Appendix E2

Fugitive Dust and Effects from Changing Water Table at Bristol and Cadiz Playas

ESA

HydroBio
Advanced Remote Sensing

Fugitive Dust and Effects from Changing Water Table at Bristol and Cadiz Playas, San Bernardino County, California

August 30, 2011

Executive Summary

This investigation characterizes soil chemistry and structure on the Bristol Playa and the immediate margins to evaluate the relationship between groundwater and surface soils. Cadiz Playa is interpreted in relation to Bristol Playa because it is highly similar. The study seeks to assess whether the playa surfaces could become a significant source of dust like certain other playas in the Mojave Desert, such as the Owens and Franklin Playas. The study concludes that the soil and water chemistry of both Cadiz and Bristol Playas have very low quantities of the sodium salts of carbonate, bicarbonate and sulfate that are known to cause severe fugitive dust storms from Owens and Franklin Playas.

Bristol Playa does produce fugitive dust from erosion by sand grains driven by high wind across the playa surface. In this process, the quantity of sand available on the playa margin is responsible for the magnitude of the dust release. The available sand appears to have diminished over time and this is hypothesized to be due to the action of a mix of weedy species that have grown increasingly dominant over the past 50 years. Hence, the severity of Bristol Playa fugitive dust is hypothesized to be diminishing with time. Changes in groundwater level will likely have no impact upon this relationship.

Cadiz Playa appears to be the sink for the sand blown from the region of the Bristol Playa directly upwind to the northwest. This sand tends to be stabilized by the growth of Russian thistle (tumbleweed). Cadiz has the same chemistry but due to the copious sand dunes around the shore, particularly in the north to northeast regions, large amounts of sand are available to erode the playa surface. Dust storms from Cadiz Playa will likely not diminish in the future regardless of the depth to water beneath the playa.

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1. Introduction and Purpose

Desiccation of arid land saline water bodies has led to severe air quality problems and threats to human health and welfare at sites like the Aral Sea (Micklin, 1988) in Central Asia and the Owens Lake, in eastern California (Saint-Amand et al. 1986). The purpose of this investigation is to evaluate whether changes in water table levels below Bristol and Cadiz Playas could result in an increase in the generation of dust above existing conditions.

The analyses presented here were performed after field investigations on November 9, 2010, and on August 23, 2011. During both trips observations of both playa surfaces were made, vegetation and sand deposits were identified, soil samples were obtained and observations were made of features that indicated the nature of windborne fugitive dust releases from the Playas and the surrounding area. An air tour over Bristol and Cadiz Playas and surrounding region was made prior to the investigation on the ground for observations of the physiography, indications of hydrology and wind erosion effects and to obtain photographs for documentation and interpretation. An additional field trip was accomplished on August 23, 2011 for the purpose of gathering samples from the Cadiz Playa for confirmation that the playa chemistry is equivalent to Bristol Playa.

The Cadiz Groundwater Conservation, Recovery, and Storage Project (Project) proposes the adaptive management of groundwater in the Cadiz Valley as part of a groundwater project for southern California public water supply (CH2M Hill). The major focus of this investigation was to evaluate mechanisms for dust release and the role played by hydrology within the Bristol Playa region that lies adjacent and downgradient of Fenner Gap, the location contemplated for Project production wells (CH2MHill, 2010). This research agenda included evaluating the hydrology of the playa and its relationship to air quality. A minor focus is the evaluation of these same aspects for the Cadiz Playa that is located southeast of Bristol playa, and separated from it by a low alluvial divide that rises 52 feet above the lowest part of Bristol Playa and 104 feet above the Cadiz Playa (Bassett et al. 1959). Although the literature focuses on Bristol Playa the same processes are occurring on the Cadiz Playa. Likewise, this analysis focuses primarily on Bristol Playa also because of its proximity to the Fenner Gap, Cadiz Playa is then compared to Bristol Playa.

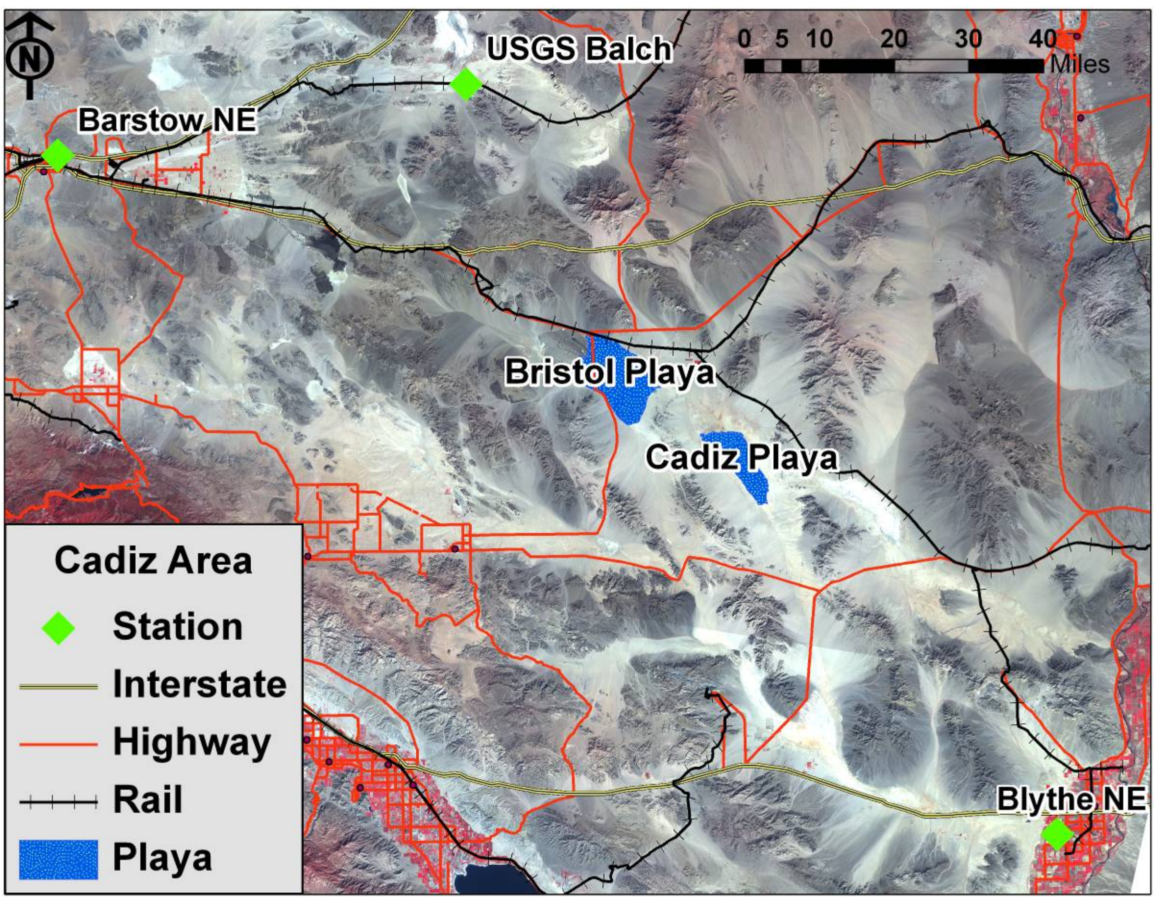
2. Physical Setting

The Bristol Playa lies in Cadiz Valley, California (Figure 1). The biome here is Mojave Desert, characterized by low scrubby vegetation cover and intense aridity. Vegetation on and around the Playa is dominated by two native shrub species, creosote bush and two saltbush species, four wing saltbush and cattle saltbush. The saltbushes occupy salinized zones next to the Playa and intergrade with creosote bush that tends to occupy non salt-affected soils farther away from the Playa margin. Appendix A defines terms used in this report. Note that Lake and Playa are used here interchangeably ("Lake" on some figures), however, both Bristol and Cadiz are more properly termed playas because there is no geologic record that they were ever inundated (Rosen, 1991;Handford, 1982).

The long-term annual average precipitation at Mitchell Caverns, located at an altitude of 4,350 feet in the Providence Mountains approximately 40 miles north of Bristol Playa, is 10.47 inches measured from 1948 to 2004). Amboy, located along the north shore of Bristol Playa, is represented by two stations, Amboy – Saltus Number 1, with an elevation of 624 feet and a long-term annual average precipitation of 3.28 inches (from 1967 through 1988) and Amboy – Saltus Number 2, with an elevation of 595 feet and long-term annual average precipitation of 2.71 inches (1972 through 1992). Over millennia, Bristol and Cadiz Playas have acquired economically viable deposits of evaporite minerals that are currently being mined (Gale, 1915; Handford, 1982).

Rainfall in the surrounding area increases proportionately to elevation (Figure 2; derived by annualizing the data presented by CH2MHill [2010]). Consequentially, large rainstorms may generate runoff that flows down the alluvial fans to deliver water to the Playa and surrounding area. Distributaries of these drainages are evident on the Playa with sparse vegetation of saltbush growing out for a kilometer or more onto the Bristol Playa away from the ecotonal boundary of shrubs around the lake margin.

Figure 1. Location Map showing the two important playas in the Cadiz Valley and locations of three weather stations used in selection of satellite data for analysis of blowing dust and salt on the playa surface.



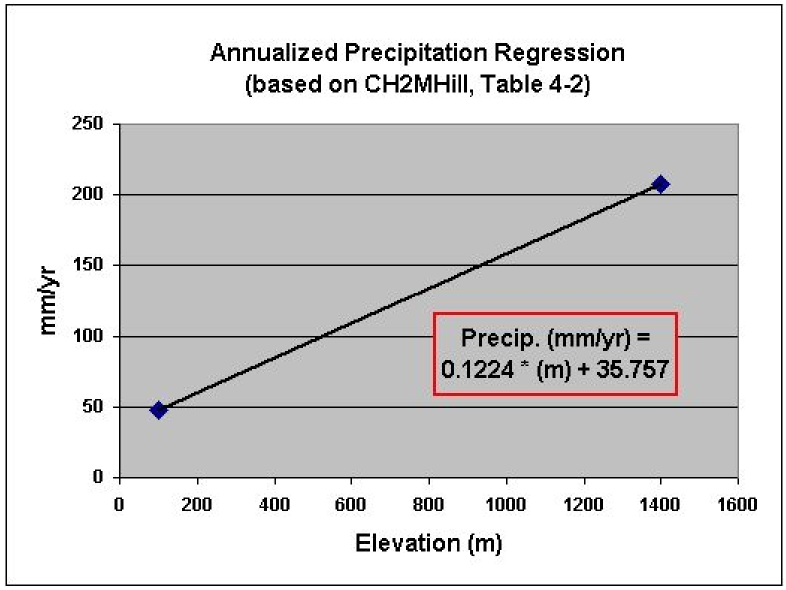


Figure 2. Annualized curve of precipitation with elevation based upon data in CH2MHill (2010) Table 4-2.

The hydrology of Bristol and Cadiz Playas is directly related to the watershed catchment and the rainfall that is received. Figure 3 provides a map of average annual rainfall within the watershed that feeds both playas. The majority of the catchment, especially the highest elevations, is located above the Fenner Wash to the north. The fans and drainages from Fenner Wash provide occasional short-term surface flows that deliver water to each of the Playas.

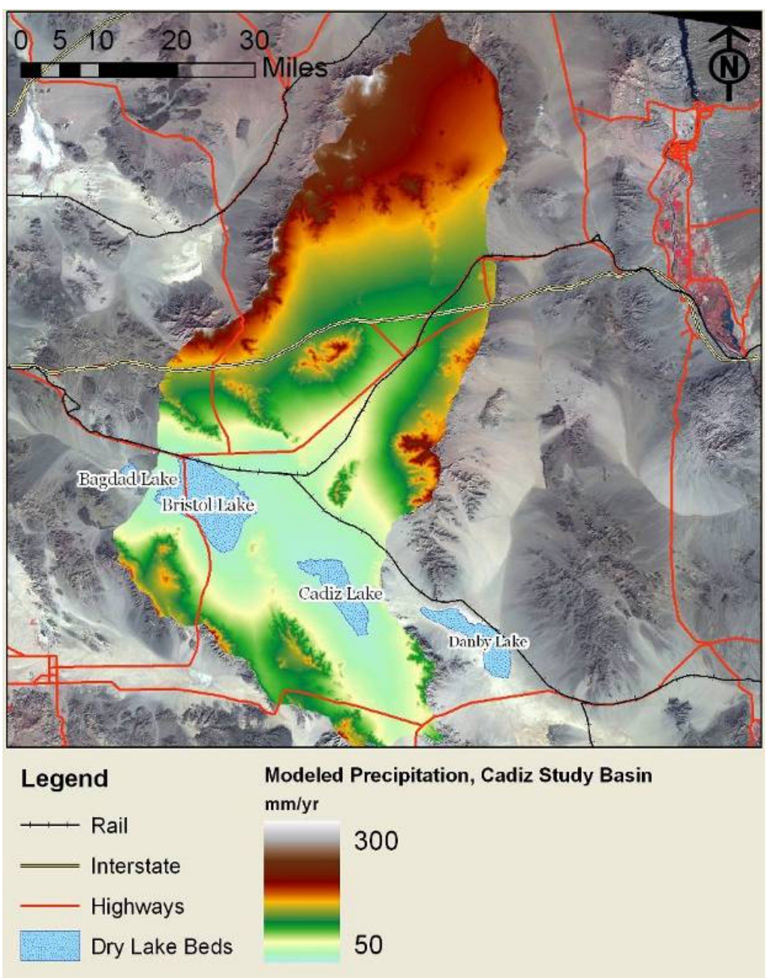


Figure 3. A map of annual average precipitation calculated from digital elevation model data and the relationship shown in Figure 2.

