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Delineating Playas in the Arid Southwest

A Literature Review

William Brostoff, Robert Lichvar, and Steven Sprecher

April 2001

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Playas of the arid Southwest can be unambiguously identified in a geologic context. However, identifying those portions of playas that are defined as ?Waters of the United States? (WoUS) in the Clean Water Act (CWA) and thus under the jurisdiction of the Corps of Engineers (Corps) and other Federal agencies charged with enforcing the CWA is sometimes problematic. While the WoUS definition specifically includes playas, the guidance for playa delineation is not as highly developed as for wetlands. Delineating WoUS, as per-formed by the Corps or by others to comply with Corps regulations, involves determining ?Ordinary High Water? (OHW). However, under certain circumstances, the indicators provided in Federal regulations and available technical information for determining OHW have been found to be insufficient when applied to playas. Consequently, some delineations performed to date have involved the development of local indicators by integrating observational data obtained during cyclical inundation, information available for delineating wetlands, and inference based on technical knowledge. Examples of local indicators include small-scale cracks in the soil surface, soil algal crusts, and phreatophyte mounds. This report summarizes the pertinent literature and provides examples of case studies in delineating playas. This review, however, is not intended to provide protocols for delineating playas or to be interpreted as guidance provided by any Corps District or Headquarters, U.S. Army Corps of Engineers. Rather, the scientific background and technical application needed for perform-ing specific delineations are reviewed.

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Delineating Playas in the Arid Southwest

A Literature Review

William Brostoff, Robert Lichvar, and Steven Sprecher

April 2001

Prepared for
U.S. ARMY DUGWAY PROVING GROUND
U.S. ARMY WHITE SANDS MISSILE RANGE
U.S. MARINE CORPS, AIR–GROUND COMBAT CENTER
EDWARDS AIR FORCE BASE

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Abstract: Playas of the arid Southwest can be unambiguously identified in a geologic context. However, identifying those portions of playas that are defined as "Waters of the United States" (WoUS) in the Clean Water Act (CWA) and thus under the jurisdiction of the Corps of Engineers (Corps) and other Federal agencies charged with enforcing the CWA is sometimes problematic. While the WoUS definition specifically includes playas, the guidance for playa delineation is not as highly developed as for wetlands. Delineating WoUS, as performed by the Corps or by others to comply with Corps regulations, involves determining "Ordinary High Water" (OHW). However, under certain circumstances, the indicators provided in Federal regulations and available technical information for determining OHW have been found to be insufficient when applied to playas. Consequently, some delineations performed to date have involved the development of local indicators by integrating observational data obtained during cyclical inundation, information available for delineating wetlands, and inference based on technical knowledge. Examples of local indicators include small-scale cracks in the soil surface, soil algal crusts, and phreatophyte mounds. This report summarizes the pertinent literature and provides examples of case studies in delineating playas. This review, however, is not intended to provide protocols for delineating playas or to be interpreted as guidance provided by any Corps District or Headquarters, U.S. Army Corps of Engineers. Rather, the scientific background and technical application needed for performing specific delineations are reviewed.

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PREFACE

This report was prepared by William Brostoff, Ecologist, Engineer Research and Development Center (ERDC), Waterways Experiment Station, Vicksburg, Mississippi; Robert Lichvar, Ecologist, ERDC, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire; and Steven Sprecher, Soil Scientist, U.S. Army Corps of Engineers, South Bend, Indiana.

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Bill Sipple, EPA, and Jim Wakeley, Environmental Laboratory, ERDC, generously provided comments on the draft manuscript. Both provided critical insights into wetland delineation protocols based on their broad experiences. Russ "Bubba" Pringle, Natural Resources Conservation Service, shared his knowledge of soils, thereby providing the basis for many discussions of pertinent playa delineation issues.

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A Literature Review

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INTRODUCTION

The Federal government regulates filling activities in certain parts of the landscape (including wetlands, tidal waters, lakes, rivers, streams, intermittent streams, mudflats, sloughs, prairie potholes, wet meadows, natural ponds, and playa lakes) under the provisions of the Code of Federal Regulations (33 CFR 328.3 [a]) implementing Section 404 of the Clean Water Act (CWA). The Corps of Engineers (Corps) and others perform jurisdictional delineations of playas (and other landscape features) to determine whether certain areas are subject to Section 404 regulations.

A playa is "[t]he flat-floored bottom of an undrained desert basin that becomes at times a shallow lake which on evaporation may leave a deposit of salt or gypsum."* While identifying playas in a geologic context is relatively unambiguous, delineating those areas of playas under the Corps' jurisdiction, particularly those of the arid southwestern United States (which differ geomorphically and ecologically from other playa types in the United States), has been found to be problematic (e.g., Doub and Colberg 1996, Lichvar and Sprecher 1996). This document considers the scientific background forming the basis for performing delineations of such playas.

Because the same personnel who routinely delineate wetlands are sometimes involved in the delineation of playas, there has been an inclination to adopt wetland delineation protocols to playas. However, there are differences in both the rules for and the characteristics available for differentiating wetlands and playas from their respective adjacent habitats. In the case of wetlands, there are formal definitions and guidelines. Wetlands are identified on the basis of three parameters (or their respective indicators): soils, vegetation, and hydrology, as specified in the Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987). Wetland hydrology must, by definition ("frequency and duration criteria"; Office of the Chief of Engineers 1992, 1994), be met for 1–2 weeks of the year or 5% of the growing season. For playas, the guidance is included in the definition of "Waters of the United States" (WoUS):

> "The term 'waters of the United States' means (1) all waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide; (2) all interstate waters including interstate wetlands; (3) all other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce...; (4) all impoundments of waters otherwise defined as waters of the United States under the definition; (5) tributaries of waters identified in [items] (1)–(4) [of this definition]; (6) the territorial seas; (7) wetlands adjacent to waters (other than waters that are themselves wetlands) identified in [items] (1)–(6) [of this definition]" (33 CFR 328.3[a]).

All of these waters, except wetlands (which may cooccur with non-wetland WoUS), are delineated to the extent of Ordinary High Water (OHW) or high tide levels. The OHW is defined as

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* *Webster's Third New International Dictionary*. Springfield, Massachusetts: Merriam Webster, 1964.

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> "...that line on the shore established by fluctuations of water and indicated by physical characteristics such as clear, natural, lines impressed on the bank, shelving, changes in the character of the soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding area." (33 CFR 328.3[e])

Like many wetlands, both the soils and vegetation of playas usually clearly contrast with those of adjacent habitats. Like many wetlands, playas are wet only intermittently. However, application of wetland hydrology, soil, and vegetation delineation protocols to playas is moot because (1) The soils generally do not develop recognized characteristics that might be used to determine whether they were hydric in response to inundation. (2) The vegetation, particularly that which might be classified as obligate or facultative, does not characteristically grow on playa surfaces because of harsh conditions. (3) Playas are by definition intermittently covered with water, the extent of cover changing rapidly on both short- and long-term time scales (e.g., Kubly 1982), making any possible "frequency and duration" criteria for hydrology problematic to assess.

Detailed data on the temporal and spatial extent of inundation of playas may not be readily available from conventional sources such as satellites or aerial photography because of high costs and restricted access. Even if such information is readily available, determining jurisdictional boundaries would be technically complex and involve a clear understanding of the environmental conditions during the time the data were collected. As will be discussed below, the horizontal and vertical extent of inundation varies in response to rainfall and groundwater input, evaporation and percolation output, and wind-induced water movement.

This review summarizes the available technical knowledge of possible indicators of OHW to be used in delineating playas in the arid southwestern United States. It is based on the technical and "gray" literature (including delineations) as well as consultations with various Federal agencies involved with identifying and managing playas. This review, however, is not intended to provide specific guidance for delineating playas or to be interpreted as guidance provided by a Corps District or Headquarters. Rather, the scientific background and technical application needed for performing specific delineations as well as case histories are reviewed such that they can be applied as needed in a case-by-case basis.

