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VEGETATION DENSITY AND VAPOR PRESSURE DEFICIT: POTENTIAL CONTROLS ON DUST FLUX AT THE JACKPILE URANIUM MINE, LAGUNA PUEBLO, NEW MEXICO

Reid Brown[1] and Daniel Cadol[2]

[1]Uranium Recovery Program, Wyoming Department of Environmental Quality, Cheyenne, WY, 82001; reiddbrown@gmail.com
[2]New Mexico Institute of Mining and Technology, Socorro, NM, 87801; Daniel.Cadol@nmt.edu

Abstract—A recent study investigated various processes that control dust transport at a former uranium mine in Laguna Pueblo, New Mexico. Two processes were found to be important in controlling dust transport at the Jackpile mine site: vegetation and soil moisture content inferred from the vapor pressure deficit (VPD). To determine the importance of vegetation, two dominant species were considered: juniper and grass. Dense juniper stands had higher soil uranium concentrations compared to other vegetation types and densities. Moderate and sparse stands had median soil uranium concentrations equal to or less than grass-dominated systems. This suggests that there is a critical stand density that reduces wind speed between individual plants, reducing scour. Designing dust mitigation strategies to maintain stands at this critical density could be important for future site remediation. Seasonal effects on wind speed and soil moisture were also considered. The results showed that dust flux was the greatest in the spring. Unexpectedly, dust flux in the winter showed a marked decrease compared to the other three seasons despite having the highest two recorded wind gusts and a similar sustained winds profile compared to spring. Weather data collected on site was used to calculate the VPD to use as a proxy for soil moisture. The winter experienced the lowest VPD. A low VPD indicates there is more moisture in the air reducing the gradient driving soil moisture evaporation. Based on the positive relationship with dust flux, calculated VPD was able to reproduce seasonal trends of soil moisture reliably and is a good proxy for soil moisture when that data is unavailable.

INTRODUCTION

For nearly a century, factors controlling dust generation and transport have been a major topic of interest in the global scientific research community. These studies have covered wind-tunnel studies to field research, ranging from the pebble scale up to the landscape and even global scale (Bagnold, 1936; Lyles and Schmeidler, 1974; Gibbens et al., 1983; Gillette and Stockton, 1989; Dong et al., 2004; Ajmone-Marsan et al., 2008; Ben-Ami et al., 2012). All this effort has been focused on dust generation, transport, and deposition, because these are important processes that span multiple disciplines from soil formation to contaminant transport to human and environmental health. There are a myriad of sources and factors, both natural and anthropogenic, that influence dust generation and transport. One anthropogenic source of dust that is of particular interest to New Mexico is dust generation caused by mining activities. New Mexico has a long history of mining activities throughout the state, with operations both large and small. The size of the mine, topography, vegetation and climate all influence the amount of dust that can be produced during a mine's life. Both active and improperly reclaimed mines can increase dust generation compared to natural systems (Gillette, 1980; Silvester, 2009) and transport contaminants, degrading local air quality as well as being integrated into the soil where the dust is deposited (Reheis, 1995). Here, we investigate the processes controlling the mobilization and deposition of mine-sourced dust from the Jackpile Mine, a former uranium mine located in northwestern New Mexico that is currently being reclaimed. The Jackpile Mine is located within the Laguna Pueblo, New Mexico, approximately 50 km west of Albuquerque (Fig. 1).

Dust generation has been shown to be significantly less in vegetated plots compared to bare plots of land (Merino-Martín et al., 2014). Vegetation, or lack thereof, at a site impacts the roughness of a surface, which is an important factor in both dust generation and deposition. Surface roughness is a first-order control on resistance to the movement of wind. This increased resistance from surface characteristics increases the displacement height, below which there is limited turbulence and wind velocity, promoting gravitational settling of suspended particles. For example, at the Jackpile Mine site, there are several scales of surface roughness. There is topographic relief, which can range on the order of 10-100 meters, and vegetation variation, which can range in heights from 0.3 m to 2.0 m. Taller surface obstructions vertically displace the wind column due to an increase in the height at which the wind velocity is equal to zero (zero-plane of displacement – Z_d) (Fig. 2). Surface roughness of a vegetated area is determined by vegetation height with the Z_d typically estimated at 0.7 times the vegetation height (Z_{veg}) (Dingman, 2008). Slower wind velocities have a reduced vertical component of turbulence and thus reduce the particle sizes that can remain suspended. If the surface roughness elements are tall or dense enough, the near-ground wind speed can decay to zero (Stearns, 1970). Vegetation cover has been shown to reduce dust flux (Van de Ven et al., 1989; Breshears et al., 2009; Merino-Martín et al., 2014) and promote deposition by physically trapping sediment