The northwest to southeast trending valley floor is roughly aligned with the direction of the highest winds as determined from the USGS Balch weather station located approximately 40 to 50 miles northwest of the Bristol Playa (Figure 1). Figure 4 was generated for winds of nine meters per second (about 20 miles per hour) because winds of this magnitude are expected to produce copious fugitive dust from dust sources. It shows that winds from the southeast through southwest are only a small fraction of the winds from the west. Note, however, that the USGS Balch station is located in a windgap that is generally aligned west-to-east that induces a forcing influence on the direction of westerly winds. Likewise, the northwest-southeast topographic trend of the Cadiz Valley likely influences a forcing upon the direction of winds of sufficient velocity to move particles. This is aptly illustrated by visible traces of cinder movement from the basalt flow northwest of the Bristol Playa (Figure 5).

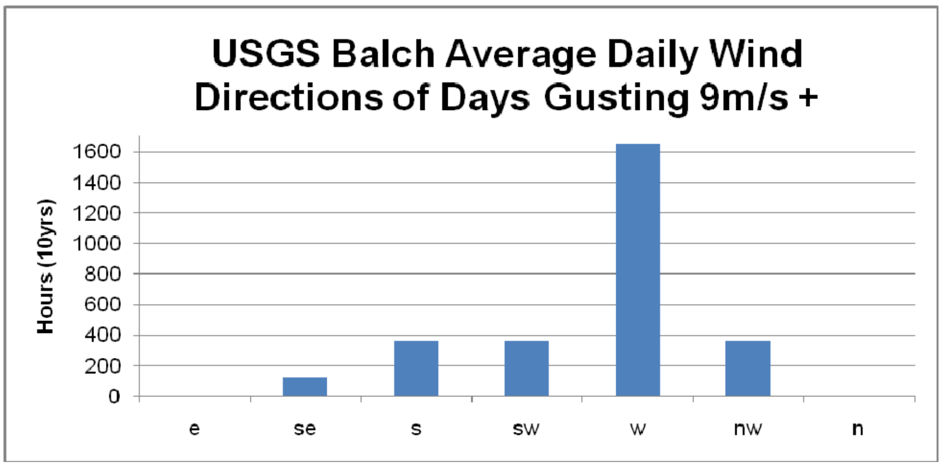


Figure 4. Wind directions in hours totaled for the 10-year record for the USGS Balch weather stations. Each directional pie slice is 45 degrees; e.g., west is from 247.5° to 292.5°.

Figure 5. Indication of prevailing direction of high winds shown by wind-drift cinders from Amboy Cinder Cone and surrounding features. (Image courtesy of Google Earth)

That significant and potentially disruptive sand movement has occurred historically in the region adjacent to the Bristol Playa is illustrated by the athel trees that were planted for dune control along the Atchison-Topeka and Santa Fe Railroad grade that passes from east to west (Figure 1). Athel trees were planted where problems with sand were encountered by the railroads through the Mojave Desert that were emplaced specifically for sand control (Trainweb, undated). The overview from the air and while driving along two miles of the railroad track to access the Bristol Playa indicated that drifting sand is not a concern in recent decades since no recent deposits of sand were noted in this area. Hence, the athel trees appear to be superfluous today, indicating that conditions may have changed from the time when they were planted.

3. Mojave Desert Playas Known to Release Significant Dust

Owens Lake is a well understood source of windborne fugitive dust—formerly identified as the largest single source of dust in the United States (Great Basin Unified Air Pollution Control District [GBUAPCD, undated]). The air quality problems at Owens Lake are known to result from salt chemistry interaction with the clay-to-sand lakebed substrate, thus implicating salts as the driving factor for the fugitive dust problem.

Owens Lake has been the terminus for the Owens River during the past several thousand years with evaporation concentrating the salts received from regional runoff (Gale 1915, Jayco and Bacon 2008). The dominant cation is sodium and the dominant anions, listed in order of solubility are carbonate-bicarbonate, sulfate and chloride, with about 10% of other elements (Saint-Amand et al. 1987).

Owens Lake salt chemistry and efflorescence have been identified as the causal factor for extreme levels of windborne dust through a temperature-controlled process that occurs during the winter (Saint-Amand et al. 1986, 1987). Below a temperature of 65°F, thenardite, an anhydrous form of Na_2SO_4 hydrates to form mirabilite.

The addition of ten molecules of water causes mirabilite to occupy about 4.1 times the volume of thenardite, fracturing soil crusts and separating particles. During warm sunny winter days when temperatures often exceed 65°F, the mirabilite loses the water from its crystal structure to form amorphous thenadardite that is light, fluffy and prone to wind erosion (Saint-Amand 1987). At 50°F, the same process converts the decahydrate carbonate salts thermonatrite that occupy 4.8 times the volume to natron when it dehydrates. This disrupts the surface crust in the same manner. Appendix A provides the chemical equilibria for these reactions and identifies the ions that make up these salts.

The loss of water molecules from natron due to evaporation on clear warm winter days at >50°F creates fluffy, easily-lofted surface salts as amorphous trona. Together with the affects of amorphous thenardite, the damaged crust enables a wind of only 15 mph (and possibly less) to ablate carbonate- and sulfate-rich dust from the lakebed surface (Saint-Amand 1987). This temperature controlled hydration/desiccation of Owens Lake salts is the key aspect for creating the single largest source of respirable dust in the United States (GBUAPCD, 2008). High winds in combination with temperature-induced salt metamorphosis have released an estimated 80,000 metric tons of particles in single storms from the untreated lakebed (Gill and Gillette, 1991). The air quality problems at Owens Lake have prompted large-scale, highly expensive efforts to control the dust releases (GBUAPCD, undated).

Owens Lake represents an interesting case in air quality that is very different from other playas in the Mojave Desert owing to the fact that desiccation was caused by diversion of its surface water supply rather than climate influence, and so represents only a one hundred year period of desiccation. This compares to the likely continuous desiccation of the Bristol Playa, hypothesized to have been dry since its inception thousands of years ago (Handford, 1982; Rosen, 1991).

Studies of playas in the Mojave Desert indicate a strong relationship between saline hydrology, capillary transport and salt chemistry. Reynolds et al. (2007) found that playa surfaces are dynamic with depth to water, rainfall and rates of evaporation—these factors influence dust release along with salt chemistry. Dry playas with deep groundwater give rise to little or no dust if undisturbed.

Franklin, Soda, and West Playas have surface sediments that give rise to significant dust. Reynolds et al. (2007) focused mainly upon Franklin Playa that has halite, trona, thenardite, and burkeite surface evaporites deposited from groundwater capillarity and evaporation. These salts are the same species as found on the Owens Lake Playa and are formed from carbonate, bicarbonate and sulfate that give rise to windborne dust. In these systems the release of windborne dust was primarily related to the formation of fluffy efflorescence, likely the same effect of temperature controlled salt crystal metamorphosis found by Saint-Amand et al. (1986) at Owens Lake. Salts occur in very high concentrations in the Owens Lakebed surface up to 70% by weight, dominated by carbonate, bicarbonate, and sulfate ions (GBUAPCD, 2010).

Halite (sodium chloride, table salt) is not implicated in the literature as fostering surface release of windborne dust and appears to be protective of the surface since it forms hardened crystals. Groeneveld et al. (2010) found that ultra-thin crusts of halite seal playa surfaces to render them resistant to desiccation. Where this occurs, the underlying playa substrate tends to remain moist. In an active capillary environment dominated by salt species, this condition may be transitory. Breit et al. (2009) found that salts accumulated through capillary rise in the near surface (0 to 20 centimeters) on the Franklin Playa were depleted in chloride and enriched in carbonate in relation to deeper positions. Hence, even if chloride is present with sodium carbonate and sulfate, these other salt species may dominate the process for creation of loose fluffy surfaces to induce windborne dust.

Because of calcium chloride's lack of hydration (though this salt has hygroscopic properties that may pull water from air close to water vapor saturation), this salt has the same properties for tacking and sealing loose surfaces as sodium chloride. These properties were confirmed in the laboratory using diluted solutions of saturated calcium chloride (obtained from the Tetra Chemicals mine on the Bristol Playa) on loose clay and silt surfaces as discussed below.

4. Field Data from Bristol Playa and Cadiz Playas.

The Bristol Playa was investigated on the ground on November 9, 2010, and the Cadiz Playa was visited on August 23, 2011as described in Appendix B. Aerial overflight was also conducted in the morning before exploration on the ground. Two samples from Bristol Playa were collected and analyzed for dominant salt ion content in preparation for this report. Samples were also collected from the Cadiz Playa to confirm that the salt chemistry is the same as on the Bristol Playa. These samples are being processed at the time of this report and a confirmation letter for their chemistry will be attached.

Conclusions derived from the field inspections are as follows:

(1) The release of dust from both Bristol and Cadiz Playas and margins is the result of the physical process of windblown saltation of sand particles that debride the surface.

(2) Sand grains are rare on the bare Playas, but may be blown across in high winds. There are aeolian deposits of medium sand that are trapped in near shore features of both Bristol and Cadiz Playas. Small patches of the Bristol Playa showed obvious signs of recent wind erosion activity from saltating sand grains (Point 8, Appendix B).

(3) The majority of the wind erosion is taking place within the shrub-occupied coppice mounds around the outer margin of the Bristol Playa. Erosion of these features provides the sand to debride the surface. The margins of the Bristol Playa appear to be deflating, overall.

(4) The Bristol lakeshore can be divided into saltation and accumulation zones. The source zones provide the eroded particles that are carried in high winds. Much of this material is deposited into an accumulation zone within the gentle alluvial divide between Bristol Playa and Cadiz Playa to the southeast.

(5) Judging by the easily lofted particles, the accumulation zone southeast of the Bristol Playa can be a significant source of blowing dust. Weak crusting following rain may offer temporary protection of the surface: however, high winds with saltating sand grains can destroy this crust and render the surface highly emissive.

(6) No evidence was found for dust releases as affected by groundwater capillarity such as at Owens and Franklin Playas. Such patches are indicators of sodium sulfate- and carbonate-dominated groundwater chemistry. This chemistry is lacking on both the Cadiz and Bristol Playas, as discussed below.

(7) While the Bristol shore appears to have been deflated, much of this sand appears to be trapped within dune fields at the north to northeast margin of the Cadiz Playa. This sand is a reservoir that may impact the Cadiz Playa by releasing sand.

Observations of Satellite imagery in Section 7 support the conclusions in 4, through 7, above. Figure 6 shows a rough interpretation of “source” and “accumulation” areas noted during the field work and during interpretation of Satellite data in Section 7.

5. The Bristol Playa and its Chemistry

Both Bristol and Cadiz Playas have histories of solute mining activities. At present, two companies are collecting and marketing both solid sodium chloride and liquid calcium chloride that drains in a natural mix with small amounts of other minor ionic constituents. The calcium chloride is concentrated from native brine that drains from a series of trenches that generally flow by gravity. Evaporative concentration causes sodium chloride to precipitate, leaving a nearly pure solution of calcium chloride (bulk density of around 1.35). Gale (1951) reported the chemical constituents in brine that was collected from a 50 foot deep test hole in the Bristol Playa (Table 1) showing that chloride was the dominant anion and calcium and sodium were the dominant cations with extremely low concentrations of bicarbonate and sulfate.

Table 1. Ionic constituents in Bristol Playa brine reported by Gale (1951). The ionic species sum to 100 percent.

