Evaluation of Sunnyside Cogeneration Associates SCA #2 Ash Landfill Construction Permit Application

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This review of SCA's application to construct the SCA #2 landfill is organized as follows. First, I present comments and concerns regarding the permit and proposed construction measured against potentially applicable regulations and requirements. Second, I raise issues of technical concern arising from the application and supporting documents. In many cases, these issues are evaluated against observations regarding the performance of the SCA #1 facility, including prior commentary on the groundwater discharge permit.

Problems with Site Location

SCA claims that the location of SCA #2 was purposely chosen to be in a "small side canyon," that "does not have regular surface water flows" as if this were advantageous to the site. This canyon is 42 meters deep relative to the pediment at the top of the cliff on its north side. The depth of this canyon has been produced by downcutting resulting from intermittent surface water flows in the very canyon SCA proposes to construct its landfill. Thus, SCA's choice of siting location for SCA #2, and UDWQ's approval of that location, is inconsistent with its stated goals and thus is arbitrary.

Other geologic problems with the SCA #2 landfill site are illustrated in Figure 1. This particular canyon is actively eroding headward into the book cliffs. In particular, there is a nickpoint in the streambed immediately above the proposed landfill. A "nickpoint" is a sharp change in the channel slope of a streambed. In addition, multiple converging rills in the shale bedrock below the nickpoint show that the stream system is actively gathering overland surface flows during storm events. In other words, the proposed site is in the path of an actively eroding intermittent stream just below the point where flows are gathered and the stream gradient increases.

Engineering drawings (appendix B, April 5 2013 Groundwater Discharge Permit) suggest that the slot canyon will be filled to the approximate elevation of the nickpoint. Thus, the influence of gathered flows and increased run on gradient will not be "covered" until closure. However, the areas above the completed landfill is steep, and run on velocities will be high.

The concave upward shape of the stream profile (Fig. 1) reveals the inevitable fate of landfill SCA #2. Filling of the canyon will interrupt the concave upward stream profile and the stream will inevitably respond by rapid downcutting through the closed facility, washing its contents down slope. The proposed site is poorly chosen. It is not just in a floodplain, but it is in an actively eroding stream channel.

I am aware that SCA's contractor has conducted hydrologic modeling, but the modeling is inadequate for the purposes of review and evaluating the safety of the site (appendix B, April 5 2013 Groundwater Discharge Permit). It includes tabular data regarding fluxes to and from engineering features on the site, or run off from open or closed features of the landfill. However, there are no estimates of run on to the landfill. Additionally, only fluxes (not velocities) are presented.

The capacity of a flowing stream to transport sediment, in this case coal ash, scales to the 3rd to 4th power of velocity. The increased gradient and gathered flows just above the site will both contribute greatly to the erosive capacity of flood events. However the same problem exists if the landfill were constructed, filled to capacity, and closed. In addition to the tendency to downcut as described above, the stream gradient is very high above the nickpoint. The average gradient along the stream is nearly 22%, and reaches a maximum of nearly 50%. When run on events occur, the water velocity may be very, very large, and the capacity to scour and transport ash enormous.

There is no logical explanation in the construction permit application, groundwater discharge permit application, or other available documents supporting why this location for SCA#2 was chosen. There are extensive flat pediment surfaces nearby upon which such a landfill could be located. These pediments are underlain by impermeable Mancos Shale and the depth to water will be substantial. Why anyone would forego such a setting in favor of emplacement in a slot canyon is difficult to understand and is unexplained in the permit application materials.

