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The Interaction of Aeolian and Fluvial Processes in Dry Washes on the Colorado Plateau, USA

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The Interaction of Aeolian and Fluvial
Processes in Dry Washes on the
Colorado Plateau, USA

Beau J. Walker

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Master of Science

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ABSTRACT

The Interaction of Aeolian and Fluvial Processes in Dry Washes on the Colorado Plateau, USA

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In the past decade there has been a call for integrated studies that examine the interaction of fluvial and aeolian processes (Belnap et al., 2011; Bullard and Livingstone, 2002). In this study, we examined the role of land-use, weather, and soil type on the flux of aeolian material into dry washes on the Colorado Plateau in central Utah, USA and western Colorado, USA. Our goal was to quantify the impact of individual deposition and erosion events by correlating weather and land-use data with a combination of measurement methods including dust collection via dust traps, GPS surveying, and close-range photogrammetry. Our data suggest that there is an interaction between these processes and that seasonality and land-use play a large role in determining the strength of this interaction. Particularly, high land-use and dry, windy conditions were most conducive to the surface movement of sediment and subsequent removal of that sediment by fluvial processes.

Keywords: erosion, aeolian, fluvial, Colorado Plateau, dust, nutrient loss, land-use, desert

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1. Introduction

The erosion of dryland soils is an increasing problem worldwide (D'Odorico et al., 2013; Field et al., 2010). In dryland areas, the processes of soil erosion by wind and by water have traditionally been studied separately, despite the fact that these processes are often linked (Belnap et al., 2011; Bullard and Livingstone, 2002). As a result, many researches have made a call for integrated studies that examine the interaction of fluvial and aeolian processes (Belnap et al., 2011; Bullard and Livingstone, 2002; Bullard and McTainsh, 2003; Sankey and Draut, 2014; Ta et al., 2014).

Much soil-erosion research focuses on the impact of aeolian processes on soil particle movement (D'Odorico et al., 2013; Field et al., 2010). The increase in airborne sediment from dryland regions has been linked to a wide range of ecological impacts, such as accelerated rate of snowmelt, altered plant-nutrient dynamics, and soil and sediment loss (Field et al., 2010; Li et al., 2013; Painter et al., 2010). Additionally, it has been linked to negative impacts on human health such as respiratory problems and traffic accidents from decreased visibility (Field et al., 2010; Li et al., 2013; Painter et al., 2010). There has also been research on the role of fluvial processes, for example flash-flooding events from monsoonal rains in the Desert Southwest (Belnap et al., 2011; Godfrey et al., 2008).

Many factors contribute to erosion by aeolian and fluvial processes. Dryland soils usually lack significant vegetation cover and are easily disturbed, which makes these soils especially susceptible to erosion by both wind and water (Belnap et al., 2014; D'Odorico et al., 2013; Reheis and Urban, 2011). Soil texture, soil crust, vegetation cover, land-use patterns, and weather have all been shown to play a significant role in the erodability of soils (Belnap et al., 2014; Reheis and Urban, 2011). Many studies have also shown a strong

seasonal correlation with aeolian or fluvial erosion (Bullard and Livingstone, 2002; Bullard and McTainsh, 2003; Ta et al., 2014; Xu et al., 2006).

While previous research has focused on the effects of suspended dust particles (Field et al., 2010; Munson et al., 2011; Painter et al., 2010; Reheis and Urban, 2011), the impact of the mass movement of larger soil particles, which move across the soil surface by saltation or surface creep, is poorly understood. The mass movement of larger soil particles is a concern is of particular concern on the Colorado Plateau, where the erosion of sediment by wind (aeolian) processes and by water (fluvial) processes has been increasing (Munson et al., 2011; Reynolds, 2001). The Colorado Plateau is particularly vulnerable to the disruption and acceleration of natural erosion processes in both sand dominated systems and clay dominated systems (Belnap et al., 2014; Carpenter and Chong, 2010; Godfrey et al., 2008). An increase in erosion could lead to an increased flux of sediment with their associated salts into washes, via aeolian processes, but ultimately be moved to streams and rivers via fluvial processes. Sediment and salt loading of waterways is particularly concerning in areas dominated by Mancos Shale because these soils have high concentrations of salt and selenium (Carpenter and Chong, 2010). On the Colorado Plateau, and in other regions as well, the influx of sediment and salt into waterways could have detrimental effects on human health, agriculture, and ecosystem processes (Belnap et al., 2011). Observations by USGS field teams at research sites across the Colorado Plateau suggest that larger soil particles collect in washes via aeolian processes and then are washed away during large rain events to the Colorado River watershed, providing a flux of aeolian sediment into rivers and streams (Belnap et al., 2011; see also Figure 1). The problem of aeolian erosion of sediment has other potential impacts, including the potential

of accelerated loss of soil nutrients from source areas to waterways, and the potential for sediment loading in the rivers, which is risk for river ecosystems (Ballantyne et al., 2011; Neff et al., 2003; Xu et al., 2006).

Although many studies have shown that there is strong seasonal correlation between erosion events (Phillips et al., 2011; Reheis and Urban, 2011, 2011), there is still a need to understand event-specific processes to quantify how much material is being moved by the combination of these processes. For example, in dryland areas, one windstorm or one large precipitation event can have a significant impact on the total amount of erosion during an entire season (Godfrey et al., 2008). In this study, we make an initial step to study linked aeolian and fluvial processes at an appropriate temporal scale on the Colorado Plateau in central Utah, USA and western Colorado, USA. We examined the role of land-use, weather, and soil type on the flux of aeolian material into dry washes. Our objective was to understand the interaction between aeolian and fluvial processes across a gradient of land-use on clay and sandy soils. Ultimately, our goal was to quantify the impact of individual deposition and erosion events by correlating weather and land-use data with a combination of measurement methods including dust collection via dust traps, GPS surveying, and close-range photogrammetry.

2. Methods

2.1 Site Selection

All of our sites were located on the Colorado Plateau, located in southeastern Utah, USA (Figure 2A). During summer 2011, we performed an initial survey across the Colorado Plateau of more than 200 dry washes or arroyos. We chose to survey washes on either a clay (Mancos shale; clay content >20%, sand content <60%) or sand substrate (Sandstone;

clay content <30%, sand content >50%). For each site, we took photos and GPS coordinates, measured the dimension and flow direction of each wash, described the surrounding vegetation and substrate type, and made an estimation of land use. From the group of surveyed washes, we chose 11 sites with washes with similar dimensions (a width ranging from 1 – 4 m and a depth ranging from 0.4 – 1 m), and similar vegetation cover (ranging from 10% - 30% cover of grasses and small or medium sized shrubs). Additionally, we chose sites that varied across a gradient of land use types ranging from low to high levels of grazing and OHV use (Table 1).