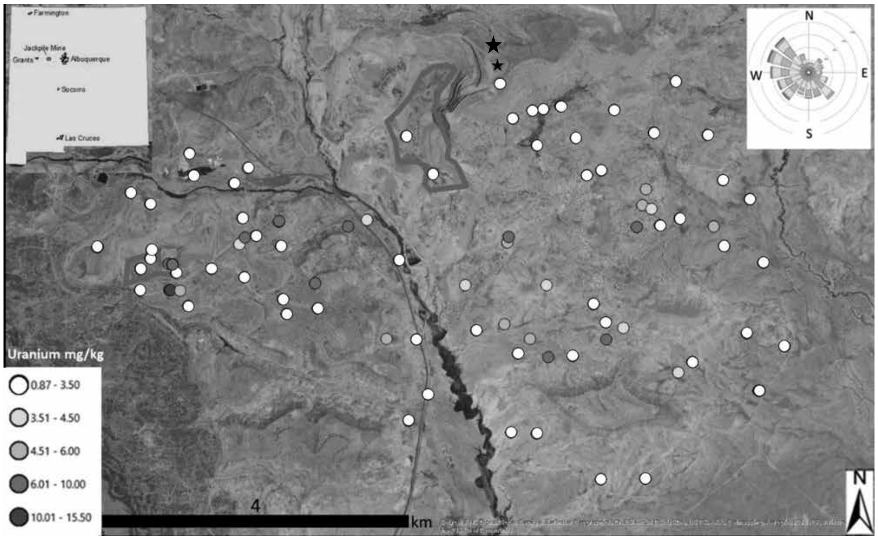

FIGURE 1. The lightest circles are soil samples with a soil uranium concentration at or below site background level as determined by NURE data (Smith, 1997). Remaining soil samples above site background levels with uranium centration increasing with shade of gray. The darker the shade of gray the higher the soil uranium concentration. The pits are outlined in gray. Windscale in upper right; see Figure 3 for more detail. Weather station location denoted by the black star.

particles (Van de Ven et al., 1989). For arid environments, even sparse vegetation is important for reducing soil loss since vegetation height is more important than vegetation density in reducing erosion (Van de Ven et al., 1989).

In addition to vegetation cover, soil moisture is an important factor in the erodibility of a soil. A completely dry soil is much more erodible compared to a damp soil (Elmore et al., 2008). Increased soil moisture content can cause small friable soil particles to form larger aggregates, which are more difficult to mobilize by wind. Not every weather station has the ability to measure soil moisture, and for those that do, the probes can fail. We wanted to come up with a proxy for soil moisture that could be widely applied to weather stations and data sets lacking soil moisture data. We settled on the vapor pressure deficit (VPD), which is a measure of the difference between saturation pressure and the actual vapor pressure. This difference is a key component in evaporation and represents the gradient that drives vapor transport away from the evaporating surface. During the winter, grass is dead and juniper transpiration is depressed. Large weather systems could bring in moist air but would likely be associated with precipitation events or at least reduce the evaporation of moisture from the soil. There are no large water bodies near the mine site, thus the largest source for the moisture is the soil.

The Jackpile Mine site, which is located in an arid setting, is an ideal location to test both vegetation density and VPD as controls on dust transport. The disturbed landscape combined with sparse rainfall and windy conditions should produce source areas of dust across the site. According to the U.S. EPA National Priority Listing (USEPA, 2012), the metals of concern at the site are uranium, chromium, manganese, cobalt, vanadium and zinc Site remediation efforts were carried out in 1995, consisting of covering waste rock piles and re-contouring unstable pit walls and waste piles (U.S. Department of the Interior, 1986). Vegetation was planted to reduce erosion. In 2007, a compliance assessment was conducted and failed (U.S. Department of the Interior, 1986). The mine site was proposed to the National Priorities List in 2012 and became a Superfund designated site in 2013.

Dust traps were installed across the mine site, in areas with different vegetation types and densities, to collect windblown sediment. In addition to the mass of sediment collected, the mass of known contaminants bound to the dust will also be informative. Soil concentrations of the contaminants of concern listed above were analyzed for a representative range of vegetation types. Pairing climate data with dust flux collected concurrently helped refine our knowledge on the relationship between local climate, vegetation and dust transport.