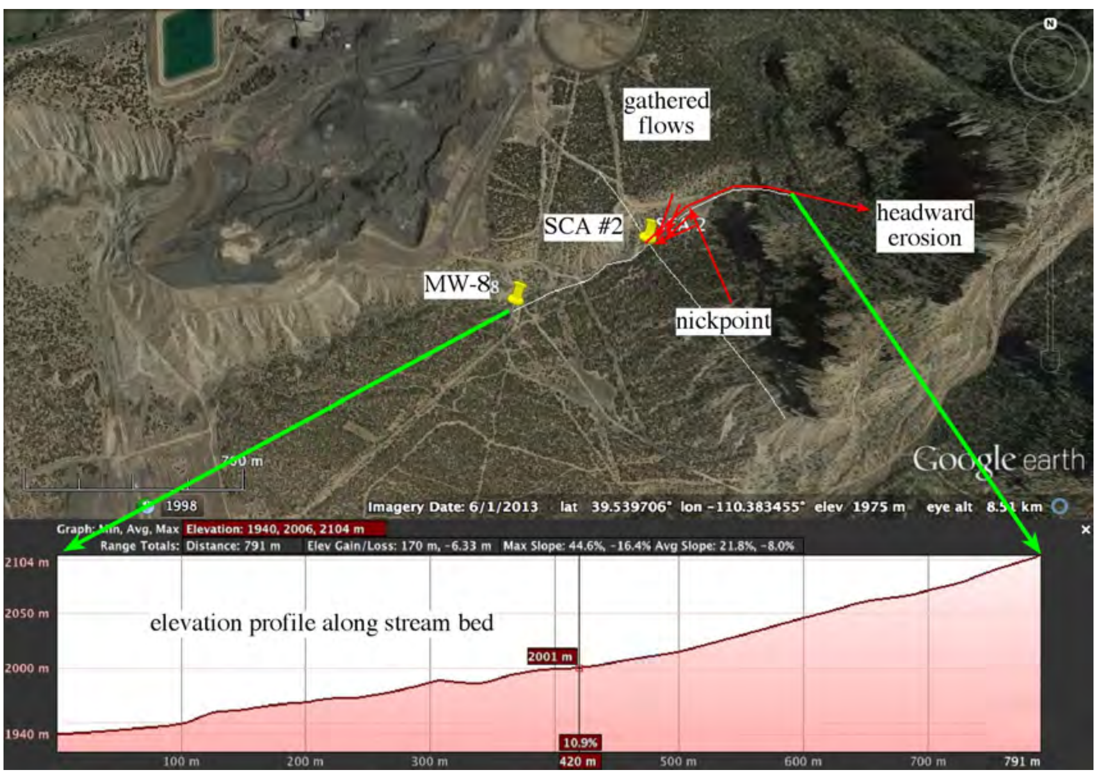

Figure 1. Location of the SCA #2 landfill according to coordinates given in the construction permit application. See text for discussion.

Dust

My second area of primary concern is dust. The applicant posits that the new location of the landfill "*will reduce the potential for dust near local residences*" p. 5. This is incorrect at face value, for the following reasons:

- Distance
    - SCA #2 is 1.4 km from "old" Sunnyside.
    - SCA #1 is 2 km from "old" Sunnyside.
    - SCA #2 is 2.5 km from Columbia.
    - SCA #1 is 3.7 km from Columbia.
    - In summary, some residential areas are closer and overall the differences in distance are not substantial.
- Wind
    - Cyclonic (i.e., cold/cool season) storm fronts are typically preceded by southwesterly winds. The canyon offers no windbreak, but rather acts as a funnel.
    - After cyclonic fronts pass, winds change to the northwest. Observation of SCA #1 shows that the cliff face there offers little leeward protection for the mobilization of dust (see below).
- Chemistry
    - TCLP analysis of ash in the record indicates that inhalation of dust is likely to be caustic, as final solution pH was >12. This is consistent with the use of limestone in the combustion process, which produces lime (CaO) as a combustion product in the ash.
    - Glass occurs in the ash as sharp shards.
    - The inhalation of caustic dust accompanied by glass certainly poses a health hazard.

Furthermore, past and ongoing dust releases from SCA #1 provide little confidence in SCA's ability to manage fugitive releases at SCA #2.

Empirical Evidence of Dust Dispersal. Figure 2 shows the location of soil, sediment, and snow samples taken by me. Snow samples were taken from the surface of undisturbed snow on Feb. 1, 2014 (Fig. 2) to characterize dust that had been emplaced on the surface of snow that fell between Jan. 29-31, 2014 (NRCS, 2014). Snow was placed into a plastic bag and allowed to melt. Approximately 50 ml of agitated water were transferred to a 50 ml centrifuge tube and centrifuged. After ~40 ml were decanted, the remaining water was re-agitated, and ~40 drops transferred to a 22 mm microscope slide cover slip and allowed to dry. The cover slip was then mounted to a standard microscope slide with ZRAX mounting agent. Soil, ash and sediment samples were collected Feb. 1, Mar. 17, and April 7, 2014. Soil and sediment samples were boiled in 30% H_2O_2 for 1 hr. to eliminate sapropel particles that may look like glass fragments under the microscope. These were then mounted in a similar fashion with ZRAX. Ash fragments were ground with a mortar and pestel and also mounted with ZRAX.

Figure 2. Top image shows the location of glass-bearing soil, sediment, and snow samples. Bottom image shows the location of ash samples from material that has fallen from haul trucks, as well as the location of glass-bearing wetland sediment and nearby soil.