2.2 Site Instrumentation

The duration of our observational study was from March 2012 to June 2013. We installed instrumentation at each site in late spring of 2012 (Figure 2A). We used three different approaches to attempt to quantify the movement of aeolian sediment into washes: surface dust traps, Real Time Kinematic surveying, and close-range photogrammetry. In addition to these three approaches, we also installed weather stations to record site-specific climate data at a subset of the washes.

2.2.1 Dust Traps

We installed three pairs of dust traps (buckets) on either side of each wash to measure surface creep of dust. We constructed and installed our dust traps according to the protocol already established by the USGS for research sites in Factory Butte, Utah and Badger Wash, Colorado. We positioned the dust traps to capture saltating material based on prevailing wind patterns on the Colorado Plateau. The vast majority of spring wind storms arise from the south-west (Phillips et al., 2011). This dust trap setup is similar to other conventional methods of measuring erodability, including sediment traps such as the

Big Spring Number Eight (BSNE) and Modified Wilson and Cook (MWAC) samplers. The strength of this approach is that it can integrate movement across an entire season, but provides limited information about individual erosion events.

2.2.2 Wash Transects

At each of our 11 sites we also identified and permanently marked six GPS transects within a 30 m segment of the wash. We used 0.3 m stainless steel nails on either side of the wash to delineate the ends of each transect and to establish a permanent marker for a real-time kinematic (RTK) GPS surveying unit base station. This allowed us to relocate each transect when we returned during a later sampling period. After installing each transect, we performed an initial GPS survey of the wash profile along each transect with a ProMark3 GPS RTK rover and base station. Our survey included both coordinate locations and a z-value taken at 3-10 cm intervals along the transect. The benefits of this method are that transects stay in place and the cross-section change of the wash at each transect can be measured with high precision. However, the transect method does not allow for a calculation of changes in volume or mass into the wash. Additionally, difficulties in establishing satellite connections sufficient to maintain high precision with the RTK unit resulted in fewer complete transects and highlighted the challenges of using this method.

2.2.3 Short Range Photogrammetry

In addition to dust traps and wash transects, we installed game cameras at 9 of our 11 sites for close-range photogrammetry. Photogrammetry has widespread applications, ranging from robotics, industrial applications, and research (Carbonneau et al., 2003; Fabio, 2003). Large-scale photogrammetry has long been used at large-temporal scales in ecology (Roughgarden et al., 1991). Close-range photogrammetry has recently been used to

characterize such things such as surface roughness, gully formation, and vegetation growth (Carbonneau et al., 2003; Dandois and Ellis, 2013; Gessesse et al., 2010; Kirby, 2006; Rieke-Zapp and Nearing, 2005; Sankey and Draut, 2014). However, one problem with most photogrammetry systems (lidar, etc.) is that they are expensive and require other expensive equipment. In these cases, close-range photogrammetry can be cost prohibitive and does not lend itself well to continuous or frequent monitoring. The availability of low-cost solutions and high-quality cameras means that short-scale photogrammetry is a better option than previously. We used game cameras to overcome these obstacles. At each of our 9 sites with a photogrammetry set up, we installed a pair of 2011 Bushnell Trophy Cam 8MP Game Cameras. We followed the general protocol in BLM Technical Note 428 for our photogrammetry setup (Matthews, 2008). Three major requirements of a photogrammetry set up include: 1) cameras must be perpendicular to the object of interest; 2) cameras must be placed so that resulting images have a 60% overlap; and 3) in the case of paired cameras, images must be taken at the same time. We suspended the cameras horizontally 1-2 m above the wash bottom so that the cameras were nadir to the ground and there was at least a 60% overlap between images from the pair of cameras. We used the Time Lapse mode to calibrate each camera to take pictures simultaneously every hour.

2.2.4 Weather Stations

We also installed weather stations at three sites. Locations for the weather stations were chosen based on the proximity to other sites without weather stations. This allowed us to capture the variability in weather across our 10 sites. Each weather station consisted of a Decagon EM50 Data Logger, a Davis Cup anemometer, an ECRN-100 High Resolution Rain Gauge, and either a 5TM soil moisture and temperature sensor or an EC-5 soil

moisture sensor ([Decagon, Inc., Pullman, WA](#)). We configured each data logger to record measurements every hour at the same time the game cameras took photos. By using close-range photogrammetry we can measure changes in wash topography associated with individual events. These changes can be the accumulation of material due to Aeolian deposition or the loss of material due to fluvial processes. This high-resolution approach allows for the identification of specific events that alter the material in a wash. However, this method is limited because it is a topographic measurement rather than a mass based measurement and does little to describe within-wash redistribution.

2.3 Data Collection

Our study period ran from spring 2012 to summer 2013. We collected data at four intervals: April-July 2012, July-October 2012, October 2012-March 2013, and March-June 2013. During each interval we collected sediment from each of the dust traps, downloaded photos from the cameras and weather data from the data loggers, and performed RTK measurements of the wash profiles along the transects. After each collection interval, we brought the sediment samples from each site back to the lab and dried and weighed them.

2.4 Data Processing

In order to process the game camera images we first used a batch process to crop each image to remove the time stamp in Adobe Photoshop Creative Suite 4 (see www.adobe.com). Next, we selected the images to be processed according to the time they were taken. Although we collected images every hour, we only analyzed images taken at noon for each site because this minimized the amount of shadows present in each image. Additionally, we removed any images from the analysis that had snow in them.

We used Agisoft Photoscan Pro to generate point clouds from each pair of images (see www.agisoft.ru). Agisoft Photoscan allows batch processing of images through a Python scripting interface. We exported each point cloud as an .xyz file. We used a cloud-to-mesh approach to compare point clouds (Fabio, 2003; Remondino and El-Hakim, 2006). We performed the processing of point clouds in Matlab 7.12 on Brigham Young University's supercomputer (www.marylou.byu.edu), following the general process described in Figure 3. We used a mean nearest neighbor algorithm to flag faulty or erroneous point clouds. We then plotted each flagged point cloud to confirm visually that the point cloud was faulty. We calculated the difference between a point cloud and its subsequent or preceding point cloud. We analyzed point clouds at 24 hour and 1 week intervals. To calculate the difference between point clouds, we first aligned or registered each point cloud to make sure that the coordinate system was the same. Second, we interpolated each point cloud to a mesh. Finally, we subtracted the second mesh from the first mesh and exported the percentage positive change between the two meshes.