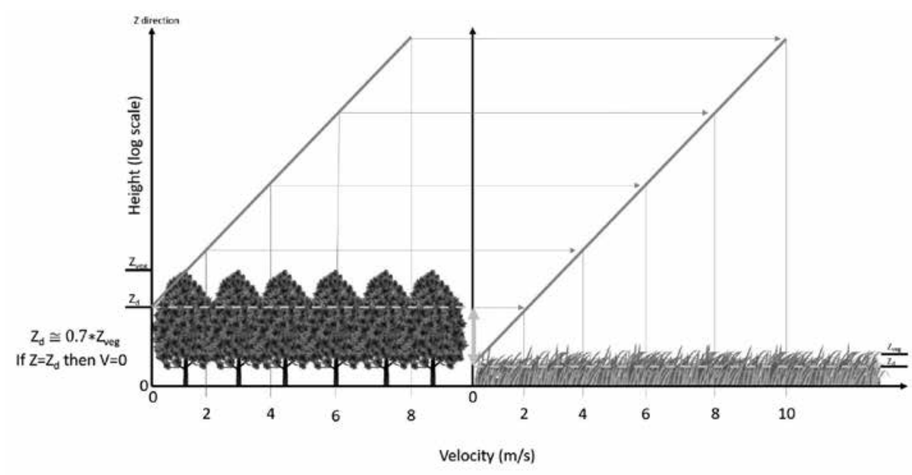

FIGURE 2. The impact of changing vegetation height (Zveg) on the zero-plane of displacement (Zd) and the wind velocity profile. Height (Z) is given in log-scale (after Dingman, 2008 and Bagnold, 1941).

MINING HISTORY, GEOLOGY, AND CLIMATE

The Jackpile ore body is a tabular, sandstone-hosted deposit. The Jackpile Sandstone is located in a 21-km by 56-km depression in the Brushy Basin Member of the Morrison Formation, which is Jurassic in age (Schlee and Moench, 1961). Its thickness ranges from 0-61 m and is generally treated as the upper member of the Morrison Formation in its locale (Nash, 1968).

The Jackpile Sandstone is arkosic and was derived from granitic, volcanic and sedimentary rocks (Nash, 1968). The study site is predominantly composed of mesa tops overlying Cretaceous sedimentary rocks and Quaternary valley fill. There are rocks of Jurassic age exposed, but these are less extensive in the area compared to Cretaceous rocks and Quaternary sediments and are primarily limited to mesa slopes (Moench and Schlee 1961; Nash 1986). Jackpile Mine was leased and operated by Anaconda Minerals Company, a division of Atlantic Richfield Company, from 1951–1983. During that time 400 million tons of rock were moved and 25 million tons of ore were removed. The ore grade averaged 0.1-1.3% U_3O_8 (U.S. EPA, 2012). Rock material was considered waste if the uranium grade was less than 0.06%.

The climate is semiarid, with the site receiving most of its annual rainfall during the monsoon season from July to August. The rest of the year is generally dry with occasional snow in the winter. The spring windy season is dominated by winds from the west and northwest. Throughout the year winds from these directions consistently average the highest wind speeds as well as have the highest gust speeds. Though winds come from all directions, the majority of the aeolian transport is expected to be toward the southeast of the main pit.

EXPERIMENTAL DESIGN

Site selection for dust traps was primarily based on two factors: (1) distance from the main Jackpile pit and (2) vegetation type, enabling analysis of the effect of these two variables on dust flux. The two prominent types of vegetation in the area are a 30- to 40-cm tall grass and 2+-m tall juniper woodlands. Vegetation density ranged from bare ground to sparse (gap between individual plants >5x vegetation height), moderate (5x height > gap > 1x height), and dense (1x height > gap). Sites were assigned to each vegetation density class. The class assignments were not quantitatively measured but were estimated by inspection. More emphasis was placed on vegetation type than soil type. Soil analysis was not carried out as part of the project but should be considered in future work.

Fifteen vertical sets (stems) of Big Spring Number Eight (BSNE) dust flux traps were installed across the study site. The dust traps consist of a round metal post with four dust traps attached at heights of 0.25, 0.5, 1.0 and 1.5 m above the ground surface. The traps have a tail fin and are designed to pivot around the central post like a wind vane and always point into the wind. Dust samples were collected roughly every two months to allow enough sample to be collected to process and yet still test seasonal impacts on dust transport. Dust flux was calculated by dividing the measured mass of a dust sample by its collection time and by the area of the trap opening. Because of the remote location we were unable to capture individual wind events. However, the traps are designed to prevent collected dust from being blown out even if multiple wind events are sampled during a collection period.

