP website. The Manual states "The networks associated with the NADP consider wet-deposition (AIRMoN, MDN, and NTN), atmospheric mercury (AMNet), and atmospheric ammonia (AMoN). Selection of monitoring sites within the NADP is based on the site's potential to: provide insight into changing atmospheric chemistry, help assess the contributions to sensitive ecosystems, and help validate atmospheric models. Of particular interest are major ***physiographic, agricultural, aquatic***, and forested ***areas within states, regions, and ecoregions***." (emphasis added). Table 1 is excerpted from the NADP site selection and Installation Manual.

Table 1. NADP Site Classifications.

Site Classification	Population within 15km of the site (people/km^2)
Isolated (I)	< 10
Rural (R)	10 – 99
Suburban (S)	100 – 399
Urban (U)	≥ 400
Research/Provisional (P)	na

After collecting dry deposition samples in our program for 2.5 years, I clearly understand why standard protocols have NOT been established for dry deposition. There are myriad variables associated with dry deposition sampling and existing reports that include dry deposition only describe specific methods to meet specific project goals. These include, but are not limited to: near and far field agricultural activities, (e.g. Winter et al. 2002, Anderson and Downing, 2006;

i.e. plowing and tilling can be a source of dust and between plantings, bare soil can be a significant source of dust during wind events). The dust flux in an arid urbanizing area may be as much as twice that before disturbance but decreases when construction stops (Reheis and Kihl 1995). In addition to just the dust, some studies have determined that dry deposition may contain more P and N than wet deposition samples (Ahn and James 2001; Anderson and Downing 2006; Winter et al. 2002). Conversely, in higher precipitation areas, wet deposition is the most dominant form of deposition and generally reflects long-range transport, while dry deposition is more linked to local pollution levels (Balistrini et al. 1995).

Several reports indicate that dust can travel great distances. Much of this evidence has been collected comparing wet and dry deposition in the Iberian Peninsula. Notably, Loye-Pilot and Martin (1996) suggest that in rainy areas dry deposition can be ignored, but dry deposition can be the dominant fraction in arid and semiarid regions where intense dust loadings take place and it is important to separate wet and dry deposition (Loye-Pilot and Martin 1996). Dry deposition can dominate the atmospheric delivery of particulate matter, including total phosphorous, Ca^{2+}, Mg^{2+}, and K^{+} in the Sahara Desert (Morale-Baquero, et al. 2013). It is noteworthy that the sampling area, in the Sierra Nevada Mountains of southern Spain, is approximately 160 km from the north shore of Africa (the source being identified as the Sahara Desert). Despite this distance, the mean of 108 samples over two years was 23.6 mg m^{-2} day^{-1} of total particulate matter in dry deposition samplers (range = 0.3–105.8 mg m^{-2} day^{-1}) and 6.8 mg m^{-2} day^{-1} in wet deposition samples (range = 0.0–95.8 mg m^{-2} day^{-1}). Of this total particulate matter, approximately 50 ug or 0.16% was P (Morale-Baquero, et al. 2013).

One of the most extreme examples of dry deposition lies in the evidence of transoceanic transport (Yu et al. 2015). They based their estimate on 3-D distributions of aerosols from Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) from 2007 to 2013. This was an improvement on the previous standard for satellite estimates of dust deposition using the Moderate Resolution Imaging Spectroradiometer (MODIS) that provides only a two-dimensional view of the transport [Remer et al., 2005]. In short, from the 7-year study the annual average deposition of North African dust in the Amazon (i.e. excluding local sources from fires, etc.), was estimated to be 28.9 kg ha^{-1} yr^{-1}. Furthermore, based on analysis of the dust in the Sahara, the deposition of P in the Amazon Basin was estimated at 780 ppm (Bristow et al., 2010).