2.5 Data Analysis

We performed all data analysis in R (R Core Team, 2013). We assessed the data for assumptions of normality, independence, and equal variance. We used ANOVAs to assess the difference in means of sediment mass between substrate types and season. We compared these results with results from a Kruskal-Wallis test for non-parametric data and used Levene's test to assess the assumption of equal variances of the response variables among soil types with the car package in R (Fox and Weisberg, 2011). We used a post hoc Tukey's Honestly Significant Difference to assess comparisons between groups of soil type and also between disturbance levels. We performed AIC model selection using the

glm function to compare predictors of positive change from our photogrammetry measurements (Venables and Ripley, 2002). We also built a predictive model of percent positive change using weather data with regression trees (Hothorn and Zeileis, 2013). To test for potential multi-collinearity between explanatory variables, we first assessed correlation between explanatory variables and ran the regression tree models with and without highly correlated variables included. The final trees with and without correlated variables were identical. We pruned the trees by minimizing the cross validation error and allowing each explanatory variable to only be present on one branch of the tree. Additionally, we drew box-and-whisker plots to show the substrate*sampling-interval interaction of sediment collected in each bucket. We plotted transects from the RTK profiles in R and used the splancs package to calculate the change in area between sampling intervals (Rowlingson and Diggle, 2013). We also used t-tests to compare weather data between time periods. We compared the results of each instrumentation method (i.e. dust traps, transects, and photogrammetry) by calculating Pearson's correlation coefficient between each instrumentation method. We generated the map of our sites using Mapbox (www.mapbox.com).

3. Results

3.1. Dust Trap Data

Overall, there was not a significant difference between upwind dust traps (mean = 299.1 g) and downwind dust traps (mean = 116.2 g; $t = -1.357$, $df = 40.672$, $p\text{-value} = 0.1823$). The total mass of sediment moved during our study period was greater on average at our sand sites than our clay sites, but this difference was only statistically significant during the winter (Figures 4A and 4b; Table 2). All sites experienced greater

upwind dust trap deposition during the spring of 2012 than the spring of 2013 in spite of a shorter sampling period (Table 2). The difference in the average accumulation of sediment between seasons and between substrate types was not statistically significant (Figure 4a and Table 2). The accumulation of sediment in washes, inferred by the difference in sediment collected in upwind and downwind surface samplers, was greater during in spring and summer (July 2012, October 2012, and June 2013 collection periods) than during the winter (March 2013 collection period; see Figure 4b and Table 2).

We were able to explain 79% of the variation in the amount of sediment deposited in our upwind dust traps by disturbance type and seasonality (Figure 5). The highest levels of deposition were found in sites with OHV (off-highway vehicle) disturbance during the spring of 2012 (Figure 5). We also were able to explain 73% of variation in the difference between upwind and downwind dust traps by disturbance type and seasonality (Figure 6). Again, the highest difference in sediment between dust traps (and presumably sediment deposition in the wash) was found in OHV sites during the spring of 2013.

3.2 Weather Data

We took continuous weather measurements at three sites during the study period. There was a significant difference in the average weekly wind speed between April-July 2012 (mean = 2.8 m/s) and March - June 2013 (mean = 1.7 m/s; $t = 3.629$, $df = 7.451$, $p\text{-value} = 0.008$). However, there was not a significant difference in total weekly precipitation between April-July 2012 (mean = 6.4 mm/week) and March - June 2013 (mean = 3.4 mm/week; $t = 0.644$, $df = 5.637$, $p\text{-value} = 0.545$).

3.3 Transect Data

In both late summer and fall washes tended to lose sediment, while they aggraded in spring/early summer 2013. The largest movement of sediment out of the wash was from July 2012 to October 2012 when the average wash cross-sectional area increased by 0.49 m². During the winter, the average wash cross-sectional area was effectively static, with the average wash area increasing only 0.02 m² between October 2012 to March 2013. There was evidence of slight accumulation of material between March 2013 to June 2013 with the average wash area decreasing by 0.06 m² (Table 3). Over the 14 months of our study the average wash had a net increase of 0.16m² in cross sectional area, which translates to an actual net loss of sediment from the wash.

3.4 Photogrammetry Data

We were able to explain between 47 – 63 % of the variation in change in our 3D models using weather station data (Figure 7; Figure 8). Across all sites, the most important variables in accumulation of material in washes were low precipitation and high wind speed. For clay sites alone, the most important variables were precipitation, season, and volumetric water content of adjacent soils. Weeks at both clay and sand sites that saw less than 10.5 mm of precipitation per week and that had average wind speeds greater than 1.52 m/s saw the most deposition (Figure 7). Conversely, weeks where the average precipitation exceeded 10.5 mm saw the most material flux, presumably through fluvial erosion. This was also true for clay sites. Weeks at clay sites that saw less precipitation than 10.5 mm per week saw the most positive change during the summer, and weeks at clay sites with more precipitation than 10.5 mm per week saw more negative change (Figure 8).

Our model selection results agreed with the regression trees (Table 4). Whether or not threshold friction velocity was exceeded during the week and the amount of weekly precipitation were the variables that determined the amount of positive change in our best model (Table 4; Belnap et al., 2014).

3.5 Correlation of Data Collection Methods

Interestingly, there was no significant relationship between the seasonal movement of surface material from adjacent landscapes and changes in wash cross section. Pearson's correlation coefficient between our dust trap (upwind) data and transect data (change in area) was 0.33 (p-value = 0.52). For net mass accumulation (upwind – downwind) data and cross-sectional area, Pearson's correlation coefficient was 0.11 (p-value = 0.85). Pearson's correlation coefficient between our surface input data (upwind) and photogrammetry data (percent positive change), was -0.26 (p-value = 0.26), and for our net Aeolian movement (upwind – downwind) data and photogrammetry data (percent positive change), Pearson's correlation coefficient was -0.02 (p-value = 0.9235). Pearson's correlation coefficient between our photogrammetry data (percent positive change) and transect data (change in area) was 0.24 (p-value = 0.70).