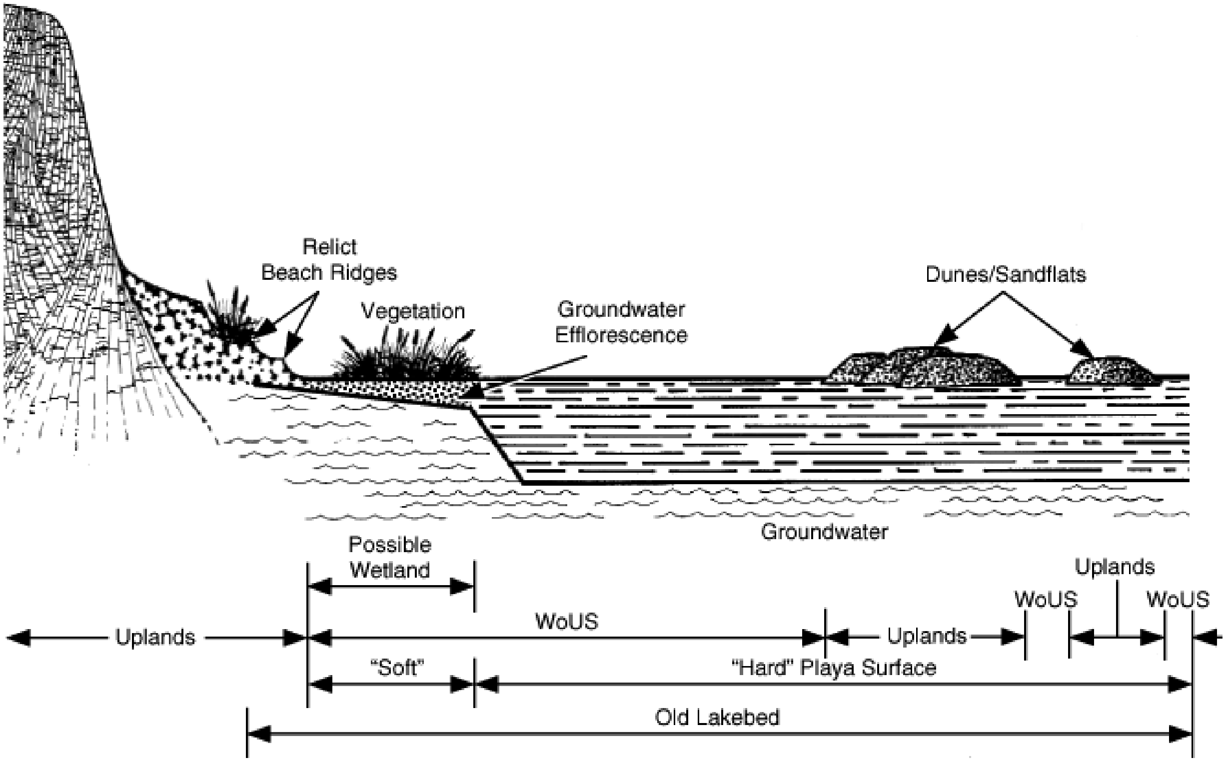

Figure 1. Conceptual diagram of a playa. Note that the area marked "soft" would be a wetland only if hydrophytic vegetation, hydric soils, and appropriate hydrology existed; it would be a non-wetland WoUS if it had nonhydrophytic (or no) vegetation and nonhydric soils, but met the hydrology criteria. The area marked "hard playa" ponds water but lacks both hydrophytic vegetation and hydric soils and therefore is considered a non-wetland WoUS. Areas located above the dunes/sandflats are considered uplands.

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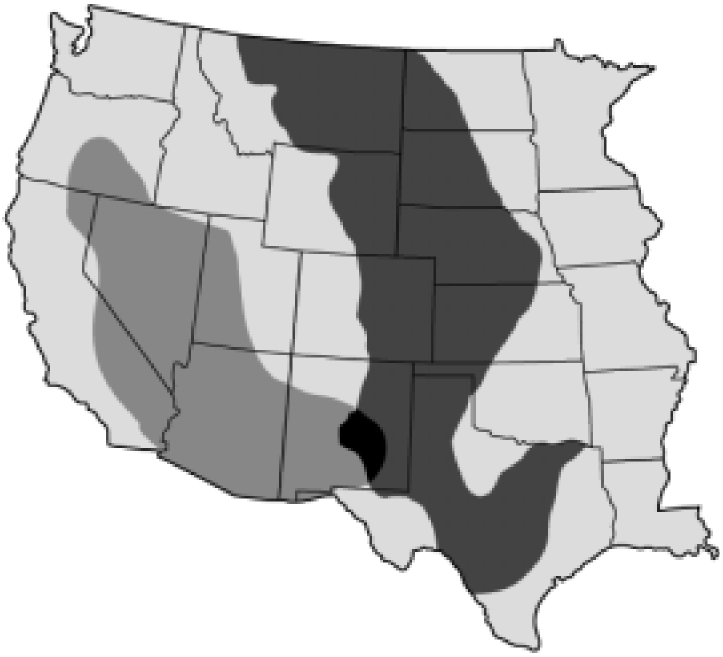

Figure 2. Distribution of desert southwest playas and high plains pluvial lakes. (After Stone 1956, Motts 1970, and Nelson et al. 1983.)

PLAYAS

The term playa as used for the past 100 years (Johnson and Oliver 1997) is broadly defined as the flat and generally lower portions of arid basins with internal drainage that periodically flood and accumulate sediment (Neal 1975) (Fig. 1). Playa is the Spanish word for shore or beach, but in English-speaking countries has generally come to mean the landform described. Neal and Motts (1967) refined this definition by adding that the surface is covered with water less than 50 percent of the year, that is, playas are dry most of the time; Motts later (1970, 1972) suggested this figure should be 25 percent. Shaw and Thomas (1989) add to this general definition that the margins show evidence of evaporite accumulation and/or lacustrine activity. Rosen (1994) further added that playas have negative hydrologic balances and that they be entirely continental (i.e., no connection to the ocean). Most recently, Briere (2000) redefined them as having a negative water balance for over half of each year and dry for 75% of the time. Implicit or stated in all of these definitions is that playas of the sort considered herein are typically vegetation-free surfaces of Pleistocene lacustrine sediments.

The playas covered by this review (primarily those of the deserts of California, Nevada, Utah, and parts of Arizona, New Mexico, and southeastern Oregon [Fig. 2]) originated as Pleistocene lakes (e.g., Kerr and Langer 1965) but dried as a result of climatic change or from change in stream inflow or outflow. In all of the United States, there are about 300 large playas, at least 120 of which are the relicts of Pleistocene lakes (Cooke et al. 1993); Neal (1975) estimated that there are about 50,000 playas on earth, the vast majority being a few square kilometers or less in size. Fewer than 1,000 cover more than 100 km^2 (38.61 mi^2). Motts (1970) is reluctant to call the smaller features (<609.6-m- [2000-ft-] diameter) playas and prefers the term “microplaya.” Doub and Colberg (1996) refer to playas under 15.2 m (50 ft) in width and/or diameter occurring in clusters within uplands as “playettes.” Similarly, Rundel* refers to small playas as “playitas.” In the older literature (Stone 1956), when playas contain water, they are referred to as playa lakes; when they are dry they are called dry lakes; when wet by seepage they are termed salinas; other synonyms include clay flats, salt marshes, and borax marshes. On USGS topographic maps, they are denoted as intermittent lakes.

There are several sorts of playas and playa-like entities with distinctly different geologic origins; these are discussed below to the extent that they provide information on possible indicators for use in delineation. The classification and nomenclature of these landforms are discussed in Shaw and Thomas (1989), Rosen (1994), and Johnson and Oliver (1997); Stone (1956), Stevens (1988), and Briere (2000) present synonymies of playa classification and terminology. For example, although referred to as playas, the “pluvial lake basins” of west Texas originated during the Pleistocene along pluvial streams (e.g., Reeves 1966) and developed further in response to a range of environmental factors; their current soils and vegetation are in marked contrast to those under consideration.

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* Personal communication, Dr. Philip W. Rundel, Professor of Biology, UCLA, Los Angeles, California, 1995.