Microscopic examination of snow, sediment, and dust samples reveals that fugitive dust emissions have spread glass far and wide, including public parkways (614 soil, downwind snow) and schools (613 soil). Particularly surprising is finding glass in snow 4.5 km south of SCA #1 in (upwind) snow that had been on the ground only a short time

(Fig. 2). Figure 3 illustrates the presence of glass in soil, sediment, and snow samples compared to crushed glass that has fallen from haul trucks.

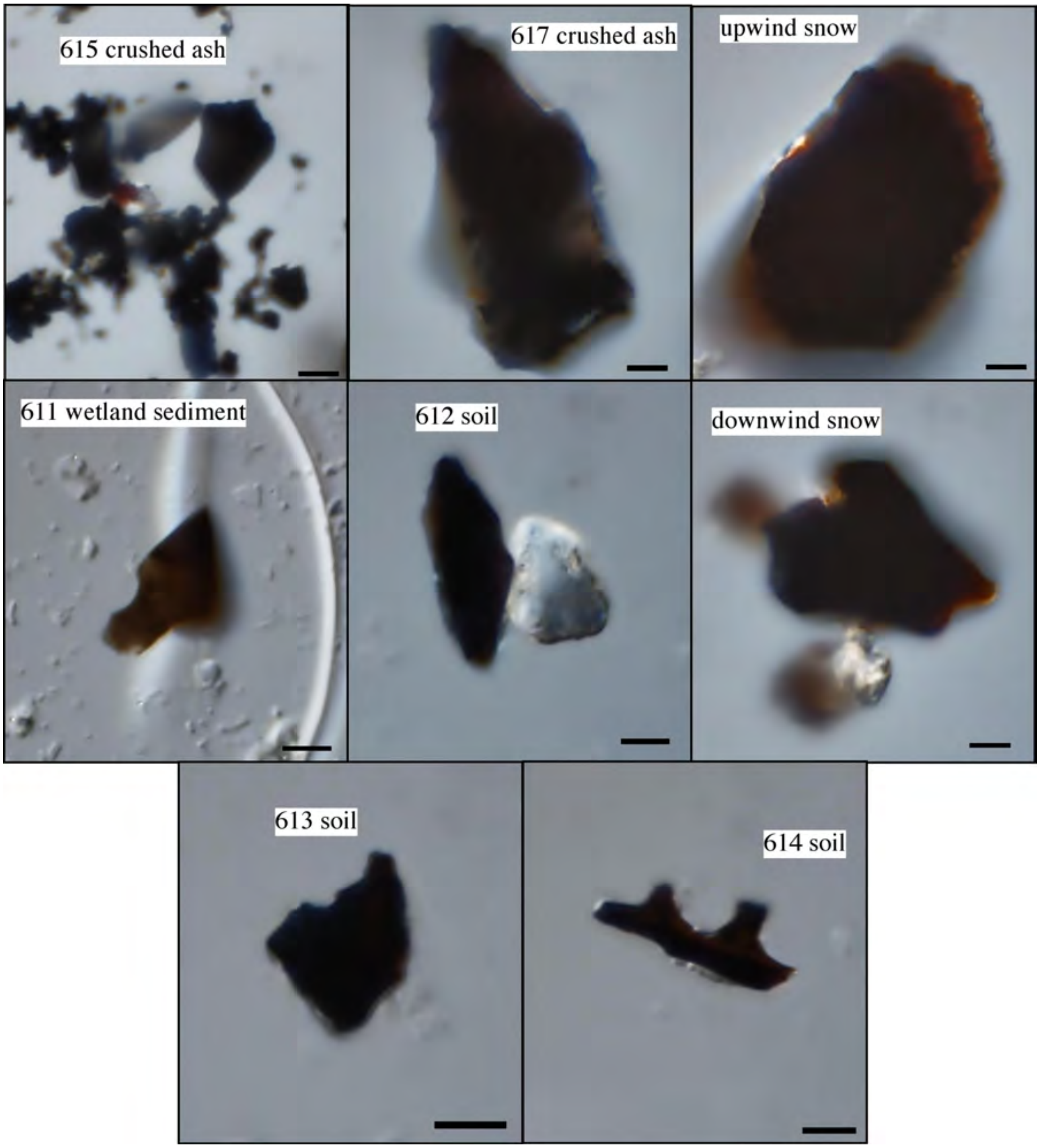

Figure 3. Photomicrographs of crushed ash, snow, wetland sediment, and soil. Sample locations are given in Figure 2. Evidence for the dispersal of ash from SCA #1 appears to be ubiquitous. All scale bars are 5 microns.