In the US, one of the most noted examples of mobilized sediment/dust from Owens Lake (Figure 3). The average silt and clay flux (rate of deposition) in southern Nevada and southeastern California ranges from 4.3 to 15.7 g m^{-2} yr^{-1}, but in southwestern California the average silt and clay flux is as high as 30 g m^{-2} yr^{-1} (Reheis et al. 1995). Documentation of the Owens Lake diversion debacle is a clear example. The dried lake bed of Owens Lake in Inyo County, California, has been identified as the likely largest single source of particulate matter pollution in the United States (U.S. Environmental Protection Agency (EPA), Air Data, 2003, available at http:// www.epa.gov/air/data). Gillette et al. (2004), from a combined modeling and measurement process, estimated that 1 × 10^6 to 3.8 × 10^6 t of dust $year^{-1}$ are emitted from lake bed of Owens Lake. Dust emissions from single storms have been estimated at 80,000 t (Figure 3). How far does this dust travel? Reheis (1997) estimated deposition rates at a sampling site approximately 40 km downwind from Owens Lake to be about 20-25 mg m $^{-2}$ d $^{-1}$ during 1992. After a fire in the vicinity occurred during the 1992-93 winter the total dust flux increased to 30-40 mg m $^{-2}$ d $^{-1}$. Notably, however, by May 1993 wind had completely stripped the burn surfaces of fine soil particles and charcoal and deposition returned to the 1992 values (Gillette et al. 2004).

While no estimates of P concentrations in Owens Lake dust could be found, it may be reasonable to assume that Owens Lake has been part of a terminal lake system for many thousands of years or beyond, and hence P concentrations in dust may be similar among Great Basin terminal lakes. Sediment samples in and around Utah Lake have been reported by Abu-Hmeidan et al. (2018). The mean of 93 samples = 690 mg kg^{-1}. Abu-Hmeidan et al. (2018) believed that these samples were remnants of ancient Lake Bonneville sediments. Another remnant of Lake Bonneville, the dry lake bed of Sevier Lake contains 800 to 2200 mg P kg^{-1} (Carling and Avner, unpublished data). Lake Bonneville most recently formed during the last part of the last ice age at about 25,000 years ago. It was large, covering nearly half of Utah (Figure 1). Sevier Lake is located in west-central Utah, in the southern portion of Lake Bonneville, about 160 km SW of Utah Lake (Figure 2).

Figure 2 also shows the location of the current NADP sampling sites in Utah (NE Utah, Eastern Uinta Mountains, Green River, Canyonlands NP and Bryce NP). All of the sampling sites are in the northern or eastern parts of Utah, far away and over at least one mountain range (the Wasatch Mountains; reaching 9000 to 12000 ft elevation), from ancient Lake Bonneville and its remnant playas, This range restricts and captures or deflects large quantities of moisture and contaminants and would certainly restrict much of the dust leaving the Sevier Lake playa and the west deserts of Utah from reaching the NADP samplers located east of the Wasatch. As such, even if P were analyzed in the NADP samples, data would represent only broad regional to multi-state-scale deposition, with little regard to the blocking effect of Wasatch Mountains or the local importance of dust and nutrient sources from the playas in the Great Basin. Hence there is minimal influence from Lake Bonneville sediments at these sites.

Alternatively, with minimal topographic impedence, Utah Lake is likely continually supplied with phosphorus-rich dust from the dry lake bed of Sevier Lake and the Great Salt Lake Desert. For example, as reported in the Deseret News on April 16, of 2018:

> "SALT LAKE CITY — High winds carried dust from a dry lake in Millard County to the Wasatch Front, where multiple counties had pollution warnings in effect due to the dust storms. The National Weather Service in Salt Lake City said much of the dust along the Wasatch Front was the result of winds whipping up dust from the dry Sevier Lake."

The location of Sevier Lake, immediately upwind (southwest) of Utah Lake, is of particular interest for the quantity and nutrient content of its dust. Yet, today, there are no NADP sites within 150 miles of Sevier Lake or Utah Lake.