4. Discussion

4.1 Interaction Between Aeolian and Fluvial Processes

Our results suggest that there was an interaction between aeolian and fluvial processes at our sites. First, our sediment trap data suggest that there was a net influx of eroded sediment into the washes at each site. The average amount collected per site in our upwind traps was greater than the average amount collected in our downwind buckets. However, this difference was not significant, most likely because wash orientations varied

for each site and wind direction was variable over time. Second, our transect and close-range photogrammetry data suggest that once sediment had been deposited in the wash, it was removed in part by fluvial processes. For example, we saw a seasonal trend in the decrease in wash area (i.e. an accumulation of sediment into the wash) and increase in wash area (i.e. a loss of sediment out of the wash). For our close-range photogrammetry data the variables of windspeed and precipitation were most important in determining the percent positive change (accumulation) of sediment into the wash (Figures 7 and 8). Low precipitation levels and high windspeeds were correlated with higher percent positive change (accumulation) in the wash, while high precipitation levels were correlated with a lower percent positive change, or loss (Figures 7 and 8).

4.2 Factors Influencing Erosion

As in other studies (Belnap et al., 2014, 2007; D’Odorico et al., 2013; Reynolds, 2001), the level of disturbance was a significant factor in the movement of sediment at our sites on both sandy and clay substrates. In our study, sites with OHV-use saw more movement of sediment than sites that were only grazed or had low disturbance levels (Figures 5 and 6). Site disturbance was the major driving force in both aeolian movement of sediment (in upwind buckets) and net mass movement of sediment into the washes (upwind – downwind buckets; see Figures 5 and 6). Site disturbance also had an impact on the net flux of materials into the wash, as measured by our transect measurements (Table 3). Our results cannot directly address what role disturbance has on the loss of sediment because we did not include disturbance as a variable in our analysis of our photogrammetry data.

Although surface disturbance of sediment has been cited on many occasions as a concern for land managers, it is most often in the context of aeolian erosion alone (Belnap et al., 2014, 2007; Field et al., 2010; Reheis and Urban, 2011). However, given the potential interaction of aeolian and fluvial processes, the surface disturbance of sediments has potential significant impacts on water quality as well, especially on Mancos shale, given the high selenium and salt concentrations in those soils (Carpenter and Chong, 2010). In a previous study, Belnap et al. (2014) showed that Mancos Shale-based soils were particularly susceptible to surface disturbance and eroded more readily after a disturbance event than sandy soils, although sand sites were more susceptible to erosion than clay sites generally.

4.3 Role of Seasonality in Sediment Movement

We found that the aeolian movement of sediment at our sites was greatest during spring and early summer. Many other studies examining the role of seasonality in the aeolian movement of sediment have confirmed the role of spring and early summer on total erosion (Belnap et al., 2014; Munson et al., 2011; Reheis and Urban, 2011). In this study, results from all three of our data collection methods (i.e. dust traps, RTK transects, and photogrammetry) showed that dry and windy conditions were most conducive to the surface movement of sediment. Furthermore, our results show that there is a significant interaction between aeolian and fluvial processes. For example, wind gusting can deposit material into the wash, then a rain event with water flow through the wash can carry the deposited material to surface waters. Prior studies have also showed that there is a strong seasonal interaction between aeolian and fluvial processes (Bullard and Livingstone, 2002; Ta et al., 2014; Xu et al., 2006). Notably, our study shows that the interaction between

aeolian and fluvial processes may occur at hourly, daily, or weekly temporal scales, and that more research is needed to further quantify this interaction.

4.4 Comparison Between Sampling Methods

We found virtually no correlation between our three sampling methods. This is due, in part, to the fact that dust traps, RTK transects, and close-range photogrammetry measure different processes. Dust traps measure total surface movement at whatever temporal scale samples are collected, independent of whether dust actually deposits in the wash. Additionally, dust traps rely on an assumption of that the prevailing upwind and downwind directions remain constant, when the reality is more complex. While the assumption of a prevailing wind direction may be true on a regional and seasonal scale, in our sites we saw much more variation in wind direction at our sites at hourly, daily, and weekly temporal scales. As a result, our fixed dust traps did not capture the total amount of sediment because they were oriented in one direction. Another limitation is that dust traps are unable to measure any fluvial erosion within the wash that occurs through rain-events.

RTK transects, on the other hand, are able to accurately measure both aeolian deposition and fluvial erosion by measuring the actual wash profile in terms of wash cross-section area. However, because the measurement is two-dimensional RTK transects cannot quantify the mass or volume of sediment accumulated. Additionally, obtaining transects is very time intensive, so the temporal resolution depends on the sampling frequency. The cost of the RTK unit, the set up time, and the challenges of accessing enough of the satellite network while in canyons or areas with cliffs or hills can make the RTK an unreliable and costly option.

Close-range photogrammetric methods with game cameras can overcome the sampling frequency limitation, but require a more involved site set up and significant post-processing. Close-range photogrammetry techniques can be used to study erosion and deposition at smaller temporal scales. Our close-range photogrammetry methods were able to account for 47 – 63 % of the variation in site level change. Although we analyzed our data at a weekly scale to ease the analysis process, our method allows collection and analysis of field data at much smaller scales, and at significantly less-cost than LiDAR or other remote sensing setups. Close-range photogrammetry offers many other advantages over the other methods we used.

5. Conclusion

In conclusion, our results indicate that there is a likely interaction between aeolian and fluvial processes, and that this interaction can be exacerbated by soil-type, seasonal weather changes, and land-use patterns. Our study highlights that more research is needed to better quantify the interaction between these processes and to better understand the variables involved. Our data indicate that land managers should take the interaction of these processes into account.

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7. Tables

Table 1 – Table showing detailed site characteristics for each site.