Macroscopically, substantial quantities of ash are being mobilized off of SCA #1 and reaching local residences. I have visited the site on relatively calm as well as blustery days. I have never observed a day when the dust remained immobile, despite so-called pozzolanic effects referred to in the permit application.

Figure 4. Upper: Fugitive dust blowing from SCA #1 to the northeast on Mar. 17, 2014. View is to the southeast. Lower: Fugitive dust blowing from SCA #1 north toward East Carbon-Sunnyside. This photo was taken on or about April 15, 2014. View is toward the west.

Quantitative Bounds of Dust Dispersal. To establish some context for the dispersal of ash, dust dispersal patterns related to a storm front that passed through the area Mar. 17, 2014 were examined using HYSPLIT (Rolph, 2013; Draxler and Rolph, 2013) for winds at 10 m above ground level. As noted in Figure 5, dust was blown across old Sunnyside and towards Columbia for much of the day. At midday on Mar. 17, a cold front passed the area. For at least 8 hours prior to this, winds on the order of 3-4 m/s blew from the southwest, potentially dispersing ash over the eastern portion of East Carbon—Sunnyside. After the front passed, strong winds out of the northeast (11-15 m/s) dispersed ash to the southeast, potentially affecting residents of the small community of Columbia (Fig. 5).

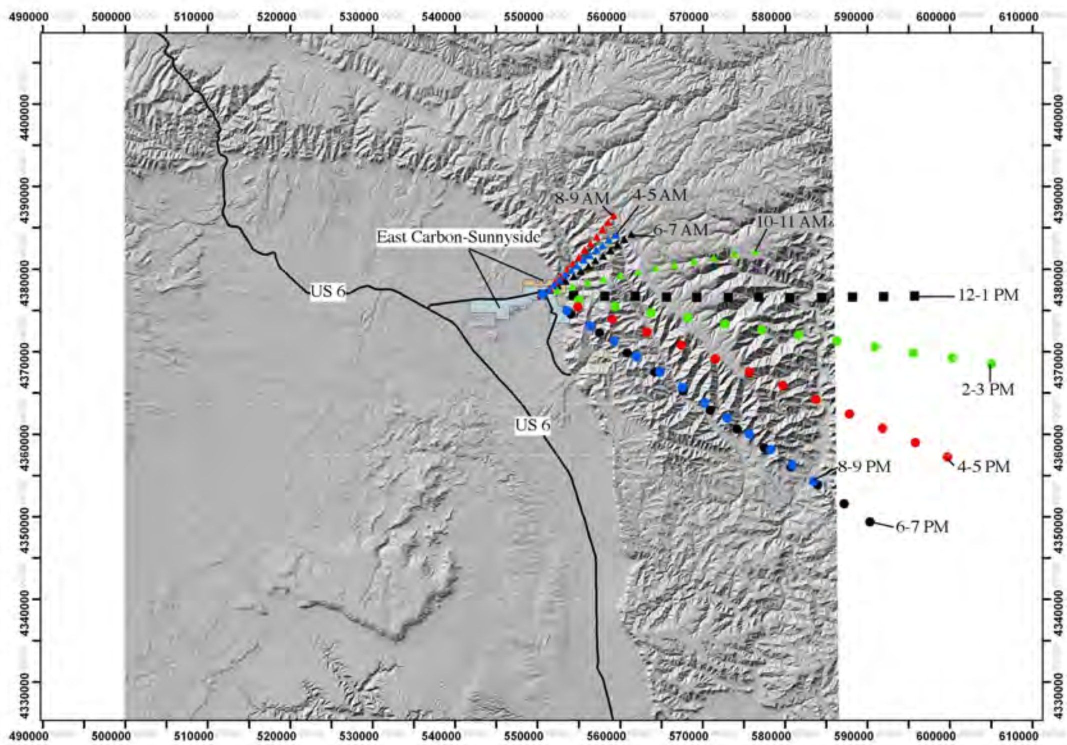

Figure 5. HYSPLIT ash trajectories calculated for 1 hr. time intervals and for 10 height above the surface for March 17, 2014. The starting point is SCA #1. See text for discussion.

In general, cyclonic storm systems likely redistribute ash from the landfill to the northeast and southeast a number of times per year as cyclonic fronts pass over the area. We have examined weather station records at Price, Utah from Oct. 1, 2013 to Mar. 30, 2014 (NCDC, 2014) to evaluate the number of windy days in that 181-day time window. The record is not entirely complete. Six days of barometric pressure and 3 days of average wind speed values are missing.