Furthermore, dust mobilized from a dry lake bed such as Owens Lake or Sevier Lake can amount to many thousands of tons of dust per year and with this being sedimentary dust, Sevier Lake is located approximately 150 km SW from Utah Lake (equidistant as that between the Sahara Desert and Southern Spain, for comparison). Moreover, the dry lake bed of Sevier Lake is large, about 1.6 X larger than that of Owens Lake, CA, (453 vs 280 km^2), and 1.5 X larger than Utah Lake itself (383 km^2). Hence, mobilized Sevier Lake sediment is potentially a source for large quantities of nutrients that reach Utah Lake. The two primary questions are: What is the dust load that reaches Utah Lake and what is the content of P and N?

Local sources may also be important (Balistrini et al. 1995, Reheis and Kihl 1995).. This would be particularly true in the enclosed Utah and Salt Lake Valleys where temperature inversions, and evening easterly downslope winds carry urban aerosols and particularly N directly over the lakes. (e.g. Durbin et al. 2001). For example, Dr. David Richards, resident of the lakeside community of Vineyard, reports that a local haze over the lake occurs most mornings as natural evening temperature inversions develop over the relatively cool lake nearly every evening.

Dr. Wood Miller, Professor of Engineering, BYU has collected bulk atmospheric deposition samples from 9 locations surrounding Utah Lake over the last 2.5 years. These particular samplers included a funnel with the mouth approximately 1.5 ft in diameter leading to a storage cylinder. Samples were retrieved after each rainfall. Unlike the bulk deposition samplers designed and used by USGS, it is possible that dust that settles on the slope of the funnel could get resuspended with successive winds and lost to the sample; hence providing a conservative estimate of deposition. Yet, overall mean concentrations among all sites and 299 samples were 0.798 mg/L for TP and 3.289 mg/L for TN (unpublished data). With an estimated 16 inches average annual rainfall, this amounts to conservative estimate of approximately 110 tons of P added to the lake surface annually. Notably, the three sites with the lowest values for P were 3-4 miles east of the lake and 400 ft or more above the lake surface elevation, near the foot of the mountains, while the higher measurements were nearer to the lake, a possible reflection of the diurnal down-slope (easterly) breezes as well as the proximity to an urban environment and active construction and agriculture.

The proportion of contribution from intra-basin transfers from the sediments of ancient Lake Bonneville or from local airshed sources, (e.g. agriculture, construction, etc. including rural and suburban and urban) remains to be more carefully evaluated and is not a part of this scope. But with Utah County often recognized as the fastest growing urban population in the US, these urban disturbances, encroaching further and further upon the shorelines of Utah Lake, this activity is highly unlikely to change any time in the near future and it is our responsibility to develop an accurate accounting of these potential sources of nutrients to the Lake.

We believe that to ignore the combination of heavily urbanized and continued development within the nearfield watershed, intensive agricultural use, as well as regional dust storms from Sevier Lake, would ignore significant quantities of urban and rural sources of nutrients that may reach the lake. NADP appears to recognize these types of unique circumstances in their narrative for site design:

> “….designated as Guidelines. These criteria are recommendations based on scientific judgment. Due to practical siting considerations and research goals, it may not be possible for sites to meet one or more of these criteria. Failure to meet these criteria does not prohibit a site from either joining, or remaining in an NADP network. Again, the extent of the departure from these criteria may designate the site as *Research/Provisional*.”

SOURCE: UTAH GEOLOGICAL SURVEY

Figure 1. Location of ancient Lake Bonneville, current Great Salt Lake and Utah Lake.