Site Name	Latitude	Longitude	Elevation (m)	Parent Material	Channel Width (m)	Channel Depth (m)	Channel Flow Direction	Distance to weather station (km)	Weather Station	% Plant Cover	veg type	Grazing Level
Hank A	38.26	-110.77	1,489	Mancos	1	1	NNE	3.2	HankB	10%	ms	medium
Hank B	38.27	-110.80	1,463	Mancos	2	1	NNE	0	HankB	5%	ss	medium
Hank C	38.27	-110.81	1,456	Mancos	2	1	NE	0.8	HankB	5%	ss	medium
Site G	38.87	-109.85	1,405	Mancos	4	0.5	NNW	0	SiteG	10%	ss	heavy
Site J	38.92	-109.43	1,340	Mancos	2	0.6	S	36.2	SiteG	20%	ms	medium
Site K	38.91	-109.40	1,300	Mancos	1	1	S	39.9	SiteG	15%	ss	medium
Site M	39.15	-108.54	1,504	Mancos	1	0.8	SW	4.3	GJ Airport	20%	ms	ohv
average for Mancos sites:					1.9	0.8	n/a	12.1	n/a	12%	n/a	n/a
Site H	38.84	-110.03	1,320	Sandstone	3	1	W	15.6	SiteG	20%	ms	medium
Site I	38.80	-110.06	1,292	Sandstone	1.4	0.7	NW	20.1	SiteG	20%	ms	medium
Site L	38.56	-109.51	1,365	Sandstone	1.5	0.6	SW	0	SiteL	30%	ts	none
average for Sandstone sites:					2	0.8	n/a	11.9	n/a	23%	n/a	n/a

Table 2 – Table showing mean sediment collected by dust traps during each collection period.

Period	Type	Mean Sediment Per			
		Bucket (g)	Upwind (g)	Downwind (g)	U - D (g)
April – July 2012	Mancos	321.4	453.0	189.6	263.4
July – October 2012	Mancos	117.6	135.2	91.8	43.4
October – March 2013	Mancos	14.3	30.3	15.0	15.3
March – June 2013	Mancos	31.0	32.8	29.8	3
April – July 2012	Sand	1049.7	1293.1	806.2	486.9
July – October 2012	Sand	227.8	316.5	140.1	176.4
October – March 2013	Sand	105.9	184.4	35.7	148.7
March – June 2013	Sand	180.5	279.2	81.8	197.4

Table 3 – Table showing data from RTK transects for each collection period.

Site Name	Substrate	Period	Δ in wash area (m ²)
SiteM	clay	Jul - Oct	
SiteG	clay	Oct - Mar	-0.05232808
HankB	clay	Oct - Mar	0.20485
HankA	clay	Jul - Oct	0.227884862
Sitel	sand	Jul - Oct	0.74755
Sitel	sand	Oct - Mar	-0.07625
Sitel	sand	Mar - Jun	-0.06355

Table 4 – AIC models of photogrammetry data. TFV = threshold friction velocity.

Model#	Formula	K	AIC	AICc	Δ AICc	Step 1	AICc Weights (wi)
1	$\text{gust} + \text{ws} + \log(\text{precip} + 1)$	3	27.75	28.5775862	3.7137931	0.1561565	0.032681053
2	$\text{gust} + \text{ws}$	2	25.95	26.3637931	1.5	0.47236655	0.098858747
3	$\text{gust} + \log(\text{precip} + 1)$	2	25.78	26.1937931	1.33	0.51427353	0.107629205
4	$\text{ws} + \log(\text{precip} + 1)$	2	25.79	26.2037931	1.34	0.51170858	0.107092402
5	$\text{tfv} + \log(\text{precip} + 1)$	2	25.74	26.1537931	1.29	0.52466254	0.109803459
6	$\text{gust} * \log(\text{precip} + 1)$	2	24.8	25.2137931	0.35	0.83945702	0.175684897
7	$\text{ws} * \log(\text{precip} + 1)$	2	25	25.4137931	0.55	0.75957212	0.158966269
8	$\text{tfv} * \log(\text{precip} + 1)$	2	24.45	24.8637931	0	1	0.209283969

Key

gust: mean gust (m/s) per week

ws: mean wind speed (m/s) per week

precip: total precip (mm) per week

tfv: # of hours per week with average wind speeds above TFV

8. Figures

A.



B.



Figure 1 – Deposition and erosion of aeolian sediment in a wash at Swing Arm, Factory Butte, UT. A (left) show the wash full of windblown sediment, and B (right) shows the empty wash after a rain event. Photos courtesy Adam Kind, USGS (Belnap et al., 2011), and Beau Walker.