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- *Playa lakes, pluvial lake basins, playa wetlands.* On the southern High Plains of Texas and New Mexico (and also extending throughout the Southern Great Plains to include Colorado, Kansas, and Oklahoma), there are some 30,000 small (<1.6 km [1 mi] diameter), ephemeral lakes, with geological origins in ephemeral or relict stream channels (Nelson et al. 1983, Cooke et al. 1993, Gustavson et al. 1994; see also review by Reeves 1966). These are generally small, internally drained circular depressions that collect runoff and focus recharge to the Ogallala aquifer. They are typically flooded 1–3 months each year and the flooding may eliminate vegetation from the lower portions (Gustavson et al. 1994). Briere (2000) denotes them as being transitional between a playa and a lake; neither dry more than 75% of the time nor wet more than 75% of the time. There may also be a gradient in both plant species composition and abundance with increasing depth and period of inundation (Gustavson et al. 1994). These playas, when flooded, range from nonsaline, when flood water is lost via deep percolation to a water table, to saline, when water is lost through evaporation (Wondzell et al. 1990).
- *Pans.* The term pan (panne) is used in a range of ways. In Southern Africa, Australia, and occasionally in the United States, it (or salt pan or lime pan) is synonymous with playa (Johnson and Oliver 1997); in the United States pan or clay pan may refer to small playa or playa-like areas that are generally unvegetated (Shaw and Thomas 1989). Clay pan may also refer to a variety of other similar but not geologically related features such as vernal pools. Salt pan is also used to denote small, nonvegetated depressions in coastal salt marshes.
- *Sabkha*. Sabkhas are coastal saline flats in North Africa closely resembling playas in appearance and characteristics. They are hard, salt-encrusted, flat surfaces lying above the high tide line but occasionally becoming inundated with seawater during storm conditions (e.g., Akili and Torrance 1981, Briere 2000). Sometimes, playas are inappropriately (Briere 2000) referred to as continental sabkhas.
- *Dayas (North Africa), Balte (Libya), Dongas (Australia), Vleis (southern Africa), Chor or Sor (Central Asia).* These are small depressions on flat expanses of limestone or calcrete areas that may intermittently flood (Cooke et al. 1993) and thus bear some resemblance to playas.

LANDSCAPE SETTING OF PLAYAS

Playas represent about 1.1 percent of the land surface area of the Mojave and Sonoran deserts in California, Arizona, and Nevada, as well as of the Sahara, Libyan, and Arabian Deserts (Stone 1956). Playas are a distinct part of the landscape; although their surfaces often represent Pleistocene lakebeds, portions of the relict lakebed surface may be covered by dunes (composed, at least in part, of alluvial material deposited by streams feeding the former lake) and alluvial slopes (Motts 1970) (Fig. 1). The geomorphology of playas may be quite complex. For example, in the Mojave Desert, where three playas are situated on what was Pleistocene Lake Thompson, two (Rosamond and Rogers playas) are thought to be at the level of the original lakebed, but a third (Buckhorn) is somewhat higher in elevation. The latter may have a different genesis.* Frequently, small playas may occur near the margins of larger playas in depressions defined by dunes, or behind relict beach ridges on the edges of playas (Stone 1956). An example of such a formation exists in the vicinity of Troy Dry Lake, California, where 20–30 small playas developed in the very slight depressions in the alluvial material bordering the main playa (Stone 1956). Similar such playas exist at Cuddeback, Rogers, Rosamond, and Buckhorn Dry Lakes, California. Small playas may also occur in irregularities in alluvial fans that are far removed from larger playas, in enclosed basins formed by faulting, or other depressions formed by similar processes (Stone 1956). The edges of most barren playas are characterized by an increase in vegetation, sediment size, and slope. Geologically, these edges may represent relict wave-formed bars, beach ridges, or alluvial deposits. These changes, while generally abrupt, may be sometimes very gradual without clear boundaries (Neal 1965). Although playas are defined in part as internally drained, the playa boundaries as geologically defined may not correspond to boundaries that currently are or could become inundated. Further, the historic boundaries of inundation may not correspond to current patterns.

PLAYA HYDROLOGY

Few technical data are available documenting the areal extent of inundation of playas; playa hydrology has been reviewed recently (Rosen 1994) with the conclusion that relatively little is known. Water may accumulate on playas from surface runoff, direct precipitation, or groundwater discharge. Annual variation is such that a particular playa may not become flooded at all during a particular year or remain flooded for up to three years (Cooke et al. 1993). This is due in part to the nature of precipitation in the desert. Rainfall occurs in

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* Personal communication, Dr. Anthony Orme, Professor of Geology, UCLA, Los Angeles, California, 1995.

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storms and may range from a fraction of an inch (which may not cause appreciable flooding) to an amount greater than the total rainfall of the preceding year (which can very quickly flood a playa) (Stone 1956). In an examination of 45 California playas over three consecutive years, Kubly (1982) reported that during 1978, 65% of playas ponded water, but 45% and 30% ponded water in 1979 and 1980, respectively (see also Table 1, pg. 14). The inundation period is influenced by many variables, including the geometric, geomorphic, soil, and vegetation characteristics, as well as evaporation rates (as influenced by climatic conditions, water salinity, and geometry of the water body itself). Some playa surfaces are impervious to infiltration of surface water while others have enormous capacity for absorbing and transporting moisture (Neal 1965). In yet other instances, groundwater may be the predominant source of surface water to a particular playa; in these instances, the water level may be stable or at least less variable than playas whose surface water budget is largely dependent on precipitation (these geomorphic characteristics are discussed below).

The spatial extent of ponding varies as well; Kubly (1982) reports that on any given playa the extent of water coverage ranged from small, scattered ponded regions to more than 90% of the surface area. One serious confounding influence for delineations based either on the extent of ponded water or remnants (“indicators”) on dry surfaces is that of wind-induced water movement. Stone (1956 and references contained therein) describes instances in which water may shift considerable distances, or be driven toward one end of a playa during a windstorm. Malek et al. (1990) report that the area ponded with water in the playa in Pilot Valley, Utah, may move several miles in response to changes in wind direction. Sheets of water have been observed to breach minor drainage divides on playa surfaces during periods of high wind (Lines 1979), thus resulting in changes in the areal extent of coverage until the next flooding or drying cycle. Motts (1972) commented on the high rate of water movement on playas (Rogers and Rosamond Playas, California) in relation to wind velocity; although he reported rates of up to 1.82 m (6 ft) per minute in response to a 42-mph wind, he did not report on the areas occupied by standing water. Also on Rogers Playa, Dinehart and McPherson (1998) report wind-induced changes in water depth of more than 0.3048 m (1 ft).

Another important caveat is that drastic changes in the areas inundated can occur over relatively short periods because of anthropogenic and natural changes in groundwater level causing land subsidence and the formation of giant desiccation cracks (e.g., Blodgett and Williams 1990). Recently opened giant desiccation cracks have been documented to drain a substantial amount of water, and consequently rapidly decrease the area of inundation at Yucca Lake, Nevada Test Site, Nevada (Doty and Rush 1985). At Rogers Playa, the bulk of a 2.54-cm (1-in.) rainfall in 1983 is reported to have drained into a newly formed desiccation crack within 24 hours (Blodgett and Williams 1990). Interestingly, the shifting of water back and forth due to wind may smooth out irregularities in the surface. This smoothing factor may have application in determining the extent of previously ponded water. Data on evaporation rates could provide information useful to OHW delineation, but few are available. Stone (1956) estimates the average annual evaporation rates in southern California deserts at 203.2–228.6 cm (80–90 in.) per year. In applying this figure to a 2.44-m (8-ft) flooding (normally, playas flood to depths of only a few inches) of Silver Dry Lake, he reported the calculated figure to be a slight underestimate. Some examples of evaporation times and rates are given in Table 1. Interestingly, salt crusts can reduce water evaporation rates to 2% of non-salt-crusted surfaces (Chen 1992) and may be associated with groundwater levels at or nearer the surface than in the absence of the crust.

Data pertaining to groundwater level of soft playas are similarly scarce. Many soft playas (see below) tend to have dry surfaces during the summer and wet during the winter (e.g., Stone 1956). On playas in Pilot Valley, Utah, the water tables vary from 3 to 5 cm (1.18 to 1.96 in.) from the surface during the wet season to about 30 cm (11.81 in.) during the dry season, though the soil remains moist all year (Malek et al. 1990). When groundwater is at the lower level, a salt crust forms.

INDICATORS OF ANTECEDENT HYDROLOGIC CONDITIONS

Once standing water has evaporated from or percolated into the substratum at a particular site, a range of indicators may remain or develop that can be used to provide evidence of previous ponding. Characteristics of playas that might provide information on antecedent hydrology are discussed here from the perspectives of surface morphology, soils, and vegetation.