I define high-wind days as: a) those where the barometric pressure was >1 standard deviation below the corresponding monthly mean, and b) where the average wind speed was >1 standard deviation above the mean. Although wind speed directly affects dust emission, barometric data act as a check on the number of cyclonic fronts. Accounting for missing data, there were high-wind days 14.9 to 18.2 % of the time. In this arid region, precipitation accompanying convective fronts is unlikely to be a major factor in suppressing ash dispersal. In Price, only 3 days in this 6-month period received >2.5 mm precipitation, and only one of those qualified as a high wind day. In addition to cyclonic winter storms, winds associated with convective storms, especially during the summer monsoon season, will also disperse ash.

There is a well established literature and associated quantitative expressions for evaluating the movement of dust, including fluxes, threshold wind speeds (shear velocity, u*), soil moisture content, vegetation, particle size distribution, saltation height and flux, interparticle forces, and surface roughness (e.g., Kok et al. 2012).

Kok et al. (2012) noted that the onset of grain saltation is critical to dust release as it is the impact of bouncing grain aggregates striking the ground or grains impacting dust aggregates produce most releases. Quantitative expressions of dust fluxes (mass/unit area/unit time) scale with u^{*2} to u^{*4} (Till and Groban, 2008; Lancaster, 2009; Kok et al., 2012). Thus, this parameter is especially critical. u* can be defined as: a) the wind velocity near the surface required to produce saltation of a grain of a given size and density, or b) the velocity at the top of the saltating zone, which appears to range from 0.02-0.03 m height, regardless of wind speed, where values for u* generally fall in the range of 0.1-1 m/s (Lancaster, 2009; Kok et al., 2012), corresponding to the saltation of 50-500 μm grains at the 1850 m elevation of East Carbon—Sunnyside, assuming ash grains have a density of 2.65 g/cm^3. This assumption is conservative as ash fragments I have collected along public roads around SCA #1 are vesicular and much less dense than 2.65 g/cm^3.

Large ranges in fluxes are due primarily to uncertainty in u*. Analytical expressions for dust fluxes are widely available (Kok et al., 2012), but adapting them to the SCA facility is difficult because few required input parameters are known or can be reliably estimated. Instead, I adopt a combined empirical--stochastic approach, where measurements of the vertical dust flux (F_v) and u* in Mali, Australia, the Yukon (Canada) and Texas (USA) (Nickling, 1999; Lancaster, 2009) are employed as analogues to bound potential fluxes at the SCA landfill. These are regions of the world where dust emissions have been measured and quantified.

Given the importance of u* in dust flux estimates, it is important to estimate this parameter at the top of the saltation zone (0.03 m). From eq. 2.18 of Kok et al. (2012)

$$(1) \qquad \bar{u}(z) = \frac{u^*}{\kappa} \ln\left(\frac{z}{z_o}\right)$$

$\bar{u}(z)$ is the average wind speed as a function of height z above the ground surface, κ is a constant that equals 0.40, and z_o is the surface roughness length. z_o is a measure of obstacles to near surface winds such as natural topography, rocks, vegetation, etc., and is also the height above the ground surface where the logarithmic decay of wind speed extrapolates to 0 as the ground surface is approached.

For a z_o of 0.02, $\bar{u}(z)$,=u*=0.35 m/s at the top of the saltation zone (0.03 m). This velocity corresponds to the median of empirically measured values as discussed below. To place this in context, z_o=0.03 is considered appropriate for an open flat terrain with grass, whereas 0.005 corresponds to snow or mud flats (WMO, 2008). The SCA #1 and #2 landfill surface ought to lie between these endmember values, as the surface is constantly graded and is vegetation free. Inspection of eq. 1 shows that lower values of z_o produces much higher wind speeds near the ground surface. For most calculations that follow, I assume that z_o=0.1.

Table 1 indicates the range of possible dust fluxes during the Mar. 17, 2014 storm, using the empirical expressions in Lancaster (2009; and refs. therein) and mean hourly velocities at 10 m derived from HYSPLIT (Fig. 5). A conservative estimate of the area of the active surface of SCA #1 from aerial imagery is 4.9 ha (48,562 m^2), and the vertical flux of dust was normalized to this area to obtain a total dust flux $F_{v\text{-}tot}$.