Sample locations for a broader soil survey were selected using a random sampling scheme. The study area was divided into four zones: Mesa Woodland, Mesa Grass, Valley Woodland, Valley Grass Sample points were randomly generated within each zone. A total of 120 sample locations were generated, with a minimum distance between points of 300 m. This helped cover a larger area with a small sample size to reduce bias for collecting several samples close to each other. The pre-mining background levels of uranium in the soil were estimated using a subset of the National Uranium Resource Evaluation (NURE) data collected in the immediate vicinity of the mine site in the 1970s (Smith, 1997). Unfortunately, the NURE survey did not include Laguna Pueblo lands and the author was unable to find site specific data for background soil uranium levels in U.S. EPA reports or from the mine operator.

Sediment samples were processed using the EPA 3052b digestion method. In many cases, dust samples were digested in entirety due to small sample size. During sample preparation, soil samples were sieved to remove gravel larger than 2.0 mm. Soil samples were ground with a ring and puck for homogenization and to aid digestion. Dissolved samples were diluted as needed and analyzed on an Agilent 7900 ICP-MS. Dust samples typically had too little mass and were not diluted. Doing so would have yielded heavy metal concentrations in dust below the minimum detection limit of the ICP-MS.

A weather station was installed on top of Gavilan Mesa at the northern end of the study area to get site specific meteorological data. This location was chosen because it was far from the edges of the mesa, and there were no nearby vegetation obstructions. The area had a large unobstructed fetch in all directions, and, as the high point in the study area, it likely received the maximum wind speed. We did not install soil moisture probes on site, but the weather station collected relative humidity and temperature hourly. From these parameters, we were able to calculate the VPD.

We chose to use permutation tests to compare mean values of dust flux between seasons as well as the concentration of uranium on sediment samples. This was done to address non-normality in our datasets associated with a few important but extreme wind events and right skewed soil uranium concentrations. The result of the permutation test is a p-value that indicates the likelihood that the two datasets were randomly drawn from the same population and could generate the observed means (Helsel and Hirsch, 2002). We chose a threshold of significance to be $\alpha=0.05$; this is the typical significance threshold used in the scientific community, yet the authors acknowledge it is also somewhat arbitrary. If the p-value ≤ 0.05, then the means are deemed to be different, implying the samples are from different populations.

RESULTS AND DISCUSSION

Dust transport was observed throughout the year, primarily driven by the strongest winds coming from the west-northwest. Annual and seasonal data all showed similar trends (Fig. 3). Dust flux varied seasonally, likely due to seasonal variations in average wind speed as well as seasonal weather patterns that control soil moisture. Both vegetation and topography during active mining and subsequent reworking impacted the wind profile, influencing deposition of uranium-bearing dust

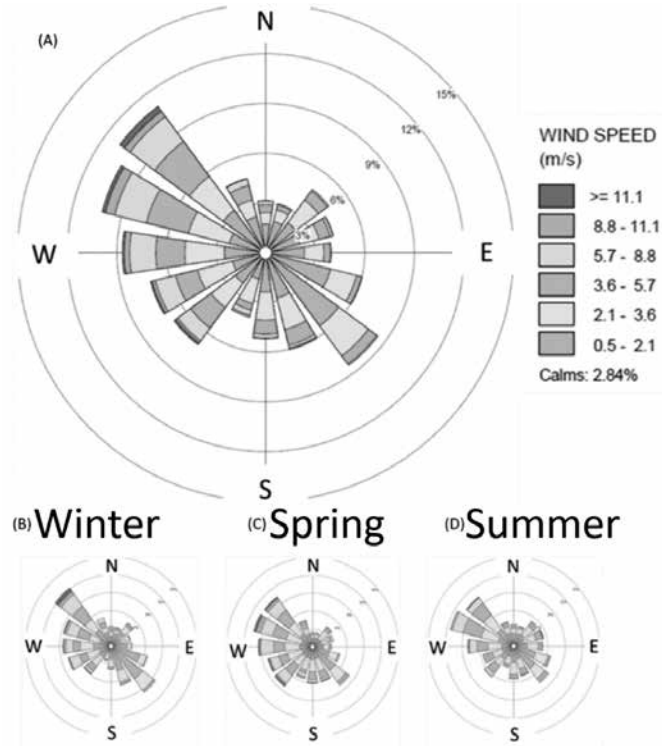

FIGURE 3. **A**) Each wedge corresponds to a direction the wind originates from with the length of the wedge corresponding to the percent of time coming from that direction. The colors correspond to the wind speed, closest to center are the lowest wind speeds. The darkest shade of gray corresponds to the highest wind speeds and is also the outermost bin. **B**-**D**) are the seasonal data. Standard season dates were used to split the data into each season.

and leading to higher uranium concentrations in valleys relative to mesa tops and in dense juniper stands relative to other vegetation communities. The concentration of uranium in dust collected at 1.0 m and 1.5 m was significantly higher than in bulk soils (p=0.046). There was no difference between dust collected at 1.0 m and 1.5 m or in the finest soil fraction with a grain diameter less than 0.063 mm (p=0.92). The similarity in uranium concentration of the fine soil fraction and the dust indicates that aeolian transport preferentially mobilizes the finest soil fraction, which also has the highest heavy metal concentration (see discussion in Brown (2017) for more details about why small size fractions absorb metals).