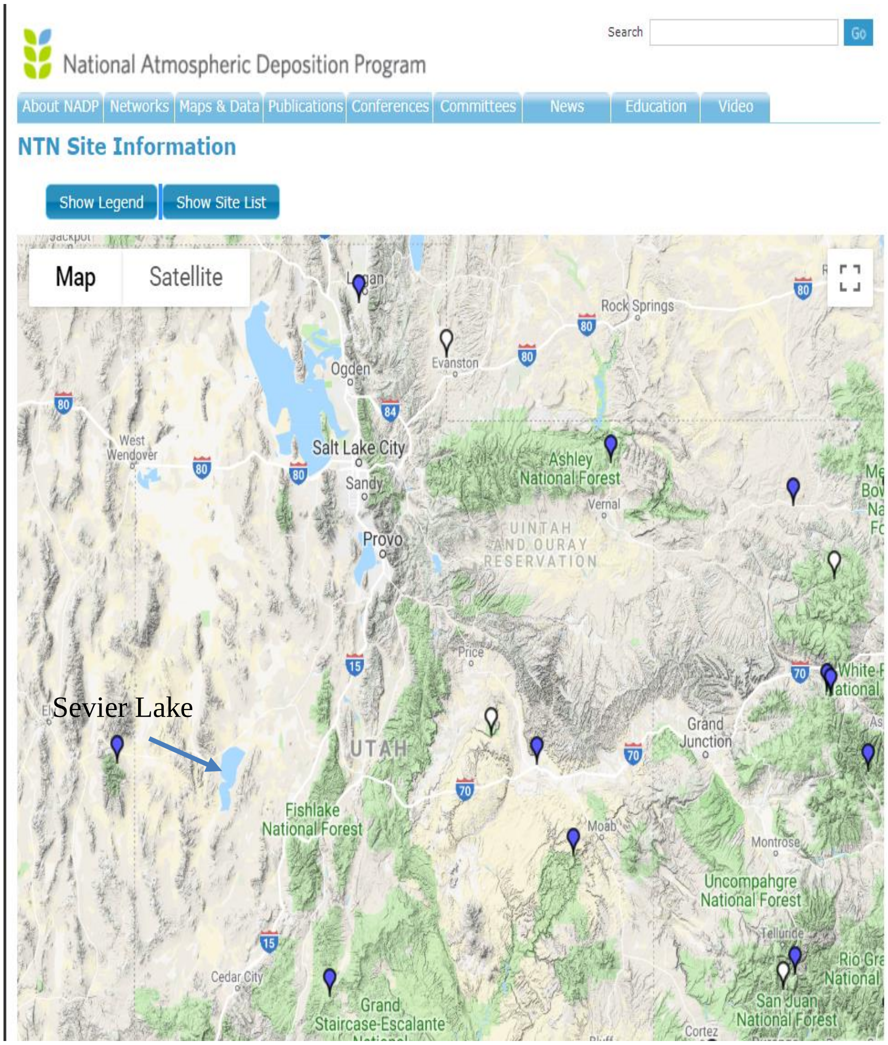

Figure 2. A broader map of Utah which includes portions of Idaho, Wyoming, Colorado, Arizona and Nevada. Note the current location of the NADP sites in Utah (NE Utah, Eastern Uinta Mountains, Green River, Canyonlands NP and Bryce NP).

Figure 3. Photo of dust mobilized from the dry bed of Owens Lake, CA (From Tyler et al. 1997).

Figure 4. Inversion over Salt Lake Valley.