Cations	Ca^{++}	calcium	25.30%
	Na^{+}	sodium	23.60%
	Mg^{++}	magnesium	1.10%
Anions	Cl^{-}	chloride	49.95%
	HCO_3^{-}	bicarbonate	0.05%
	SO_4^{--}	sulfate	0.04%

Rosen (1991) reported similar results to Table 1 stating that chemical analyses of shallow groundwater from beneath Bristol Playa show sodium, calcium, and chloride dominate the ions in solution while these ions plus small amounts of magnesium and potassium increase toward the Playa center.

In conclusion, the Bristol lacks the chemistry that has been implicated in the release of dust from other playas in the Mojave Desert. Instead, the presence of sodium and calcium chloride likely induces surface crusting that is resistant to abrasion and will aid in reducing windborne dust.

The two surface soil samples (top ¾ inch) from the Bristol Playa were analyzed by IAS Laboratories in Phoenix, Arizona (Table 2). These results show that the samples are high in sodium and chloride with sulfate in small quantities that increased from the Playa edge.

Table 2. Test results in weight percent from two near surface soil samples taken from Bristol Playa. The other soil constituents (making 100%) were silica minerals.

	Ca	Na	Cl	SO_4	CO_3	HCO_3
Point 4	0.55	9.25	8.1	0.96	ND	0.0092
Point 5	0.42	2.95	1.91	1.15	ND	0.012

There was a significant difference in the sodium chloride between the Sample Points 4 and 5. At Sample Point 5, weak patterns of drainage pans were present that may indicate that the sodium chloride has been removed by runon and runoff processes. Although sodium sulfate has been implicated in dust releases for other playas, this ion is in restricted supply within the two samples, especially from Point 4, relative to chloride. At Point 5, however, the sulfate is in relatively high concentration relative to chloride but it must be remembered that where sodium sulfate is implicated in dusty conditions, it is in very high concentrations (>10%, of the weight of the sample). This is the case for the Owens Lake system where salts of sodium carbonate, bicarbonate and sulfate may exceed 50% (GUBAPCD, 2010). In both samples from Points 4 and 5, much of the sulfate is likely loosely bound with calcium to create gypsum or anhydrite (up to 36 to 57% of the sample fraction if in ionic balance with Ca).

The samples from Bristol Playa lack the ionic chemistry that has been found to be conducive to fugitive dust released from playas in the Mojave Desert—heavy dominance by sulfate, carbonate and bicarbonate ions. The presence of ions that demonstrably create resistant crusts, sodium chloride, supports that the dust that is released from the Bristol Playa and its margins is not directly influenced by groundwater hydrology.

Confirmation of the chemistry of the Cadiz Playa, hypothesized to be equivalent to Bristol Playa, i.e., dominated by Ca, Na and Cl is pending at the time of this report and are being analyzed at IAS Laboratories as were the Bristol Playa samples.

6. The Bristol Playa and its Hydrology and Sedimentology

Handford (1982) described the sedimentology and genesis of the evaporite of Bristol Playa. The system contains a bull's eye pattern of halite in the center of Playa surrounded by interbedded sediments, gypsum, anhydrite and halite. Sediments have been deposited by sheetflow and suspension settling from ponded floodwater. Both Rosen (1991) and Handford (1982) noted that Bristol Playa probably was generated in an environment that remained dry during the majority of its many thousand year genesis.

The intermittent supply of sediment that is delivered to the Bristol Playa with storm runoff is an important factor for air quality, because the particles provide the transfer of erosive energy when propelled by the wind. The balance of the sediments on the Playa is a central control for windborne dust through a process in which the particles are (1) being deposited by runon from the adjacent alluival fans, (2) being reworked by wind, or (3) being exported from the Bristol Playa to the southeast toward the margin of Cadiz Playa. These processes are described in the next few sections.

7. Satellite Data: Salt Efflorescence and Dust Release

Images for observation of either the effect of recent rain or dust release from Bristol Playa were selected from the Landsat TM and Aster archives maintained by the USGS.

This analysis was prompted because no records of dust release are known to have been kept for the Cadiz-Bristol Playa area, nor of the surface condition of the Playa itself. The concept was to (1) be able to observe dust storms in progress to determine the dust source areas, and (2) determine whether surface salt efflorescence is present that has been implicated on strongly groundwater-coupled playas such as Owens (Saint-Amand et al., 1987) and Franklin Playas (Reynolds et al., 2007). Such salt efflorescence can be expected to follow rainy weather during the cooler season when the process of capillary supply is steady under a somewhat reduced evaporative driving force in cooler weather with higher relative humidity.

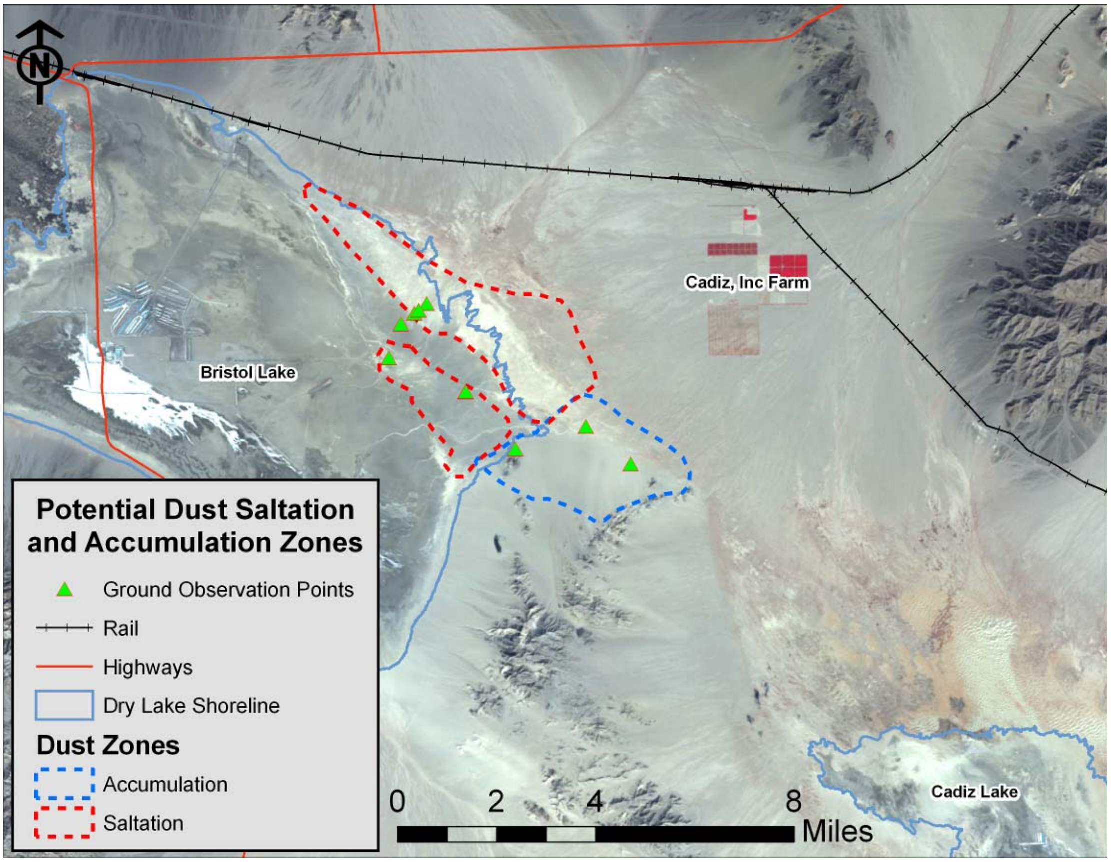
The period of this investigation was 2000 to present because the weather data to evaluate regional wind movement and rain were available, particularly from the USGS Balch station that was brought online in 2000. Nineteen satellite images were evaluated with eight chosen to evaluate possible dust storms during the satellite overpass hour when the measured wind at the USGS Balch Station were 12 miles per hour or greater. Thirteen images were selected for overpasses that fell within about two weeks of rainy periods that deposited at least one inch of rain as an average of the surrounding stations. This was the entire suite of cloud-free images corresponding to these conditions during the period of USGS Balch Station operation, except for one image from 1997 that occurred after a large rainstorm occurred in Barstow. One of the selected images served a dual purpose for both dust and rain effects. Wind and rain were averaged from records for the three weather stations whose locations are shown on Figure 1 to provide a regional perspective. The results from the evaluation of satellite data are presented in Appendix C.

Of the eight images analyzed for blowing dust, three contained visible traces of actual dust releases, an incidence of 38%. One hypothesis for why high magnitude wind did not cause higher incidence of blowing dust is that the winds near Bristol Playa were low. However, sustained high winds in the Mojave Desert are driven by frontal passage that affects the entire region as indicated by the averages of winds and rain from the three weather stations. Thus, even if high winds are present, special circumstances may be required to develop severe dust storms, likely including the breakdown of the weak crusting in re-deposited material that was evident during field work (Appendix B).

In two of the three dust images contained in Appendix C, the high levels of dust release were from the zone found to have deposited accumulations of fine textured soils. These deposits are shown on Figure 6 that was mapped from observations in the field and on satellite data. The boundaries on Figure 6 are only approximate. The saltation zone that extends into the Bristol Playa likely generates much less fugitive dust than the larger area mapped to the north, because the source of supply for saltating sand grains is from the opposite (northwestern) margin of the lake or from sand that was carried onto the Playa by wadis during storms that generated significant runon.

The Cadiz Playa showed extreme levels of dust blowing on one image, 11-25-2002 (Potential Dust Scene 2, Appendix C), with the dust occurring on the north half of the playa in the region where dunes were located upwind. This contrasts with the southern half of the playa which remained clear, underscoring the importance of sand erosion of the lakebed surface.

Figure 6. An interpretation of areas of saltation source and deposition. Boundaries are approximate. The dune field north of Cadiz Playa is also an accumulation but mostly of sand within dunes. The reddish color is from the growth of Russian thistle that tends to stabilize the sand within the dune field.



8. Sand Balance for the Bristol Playa

A number of observations lead to two hypotheses discussed below concerning the sand balance in the Cadiz Valley around Bristol Playa. These observations are:

- Coppice mound shapes around the northern Playa margin trend toward tall, narrow and oriented with their axes northwest to southeast, parallel to the dominant high magnitude wind direction. This is an indicator that the coppice mound shapes are ventifacts, eroded around there bases by saltating sand.
- Coppice mounds may not be undergoing replacement. Significant numbers of coppice mounds appear to be capped by dead shrubs and hence will not remain since coppice mounding requires the interaction of sand movement and new shrub growth. During field work, several young saltbush were observed; however, these were not accumulating their own sand reserves and stood on tap roots raised nearly a foot above the exposed Playa surface—thus suggesting that the surface on which they germinated, likely sand, was now gone. Although shrubs die of old age, about 20 to 40 years for a saltbush, the continued presence of shrubs is dependent upon recruitment. In this playa margin habitat, recruitment and

replacement of the older shrubs, in turn, depends upon collection of sand to form a coppice mound.

- Much of the Playa surface and its margins appear to be deflating. Erosional evidence (Point 8, Appendix B) was found that supported this interpretation.
- Handford (1982) described sediments derived from runon as being reworked by the wind to form barcan dunes around the Bristol Playa margins. These dunes are lacking today.
- In addition to dunes around the margin of the Bristol Playa, Handford (1982) also included a photograph of a barcan dune on the Bristol Playa. No such dunes exist today on the playa.
- The Achison, Topeka and Santa Fe Railroad planted athel trees along their railroad grade and siding adjacent to Bristol Playa. Such planting protects the tracks from dune formation and blowing sand (Trainweb, undated). In another locale prone to significant drifting sand, the Union Pacific railroad grade that passes the Kelso Dunes was also planted with athel trees. Today, there is no evidence of sand movement in the form of accumulation in the athel trees in Cadiz Valley.

The sand balance has apparently changed in the Cadiz Valley, especially around the Bristol Playa. This may derive from growth of weedy species that became naturalized during the past century. Two hypotheses are discussed as follows:

<u>Hypothesis 1: Reduction in sand supply</u>.

The Mojave Desert receives pulses of rain that are likely tied to the El Nino Southern Oscillation (ENSO). The wet pulses lasting a year to multiple years within this cycle enable runoff to potentially supply the new wave of sediments, including sand grains that play a dominant role in saltation and fugitive dust releases erosion. The precipitation analysis by CH2M Hill noted a trend of relatively dry conditions prior to the mid-1970s followed by relatively wet conditions since the mid-1970s (CH2MHill, 2010). The wet periods also foster the growth of introduced weeds, all germinating in the fall or early winter and growing through the winter including Mediterranean grass, Sahara mustard, filaree, red chess, and cheatgrass (Brooks, 2009). The weeds may form relatively intense ground cover, well above original cover of native species: this can hold sediments in place rather than allowing surface creep or entrainment. Thus, the supply of sand is now restricted due to the weedy species in the overlying catchment.