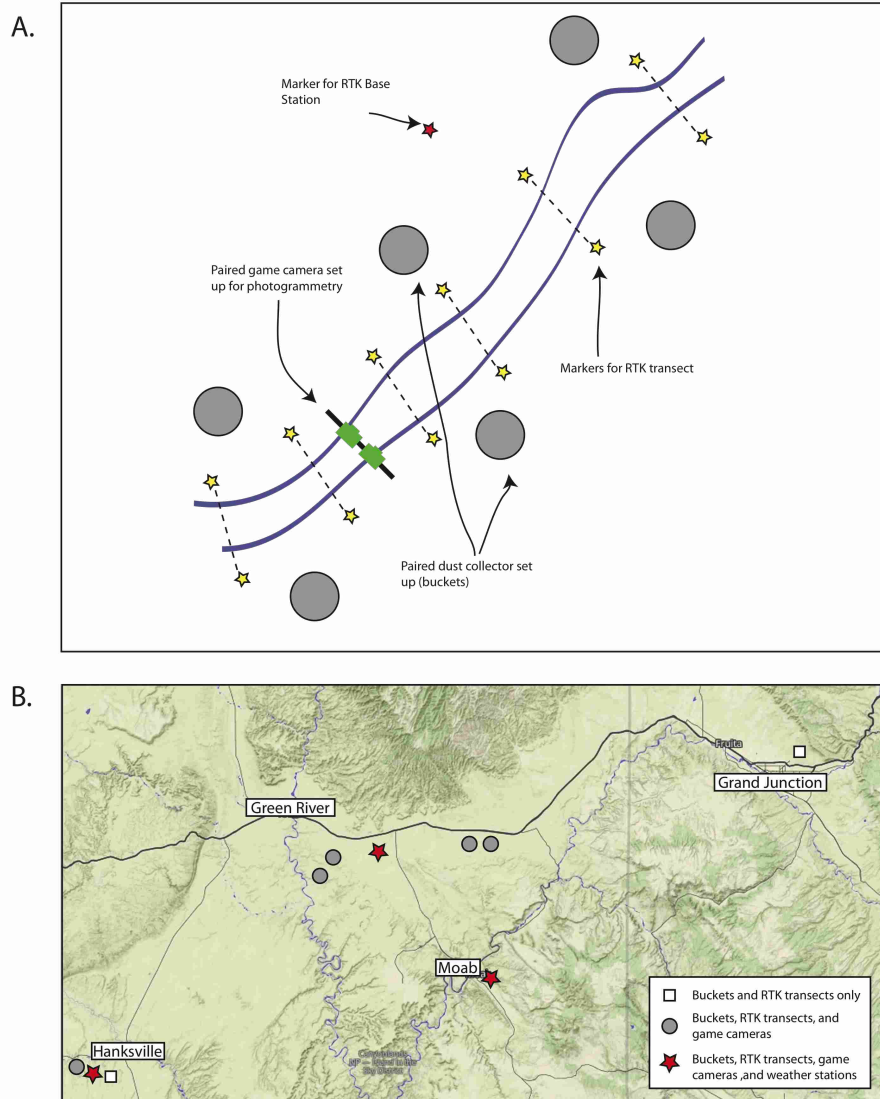


Figure 2A – map of our site locations across the Colorado Plateau from Hanksville, UT to Grand Junction, CO. Nine of those sites also had game cameras (shown by circles and stars). Of those nine, three also had weather stations installed (shown by stars). Figure 2B – Schematic showing our typical site set up. We had eleven sites with dust traps (buckets) and RTK transects.

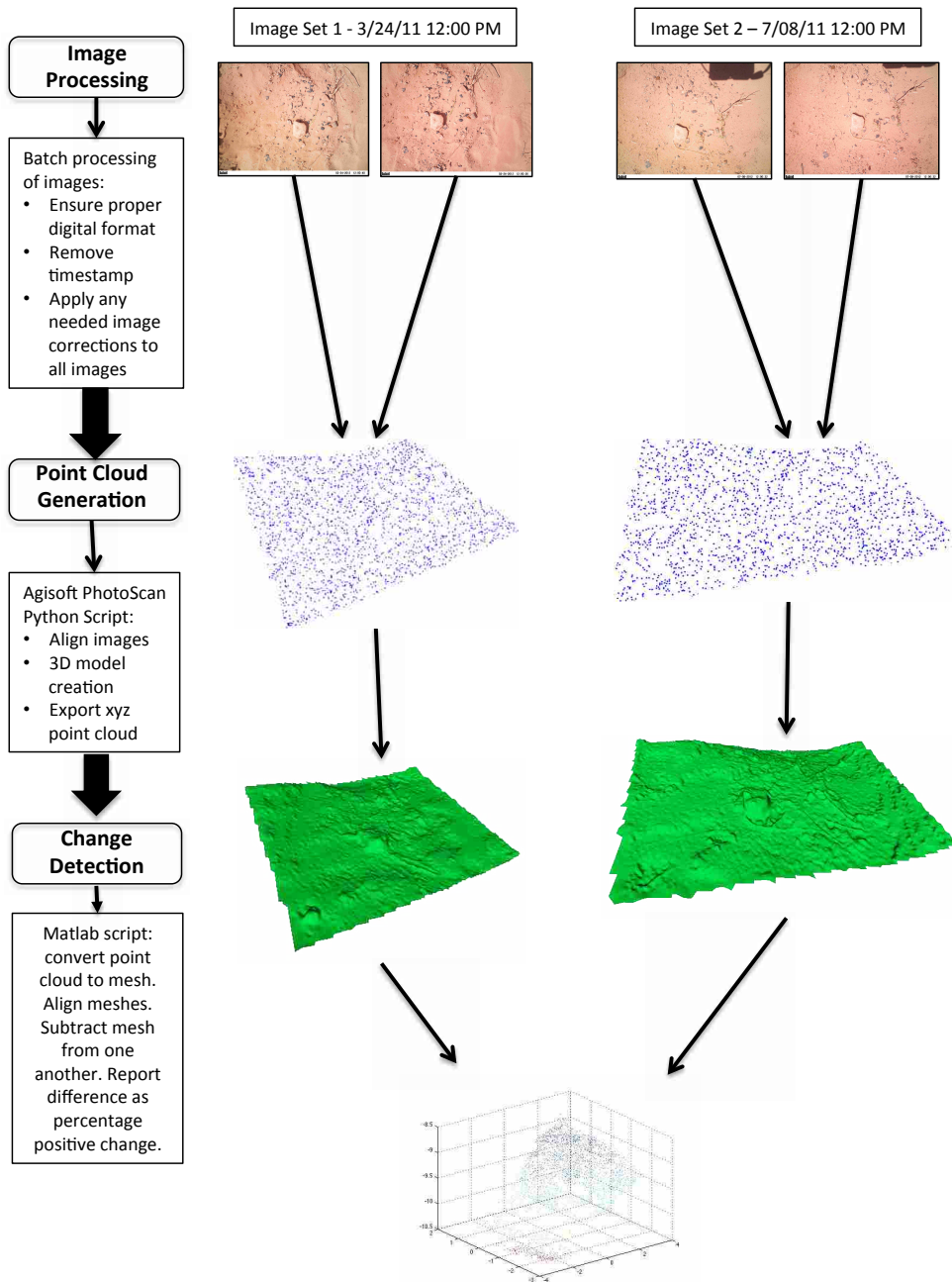
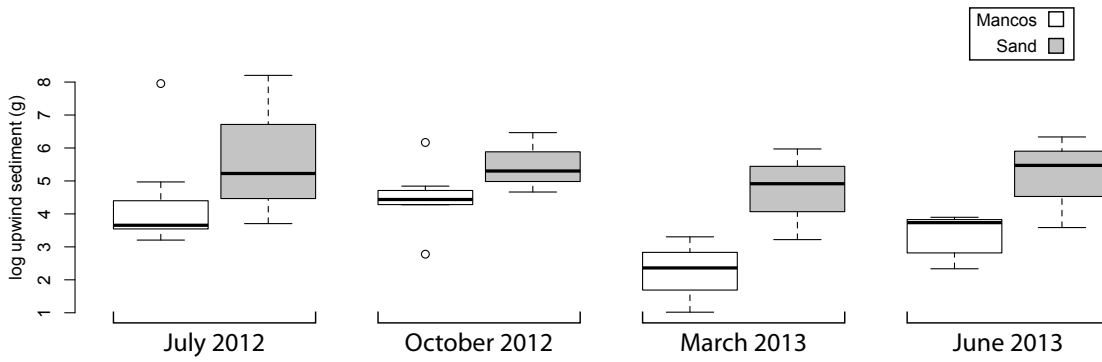


Figure 3 – Diagram showing the general process for creating and analyzing 3D models from paired images (Matthews, 2008).