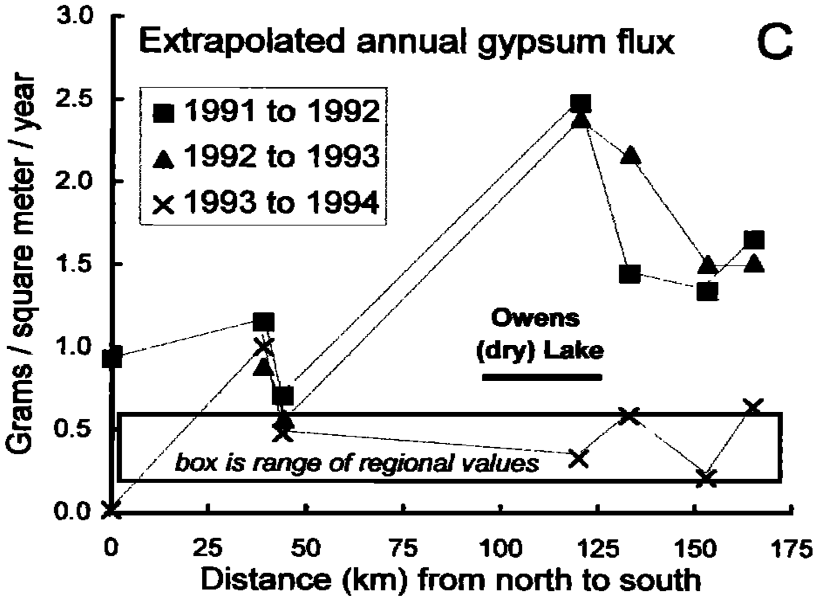

Figure 5. Estimates of gypsum dust flux from Owens Lake, CA. Note elevated concentrations extend at least 50 km from the Source. From Reheis (1997).

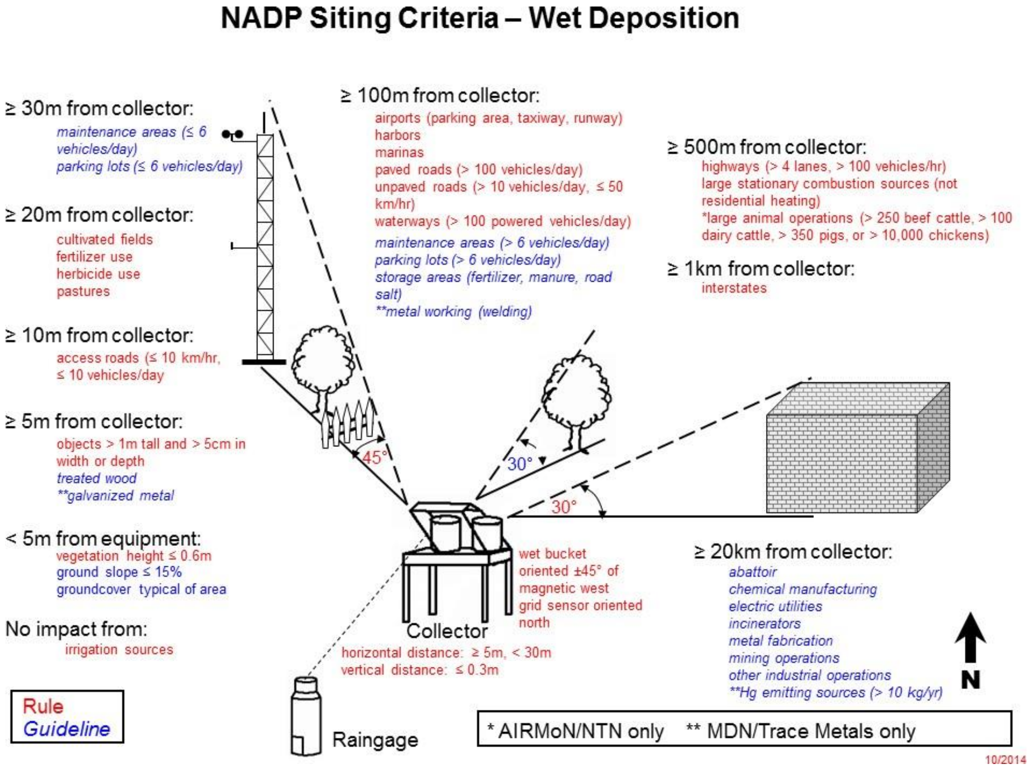

Figure 6. NADP general siting criteria for wet deposition sampling site.