Wind speed and direction were critical to this study. At the study site, the most frequent wind direction we recorded was out of the northwest (Fig. 3), likely due to the topography of the area, particularly Mt. Taylor, rising to the west of Jackpile Mine. Wind speed and direction impacted all aspects of this study, from the amount of sediment transported to the direction the dust travels to how much is deposited and where. Over the course of the study the wind patterns were remarkably consistent. Our results agree with Anaconda Mineral Company's continuous environmental monitoring program that spanned from 1977 to 1983 (U.S. Department of the Interior, 1986). This consistency suggests that our wind data are representative of long-term local trends and were similar to the conditions present throughout the life of the mine.

Soils ranged from coarse to fine across the study site. However, by mass most of the sediment particles fell in the 0.25 mm and 0.125 mm size classes for ever soil. The particle-size distribution in soils is important because soil is the erodible material that is the source of the dust. While particle shape and packing are important, on average larger particles are more difficult to mobilize (Bagnold, 1936). Between 60 and 90% (by mass) of the top 5 cm of most soils we measured consisted of particles smaller than 0.25 mm in diameter. Bagnold (1936) reported a threshold wind speed value of 0.2 m/s to transport dune sand with 0.25 mm diameter. Threshold wind speed values for transport are predicted to increase for particles smaller than 0.1 mm in diameter due to particle surface charges and due to position within the laminar sub-layer; however, the thresholds of transport for the particles observed in this study are all well within wind speeds recorded on site.

The largest mass flux for the 0.25, 0.5, and 1.0 m heights occurred during the spring sample collection (Fig. 4), an intuitive result stemming from the larger sediment particles that can be mobilized in stronger winds. Larger particles will substantially increase the mass flux since more mass is transported per grain of sediment. Our results showed little seasonal variation in the mass flux at the higher collection heights (1.0 and 1.5 m) relative to the variation at lower heights. This may indicate more seasonal consistency for the more moderate winds necessary to maintain the very fine particles in suspension that dominated flux at these heights. While the larger sand grains may not have been mobilized as often in the fall, summer, or winter, the fine particles were still being transported. This result could suggest that regional sources and wind patterns may be more important than local conditions as height above the

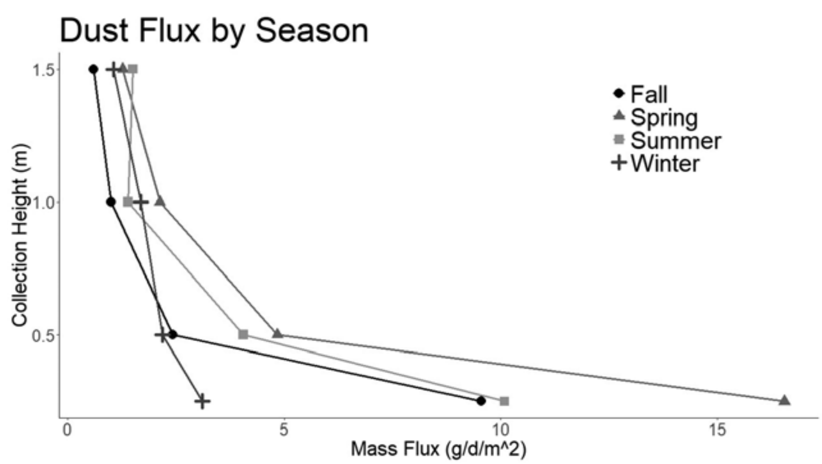

FIGURE 4. Dust flux (x-axis) plotted as a function of collection height (y-axis) and season (point shapes). Data collected in spring, summer, fall and winter are represented by triangle, square, circle, and cross dots respectively. The lines are illustrative only and not meant to be an interpolation between points.

surface increases. This would imply that managing air quality with respect to dust for communities and the environment downwind of should include management plans for both local point source and regional sources of dust.