As mentioned above, empirical expressions were used as natural analogues as analytical expressions for dust fluxes are available (e.g., Kok et al. 2012; Till and Grogan, 2008), but input parameters are usually unknown or difficult to estimate, making their use for the SCA landfill problematic. Before the front passed, total dust emission rates range may have been on the order of several mg/s to a few g/s, but may have been as much as 2-3 orders of magnitude higher after the front passed (Table 1).

Several considerations suggest that $F_{v\text{-}tot}$ could tend to toward the upper end of the range (Table 1). First, the material is largely glass, which unlike clay will have weak inter-particle electrostatic forces. Second, after emplacement the material is mechanically reworked into a flat, smooth surface devoid of vegetation, all of which enhance dust emissions. By contrast, the ash may have pozzolanic properties that act to suppress dust. However, the extent of such self-stabilization is unknown, especially where new material is constantly added to the landfill and reworked by a road grader. I have observed the landfill on occasions when dust suppression water has been applied. However, a road grader worked the landfill during the Mar. 17 windstorm with large dust releases (Fig. 4). I did not observe any dust suppression during the period of observation that day.

The full range u* values from 10 m HYSPLIT models are problematic. From eq. 1 and a fixed value of z_o, the ratio of calculated velocities at 3 cm to 10 m is constant. For z_o= 0.1, this ratio is 0.16. In other words, the velocity at the top of the saltation zone (one definition of u*) is 16% of the velocity at 10 m over a range of assumed input values (0.1 to 1 m/s) of u*. This introduces circularity in the definition and use of u*. It must be true, however, that for a fixed value of z_o, stronger winds at 10 m height must correspond to higher velocities at 0.03 m. However, as reported field values of u* seldom exceed 1 m/s (Kok et al., 2012 and refs. therein; Landcaster, 2009 and refs. therein), fluxes associated with u* >1 m/s in Table 1 should be viewed with caution. However, despite the difficulties in estimating dust fluxes in general, and lacking on-site measurements, it is clear that storm events produce large dust fluxes from SCA #1, in the range of grams per second or greater.

Table 1. Modeled total dust fluxes $F_{v\text{-}tot}$ (kg/s) from the SCA landfill based upon the regressions for Mali, Texas, Australia, and the Yukon for HYSPLIT modeled winds for Mar. 17. 2014. u was modeled as the velocity at 0.03 m height for a z_o of 0.01, where u* is 0.16 of the velocity at 10 m height. See Fig. 5 for wind paths.*

Time	Trace distance (km)	Mean velocity (m/s) @10 m height	u* (m/s) @ 3 cm height	Mali	Texas	Australia	Yukon
4-5 am	11.49	3.2	0.5088	1.45E+00	4.56E-02	2.35E-02	6.31E-03
6-7 am	13.72	3.8	0.6042	2.89E+00	9.06E-02	4.67E-02	1.26E-02
8-9 am	12.92	3.6	0.5724	2.33E+00	7.30E-02	3.76E-02	1.01E-02
10-11 am	31.91	8.9	1.4151	8.69E+01	2.73E+00	1.40E+00	3.78E-01
12-1 pm	45.35	12.6	2.0034	3.49E+02	1.10E+01	5.64E+00	1.52E+00
2-3 pm	55.29	15.4	2.4486	7.79E+02	2.44E+01	1.26E+01	3.39E+00
4-5 pm	54.72	15.2	2.4168	7.39E+02	2.32E+01	1.19E+01	3.21E+00
6-7 pm	48.62	13.5	2.1465	4.60E+02	1.44E+01	7.43E+00	2.00E+00
8-9 pm	40.06	11.1	1.7649	2.10E+02	6.60E+00	3.40E+00	9.14E-01

Background Emissions. In addition to storm events, a number of qualitative and quantitative considerations suggest that fugitive dust emissions are likely to occur at lower levels throughout the year. NOAA (2014a) and (WRCC, 2014) report values of mean wind speeds of 2.6 and 3.0 m/s at Price, UT, respectively, where the anemometer of this station is positioned at 10.1 m height. At a height of 10 m and z_o=0.02, the mean wind speed corresponds to 5.4 m/s, which compares favorably to the reported wind speed averages at the Price, UT weather station. This calculation is an important benchmark as it reproduces the median value of reported field measurements of u* (0.35 m/s) at the top of the saltation zone (0.03 m).

Reported field values of u* are log-normally distributed between 0.1 and 1.1 m/s. A logarithmic transformation of reported data (e.g., Fig. 2C of Lancaster, 2009) produces a well-defined normal distribution with a mean of -0.453±0.228, which is nearly identical to the median of -0.452, and corresponds to a u* of 0.352 m/s. Comparing this velocity against eq. 2.5 of Kok et al. (2012) corresponds to the velocity required to produce the saltation of 0.5 mm grains at the SCA #1 landfill.