<u>Hypothesis 2: Net export of sand due to lack of “backwash”</u>.

To a certain extent, saltating sand was a resource that sloshed back and forth with winds, predominantly from the northwest but also from southeast through south that can push the sand back to the northwest. Now, however, another weedy species, Russian thistle (also known as tumbleweed) has colonized the dunes in the region surrounding Cadiz Playa. Thus, any sand that is moved toward the Cadiz Playa with the prevailing direction of the high winds (to the southeast), is trapped by the Russian thistle. Russian thistle provides active wind trapping capability both when it is alive and also after it has died and tumbled, generally filling dune interspaces (Figures 7 and 8).

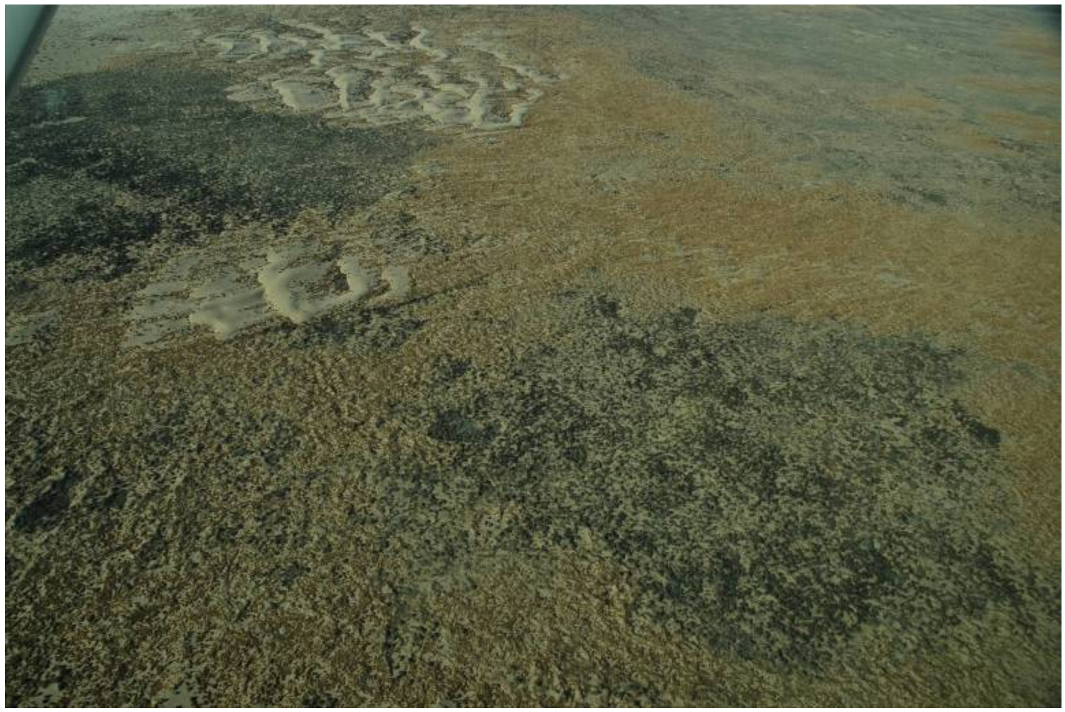


Figure 7. Photo 51 from the aerial overflight taken of a dune field near the NW corner of the Cadiz Playa 1500' above ground. The orange color is Russian thistle that grew during 2010. The dark color is patches of older weathered dead Russian thistle crowns that grew in situ or were tumbled in with the wind.

Figure 8. Photo 57 of the aerial overflight taken of the region to the northeast of Cadiz Playa. The orange coloration is the Russian thistle crop from 2010.

9. The Cadiz Playa Hydrology, Sedimentology, Sand and Dust

Formed in the same environment as Bristol Playa, Cadiz Playa has analogous hydrology and sedimentology, however, the surrounding catchments are much smaller and at lower elevation. Inflow of surface water is therefore potentially much less than on Bristol Playa. Surface flows delivered down Fenner wash apparently do not make it to the Cadiz Playa but are stopped within the sand dunes, ponding and promoting heavy Russian thistle growth leaving visible traces on the satellite imagery in Appendix C.

The Cadiz Playa was visited on the ground on August 23, 2011 to collect soil samples to confirm that the chemistry is equivalent to Bristol (dominated by Ca, Na, and Cl). The results from these samples are pending at the time of this report but are not expected to show that the Cadiz chemistry is dissimilar from Bristol. As can be clearly seen in Figure 8 the vegetation around the margin is not coupled with groundwater because the margin shows vegetation cover that is about the same as the regions upslope and away from the playa margin. By contrast, groundwater coupled vegetation is more verdant and lush compared to the surrounding desert vegetation—a condition lacking around the entire shore of the Cadiz Playa.

The Cadiz Playa region has become a sink for sand that has moved with prevailing high winds from the Bristol Playa region. For that reason, there is plenty of sand available to debride the surface during high winds. The majority of this sand is located in the north through northeast portions of the playa and theses zones apparently give rise to significant dust that erodes the surface of the playa (as seen in the 11-25-2002 (Potential Dust Scene 2, Appendix C).

10. Conclusions

- The chemistry of the Bristol Playa is low in carbonate, bicarbonate and sulfate ions that are implicated in other playas that produce major dust storms (such as Owens and Franklin Playas).
- Instead, this playa contains chemistry that has been noted to induce surface stability (Ca, Na and Cl). Cadiz Playa appears to have the same chemistry.
- Wind erosion from the Bristol Playa and immediate margins is driven by the supply of sand-sized particles that can saltate and debride the surface.
- Wetting by rainfall heals disturbances of the crust if erosion by sand grains has occurred.
- The cause of windborne dust from Bristol Playa is mechanical abrasion from saltating sand grains. This appears to be the case for Cadiz Playa as well.
- The Bristol Playa system has likely experienced a decrease in blowing dust during recent decades due to decreasing sand available for saltation and mechanical abrasion. The mechanism for this is hypothesized to be due to weedy species in the rainfall catchment above (decreasing sediment supply) and net export of sand to the region of the Cadiz Playa where it is stabilized by Russian thistle and cannot be blown back toward Bristol Playa.
- Cadiz Playa experiences the same processes.

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Appendix A. Salt Chemistry, Salt Species, and Glossary of Terms.

Temperature controlled reactions resulting in windborne dust-prone surfaces:

$$\underline{Na_2SO_4 \cdot 10H_2O} \rightleftharpoons \underline{Na_2SO_4} + 10\ H_2O$$

Mirabilite ← 65°F → Thenardite

$$\underline{Na_2CO_3 \cdot 10H_2O} \rightleftharpoons \underline{Na_2CO_3 \cdot H_2O} + 9H_2O$$

Natron ← 50°F → Thermonatrite

$$\underline{Na_2CO_3 \cdot 10H_2O} + Na^+ + H^+ + CO_3^{=} \rightleftharpoons \underline{Na_3H(CO_3)_2 \cdot 2H_2O} + 8\ H_2O$$

Natron ← 50°F → Trona

Other salt species discussed in this report:

Halite: $NaCl$
Burkeite: (a complex salt of sulfate and carbonate): $Na_6(SO_4)_2(CO_3)$
Gypsum: $CaSO_4 \cdot 2\ H_2O$
Anhydrite: $CaSO_4$

Ecologic and Geomorphic Terms used in this report:

Aeolian: wind blown; moved by the wind.

Barcan dunes: a crescent shaped wind blown deposit of sand that moves with the prevailing wind. The steep face of a barcan dune is on the lee side.

Biome: region defined by similar climate and geography. Example: Mojave Desert

Coppice mound: dune-like mound of aeolian soil collected around single or multiple shrubs generally requiring decades to establish.

Debrided: a process whereby the surface is removed by wearing, used in this report to describe the wearing away of the surface by action of saltating sindblown sand grains.

Deflation: process whereby a soil surface is lowered through windborne loss of material.

Desert pavement: collection of larger particles that were too large and heavy to be moved by the wind, hence forming an armor to protect the surface from further blowing.

Fluffy surface: dry, easily wind-lofted salts supplied by capillarity and exemplary of playa environments on the Owens Lakebed and Franklin Playas.

Ecotone: transition from one type of environment to another e.g., the unvegetated Bristol Playa and the vegetated margins. Ecotones can occur abruptly or gradually.

Efflorescence: process involving upward capillarity of soil water that strands loose deposits salt crystals at the soil surface.

Phreatophyte: species that obtain a portion of their water supply from groundwater. Creosote bush and cattle saltbush ares not phreatophytes. Four-wing saltbush is a facultative phreatophyte, meaning it can benefit from but generally does not require shallow groundwater.

Playa: a fine texture-dominated flat pan often called a dry lake.

Puffy surface: (general term given specific meaning in this work); the gently heaved surface common on the Bristol Playa.

Saltation: (from Latin for jump) process whereby the wind imparts energy to a sand grain that then flies in an arc to strike the soil, impart energy to additional sand particles and erode and release fugitive dust. During a wind storm the process of saltation causes a cascading effect tending to increase as more particles are saltated.

Sand: any particle between 0.63mm and 2mm in size. Sand is the principle agent for wind erosion and comes in three recognized fractions: Coarse sand: 0.63 to 2mm, Medium sand: 0.2 to 0.63mm, and Fine sand: 0.063 to 0.2 mm.

Sorting: a process that is Aeolian or alluvial that selects for certain grain sizes. For example, dune sand is often of about the same grain size and is therefore, highly sorted.

Ventifact: an object such as a wood, rock or coppice mound that has been carved by the action of wind and entrained sand.

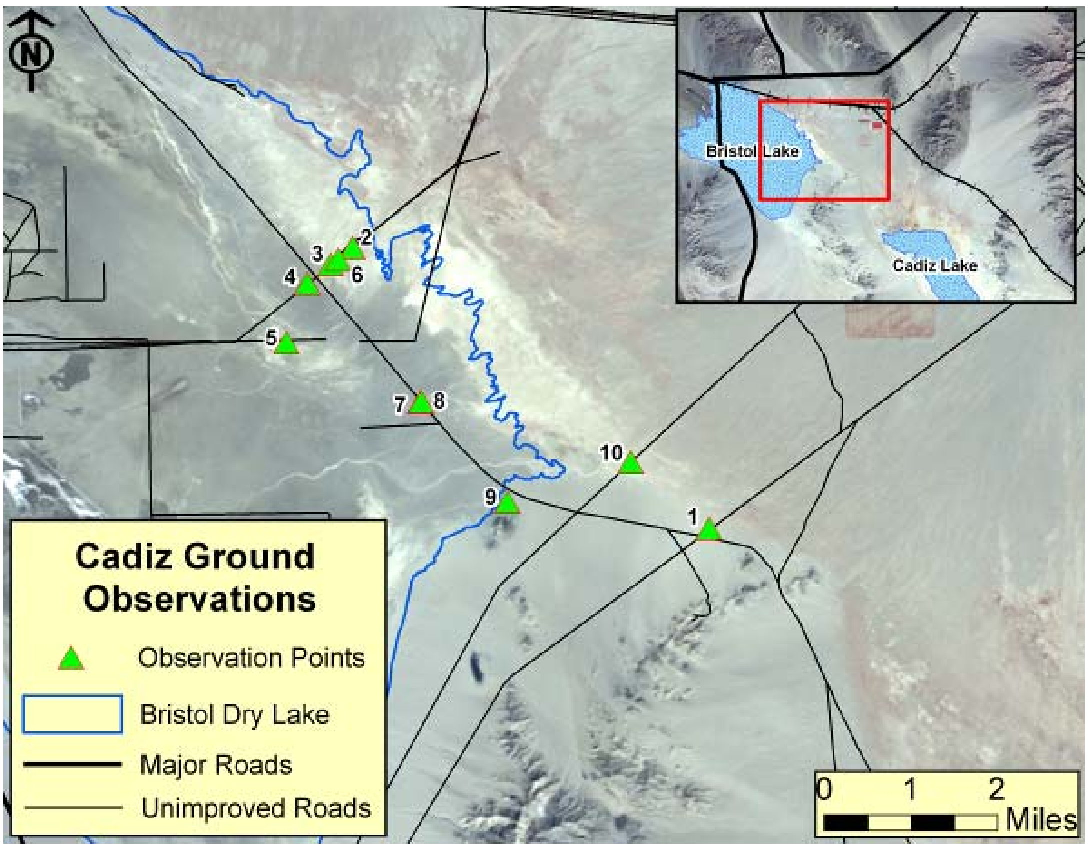
Wadi: dry wash that receives discharge from large rain events (often called flash floods).