Similar wind patterns were observed during the winter and spring sampling seasons, however these similarities were not reflected in dust flux. The two largest individual wind speeds occurred during the winter sampling period (Fig. 5). Additionally, wind blew from the west for a significant amount of time during spring and winter (46% to 38%, respectively). During both spring and winter, the wind gusted to the highest wind-speed class for about 1.5% of the time. As expected the spring recorded the greatest dust mass flux. Winter sampling period mass flux was depressed for the lowest collection height (Fig. 4). A likely cause for the reduction in dust flux during the winter is increased soil moisture due to snowfall, colder temperatures, and higher relative humidity. The time period of the winter sampling coincided with the lowest VPD measured during the study as well as the lowest mass flux collected (Figs. 4, 5).

While VPD is not a direct measure of soil moisture, we argue that it is a reasonable proxy, since it is a primary control on the rate at which water evaporates from a soil. A lower VPD reduces the potential rate at which soil loses moisture to the atmosphere. The VPD does not describe absolute soil moisture content, nor do our calculations account for wind increasing evaporation. However, we contend that while VPD may be a poor measure of soil moisture on a daily scale, it could be a representative on the month or seasonal scale where many days in a row of below annual average VPD in the winter could indicate a soil with more moisture compared to average or above average spring and summer seasons (Fig. 6). When the data is analyzed on a seasonal scale, winter is found to be statistically lower on average than spring or summer ($p < 2x10^{-16}$, $p < 2x10^{-16}$ respectively). Fall VPD was found to be statistically lower than Winter VPD ($p= 8.11x10^{-8}$), however only the last 12 days of fall were included in our data collection and likely do not represent the entire season. These results show that VPD significantly varies by season and that the low VPD coincides with the least dust flux, suggesting that VPD is a reasonable approximation for soil moisture content at the season scale.

Dust flux is not continuous throughout the collection period. Dust flux generally comes in short bursts associated with larger wind events (Brookfield, 1970). Ash and Wasson (1983) defined a measure for sand movement frequency as the number of days with recorded wind speeds above 8 m/s. For this study we adopted this convention to analyze seasonal relationships of wind speed and dust flux. Spring and fall had both a similar proportion of days with maximum wind speed exceeding 8 m/s and similar collection period length. Despite this, spring had four times the amount of dust flux at the 0.25 m collection height and double the dust flux at the 0.5 m collection height (Fig. 4). The spring season had an increasing trend of maximum daily VPD (Fig. 7), which leads to the intuitive conclusion that drying soil and frequent elevated wind speeds generates the most dust flux. Further emphasizing the relationship between VPD and wind speed can be seen in a comparison of winter and summer. The summer collection period was 32 days shorter

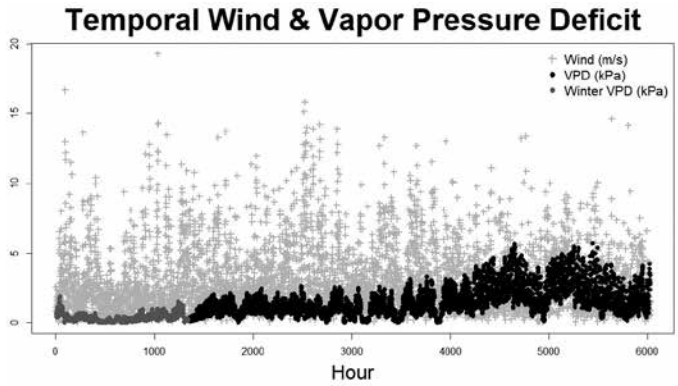

FIGURE 5. Vapor pressure deficit (VPD) in kPa and wind speed in m/s as a function of time in hours. All variables are plotted relative to the same generic y-axis scale. Both wind in m/s and VPD in kPa can use the same scale. Individual hourly wind measurements are crosses. VPD measured during the winter are light gray circles. VPD was calculated hourly.

and recorded days with winds above 8 m/s less often, yet, compared to winter, the transport of dust at the 0.25 m collection height was nearly triple and the dust flux at the 0.5 m collection height doubled (Fig. 4). Within less time the summer season was able to transport more dust, meaning that the increase in maximum daily VPD during the summer was able to overcome reduced high wind frequency (Figs. 6, 7). When the reduced length of the summer collection period is considered, it further emphasizes the importance of soil moisture as a control on dust flux and that VPD can detect these important seasonal soil moisture trends.