A.



B.

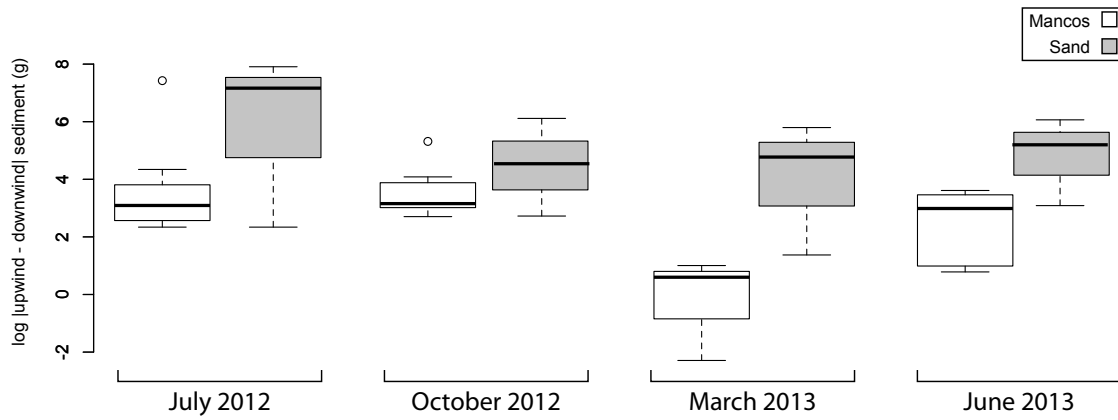


Figure 4A. Boxplot showing substrate by data collection period (season) deposition in upwind dust traps. There were no statistically significant differences. Figure 4B. Boxplot showing the absolute difference between upwind and downwind dust traps by data collection period (season) and substrate.

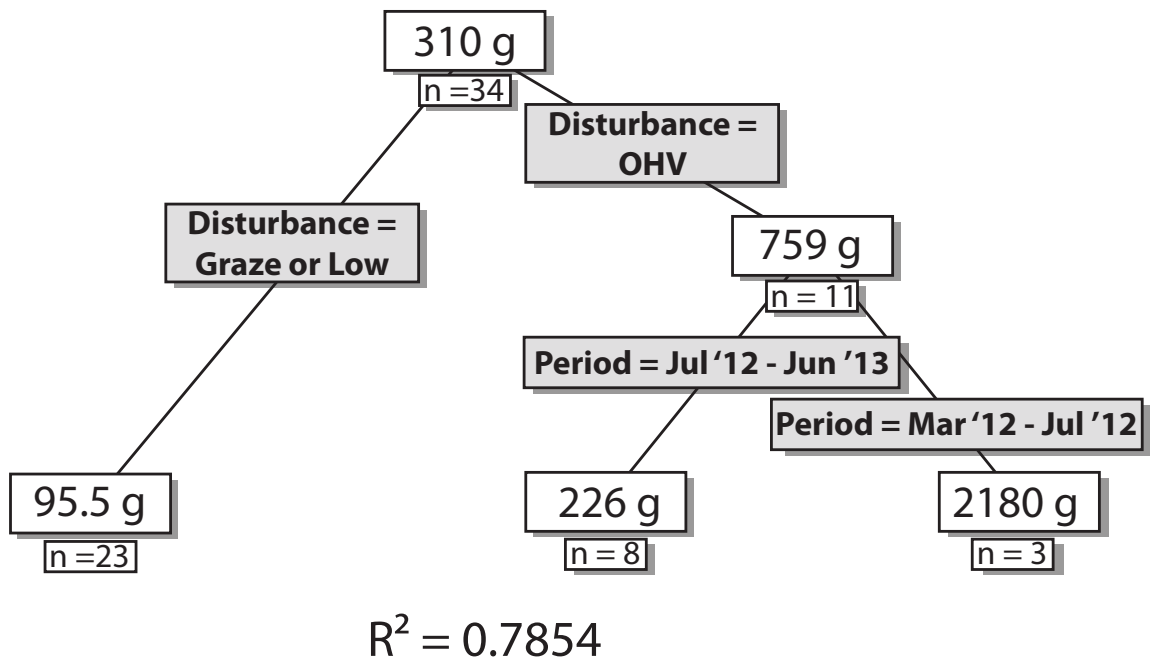


Figure 5 – Regression tree showing the variables influencing deposition in upwind dust traps.

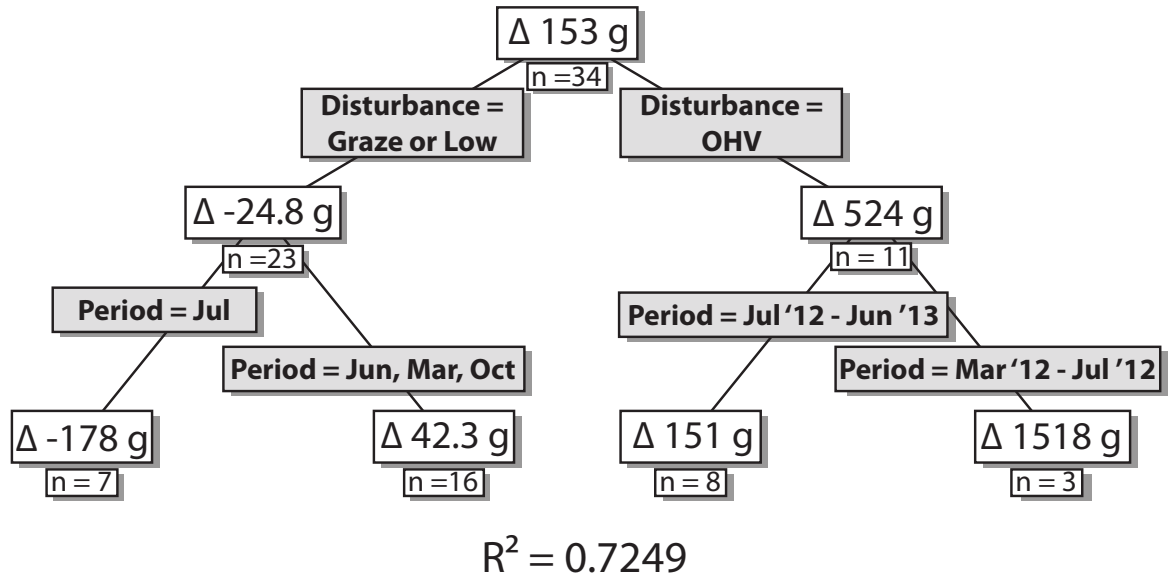


Figure 6 - Regression tree showing the variables that influence the difference between upwind and downwind dust traps.