Appendix B. Field Trip Photographs and Notes

An initial field trip was conducted on 11-9-2010 by vehicle with stops in areas of interest. A shovel was used to turn the soil to examine conditions in the top 20 cm. Notes were taken at each location. Two samples were taken at two locations, Points 4 and 5 (Figure B-1).

A second field trip was conducted to Cadiz Playa on 8-23-2011. Photos are included from that visit as Figures

Figure B-1. Points of interest visited during the ground portion of the field trip.



From field visit and comparison of the 10 points described below, it was apparent that:

(1) Shrub-occupied coppice mounds around the Bristol Playa are the source of sand that debrides the surface by saltation. The shrubby zone around the lake is generally the source area for saltating particles.
(2) The bare lakebed is not emissive unless debrided by windblown saltating sand grains. This mechanism is not directly related to the water table.
(3) Accumulation areas southeast of the Bristol Playa in the alluvial gap between it and Cadiz Playa can be a major source of dust. Weak surface crusting induced by rains can cause this zone to be protected for a while, suggesting that it takes a period of high winds to break down the crusting so that the surface becomes blowable. Once

this crust is removed, any high wind will likely create a large dust release, a condition that will last until reset by additional rainfall.

The field visit was conducted after a 20-day period of relatively warm and dry weather following rain events that totaled over an inch measured at the USGS Balch Station, 40 to 50 miles northwest of the Bristol Playa (Figure 1). Weather measured at USGS Balch is provided in Table B-1. Figure B-2 is a Landsat 5 scene from 10-30-2010.

Figure B-2. Image of the Bristol Playa and surrounding area 10 days before the field visit.

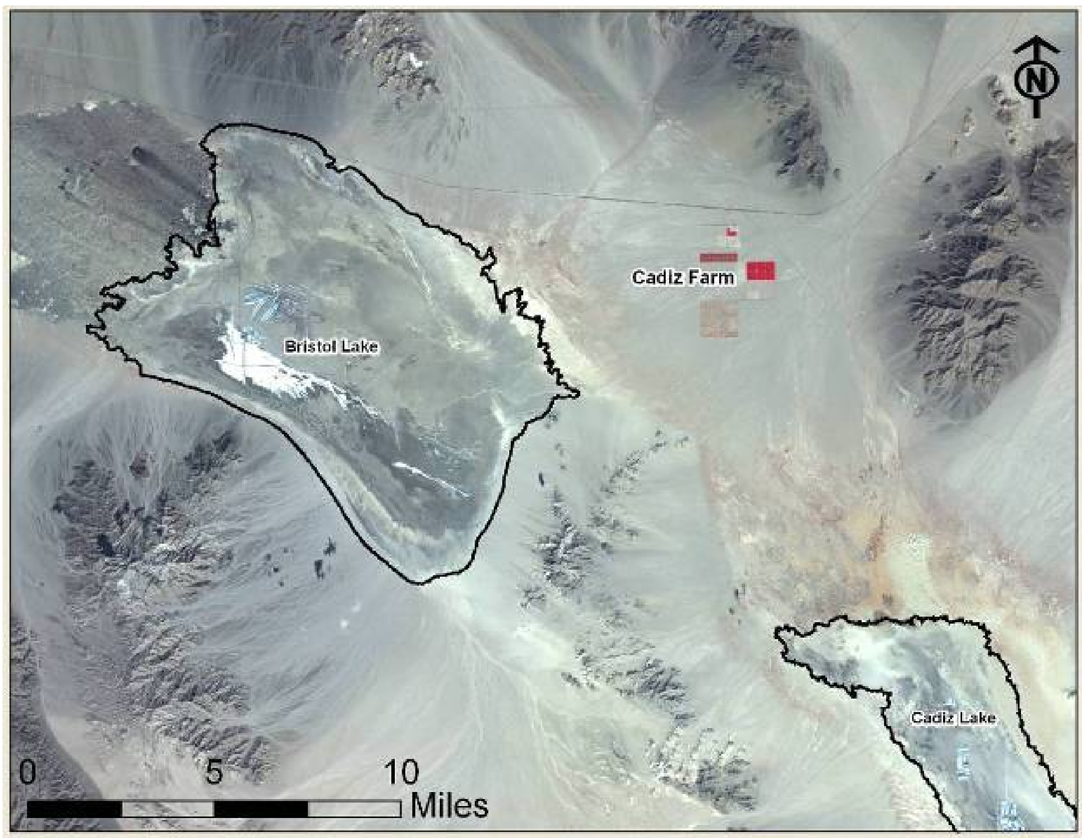


Table B-1. Weather measured at USGS Balch prior to field visit.

Date	Avg. T (°F)	Avg.Wind (mph)	Rain (in.)	LandsatTM Overpass	Date	Avg. T (°F)	Avg.Wind (mph)	Rain (in.)	LandsatTM Overpass
10/09/10	68	4	0		10/25/10	62	6.7	0	
10/10/10	72	3.5	0		10/26/10	56	3.7	0	
10/11/10	74	3.3	0		10/27/10	52	3	0	
10/12/10	76	3.7	0		10/28/10	54	3	0	
10/13/10	73	3.2	0		10/29/10	60	2.7	0.02	
10/14/10	73	3.2	0	X	10/30/10	59	9.1	0	X
10/15/10	79	4.3	0		10/31/10	56	3.4	0	
10/16/10	76	6.4	0		11/01/10	66	2.7	0	
10/17/10	71	4.1	0		11/02/10	64	3	0	
10/18/10	65	3.6	0.07		11/03/10	67	3.5	0	
10/19/10	64	2.7	0.59		11/04/10	66	3.7	0	
10/20/10	59	3.7	0.38		11/05/10	66	2.6	0	
10/21/10	62	6.6	0		11/06/10	66	4.6	0	
10/22/10	62	8.9	0		11/07/10	59	5.7	0	
10/23/10	63	10.9	0		11/08/10	54	11.1	0	
10/24/10	65	13.4	0		11/09/10	48	3.3	0	

Point 1. Downwind (SE) of the Bristol Playa. This is an area of strong Aeolian deposition where features suggestive of historic coppice mounds in the foreground have been buried. The material is very loose and high in silt content and was covered by larger, sorted, sand and gravel particles showing an incipient desert pavement. Shovels of dry soil thrown into the air generated significant dust. The surface horizons are lightly armored to about 2 cm deep by easily frangible crusting likely resulting from the one inch of rain that fell almost 3 weeks before. Remnants of weedy annual vegetation are visible.

Point 2. Coppice mounds formed at the base of a saltbush. Patches of coarse sand and some gravel have been sorted by high winds. Small dunes partially armored by this desert pavement are visible toward the left of the photo.

Point 3. At the ecotone between the unvegetated playa and the shrub vegetation higher upgradient. Note the coppiced shrub mounds in the background. The soil was puffy, pushed up by crystal pressure from below. The coppice mounds appeared to be undergoing active erosion as indicated by aspect (very tall) indicating erosion around their bases. No loose sand was visible.

Point 4. Puffy lakebed sediments on the playa beyond the shrub ecotone. The surface here resembled Points 3 and 5 with granular material below a 2cm thick crust that was moist with very slight salt efflorescence at the surface. A soil sample from this location was very high in Na (9.25%), and Cl (8.1%) with relatively low SO_4 (0.96%)—other constituents are silica minerals. No loose sand was visible.

Point 5. Puffy soils further out onto the barren Playa. The soil sample taken from the surface here was highest in Na (2.95% and Cl (1.91%) but also contained comparative levels of SO_4 (1.15%). Some medium fine sand was visible.

Point 6. This site was located after backtracking from Points 3, 4, and 5 to view more of the shrub vegetation in the ecotone region. This location is notable because of the apparent deflation to a buried clayey horizon that has characteristics of the surfaces at Points 3, 4 and 5. Coarse sand grains winnowed by high winds are visible on the surface. Note the dead shrub in the left foreground.

Point 7. Obvious deflation around a coppice mound. This location is in a wadi drained from the adjacent Playa margin about 500 m away. The coppiced saltbush in the foreground has been debrided around the base indicating a maximum saltation height of about 30 cm.

Point 8. Located about 50 m to the southwest of Point 7 and on the edge of the wadi. Obvious surface erosion features are present. This same pattern can be seen around the shovel shown at Point 7. The substrate is mostly silt and clay, so any erosion such as can be seen here generates fugitive dust.

Point 9. Volcanic hills located on the downwind margin of the Bristol Playa. The light colored deposits are highly sorted medium sand deposited by wind action. The inset shows these features at a distance.

Point 10. Accumulation area located northwest of and similar to the depositional area at Point 1. Beneath a weak crust extending about 1 cm deep, the soil was loose, silty and easily lofted. Note the loss of numerous coppice mounds in the foreground through background.

Point 11. Cadiz Playa from a location between the saltworks visible on the Appendix C Potential Dust Scenes 2. Landsat TM5 Image 11/25/2002. This surface is analogous to Bristol Playa at Points 4, 5 and 7.

Point 12. Cadiz Playa to the south of the southernmost salt works. The surface of this site is analogous to Point 11 and the mentioned Bristol Playa Points. This site was where Cadiz Playa sample 2 was obtained.

Appendix C. Observation of Satellite images

Nineteen Landsat TM satellite images were chosen for evaluation of the surface conditions on the Playa and Playa margins chosen for the period 2000 to present. This period was chosen because it coincides with wind and rainfall data available from the USGS Balch station. Two factors were of interest in this investigation (1) images of blowing dust and (2) images of the lakebed to determine whether efflorescence was occurring. To evaluate blowing dust, images were selected from days that had 12 mph average windspeed in the hour of the satellite overpass measured at the USGS Balch Station. To evaluate efflorescence and ponding effects, images were chosen following precipitation periods of one inch or more within two weeks. Eighteen images represent the entire suite of Landsat TM and Aster satellite images that occurred during the wind and rainfall conditions desired within the 10-year window.

Evidence for blowing dust was considered to be a plume that occluded or softened the ground features that it overlay. Evidence of efflorescence was taken to be a generally whitening of the surface. Table D-1 lists the images chosen to evaluate the presence of either blowing or efflorescence.

Potential days for examination of blowing dust and wetting effects were selected using data acquired from the USGS Balch, CIMIS Barstow, and CIMIS Blythe NE weather stations located within 40, 70, and 75 miles, respectively of the Bristol Dry Lake (Figure 1). To account for spatial variability of rain, data were combined and averaged between the stations. Average daily wind speeds were identified for the hour of the overpass and matched with corresponding LandSat TM5 overpass dates of the Cadiz Basin area. We estimated minimum threshold wind speed values based on previous work on emissive dry lakes and documented dust blowing dates on the Cadiz and Bristol Dry Lakes. A threshold average daily wind speed value of 12 mph was set and matched with LandSat overpass dates. All selected satellite scenes were downloaded and analyzed in false color for the occurrence of dust emission. Due to the 16-day temporal resolution of the imagery and the hourly variability in dust storms, few scenes captured active dust emissions.

The potential efflorescence scenes were selected in a similar manner by combining precipitation data from surrounding weather stations. Precipitation data from the same USGS Balch and CIMIS stations were used to identify wet periods prior to a LandSat TM5 overpass. Both large single-day, and small multiple-day storms were selected and matched with a following LandSat TM5 overpass date. Due to the generally low rainfall of the region, threshold values were informal, and scenes were selected if at least an inch of rain fell within the region during the two weeks leading up to a LandSat TM5 overpass. One exception to this scheme was from 11-12-2003 that was selected because 0.63 inch fell during that day. An image was also include from 10-10-1997 (prior to operation of Balch) because a large amount of rainfall had occurred regionally in immediate past (9.09 inches in Barstow and 0.68 inches in Blythe on 9-25-97)

Of the eight scenes chosen for analysis of blowing dust, three 3 were positive and of these, one (11-25-2002) showed very small amounts of dust released from the Bristol

Playa despite evidence of significant wind movement (25.6 mph measured at USGS Balch during the overpass, and sever dust that was released from the Cadiz Playa due to movement of the sand across the playa that was stored in the dunes. The role of sand in creating dust from the playa is confirmed with this image because the southern half of the playa, lacking upwind sand deposits is clear of dust.

Table D-1. Images evaluated for blowing dust or rain effects on the playa. Images coded for evaluating windborne dust are coded buff, rain as blue and for the co-occurrence of both, as red. average wind during the hour of the overpasses measured at USGS Balch and 2-week antecedent rain and are listed for each image. The October 30, 2010 scene was used to evaluate both potential dust and efflorescence.