Variations in soil uranium concentrations were confounding. While the pattern of soil uranium concentration is consistent with southeastward dust transport (Fig. 2), many of the soil samples were located in areas that had been disturbed by mining activities and were located in Quaternary sediments potentially eroded from Jackpile sandstone outcrops; this prohibits confidently determining the source of elevated uranium

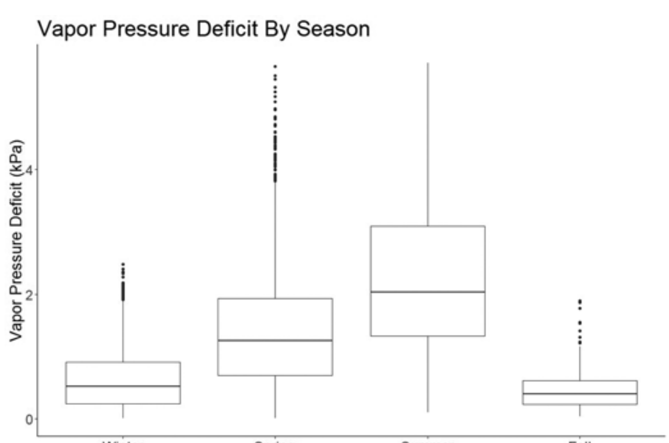

FIGURE 6. Vapor Pressure Deficit (VPD) by season. Average winter VPD is less than spring and summer VPD (p < 2x10-16). Fall VPD is less than winter VPD (p=8.11x10-8).

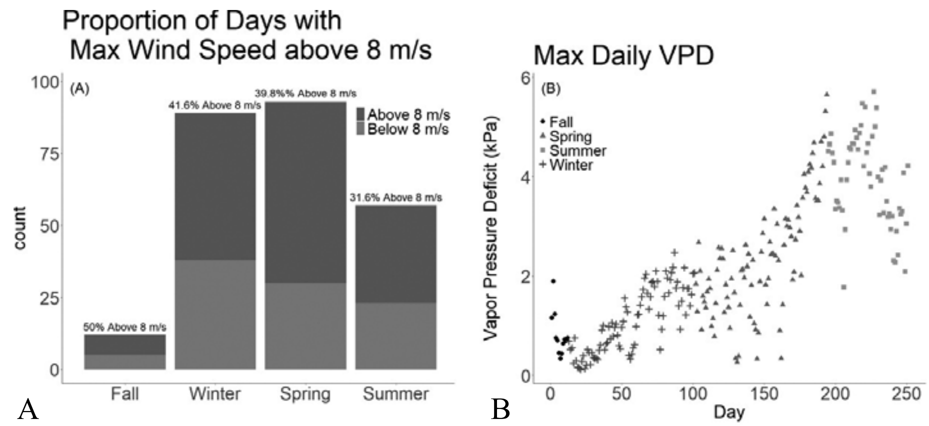

FIGURE 7. Comparison of days with maximum wind speed above 8 m/s by season. Proportions: Fall – 50.0%, Winter – 41.6%, Spring – 39.8%, Summer – 31.6% (**A**). Maximum daily vapor pressure deficit VPD by season represented by different points (**B**).

in many of the samples without additional data. That said, it is worth noting that uranium concentrations increased with dust collection height ($p<0.05$), and sample concentrations from the highest dust traps were nearly statistically elevated above site-wide soil uranium concentrations ($p = 0.052$). This suggests that dust deposition is one of several potential mechanisms that contribute to the observed increases in soil uranium concentration southeast of the mine.

Erodible sediments have different threshold wind velocities depending on their composition. The threshold velocity can be lowered by both anthropogenic and natural processes that disturb the sediment surface (Gillette et al., 1980). There were many anthropogenic sources of disturbance that would have increased the erodibility of soil. During mine operations, sources of dust included the exposed pit, rock crushers, uncovered waste rock piles, and onsite ore stock piles. Blasting and heavy machinery generate large amounts of dust, which then could be carried down wind of the source area (Silvester et al., 2009). During mine operation the waste rock piles were left uncovered, and, though less concentrated than ore, the waste and overburden contained up to 0.06% U_3O_8 (U.S. Department of the Interior, 1986). Observed wind events on site, both past and present, have been strong enough to mobilize sediment. Ore and waste rock piles exposed to these events in the past could potentially be a source of uranium-bearing dust. We were unable to conclusively source the origin of the uranium in the soil downwind of the mine; however, our results, combined with previous and concurrent research, suggest that when Jackpile mine was active, dust transport may have been a more important mechanism in altering soils downwind of the mine compared to present day.

Restoring natural vegetative cover is a critical component of the remediation process and has widely been used as one metric of restoration success. One major reason for this is that vegetation has been shown to affect wind velocity, with greater wind resistance in denser vegetation (Breshears et al., 2009; Wolfe and Nickling, 1993). Qualitative data on vegetation density was collected at each site in the soil survey. Both vegetation types were classified as dense, moderate or sparse (Fig. 8). If no juniper was present then the site was automatically considered a grassland, and thus only grasslands were classified as bare. Grasslands have a slight increase in the soil uranium concentration with increasing density. Juniper woodlands have a large increase in median soil uranium concentration for the densest stand (Fig. 8).