Objectives

The primary objective of the atmospheric deposition project is to provide quantitative estimates of wet and dry deposition to the surface of Utah Lake. While this includes local, as well as regional sources, it is not within the scope of this program as this time to distinguish between regional and local sources. Moreover, with no specific (NADP) guidelines for measuring local sources and equipment selection, sub-objectives include adopting or adapting existing methods and samplers utilized in the current literature. This will include:

1. quantify combined local and regional sources of phosphorus and nitrogen, including urban traffic, construction, intense agricultural, as well as regional sources such as Sevier Lake (i.e. specific research questions, Table 1),
2. Compare the current USGS method of collecting bulk atmospheric deposition samples (Rheis and Kihl 1995) against that utilized by Dr. Wood Miller and against the NADP wet and dry design for measuring AD,
3. Reduce insect and plant contamination by including a 250 um screen to prevent insects and other debris from contaminating AD samples and provide a comparison with unscreened (contaminated samples). This will provide an estimate of accuracy of past AD sampling efforts for Utah Lake,
4. Adjust sampler configuration to raise the samplers to 2 m AGL to match the height of ammonia deposition samplers prescribed by NADP installation protocol. We will also retain three samplers as currently configured and place beside the newly modified samplers. This will provide a comparison between the two heights.
6. Determine the decay equation of AD across Utah Lake. This will be accomplished by placing a sampler near the center of the lake.

Proposed Methods

The NADP does not currently identify a dry deposition protocol. However, as described above, different methods have been adopted to answer different research questions and obtain different types of chemical or physical data. Therefore, we are proposing a suite of sampling strategies that should help determine the most appropriate method(s) to address our research questions. Site selection is intended to include the potential for AD to reach the lake from all major directions and sources and to represent different land uses surrounding the lake (Figure 7). These include:

Near the Orem POTW, UTM = 40.27595 N, -111.7372. This location is about 50 feet from a storage shed and about 20 ft from an unused asphalt road located west of the sampler. There is a vacant field north of the sampler with little plant growth. The entire site is located within a light industrial area in Orem, Lakeshore/Lincoln Point, UTM = 40.11291, -111.78893. Located on the southern edge of a property with light farm traffic. Site was relocated on August 18, 2018 to > 100 ft from that farm road. An open field lies to the south with light brush and there is a wetland just to the east.

Mosida, UTM = 40.07712,-111.92574. Surrounded by a large field with low-lying brush scattered brush. In 2017 it was located approximately 140 ft from the nearest road. On August 18, 2018 it was moved to a location 500 ft from that road it is > 1100 ft from center pivot sprinkler irrigated fields,

The southern edge of Saratoga Springs UTM = 40.28234, -111.8706 , The southern outskirts of Saratoga Springs UTM = 40.28234, -111.8706, is located at the edge of a property (abandoned since late summer of 2018) approximately 500 ft from the highway. A small dirt road leading to the property is rarely used. There are small structures just over 50 ft away to the south, east and north. A large unused field borders the site on the south and west.

The Utah Lake to Jordan River Pump Station UTM = 40.35931, -111.8963 This is perhaps the least representative site for Utah Lake for "global" AD due to the thick phragmites beginning at about 10 m away on two sides. Small particles from the plants have occasionally been captured in the samples, though the plants likely mitigate construction dust from local housing developments. It is the closest site to the actual lake.

Specific methods include:

a. Continue using a small amount of water in the dry deposition bucket (Zobrist et al. 1993, Anderson and Downing 2006), a technique justified in that: "In contrast to solid surrogate surfaces, water exhibits the following advantageous properties: low and constant surface resistance, high sticking coefficient for aerosols, and predictable sorption behavior for gases. Consequently, the deposition rates measured to the wet surface are generally higher, by up to a factor of 4 for NH_4^+, Cl^-, NO_3^- and SO_4^{2-}, than those to a dry surface… The sampling method also allows tracing of regionally and locally emitted atmospheric pollutants."
b. Test the placement of marbles in the bottom of sampling pans (USGS; as has been used by Reheis (1997) and Reheis and Kihl (1995) and is currently being used on Great Salt Lake; Dan Jones, USGS personal communication). This type of sampler collects the compartment known as "bulk deposition" (Reheis 1997, Amodio 2014) and is less labor and equipment intensive than other methods. Briefly, "the trap consists of a coated angel food (Bunt) cake pan, or similar, painted black on the outside". In order to comply with the NADP height guideline for AirMon (ammonia) sampling, the samplers will be placed at 2m AGL and mounted on a post about 2 m above the ground. Glass marbles rest on a circular piece of galvanized hardware cloth, which is fitted into the pan so that it rests 3-