2001	Condition	2002	Condition	2003	Condition	2004	Condition	2005	Condition
3/11	1.01 in.	4/15	18.2 mph	2/25	1.19 in.	8/26	1.43 in.	2/11	1.13 in.
3/27	1.1 in.	9/22	3.99 in.	4/14	1.05 in.				
11/22	13.5 mph	11/25	25.6 mph	11/12	0.63 in.				
2006	**Condition**	**2007**	**Condition**	**2008**	**Condition**	**2009**	**Condition**	**2010**	**Condition**
2/23	1.13 in.	4/12	23.5 mph	3/14	17.9 mph	4/2	1.1 in.	10/30	14.5 mph
				3/30	13.5 mph	10/27	19.2 mph		1.05 in.

The two scenes that show significant dust release from Bristol Playa are from 4-12-2007 and 10-27-2009. In both scenes, the highest magnitude dust released was from an area of accumulation (observed during the field trip as Points 1 and 10—Appendix B). The image from 4-12-2007 is clearer than the 10-27-2009 image because it lacks high clouds and it shows a much more severe dust storm in progress (and the 10-27-2009 image is generally supportive of the same areas viewed on 4-12-2007). The dust being released from the accumulation areas can be seen to emanate directly from the ground source, while the plumes that are visible over the Playa, itself, are raised above the Playa, indicating that this is not the source of the visible plume. Examination of the small water droplet cloud sitting over the Bristol Playa in this scene can be used to gage the height of the dust plume, itself creating a shadow. The length of the shadow of the dust plumes approaches, but is less than the height of the cloud, thus, the dust plumes are lifted significantly off of the Playa below but not as high as the cloud.

From the examination of dust releases and the wind speeds measured at the USGS Balch Station, the threshold velocity for dust entrainment appears to be around 20 mph. This is an imperfect comparison because of few days recording blowing dust and the 50-mile distance of the USGS Balch Station. Still, most strong continuous winds in the Mojave Desert tend to be the product of regional-scale phenomena driven by frontal passage.

The images chosen to examine whether or not salt efflorescence occurs show that this mechanism for creation of fugitive dust is extremely limited. Only one of the images, 4-02-2009, showed the surface becoming light in a pattern suggestive of salt efflorescence. Efflorescence is important because in the systems that are prone to dustiness, pervasive whitish salt efflorescence is a common feature, particularly following rainy weather when upward capillarity can carry the salts back to the surface where they are stranded as the water molecules evaporate. Hence, if the 4-02-2009 image is indicative, this incidence is only 1in 12, or 8% (including the 10-10-1997 image). Counting this image as efflorescent, however, is not correct in comparison to Owens Lake where salt efflorescence during the winter can generate a snow white salt crust on multiple square-mile areas of the lakebed.

From examination of the satellite imagery, it can be concluded that:

(1) Significant dust releases occur from areas of accumulation identified during the field visit. The accumulation is from particles debrided off of the Playa and its margins by saltating sand grains. Areas of accumulation exist in a zone to the southeast of where the dust is initially generated. Dunes are zones of accumulation on the north through northeast margin of the Cadiz Playa.

(2) High winds (of 20 mph or greater) alone may be insufficient to cause the release of dust. This may be the result of weak surface crusting that has occurred due to recent rains a condition that can be broken down under high winds and the energies imparted by saltating sand grains.

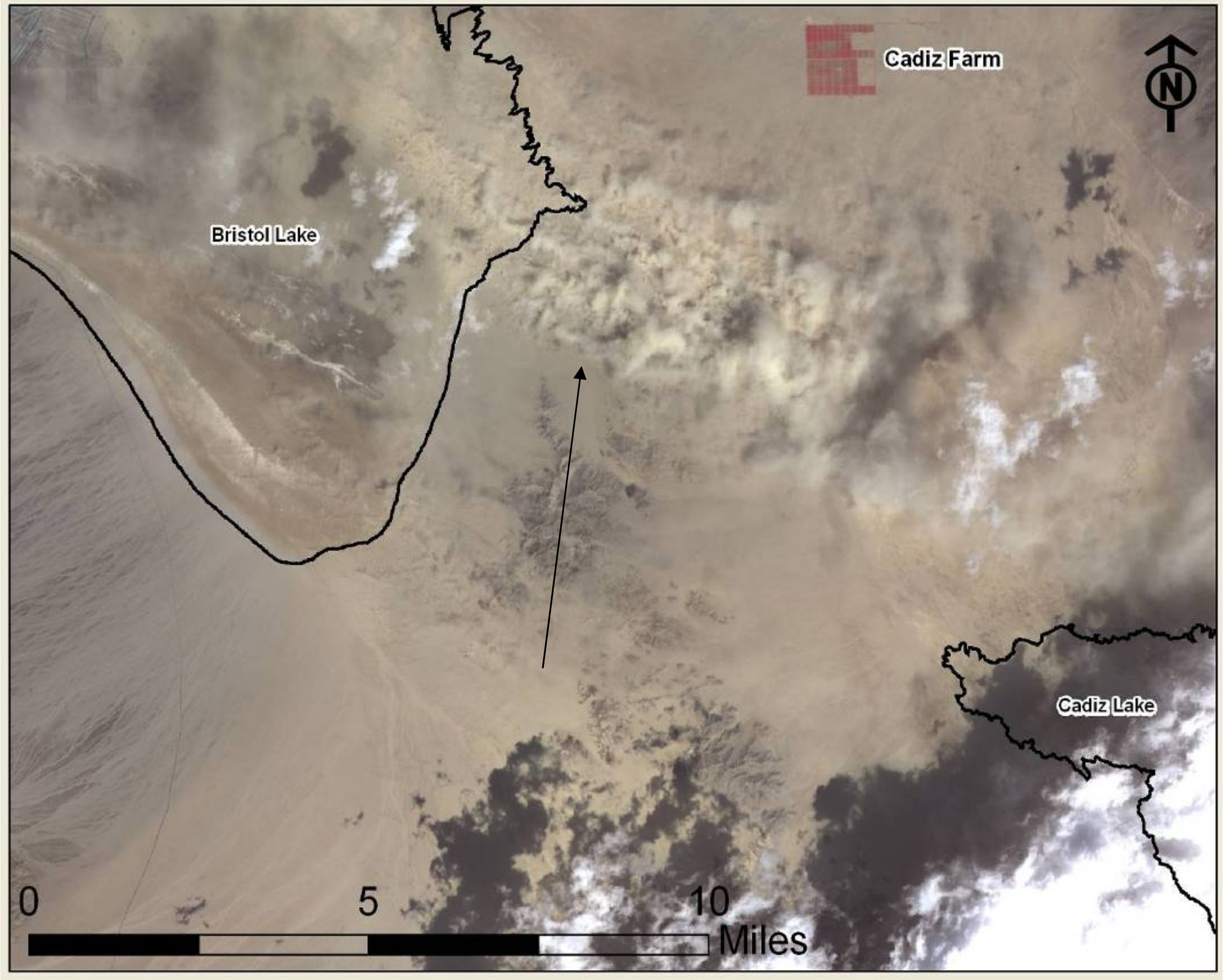
(3) both Bristol and Cadiz Playas are non-emissive unless sand is provided for saltation that debrides the surface where it tracks across with the wind.

(5) Significant rainfall appears to create only small amounts of surface ponding on the Bristol Playa. This suggests that the Playa absorbs rainfall and runon rather than causing long-term ponding. Cadiz

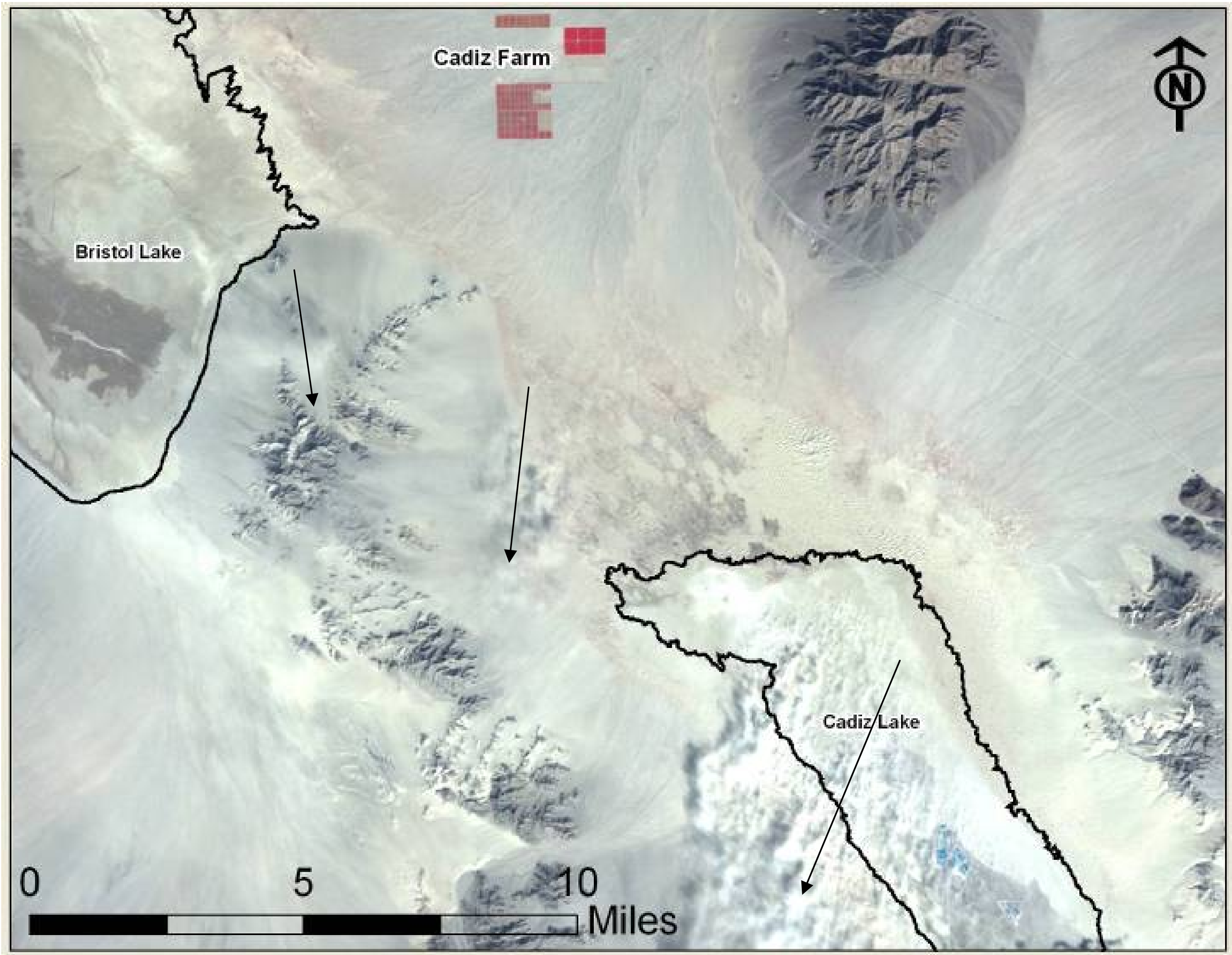
(6) Playa is much drier than Bristol Playa and has little evidence of runon from the surrounding catchments. Flooding from Fenner Wash is trapped in the dunes and does not reach the Cadiz Playa.

(y) Little to no rain-capillarity-evaporation-driven salt efflorescence appears to be part of the dust release cycle from either playa. Hence, the dust from these playas is solely a factor of the energy imparted upon the surface by wind velocity through the action of saltating sandgrains. The majority of the dust released is, therefore, silica minerals rather than salts.