Surface morphology

The surface morphology of most playas is related to several factors, the most important being the ratio between surface-water flooding and capillary discharge from groundwater (Motts 1970). There have been several attempts to classify playas and playa surfaces on the basis of this ratio because of the characteristic appearance of playas at each extreme (e.g., Stone 1956, Neal 1965, and Stevens 1988). However, because surface types may vary with time and intergrade, the value

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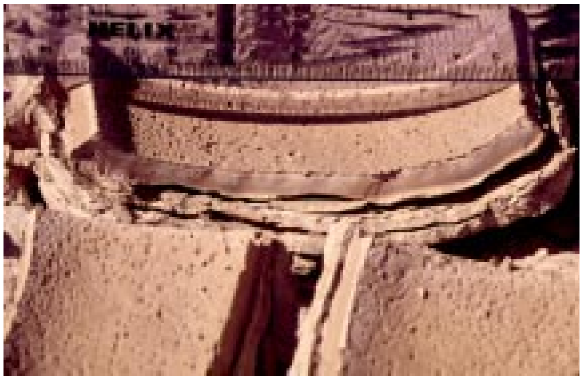
a. Aspect of a 5-ha hard playa between Rosamond and Rogers Playas, California, a few weeks after inundation and subsequent drying. Note polygons (lower left), drift lines running from left center to left bottom, and algal crusts with upturned ends (center).

b. Hard playa/upland transition. Note upland (pedicillated) cryptobiotic crusts (right edge center) grading into smooth cryptobiotic crusts (right bottom), drift marks, debris lines, and small polygons.

c. Large, flat, polygons indicative of inundation on large playas as found at Rosamond Dry Lake, California.

d. Edge of hard playa with concentric drift lines (left) and thick, stratified crusts (right) showing at least two generations of cracking. Also note vegetation (*Sueda subfruticosa*).



e. Hard (non-algal) crusts from the lowermost portion of a »2-ha hard playa. The surface is smooth, but with vesicular pores, the edges are strongly upturned, and there is very conspicuous layering.

Figure 3. Aspects of a hard playa.

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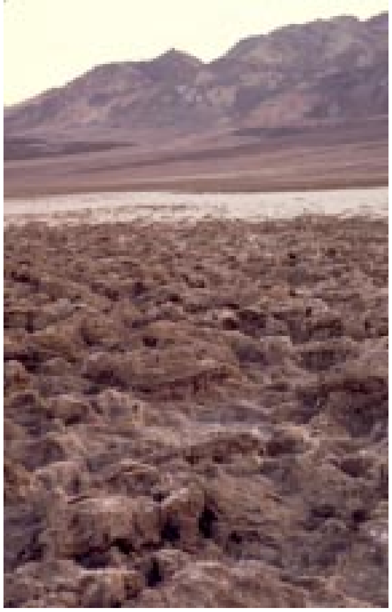
a. Soft playa at Death Valley, containing 0.5-m-diameter polygons with upturned edges



b. Soft playa at Death Valley, California, with highly irregular surface in the foreground and salt crust (white area) behind.

c. Aspect of soft playa at Death Valley, California. Salt polygons »1-m diameter. (Apparatus in background is for recording groundwater.)

Figure 4. Aspects of a soft playa.

of any such classification system is problematic. Further, any one playa may have features of more than one surficial type (e.g., Neal 1965). Two general sorts of playa surfaces exist, and several other categories and characteristics may be recognized: One extreme, a hard or fine-grained playa (Fig. 3) is characterized by having a dry, compact, generally smooth surface that does not have groundwater input and which is inundated by rainfall and surface runoff (e.g., Stone 1956; Motts 1970, 1972). This type has little microrelief except for surface crusts, mud cracks, or polygons. The surface sediments are generally remnant silt and clay deposited during the Pleistocene when the playas were indeed lakes. In this type, groundwater is at least several feet removed from the surface; groundwater depths greater than 5 m (16.4 ft) preclude discharge to the surface and favor the development of hard, dry, compact playa crusts with little or no evaporite accumulation. Consequently, they do not contain a zone of saturation or a capillary fringe near the surface because of the depth to groundwater (Motts 1970). Some degree of shine or glaze is also characteristic of these surfaces, related to fine-particle orientation. Representative playas include Mesquite, Rogers, and Rosamond, in California.

The other extreme is referred to as a soft or coarse-grained playa (Fig. 4) and is characterized by a soft, often moist, friable, puffy surface that develops from capillary input of groundwater and subsequent deposition of evaporite minerals (Motts 1970, Neal 1972). The surfaces of this playa type are loosely compacted and may be damp to dry during the summer months. Microrelief may be in the range of 5.08–7.62 cm (2–3 in.) or greater, giving a lumpy appearance. Noticeable swelling may occur after precipitation, demonstrating the property of "self-rising" ground (Kerr and Langer 1965). Capillary fringe discharge from groundwater at a depth of 5 m (16.4 ft) or less from the surface gives this form its characteristic appearance. This type can be converted to the former by flooding (Motts 1970). In fact, Tyler et al. (1997) describe a cycling between surface types at Owens Dry Lake, California. About a quarter of the playas in California and Nevada are the soft type, about 7% show characteristics of both types (Stone 1956). Representative soft playas occur at Harper Lake, California (Neal 1972), and Mesquite Dry Lake, Twentynine Palms, California (Lichvar and Pringle 1993).

Several surface characteristics, referred to as patterned ground by Hunt (1975), may be evident in the form of polygons, circles, step-like forms, and stripes. These surface formations develop as a result of wetting and subsequent drying, thermal changes (diurnal heating and cooling, freeze–thaw cycles), or chemical changes. For Death Valley, Hunt (1975) states that "patterned ground" varies in an "orderly fashion that faithfully reflects differences in the hydrologic regimen of

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the ground.” Of particular interest is that, according to Hunt (1975), surface water is associated with polygonally cracked crusts on hard surfaces, while capillary fringe input of moisture is associated with net patterns on soft surfaces.

Giant desiccation polygons, stripes, or fissures (e.g., Neal 1965, 1972; Neal and Motts 1967) are thought to be due in part to subsurface drying (due to decreasing groundwater depth). The polygons range in width from 10 to 300 m (33 to 984 ft) but are more typically 15–75 m (49–246 ft) across. The fissures, which are often found in association with the polygons, may be several hundred meters long and arranged in parallel, in concentric rings around the polygons, or around the edges of playas. Neal and Motts (1967) state “...polygon dimensions are related to...the ephemeral or long-term nature of the desiccation.” Examples occur at Rosamond Playa, where they have been extensively studied because of their hazards for aircraft operations (e.g., Dinehart and McPherson 1998); they have been observed recently at El Mirage Dry Lake, California (Brostoff, personal observation) and Salt Creek Playa, New Mexico (Lichvar and Sprecher, personal observation).

Several other smaller-scale formations, related more to surface than subsurface hydrology, are also common and provide varying degrees of inferential evidence for assessing previous inundation. These include crusts, surface cracks, and polygons. A crust is a surface layer that is generally more compact, harder, and more brittle than the soil beneath (Souirji 1991). Crusts can form from a range of causal factors: (1) rearrangement of the soil fabric as a result of wetting and drying, (2) biological factors (discussed later), or (3) externally applied mechanical pressures (e.g., rain drop impacts). The occurrence of crusts, cracks, and polygons on playas was reviewed by Stone (1956). Mud cracks form when fine-grained sediments lose their contained water; the surfaces between the cracks are known as polygons. Stone (1956) identified five types of mud cracks/polygons for playas in the southwestern United States:

- *Large five- to eight-sided polygons up to 61 cm (24 in.) in diameter and with cracks from 2.54 to 20.32 cm (1 to 8 in.) deep*. These occur around the edges of small depressions on the playa surface at Coyote, El Mirage, Ivanpah, and Roach Playas, generally immediately after rains, or around isolated inundated areas. These have also been referred to as “mud-crack polygons” (Neal 1965, Neal and Motts 1967), which are reported to be about 10.16 cm (4 in.) in diameter, a ubiquitous feature of hard playas, and the result of desiccation of fine-grained sediments.
- *Mud cracks from 0.64 to 5.08 cm (0.25 to 2 in.) deep and four- to five-sided polygons that are from 7.62 to 20.32 cm (3 to 8 in.) wide*. These often have another set of smaller polygons that may in turn be overtopped with mud curls. The primary cracks are generally less than 0.635 cm (0.25 in.) and many times deeper than wide, but the width may be as much as 2.54 cm (1 in.), thus giving the surface a characteristic blocky appearance. Representative examples are found at Rosamond Playa.
- *Shallow mud cracks from 0.32 to 0.64 cm (0.13 to 0.25 in.) deep with thin polygons of a varying number of sides that typically turn up on the edges*. These are usually less than 15.24 cm (6 in.) in diameter and may have a second generation of cracks on their surface. This type is common on hard playas, but may occur on a few soft playas. Representative examples are found at Red Pass Dry Lake.
- *Mud cracks that are usually less than 2.54 cm (1 in.) deep with polygons whose edges turn downward*. The polygons have a varying number of sides, generally five, and are commonly 7.62–15.24 cm (3–6 in.) in diameter. These are common on soft playas, but may occur on hard ones as well. Representative examples are found at North Panamint Dry Lake, California.
- *Thin, sinuous mud cracks with resulting irregular polygons*. The mud cracks are less than 1.27 cm (0.5 in.) deep and do not have a second generation on top. These are typical of salt-clay encrustations on soft playas. Representative examples are found at Troy Dry Lake and Danby Dry Lake, California.

The extent to which these five types overlap or possess unique causal factors has not been rigorously investigated. However, the various types are readily apparent in the field and often do not appear to intergrade on a small spatial scale.

Patterns associated with evaporites

Some of the cracks and polygons common on hard playas have counterparts on soft playas where evaporites can exert an influence on surface patterns.

Salt pavements or crusts are conspicuous accumulations of salt. These can be intermixed with fine silt and form surface layers ranging from a few centimeters to more than a meter in thickness. Microrelief of salt pavements ranges from a few centimeters to 30.48 cm (1 ft) (Neal 1965). Salt crusts may be seasonal, being dissolved by winter rains (Malek et al. 1990). These are common at Devils Golf Course, Death Valley, California (Neal 1965).

Salt polygons (Stone 1956, Neal 1972) (Fig. 4c) are ubiquitous features on soft playas that contain brine

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concentrations near the surface. The polygons are generally five-sided, 1.83–12.2 m (6–40 ft) in width, and bounded by ridges of salt from 0.3048 to 0.9144 m (1 to 3 ft) high. They are common, but highly ephemeral because they are obliterated during flooding. They are common at Searles Lake and Death Valley Playa, California.

Pressure-ridge salt crusts (Lines 1979) are initially flat, smooth crusts formed by evaporating surface brines. As the crust dries and additional salt is deposited on the surface by evaporating groundwater, the crust expands and forms sharp pressure ridges. The tops of the ridges fracture with upturned edges as much as 5 cm (0.19 in.) high. Diameter may be 0.3048–0.6096 m (1–2 ft). These have been described for Bonneville Salt flats in the United States and Chilean salars (Lines 1979) and are also common at the Salton Sea, California (Sprecher, personal observation).

Carbonate surfaces may occur along the faulted playa border where springs deposit minerals that form a carbonate crust. This occurs in Death Valley (Kerr and Langer 1965).

Layered mudcracks 5.08–10.16 cm (2–4 in.) deep with subtended flat or smooth surfaces are common at the lowermost areas that pond water during most inundation events (Lichvar and Sprecher 1996).

Erosion/surface impressions

"Rosette impressions" (Motts and Carpenter 1970) are distinctive markings produced on flooded playas by ice movement or ice crystal formation across mud surfaces during alternate freeze–thaw cycles. In the playa lakes of Canada, similar freeze–thaw cycles produce a characteristic granularity in the soil (Renaut 1993).

"Desert flower" patterns are those characteristic dendritic patterns 5.08–7.62 cm (2–3 in.) deep left by the erosive forces of water flowing into desiccation fissures (Motts and Carpenter 1970).

Drift lines, water marks

Although not considered in the technical literature, discontinuities in the condition of litter, drift material, and the soil surface may also provide good evidence as to the extent of recent inundation. Drift lines (e.g., Fig. 3a, b, d) are specifically mentioned in the CWA as an indicator of OHW. The presence of these markings lends more credence to establish an OHW mark if they are continuous, thus indicating a spatially defined area.

Other indicators also exist, but may appear similar on muddy but nonponded surfaces. Use of these indicators requires caution and the capability to distinguish their occurrence on ponded vs. muddy areas. For example, remnants of blown-in debris, animal tracks, boulder trails, and other objects have also been used as evidence of ponding. Tracks left by boulders and other objects possibly blown across muddy surfaces have been documented and are of particular interest at Racetrack Playa, Death Valley (see Bacon et al. 1996). Such impressions have been seen to be removed by wind erosion near Buckhorn Playa, California (Brostoff, unpublished).

Other surface phenomena

"Sticky-wet surfaces" are continuously wet regardless of season and are composed of salt, silt, and clay (Kerr and Langer 1965). They are typically associated with the salt pavement and soft crust types, e.g., Pilot Valley, Utah (Malek et al. 1990).

"Gas pits, gas holes" are conical basins 0.30–0.9 m (1–3 ft) in diameter and from 15.24 to 91.44 cm (6 to 36 in.) deep, with a smaller venthole (Stone 1956). The pits are formed while the surface is underwater and are the result of escaping gas (generally atmospheric in composition). These are found in association with mud cracks. Representative gas pits are found at Coyote, Buckhorn, and Lavic Dry Lakes, California.

SOILS, SURFACE, AND SUBSURFACE FEATURES

Soils

Federal regulations recommend soil morphology as a tool to help delineate the areal extent of wetlands and OHW levels on playas. Specific rules have been developed to distinguish hydric ("wetland") soils from upland soils (Environmental Laboratory 1987, U.S. Department of Agriculture, Natural Resources Conservation Service 1998). However, the only guidance given for using soil to identify OHW levels is "changes in the character of soil" (33 CFR 329.11[a][1]). This guidance does not identify the nature of the changes or provide quantitative thresholds of color, depth, or abundance of soil features on either side of the regulated playa boundary.

Because characteristics of both wetlands and playas develop under conditions of periodic wetness, it is tempting to apply hydric soil protocols to playa soils. Indeed, the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS) has proposed just such an indicator (Indicator TA1, Playa Rim Stratified Layers, USDA NRCS 1998) for sparsely vegetated playa rims. However, further applicability of hydric soil protocols to playas is limited by several characteristics unique to playas.

First, hydrologic regimes for wetlands are more strictly defined than for playas. In a particular intermittent lake bed, the OHW elevation may be higher than that determined by the criteria for wetland hydrology and needed to produce hydric soils. Second, hydric soil morphologies develop under conditions with sufficient soil biomass to drive the redox chemistry definitive of hydric soils. Unvegetated playas are unlikely to possess sufficient biomass to support such microbial activity. Third, pH is usually higher in playa soils than in wetland soils; consequently iron segregation features in part definitive of hydric soils (see below) are less distinct in playas than in lower pH wetlands, because iron reduces more readily at pH below neutrality than above. Until 1996, a fourth contrast existed between playa and wetland soils: the concept of "classified soil" required the possibility of natural vegetation, thereby excluding application to playas. At that time the NRCS definition of soil was broadened to include unvegetated areas if pedogenesis occurs (cf Soil Survey Staff 1996, 1998).

The "changes in the character of the soil" (33 CFR 329.11[a][1]) that are potentially useful in identifying the OHW elevation in playas include (1) accumulations of organic matter (2) iron segregations (3) salt crystals, and (4) soil structure and texture.

Accumulations of organic matter

Investigators of playas have reported two kinds of shallow organic matter accumulation from which surficial hydrologic regimes may be inferred. First, the USDA–NRCS is testing the hydric soil indicator mentioned above (TA1, Playa Rim Stratified Layers, USDA NRCS 1998). The morphology described by this indicator has already been observed in eight different playas in California (two), Utah (three), and Oregon (three).* If further work confirms the initial observations, the required morphology will be as follows.

Stratified layers starting within the upper 15 cm (6 in.) of the soil surface. At least one layer has value 3 or less and chroma 1 or it has value 2 or more and chroma 2 or less with 2% or more distinct or prominent redox concentrations as soft masses or pore linings. The upper 15 cm (6 in.) has dominant chroma 2 or less.