4 cm below the rim. “The 2-m height eliminates most saltating sand-sized particles. The marbles simulate the effect of a gravelly fan surface and prevents dust that has filtered or washed into the bottom of the pan from being blown away” (Rheis 1997). It should be noted that this 2 m height specification was unique to Owens Lake research where high groundwater is believed to bring additional salts to the surface where they crystallized upon desiccation. The USGS sampler located on the Antelope Island causeway is approximately 1.5 m above the ground level.

c. A modification of our current dry deposition protocol whereby we include placing a bowl-shaped screen approximately 10 cm below the surface of the rim and the screen is comprised of 250 um nylon mesh (standard macroinvertebrate sampling mesh size), to filter out insect and plant debris. The bottom of the bucket would still contain approximately 2 L of distilled water to facilitate catchment of the aerosols. In this way we could accurately measure deposition from wind events while isolating (for separate measurement) the controversial contamination from insect emergence or plant parts. This design has the disadvantage of not being in direct contact with a wet surface (Anderson and Downing 2006).

d. In addition, we have permission for Utah State Parks to place a platform in the open water of Utah Lake. This will inform the long-term controversial question of the appropriate decay model that describes the decline of deposition rates as airborne contaminants move across the lake surface. This will provide particular insight into loadings from smog during daily and seasonal temperature inversions as well as high wind events. The sampler will consist of the wet and dry design. Additionally, this may capture the importance of numerous roadways and agricultural fields adjacent to the lake, but which presently are suggested to be eliminated from the sampling design in accordance with the rural NADP protocols – or because they are suspected to be of minimal consequence.

e. Ensure compliance with the NADP siting criteria of the samplers (Figure 6); as the slight adjustments were made for the 2018 sampling year to move two of the samplers further away from roads that ran along the lake), the other three samplers are adjacent to agricultural and urbanized areas that reach within 100 m of the lakes edge on the north, west and east sides of Utah Lake. Perhaps the only exception to the NADP siting protocols is that the solar panel is now mounted on the table (rather than on a post extending approximately 2 m above the platform) and is approximately 20 cm lower than the top of the sample collecting buckets. We believe that this NADP recommendation (referring to galvanized steel in Figure 1;) is in reference to the original mission of the NADP, which is reducing the potential for collecting traces of the common metals and ions and Hg, that have the potential for leaching from metal components. In our case, collection of P, nitrate and ammonia is the singular goal of this project. Moreover, all our construction materials have included the use of stainless rather than galvanized steel, which has even less possibility of leaching materials. Nevertheless, we will perform a QA check on the ability of the stainless-steel structure and solar panel frame and surface to leach nutrients by wiping surfaces with a quartz-infused cloth of known mineral composition, followed by digestion and analysis for nutrients and metals (Dan Jones, USGS, personal communication).

Figure 7. Location AD samplers around Utah Lake.

Sample analysis

Samples will be analyzed in the BYU Environmental Analysis Lab. This lab is equipped with an IC and ICP-MS and follows EPA Standard Methods for preparation of standards, blanks and determining MDLs.

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The active surface of the lake (Owens) is about 280 square kilometers. Assuming a density of 2 grams per cubic centimeter for the dust, a layer only 150 microns thick could **produce the dust cloud that extends over the entire affected area. A wind of 25 meters** per second (55 mph), could replenish the entire cloud every 3 hours. Thus about 7 tons of material would be removed each second. Sustained for 24 hours, such a wind would erode 0.12 centimeters of sediment, a thickness small compared to that of the dessication crust that overlies the lake bed (Reheis 1997?).