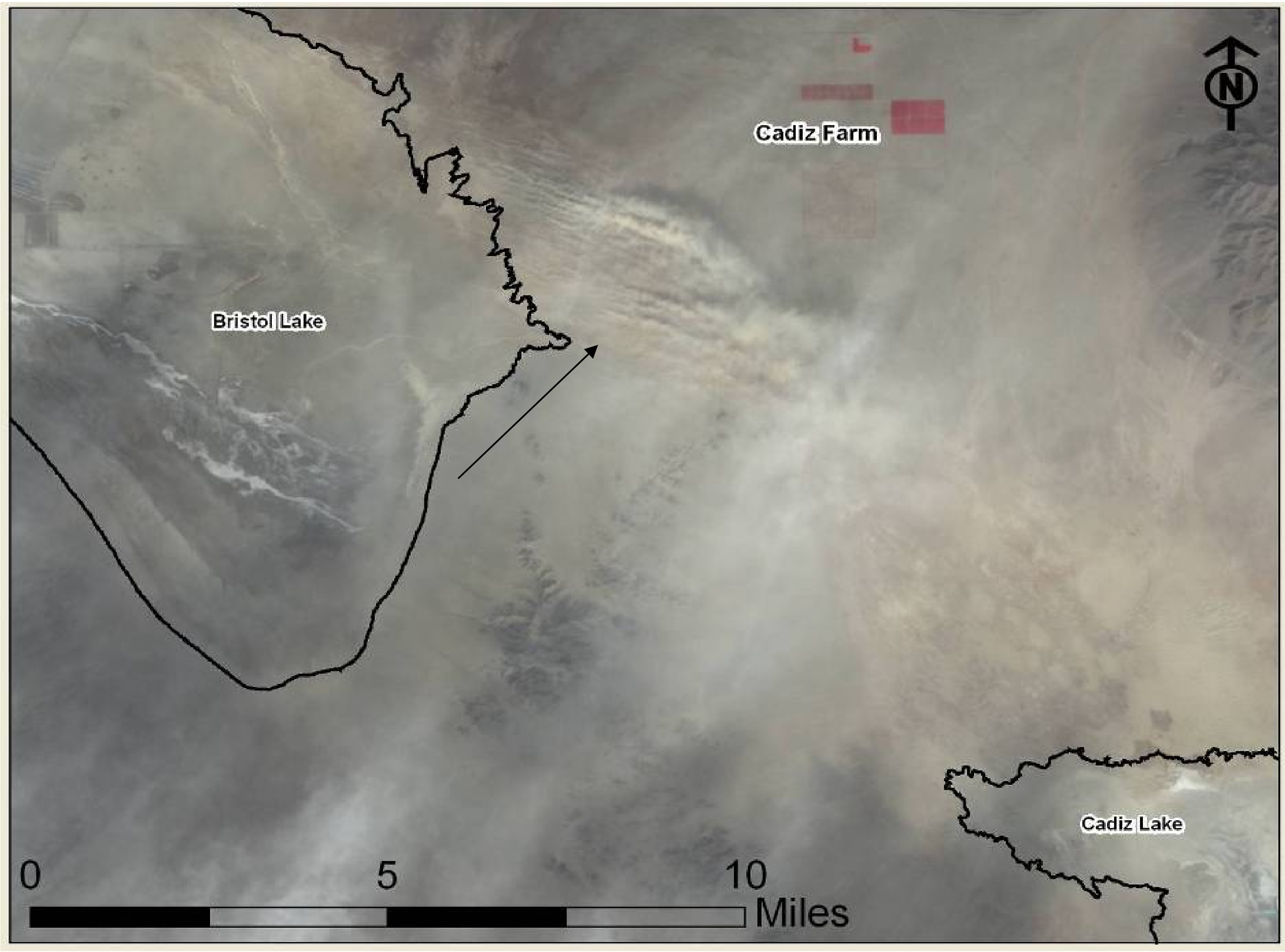
Potential Dust Scenes 1. Aster Image: 4/12/2007. Average windspeed during the hour of the overpass was 23.5 mph (at USGS Balch). Arrow shows dust plumes. Note the color difference for clouds of dust particles (buff colored) and those of water droplets (white or grayish).



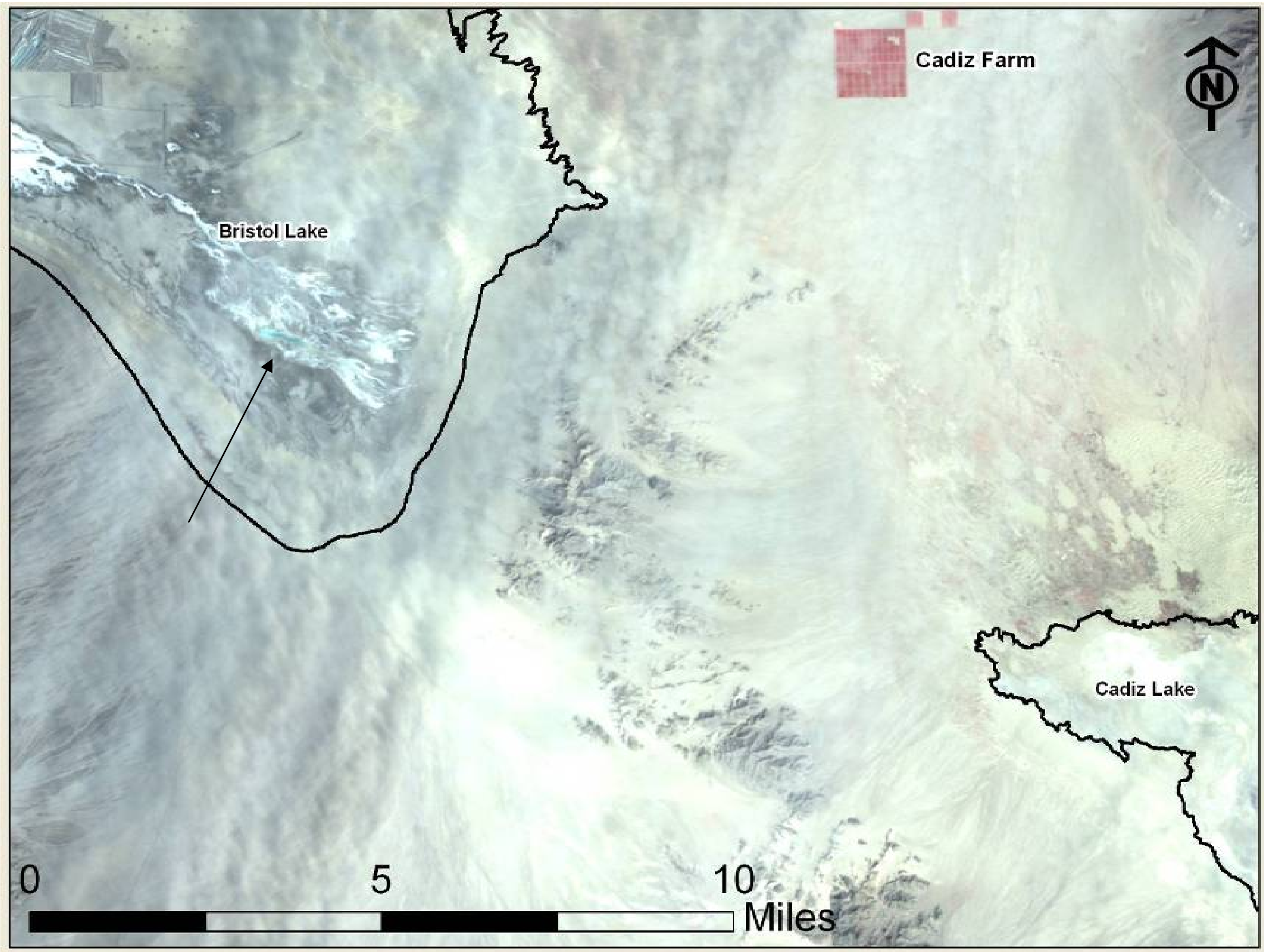
Potential Dust Scenes 2. Landsat TM5 Image: 11/25/2002. Average wind speed during the hour of the overpass was 25.65 mph (at USGS Balch). Arrows show dust plumes and their apparent direction of travel. The wind is apparently from north as can be seen in the dust leaving the Cadiz playa. The north half of Cadiz playa may be impacted by the huge reservoir of sand on the north and northeast margin.



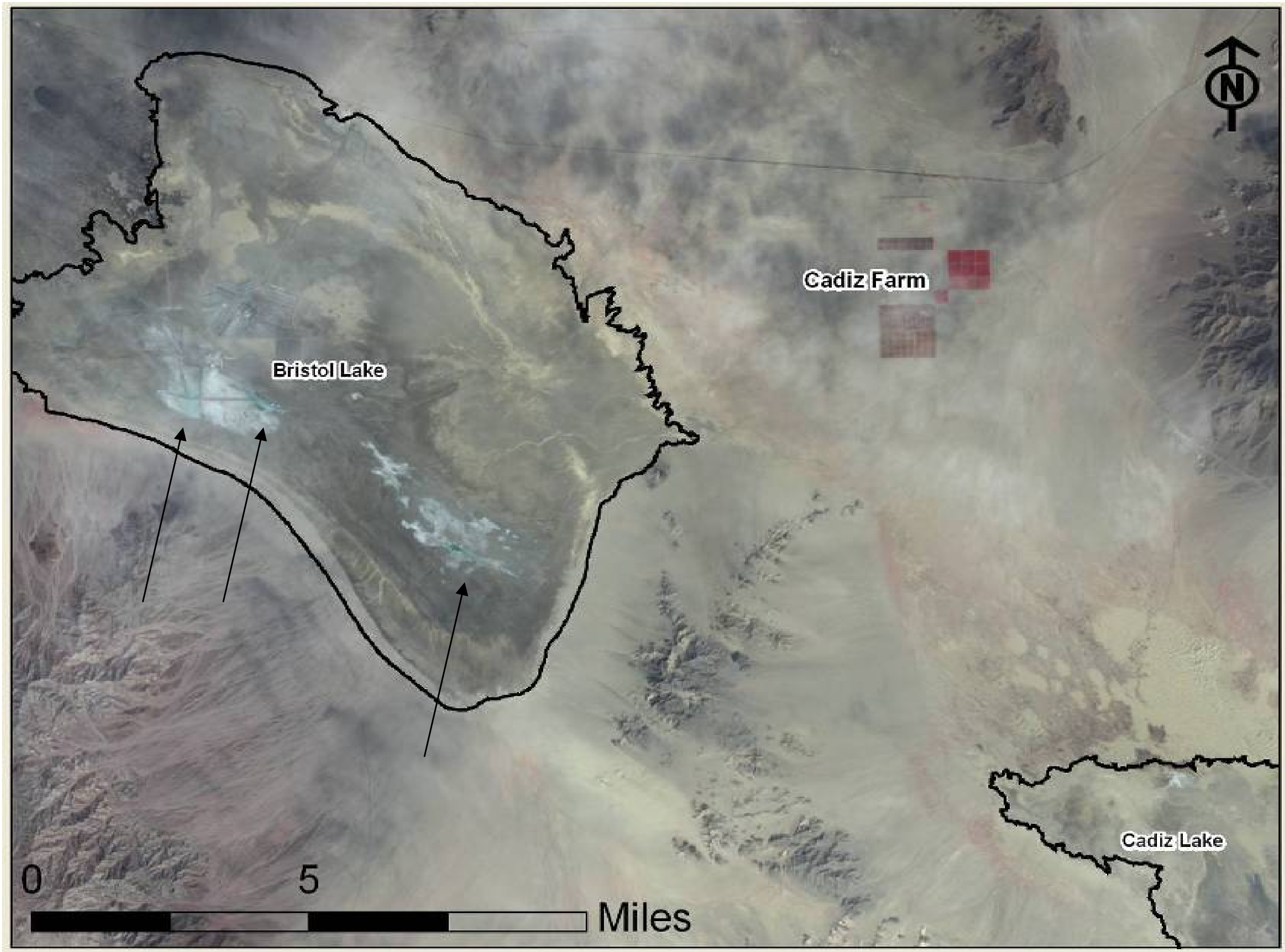
Potential Dust scenes 3. Landsat TM5 image: 10/27/2009. Average wind speed during the hour of the overpass was 19.2 mph (at USGS Balch). A high level cloud crosses the middle of this scene from SW to NE. The arrow indicates dust released from the accumulation area (Figure 6) The long tendrils of dust cloud are indicative of stripes of saltating particles.