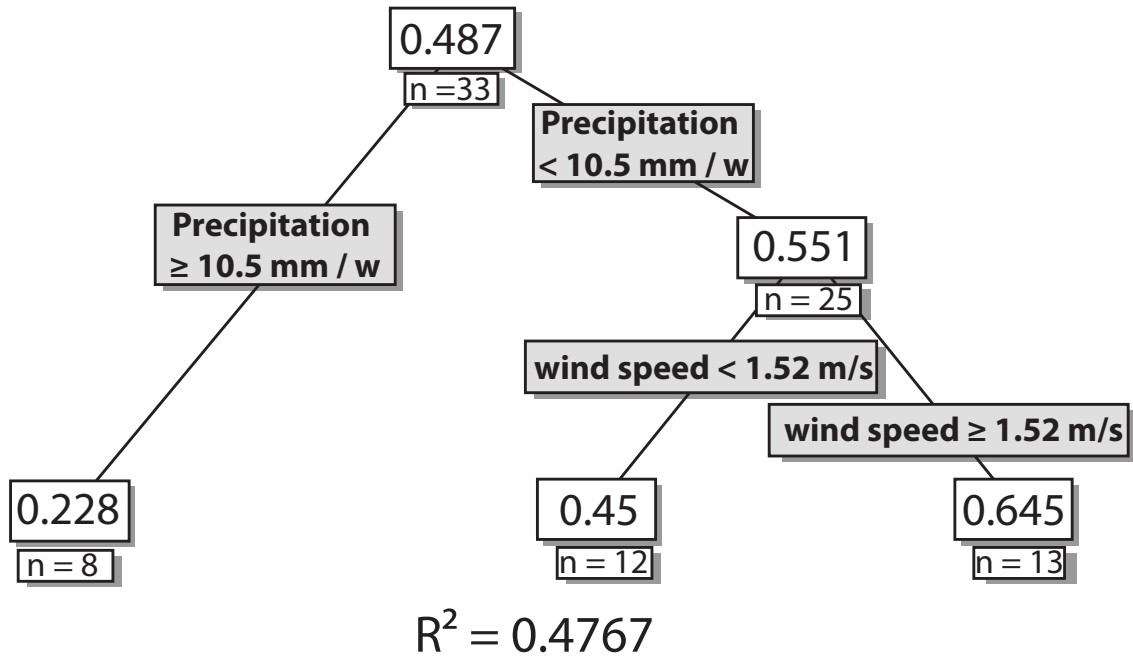


Figure 7 – Regression tree showing the variables that influence the percent positive change detected by game cameras in all three washes (sand and clay substrates).

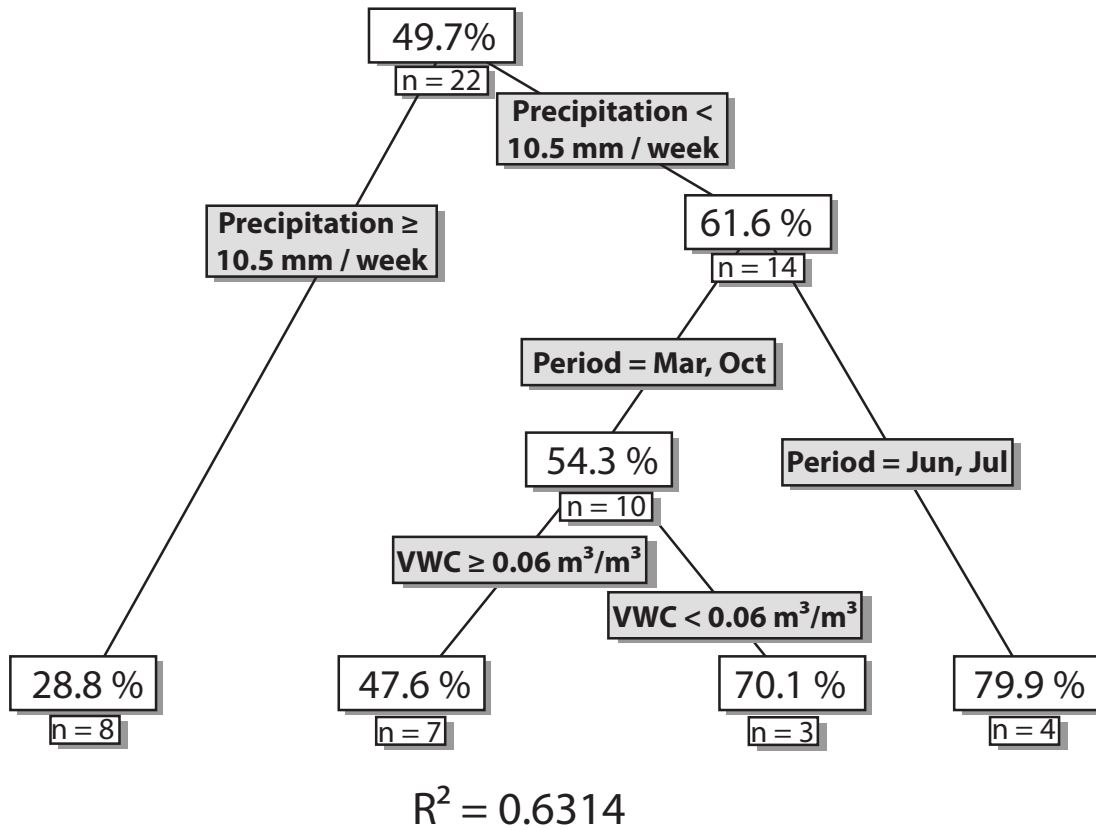


Figure 8 - Regression tree showing the variables that influence the percent positive change detected by game cameras in both washes with clay substrates.