Playa Rim Stratified Layers User Notes. This indicator is for the sparsely vegetated playas of the western United States.... [T]his indicator does not require continuous chroma 2 or less. Thin layers of chroma 3 or higher may occur as long as the upper 15 cm (6 in.) is dominantly chroma 2 or less. A minimum amount of organic carbon is not required. A layer with redox concentrations is substitutional for the dark layer. As inferred, this indicator occurs on sparsely vegetated playas and playa rims adjacent to the non-vegetated playas.

This indicator includes several possible morphologies within the upper 15 cm (6 in.) of the playa rim soil, resulting from various combinations of organic matter accumulation and/or iron segregation. (1) The entire surface 15 cm (6 in.) is very dark gray to black from organic matter accumulation; this would most commonly result from nearly permanent saturation. (2) The surface 15 cm (6 in.) of soil contains one or more thin layers of very dark gray to black organic matter accumulation, which is within or underlain by a dominantly gray (chroma 2) matrix to 15 cm (6 in.); this most common expression of the indicator would be found in seasonally ponded or saturated soils. (3) The upper 15 cm (6 in.) contains dominantly gray soils with at least one layer with iron concentrations (red mottles); no organic matter accumulations are present. (4) The wording also allows many combinations of organic matter staining and iron segregation in dominantly gray matrixes.

Although the above indicator is intended for identification of vegetated areas that saturate at least every other year for at least two continuous weeks, similar morphologies are seen in unvegetated playas with less defined hydrologic regimes. Lines (1979) and Lichvar and Sprecher (1998) have found thin black layers in playas at White Sands Missile Range and Bonneville Salt Flats, respectively. Those at White Sands Missile Range have a greasy feel and H_2S odor when wet (Lichvar and Sprecher 1998); the black layers appear to have a very high abundance of bacteria, based on light microscopy, compared to other playa substrata (Brostoff, personal observation). At least twice we have observed green, presumably chlorophyllous, matter within the surficial black layer at White Sands Missile Range in New Mexico (Lichvar and Sprecher 1998). Akili and Torrance (1981), for continental sabkhas on the Arabian Peninsula, report a similar layering of fine-grained wind-blown sand and cemented gray mud. These independent observations of organic matter layers in the surface soils of playas and playa-like entities from different parts of the world show the utility of this process for identifying seasonally wet areas in arid regions. Most environments in the arid West promote rapid decomposition of organic matter, so accumulation of organic layers should in theory be a reliable indication of unusually wet conditions. We are not aware of quantitative hydrologic monitoring along drainage catenas, however, to determine how long the soil must remain wet in order for such layers to accumulate.

Iron segregations

Most hydric soil determinations in the United States are based on the process of soil iron segregating under low redox conditions into areas of iron depletion (gray mottles or gray matrixes) and iron concentration (orange mottles). This process operates more readily under acid than alkaline conditions and also requires an active microbial community supported by moderate to large

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* Personal communication, Wade Hurt, USDA NRCS, Gainesville, Florida, 1996.

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amounts of labile organic matter. These conditions exist in most wetlands; they do not in playas in the arid West because organic matter contents are low and pHs are high. Therefore, the standard hydric soil indicator is of little use in identifying OHW levels in playas. The NRCS hydric soil indicator described above includes provisions for iron concentrations within a soil matrix that is dominantly depleted of iron. This indicator was written for vegetated rims of playas rather than unvegetated centers.

A review of the soil series descriptions of Aquisalids (salt-enriched desert soils with wetness problems) shows that iron concentrations are present in several series, but at the bottoms of the profiles rather than the tops (Boettinger 1997). Iron reduction occurs more readily at low pHs than at high. Indeed, at pH 7.9, ferric hydroxide ($Fe[OH)]_3$) does not reduce to soluble ferrous iron but rather to siderite ($FeCO_3$), and then only at very low redox potentials (McBride 1994). Given the low quantities of organic matter in most playa soils, iron reduction is unlikely to be very common near the soil surface, and indeed has not been found to be a useful indicator in unvegetated areas. Experience at White Sands Missile Range has shown that presence of iron concentrations as an indicator need not be confined to matrix chromas of 2 in all playa systems. The gypsiferous playas of that installation occasionally had 2.5Y to 10YR 5/3 matrixes with 7.5 to 10 YR 5/4 to 5/6 concentrations, so rules may have to be tailored to locally unique environments. In the gypsum-rich playas of White Sands Missile Range, iron concentrations were more often lacking than present. Work is under way in eastern Oregon to determine whether small Fe/Mn nodules in playa soils may result from reduction processes (Clausnitzer and Huddleston 1998).

Salt crystals

Salt crystals are present in the upper soil horizons and on the soil surface in some playas. There are two kinds of information that can be inferred from salt crystals: relative strength of destructive forces acting on the playa surface, and duration of hydrologic input relative to other parts of the playa. Unfortunately, absolute lengths of time for crystal growth and destruction have not been determined. Therefore, use of salt crystals for OHW determinations will infer only time scales relative to other places on the playa and not infer absolute durations of growth or erosion.

The presence of delicate salt crystals on the playa surface indicates that it has been inundated relatively recently. Erosive forces destroy fine-textured crystals if they are exposed very long without continued nourishment from subsurface waters. Quantitative rates of destruction have not been determined and depend on exposure to winds and load of eroding sands or silts within those winds, as well as rate of crystal regrowth. These cautions notwithstanding, common sense dictates that delicate crystals protruding into the air will not remain intact for years in desert environments; they must have formed relatively recently.

The use of salt crystals to infer relative durations of hydrologic input results from the relative solubilities of various crystal types. In general, playa carbonates are less soluble than playa sulfates, which in turn are less soluble than playa chlorides. As inundating surface waters evaporate, the mineral solutes become more concentrated and only the most soluble species will remain in solution. This results in concentric bands of calcium carbonates around the playa rim, gypsiferous minerals nearer the middle, and halite minerals in the center (Hunt 1966, Lines 1979). Accurate identification of individual mineral types requires use of laboratory equipment, but gross changes in mineralogy can be seen in the field. Since these different crystal morphologies often occur in concentric zones on the playa surface, it is reasonable to assume that the innermost zone was where water stood the longest and the outermost zone where water stood the least. However, the research has not been conducted yet to infer absolute durations of inundation associated with different crystal forms.

Crystals develop on playas from both surface and subsurface hydrologic inputs. Significant surface inputs to playas can often be determined by the shape of crystalline regions on the playa surface. Frequently, the playa surface will have faint zones of irregular shape that look like water has stood or flowed there because of microtopographic differences. This is strong evidence of inundation. Differences in subsurface inputs of saline waters will probably result in more diffuse boundaries between mineralogical zones.

Two other kinds of evidence for surficial inputs into salt playas are (1) thin, horizontal layers of mud in the upper part of the soil profile, and (2) solution cavities (Lowenstein and Hardie 1985). Inundating waters usually run off the surrounding landscape and carry fine silts and clays with them to the playa center. These fines will deposit as fine layers with each inundation event, with thicknesses on the order of mm rather than cm or dm. It may be necessary to inspect the top of the soil profile with a hand lens to find the mud layers.

Lowenstein and Hardie (1985) also described the micromorphology of halite crystals and layers in the soils of playas that inundate periodically. When these soils are viewed in thin section, and, less conspicuously, by hand lens, one can see mm-sized cavities (vughes) that result from dissolution of the halite mass. Individual crystals have rounded rather than sharp edges, and horizontal truncation surfaces can be seen where crys-

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tal morphology exhibits an abrupt change. Large-scale polygons (1 m [3.28 ft] or more in diameter) may also be present, with halite crystals actively growing around the raised polygon edges. Such features are strong evidence that the playa experiences contemporary inundation on a regular, though undetermined, basis.