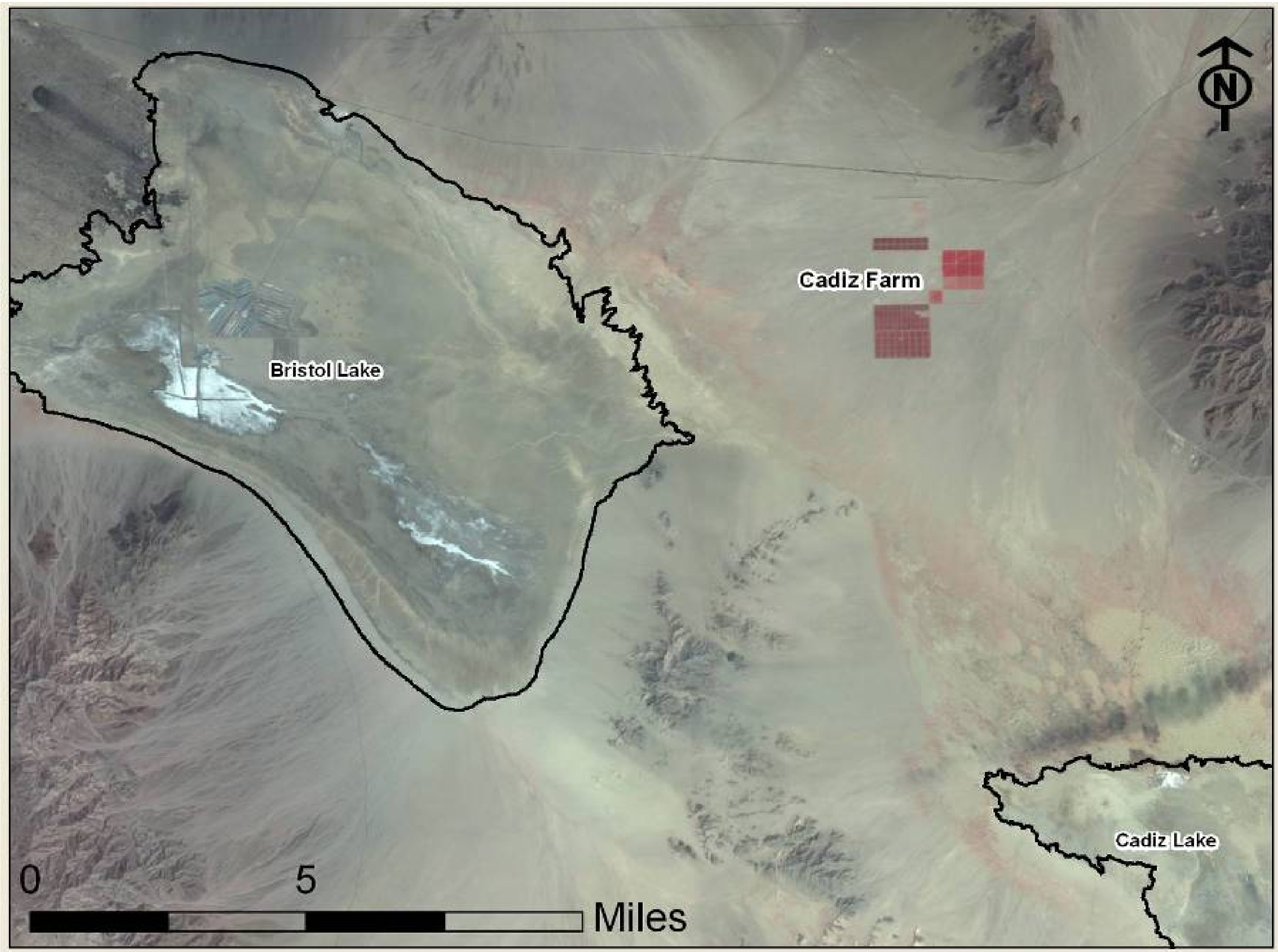
Potential Efflorescence Scenes 1. Landsat TM5 Image: 10/10/1997. 9"rain in previous 2 weeks at Barstow and 0.68 inches at Blythe (see Figure 1). Arrow shows surface ponding. Significant thin water droplet clouds are present in this image



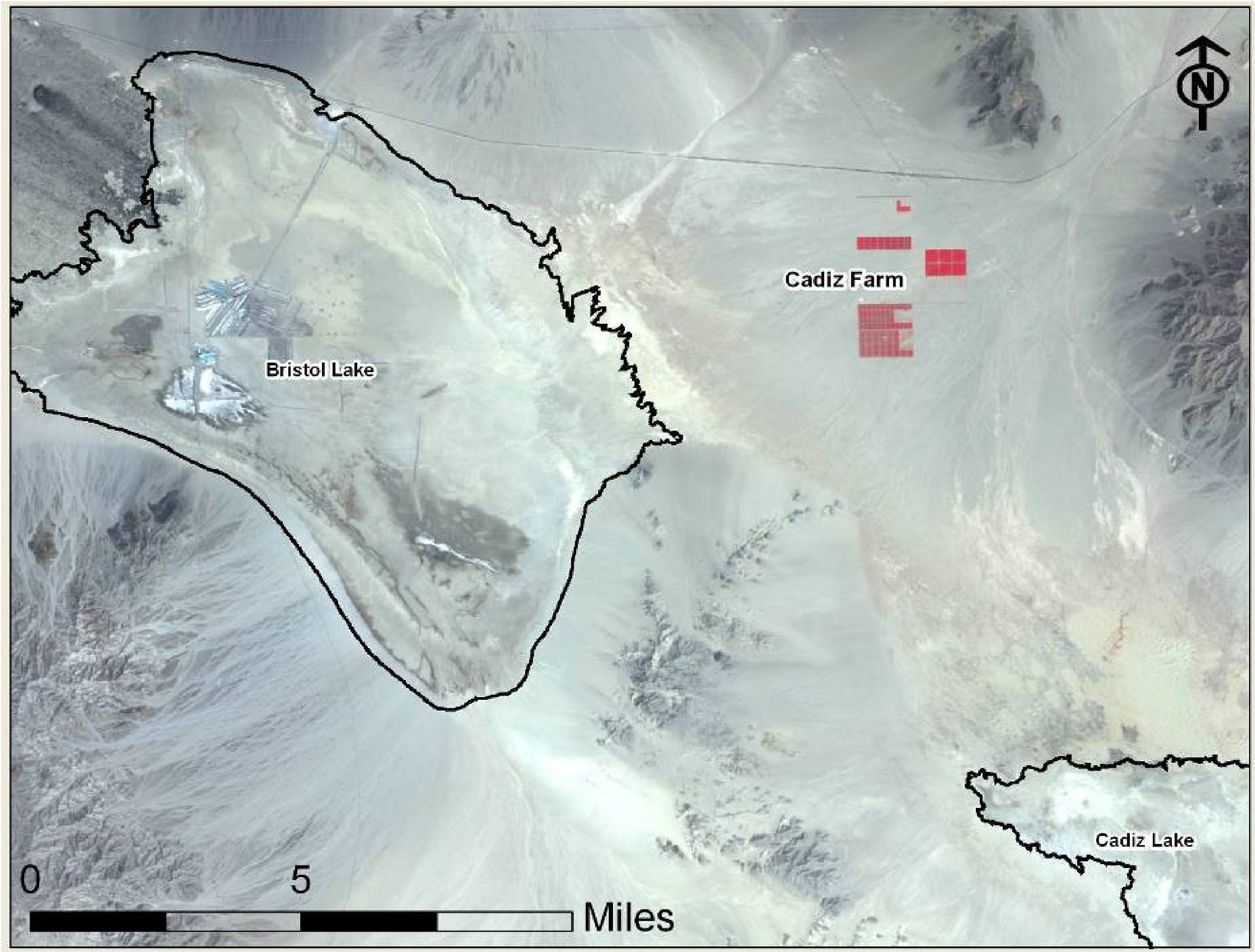
Potential Efflorescence Scenes 2. Landsat TM5 Image: 3/11/2001. 1.4" rain in previous week (average of all three stations shown on Figure 1). Restricted areas of turquoise on the Playa are ponded surface water (arrows). Clouds (thin) and shadows are present in this image.



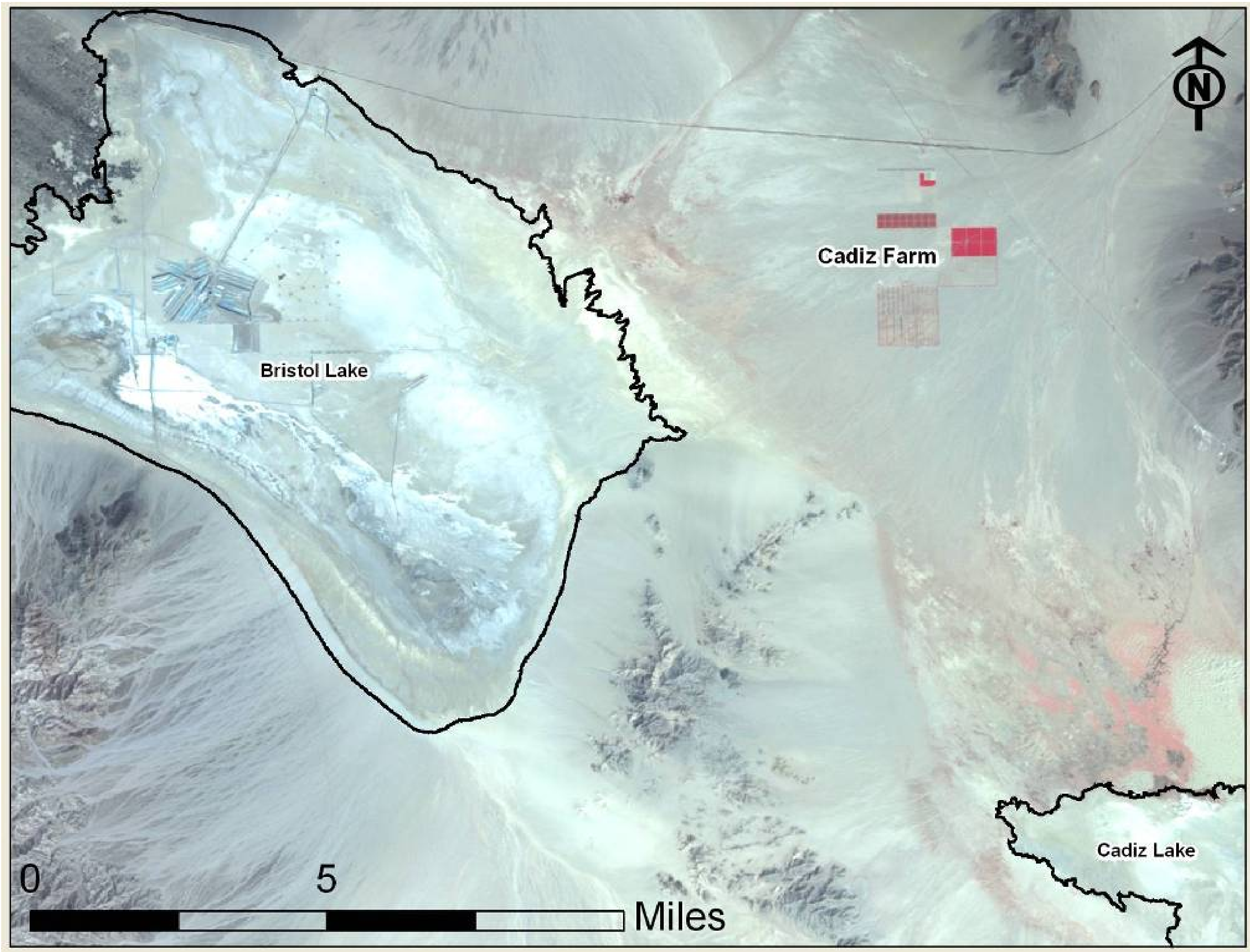
Potential Efflorescence Scenes 3. Landsat TM5 Image: 3/27/2001. Ponding is gone in this scene taken 16 days after Scene 2.



Potential Efflorescence Scenes 4. Landsat TM5: 8/26/2004. 1.4" rain in previous week (average of all three stations shown on Figure 1). Turquoise indicates surface ponding.



Potential Efflorescence Scenes 5. Landsat TM5: 4/2/2009. Possible Efflorescence. Little rain was recorded at surrounding Met stations (Figure 1). The bright red adjacent to the Cadiz Playa is a vigorous cover of Russian thistle.



HydroBio
Advanced Remote Sensing

Memorandum, September 8, 2011
To: Tom Barnes, ESA
From: David P. Groeneveld, Ph.D.

RE: Results from Soil Samples Acquired from Cadiz Playa

Attached are the results for two soil samples obtained from Cadiz Playa. The purpose for this sampling was to determine the chemistry of this playa in comparison to the Bristol Playa and with relationship to the potential for Cadiz Playa to become a dust source if the water table were to decline. Sample 1 was taken near the north end of the Tetra Chemical workings and Sample 2 was taken from the region of the south end of these workings.

The results show a playa soil that is dominated by sodium calcium cations and chloride ions. Sulfate is present at higher concentrations than at the Bristol Playa. Carbonate and bicarbonate are present at very low concentrations. The relative concentration and species of salts confirms that dust releases such as occur at Owens Lake will not occur from Cadiz Playa.

As described in other reporting, dust that arises from either Bristol or Cadiz is due to the energy imparted by saltating sand grains and this process will not be affected if depth to water changes within the region.

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Date: September 8, 2011

Submitted by: HydroBio

Report To: Scott Murray

Report #: 6641368

Date Received: September 1, 2011

SOIL ANALYSIS

Sender ID	Lab ID	* Ca %	* Na %	* SO4 %	** Cl %	*** Carbonate %	*** Bicarbonate %
Cadiz 1	950	0.77	8.38	1.25	3.27	0.044	0.39
Cadiz 2	951	1.16	4.34	1.00	1.09	ND	0.017

* Sample dissolved in DI water on a 5:1 ratio and analyzed on ICP.
**Probe analysis
***Methods of Analysis for Soils, Plants and Waters. Chapman and Pratt, 1961. p22.

ND means None Detected