The lower and more realistic value of z_o= 0.01 increases the wind velocity to ~1.0 m/s at the top of the saltation zone with ~6.0 m/s wind at 10 m for a ratio of 0.16. This ratio suggests that a mean wind speed of 2.0 m/s at the SCA landfill will produce median u* values of ~0.35 m/s at 0.03 m. In other words, mean 2.6 to 3.0 wind speeds at the SCA landfill, using Price, Utah as a surrogate, are greater than that required to produce the median observed u* and corresponding dust releases. Thus, the flat, barren surface of the active SCA #1 landfill is probably a nearly constant source of fugitive dust emissions into surrounding areas.

Using EXCEL, I generated 10^3 random numbers using -0.453±0.228 as a constraint and then transformed the random numbers back to a lognormal distribution of u*. The regressions of F_v for Mali, Australia, Yukon, and Texas were fit to the distribution of u*. The results of this modeling are presented in Table 2. Given the constraints employed, median dust fluxes from the SCA landfill are expected to be on the order of 1 to 350 g/s (Table 2), corresponding to a range of 30 to 11,000 metric tons per year.

Table 2. Modeled total dust fluxes $F_{v\text{-}tot}$ (g/s) from the 48,562 m^2 active area of the SCA landfill based upon the regressions for Mali, Texas, Australia, and the Yukon.

	Mali	**Texas**	**Australia**	**Yukon**
median	3.30E+02	1.03E+01	5.33E+00	1.43E+00
max	3.03E+05	9.51E+03	4.90E+03	1.32E+03
min	1.71E-01	5.37E-03	2.77E-03	7.44E-04

The reader should understand all of these calculations in the context of their purpose. Site specific conditions of SCA #1 are unknown and ever changing as material is added and I have attempted to estimate reasonable bounds of fugitive dust emission. However, the following conclusions are clear:

- Empirical evidence demonstrates that dust has been and is being blown into surrounding communities.
- The dust is caustic and the shards are sharp and must be considered a health hazard absent any effects of heavy metal content.
- Calculations indicate that fugitive dust releases may be large, both in response to storm events as well as background winds.
- SCA has clearly been a poor steward of their existing ash disposal facility.

Other Comments

- In section 5.0, SCA concludes that leachate will not significantly affect groundwater. SCA states: "*The different phases of the SCA #1 Ash Landfill have been in operation and/or closure during the past 20 years. Regular monitoring of ground water and surface water in the area confirms the results of the modeling which indicated no significant impacts to ground water were expected.*" This appears to be wrong given my prior analysis of apparent seepage from SCA #1.
- Introductory material discusses the economic value of SCA activities. This seems irrelevant (and self-serving) in assessing the suitability and safety of the facility. Such considerations do not mitigate against the failure to properly locate and operate landfills.
- SCA also claims in the introduction that operations occur in a manner that protects air quality, surface waters, groundwater, etc. Previous analysis by me indicates that leakage from SCA #1 is likely and the evaluation above demonstrates the releases of wind-blown ash. SCA's claim seems to be false at face value.
- Much is made concerning the re-vegetation of SCA #2 as sections are closed. When will they begin with SCA #1? Where there is vegetation on closed sections

it is sparse and rills are clearly eroding into the surface (Fig. 3). The present condition of SCA #1 does not indicate proper vegetation.