Some highly saline areas form pressure ridges of salt crust where freestanding salt crusts may form “blisters” that rise above the ground surface to heights of 5–15 cm (2–6 in.). These cracked and broken crusts have an almost bubble-like, blistered appearance that may result from a combination of surface inundation and subsurface evaporation (Lines 1979). However, caution needs to be urged in interpreting hydrology from these blistered crusts, because they may form exclusively from subsurface transport via capillary and transpirative rise and subsequent precipitation. We have seen them near the Salton Sea, California, on sides of berms and phreatophytic mounds 50 cm (0.25 in.) above the elevation of possible flooding as well as on ground underlain by extensive networks of 4-ft- (1.22 m-) deep groundwater control tiles. Their surface extent is larger than that of likely inundation, so they must result in some places largely from capillary rise of salt-saturated water. Hunt (1966) also describes such blistered crusts among phreatophyte mounds in Death Valley, California.

Soil structure and texture

The difference between soft and hard playas can be considered a difference in soil structure, which in turn can be used to infer flooding regime because soft playas form above a vadose zone and groundwater, whereas hard playas form from inundation processes. The upper horizons of soft playas have strong, very fine granular structure, are loose, very friable, have low bulk density, and often contain many fine, white, needle-shaped salt crystals. The surface horizons of hard playas have massive to weak platy structure and are dense, very hard, and nearly impermeable to water infiltration. Indeed, the soil a few inches below inundated hard playas may be dry (Stone 1956, Lichvar and Sprecher 1996).

Playas usually have finer texture than the surrounding landscape, but textural differences themselves are not adequate to serve as “changes in the character of soil” for determining the OHW level (33 CFR 329.11[a][1]). Dunes on top of the playa, however, are likely to have coarser textures than the playa bed itself, allowing for exclusion from OHW delineations.

All of the above patterns may change as a result of inundation; wind-induced water motion is a particularly effective force in smoothing surficial features from playa surfaces. Even small amounts of water, such as that of a single rainstorm, may completely alter surficial patterns (Neal and Motts 1967); some playas demonstrate regular seasonality in their surficial characteristics (Langer and Kerr 1966). Interestingly, Motts (1972) suggests that the cyclic crust formation and subsequent wind erosion is responsible for the slow lowering of the surface of playas such as Rogers and Rosamond.

VEGETATION

The relation between vegetation and OHW on playas is tenuous and often confounded by many other factors. Although the occurrence and abundance of certain species of macrophytes is central to the methodology for delineating wetlands, this is not the case for playas because of the usual (if not defining) absence of vegetation, the spatially and temporally variable hydrology, and the influences of extreme salinity and aridity. Hydrophytic vegetation (*sensu* Tiner 1991) and the associated criteria for wetland delineation are defined in the *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) and subsequent guidance from the Office of the Chief of Engineers (1992, 1995). A national list of such species has been provided by the U.S. Fish and Wildlife Service (Reed 1988), the intent of which is to assist in locating jurisdictional boundaries of wetlands. The “indicator status” of plants is a fundamental factor in delineating wetlands. Because the ratings were developed for a wetland in the Cowardin classification and later adapted for a three-parameter wetland, there are instances in which the utility of the ratings breaks down and the presence of these plants is problematic in establishing evidence for both OHW and wetland boundaries. On-ground experience has shown that the reliability of wetland plant species indicator statuses along playa edges are compromised by the occurrence of halophytes and phreatophytes responding to highly saline soils and groundwater at depths greater than included in the criteria for wetland delineation. For example, Lichvar et al. (1995) discuss problems with iodinebush (*Allenrolfea occidentalis*), rated FACW (Facultative Wetland), on soft playas. At Dugway Proving Ground, Utah, this plant is a phreatophyte and occurs in areas that have neither evidence of ponded water nor hydric soil. It is assumed that its presence is related both to groundwater within 1 m (3.28 ft) or more (which is otherwise insufficient to produce a three-parameter wetland) and its ability to tolerate saline conditions.

Playas, particularly hard playas, are commonly devoid of macrophytes because of harsh physical conditions (compact soil, high salinity, and unpredictable cycles of inundated/dry conditions). There may be sparse growth on the playa edges and along drainage channels, small depressions in the playa surface, cracks (e.g., desiccation cracks) that have filled in, phreato-

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phyte mounds, and dunes on the playa surface. When vegetation is present along the edge of a playa, it is often found on coarse textured mounds (Blank et al. 1992) and varies from less than 1 percent to as high as 25 percent areal coverage (Barbour and Billings 1988) with a low species diversity. The macrophyte species found on soft and hard playas differ greatly, although the central portions of both are devoid of vegetation. In general, plant communities on hard playas vary from xerophytic vegetation, which is stunted and shrubby compared to its conspecific upland counterparts, to halophytes of the alkaline sink scrub vegetation type. In contrast, soft playas are more typically vegetated with succulent chenopodes (e.g., *Allenrolfea occidentalis* [Stone 1956, Lichvar et al. 1995]) of the alkaline sink scrub. The dominant vegetation of many of the playas in southern California is enumerated by Stone (1956).

The vegetation found on and around playas (as well as in some similar habitats) has been classified as "alkaline scrub" by Thorne (1976) and generally consists of scattered scrub of halophytic plants mostly in the Chenopodiaceae. On occasion, representatives of the Asteraceae, Brassicaeae, Fabaceae, and Poaceae are found, but none are dominants (Barbour and Billings 1988). Barbour and Billings (1988) also state that about 20 percent of this vegetation type consists of mosaics of monocultures of single-perennial-species dominance. These habitats are typically described as poorly drained, heavy soils, usually with an underlying hardpan, of mesas, flats, playas, and sinks located throughout the Great Basin, Death Valley, and Panamint Deserts, Owens Valley, and the Great Central Valley. This classification unit may be further broken down: (1) Shadscale scrub—generally *Atriplex confertifolia*, which dominates alkaline, heavy soils, usually with a shallow hardpan. Associated plants are low and shallow rooted and include *Grayia spinosa*, *Ceratoides lanata*, *Haplopappus acradenius*, *Kochia california*, *Artemisia spinescens*, *Mendora spinescens*, *Gutierrezia sarothrae*, and *Coleogyne ramosissima*. (2) Alkalai sink scrub—A suite of species lower and more sparse than shadscale scrub generally found over playas, alkaline flats, and dry lakes where there is little drainage. Chief species include *Atriplex* spp., *Salicornia subterminalis*, *Suaeda fruticos*, *S. torreyana*, *Sarcobatus vermiculatus*, *Allenrolfea occidentalis*, and *Nitrophila occidentalis*. (3) Alkalai meadow and aquatic—This group consists of halophytic species that grow in alkaline soils where springs and seeps maintain meadows, pools, and small lakes. Representatives include *Distichlis spicata*, *Muhlenbergia asperifolia*, *Phragmites australis*, *Sporobolus airoides*, *Juncus cooperi*, *J. mexicanus*, *Scirpus nevadensis*, *S. americanus*, *S. paludosus*, *Allenrolfea occidentalis*, and *Anemopsis californica*.

Phreatophyte mounds, as found on and adjacent to many playas (Neal and Motts 1967), are raised accumulations of soil and vegetation, ranging in height from 1 to 5 m (3.28 to 16.40 ft) and having a 2- to 10-m (6.56- to 32.8 ft-) circumference, which protect the plants from adverse effects of flooding. These are found on and adjacent to many playas. Phreatophyte mounds are formed when wind-blown sand and silt accumulate around a phreatophyte growing at the level of the playa surface and build successively upward. Pioneer plants such as *Kochia californica* or *Suaeda fruticos* may be initial colonizers; as aeolian material develops around them they may be replaced by *Atriplex torreyi*, *A. confertifolia*, or *Haplopappus acradenius* as the mound increases in size (Vasek 1983). Concentric cracks, or ring fissures (Cooke et al. 1993), similar to desiccation cracks in the playa surface, may form around these mounds after desiccation or lowering of the groundwater level. Lines (1979) similarly reports that on otherwise puffy ground, hard, compact areas may form around iodinebush (*Allenrolfea occidentalis*) because of the reduction of groundwater level. Such mounds have finite life expectancies; as the mound accumulates aeolian sediment and increases in height, the distance over which roots can extract groundwater is surpassed and the plants die. Following plant death, the mound may erode. Neal and Motts (1967) suggest that surface flooding accelerates the erosion and destruction of these mounds. Unfortunately, no data exist on the relative numbers or extent of phreatophyte mounds, associated cracks, or erosion rates on inundated vs. noninundated portions of playas. Further, the location of the wetland boundary is distorted by the occurrence of phreatophytes because these FACW species typically seek out groundwater from up to 1 m (3.28 ft) or more in depth (Hunt 1966, West 1983), which is a depth greater than required to meet wetland hydrology criteria.