While there was no difference between dust flux in valley woodlands and valley grasslands, the median soil uranium concentration was higher in woodlands compared to grasslands (Brown, 2017). The bulk of the increase came from the densest stands of juniper (Fig. 8). Unfortunately, the densest stands were included only in the soil survey, and no dust traps were installed in dense juniper stands. Not knowing the magnitude of the dust flux moving through dense stands limits further discussion to speculation. However, it does reinforce the difficulty in establishing a link between horizontal dust flux and deposition rates. There are potential mechanisms that could enhance the deposition of fines even with large flux moving through the woodlands. For example, the increased surface area of the juniper and its fine, dense foliage could trap dust particles until they are washed to the ground in the next rain. Additionally, the dense stand would reduce near surface wind velocity reducing resuspension and dust flux out of the stand of vegetation.

No attempt was made to control for stand size in this study. It is very possible that continuous stand size is a critical factor in the ability of taller vegetation to promote dust deposition especially at lower stand densities. Wolfe and Nickling (1993) showed that stands of vegetation below a critical den-

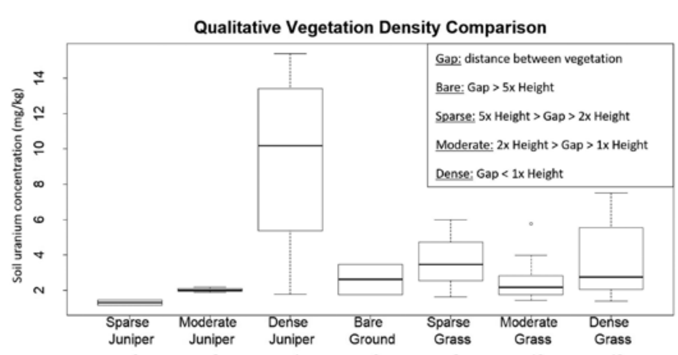

FIGURE 8. Soil uranium concentration grouped by the seven vegetation density classifications. Gap refers to the distance between the vegetation. Bare is considered areas where grass clumps were more than five times grass height apart. Sparse is vegetation that had gaps between five times and two times vegetation height. Moderate is vegetation that had gaps between two times and one times vegetation height. Dense was vegetation that has gaps less than the vegetation height.

sity can actually contribute to scour of soil between the individual plants. The critical stand density promotes skimming flow over and around the stand of vegetation so that little to no wind can penetrate the stand itself. This process could be the reason for the relatively small difference in soil uranium concentration between sparse and moderate stands of juniper compared to dense stands. In fact, median soil uranium concentrations in sparse and moderately dense stands of juniper appear to be similar to and potentially lower than median soil uranium concentrations in bare and grass-dominated systems (Fig. 8), suggesting that scour may be occurring around sparse larger vegetation. This may be due to the stand of vegetation not being dense enough to vertically displace the wind column and instead channelizes the wind between the individual plants. However, caution should be taken with this conclusion given the limited number of soil samples from sparse and moderate juniper stands. Future work, particularly in arid environments, should look at stand densities that are realistically achievable and can maintain themselves long-term after remediation has ended. If these stand densities and the stand area do not promote skimming flow of wind then other vegetative cover should be considered to protect the land surface. This is particularly important when considering the vegetative cover to place on surfaces susceptible to erosion, such as on slopes, covered waste rock piles or tailings impoundments.

CONCLUSIONS

Climate and environment are both important factors controlling the generation of dust in both disturbed and natural landscapes. Wind and VPD combine to produce seasonal variations in dust flux at the Jackpile mine site. What makes VPD a particularly attractive parameter is that it only requires two common probes used in many weather station setups: temperature and relative humidity. Many mine operators and municipalities could begin tracking VPD as a proxy for soil moisture without purchasing new equipment. The seasonal effect was primarily observed at lower collection heights suggesting that regional sources of dust generation may be more important than sources on site when local soil moisture content is elevated or at times of depressed wind speeds. Meteorological data and soil uranium concentrations are consistent with southeasterly transport of uranium from Jackpile mine pits, but the relative contribution of uranium-bearing dust from mining activities to the soil is unsettled due to unknown pre-mining conditions. Though sample size was small, vegetation stand density may be an important factor controlling the erodibility of the soil in the vegetation stand's immediate vicinity. Sparse and moderate stands were similar in soil uranium concentration to grassland systems suggesting there may be a critical stand density that needs to be achieved before significant dust deposition occurs in juniper stands. This relationship could have important implications in future remediation efforts when deciding what species to plant and where to plant them to control erosion and dust generation.

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