- There should be no waiver for an up gradient well. The inability to site up-gradient monitoring wells due to rough topography or other factors is a further indication of the unsuitability of the proposed location. The lack of such a well precludes the ability to assess changes in water quality and whether changes are due to natural variation or releases from the landfill. I reiterate that if the landfill were properly located on one of the nearby flat pediments, it would be possible to construct any number of wells up gradient, down gradient, or laterally. This would greatly enhance the ability of DEQ to monitor the facility on behalf of the citizens of Utah. There would be no ambiguity on the minimum depth to water beneath the facility.
- In section 3.6 claims are made based on "*existing site topography, subsurface evaluation, geophysical study (ReMi), site reconnaissance and other information from available geologic maps, cross sections were developed for use in the slope stability analyses*." Such data sources must be referenced if an independent evaluation is to be made.
- In section 3.9 under the subsection "Water" the report confuses porosity with permeability.
- Section 6.1 claims "*This site is not located in a 100 year flood plain and only ephemeral surface water features exist in the near vicinity*." The concept of a 100-year flood plain is used by FEMA and others for insurance and planning purposes. The lack of such a designation is meaningless to site suitability and safety. The "ephemeral" 42 m deep drainage beneath the site was clearly created by vigorous surface flows.
- Sections 6.5, 8.0 and 9.0 discuss the need to excavate ash and sediment and emplace them in an active cell or continue to monitor wells. This admission raises several questions: Who is going to keep this landfill intact after the 10-year post-closure period when water comes gushing down the "ephemeral" drainage that has a 21% grade? Who will repair erosion gullies and slumps? Who is going to clean up all of the wind-blown ash? Who will clean up the aquifer if this landfill, like SCA #1, leaks? None of these issues are addressed in the construction permit application or draft permit.
- I have reviewed to Utah Administrative Code R317-1 as referenced in the Public Notice. This is the regulation identified by UDWQ that governs the issuance of a construction permit. This regulations does not contain any specific criteria for issuance of a construction permit for a coal ash landfill. UDWQ should not issue construction permits until a comprehensive set of appropriate criteria are promulgated, following public comment, for the issuance of such construction permits.
- I am aware that SCA has constructed MW-8 at a location intended to monitor the down gradient effects of SCA #2. However, I reiterate prior comments noting that MW-8 is shown on many other documents (in the record) as near the north end of SCA #1. I have not yet seen an acknowledgment of this discrepancy or correction of the record by SCA or DEQ. I wish to point out (yet again) that the failure to unambiguously locate monitoring wells impedes the ability of stakeholders to assess the activities of SCA as well as the ability of DEQ to properly regulate their activities.

- I cannot accept the claim in section 3.5, and elsewhere, that groundwater will remain >10 feet below the ground surface as required for unlined landfills. The water table below ephemeral drainages rises and falls seasonally, as well as in response to long-term precipitation patterns. In this context the failure to find water in B-2 does not mean much. I do not believe they have enough information to support their claim.

  Furthermore, it is well understood that the potentiometric surfaces of unconfined aquifer systems mimic topography. Filling the canyon with ash will isolate the alluvial aquifer from evapotranspirative losses and the water table will respond by rising beneath the landfill. At the same time, mountain front recharge and losing stream losses in the immediately adjacent Book Cliffs will continue to supply water to the alluvial aquifer beneath the landfill. I cannot predict the height to which the water table will rise beneath SCA #2, but neither can SCA. SCA cannot claim that the water table will be >10 ft. below the base of the landfill during operations.

REERENCES

Draxler, R.R. and Rolph, G.D., 2013. HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://www.arl.noaa.gov/HYSPLIT.php). NOAA Air Resources Laboratory, College Park, MD.

Kok, J.F., Parteli, E.J.R., Michaels, T.I., and Karam, D.B., 2012, The physics of wind-blown sand and dust: Reports on Progress in Physics, v. 75, 119 pp.

Lancaster, N. (2009). In Young R., Norby L. (Eds.), *Aeolian features and processes* The Geological Society of America. doi:http://dx.doi.org/10.1130/2009.monitoring(01

NCDC, (National climate Data Center) 2014, https://gis.ncdc.noaa.gov/map/viewer/#app=cdo, accessed April, 2014.

Nickling, W. G., McTainsh, G. H., & Leys, J. F. (1999). Dust emissions from the channel country of western queensland, australia. *Zeitschrift Fuer Geomorphologie.Supplementband, 116*, 1-17.

NOAA (National Oceanographic and Atmospheric Administration), 2014, http://ready.arl.noaa.gov/HYSPLIT.php, accessed Mar. 2014.

NOAA (National Oceanographic and Atmospheric Administration), 2014a, http://www.ncdc.noaa.gov/cdo-web/datasets, accessed Mar. 2014.

NRCS (National Resource Conservation Service) 2014, http://www.wcc.nrcs.usda.gov/nwcc/view, Snotel site 1236, access March 11, 2014.

Rolph, G.D., 2013. Real-time Environmental Applications and Display sYstem (READY) Website (http://www.ready.noaa.gov). NOAA Air Resources Laboratory, College Park, MD.

Till, J.E. and Groban, H.A., 2008, Radiological Risk Assessment and Environmental Analysis. Oxford University Press, Oxford, New York, 728 p.

WMO 2008: Guide to meteorological instruments and methods of observation. WMO-No. 8, 7th Ed, 681pp.

WRCC (Western Regional Climate Center), 2014, http://www.wrcc.dri.edu/, accessed March, 2014.