Hydrology/vegetation interactions

While a considerable body of literature exists on a range of topics relating to vegetation around playas (taxonomy, biogeography, physiological ecology—including drought and salinity tolerance), there appear to be no studies of use vegetation in predicting playa areas that are intermittently inundated. Some anecdotal information exists on the relationship between vegetation and areas that flood periodically. For example, Went and Westergaard (1949) describe vegetation of hard and soft playas in Death Valley, California, after inundation (see Table 1). West (1983) provides mutually exclusive species lists of plants in "lowland" (free water table at least occasionally present at the surface) and "upland" (water table > 1 m [3.28 ft] below surface) salt-desert habitats (Table 1). The lowland group of species is mostly rated as Facultative Wetland (FACW) (Reed 1988) and is dom-

Table 1. Summary of selected specific reports on possible OHW and/or wetland indicators on playas and some annotated references.

Reference	*Focus of paper and possible indicator type*	*Geographic location*	*Summary of findings as potential indicator*
Blodgett and Williams 1990	Hydrology	Rogers Playa, California	Lakebed flooding from a 2.54-cm rainfall in 1983 drained into fissures and sink-like depressions within 24 hours.
Clarke 1979	Surface type	Coyote and Mesquite Dry Lakes, California	Both were intermittently inundated. Coyote Dry Lake demonstrated desiccation fractures and polygons that "healed" after rewetting or infilling. Following heavy rainfall, flooding, and drying in 1976, fissures up to 5 m deep, 2 m wide, and 500 m long appeared at Mesquite Lake.
Dahlgren et al. 1997	Soil, hydrology, vegetation	Owens Lake Playa, California	Roots of *Distichlis spicata* were concentrated at 10–40 cm and not deeper than 70 cm; groundwater depth was 95 cm. Anoxic conditions (as indicated by black soil layers) were present to within 60 cm. Some *D. spicata* roots and rhizomes with an oxidized rhizosphere were found penetrating ~10 cm into the anoxic soil zone.
Dinehart and McPherson 1998	Hydrology	Rogers Playa, California	A storm of 2.3 cm in Feb 1996 caused a 30.5- to 91.4-cm-deep flooding that evaporated over a one-month period.
Hunt et al. 1966 (and references cited)	Surface type	Death Valley, California	Inundation/drying is the major cause of patterned ground. However, the extent and development is proportional to salt content of soil. Polygons, generally four- to six-sided, are reported up to 10.7 m in diameter.
Hunt et al. 1966 (and references cited)	Surficial characteristics, patterned ground	Death Valley, California	<u>Lowest places (where water collects):</u> Salt crust 2.5–30.5 cm thick, complex pattern of polygons (slabs 30.5–61 cm in diameter, blisterlike forms 15.2–30.5 cm wide, arching over 2.5–5 cm high, and superimposed nets formed of irregular low hummocks. Mud below the salt may remain wet between successive flooding. <u>Frequently flooded</u>: Efflorescence of salts 1–2 mm thick. Patterns vary depending on salt content and length of inundation. <u>Intermediate flooding frequency:</u> Persistent desiccation cracks (polygons), more salt accumulation than frequently flooded areas or lowest places. <u>Infrequent flooding:</u> Netlike patterns.
Lichvar et al. 1995	Soil	Dugway Proving Ground, Utah	Soils of hard and soft playas were indistinguishable except for bulk density and the more friable consistency in the upper 30 cm of the soft playas.
Lines 1979	Vegetation	Bonneville Salt Flats and Pilot Valley Playa, Utah	*Allenrolfea occidentalis* grows along the margins of playas, on playas on phreatophyte mounds, and in channels in the playa up to 1.6 km beyond its "normal" distribution. It is normally limited to areas that contain brines less than 100,000 mg/L chloride; their distribution in channels is thought to be due to freshwater intrusion and subsequent brine dilution during rain, ameliorating effects of high salinity.
Lines 1979	Vegetation	Bonneville Salt Flats and Pilot Valley Playa, Utah	Phreatophyte mounds are more common on the soft- than hard-surface type.
Lines 1979	Classification	Bonneville Salt Flats and Pilot Valley Playa, Utah	The soft, puffy surface is most commonly found near the edges of playas where there is no flooding by surface waters except in distributary channels. These become wet at the surface only after rain or snow. The smooth, hard type most commonly occurs between the puffy type and the sulfate zone.
Lines 1979	Surface indicators	Bonneville Salt Flats and Pilot Valley Playa, Utah	As the surface dries, small desiccation polygons 5.1–15.2 cm across form. If there is no rain over a period of 2–3 weeks during the summer, a white salt forms on the surface. These desiccation polygons and salt coating disappear with only a small amount of precipitation.
Lines 1979	Surface indicators	Bonneville Salt Flats and Pilot Valley Playa, Utah	A thin salt crust developed by evaporation of surface brine that flooded parts of each playa during Oct 1975–May 1976.
Motts 1972	Surface type	Panamint Playa, California	A single flood event (1966) converted the soft type into hard; by the following winter, the surface had large areas of the soft type again.

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Table 1 (Cont'd).

Reference	*Focus of paper and possible indicator type*	*Geographic location*	*Summary of findings as potential indicator*
Motts 1972	Secondary	Rogers Playa, California	By Jan 1967, a shifting of water back and forth was effective in smoothing out 7.6- to 10.2-cm-deep ruts made by a B–52 aircraft the previous September.
Motts and Carpenter 1970	Soil	Rogers Playa, California	Each flood deposited a thin sedimentation unit that in many places graded from sand and silt near the base to clay near the top. (These in turned formed mud curls on drying.)
Motts and Carpenter 1970	Surface type	Rogers and Rosamond Playas, California	Both playas, which are subject to fairly regular seasonal flooding, may show a change in basic surface type from one year to the next. After flooding, a range of surface types (including a "puffy surface" dissimilar from coarse-grained puffy surfaces) was transformed into a mud-curl surface. Rosette patterns were also seen on flooded areas that underwent freeze–thaw cycles. Also reported on the north western part of Rosamond Playa was a "wavy, undulating" surface with a microrelief ranging from 0.6 to 1.3 cm. It was broken by irregular "zigzag" polygonal cracks 30.48–76.2 cm across, through which groundwater discharge occurred.
Neal 1965	Hydrology	Silver Lake, California	Contained water for 18 months (during 1938); maximum pan evaporation was 2.6 cm per day.
Neal 1965	Hydrology	Indian Springs, Nevada	Flooded to a depth of 45.7 cm on 21 Sep 1963; completely evaporated by 20 Jan 1965.
Neal 1968	Surface type	Harper Lake, California	After flooding during the winter of 1965–1966, the surface, which was the soft type, became the hard type. By 1967, some portions of the surface were reverting to the soft type again (in the absence of flooding).
Neal 1975	Textbook treatment of playas and dry lakes	—	
Neal and Motts 1967	Surface type	South Panamint Playa, California	The salt-encrusted area of the playa increased at the expense of other surface types.
Neal and Motts 1967	Surface type	Troy and Coyote Playas, California	Soft, puffy, porous surfaces changing to hard, dry compact surfaces depending on temporal changes in moisture.
Neal and Motts 1967	Surface type	Harper, Troy, and Coyote Playas, California	Many playas that have predominantly soft, puffy, porous surfaces will have hard, dry compact areas in the washes draining into the playas.
Stone 1956	Overview of geomorphology and natural history of many of the southern California playas (Ph.D. dissertation)	Southern California	—
Went and Westergaard 1949	Vegetation	Death Valley	Where groundwater or flooding reaches the surface, *Distichlis spicata*, *Allenrolfea occidentalis*, *Juncus cooperi* grow.
Went and Westergaard 1949	Vegetation	Death Valley	Where the water table is only occasionally at the surface, the following grow (in addition to above): *Sacrobatus vermiculatus*, *Salicornia utahensis*, and *Suaeda torreyana*.

inated by phreatophytic species similar to those reported by Hunt (1966) in Death Valley, while the upland group is dominated by upland species. In contrast to the playa surface proper, the areas around playas are often vegetated; sometimes this vegetation can be characteristic of playa edges. But a gradient does exist between the occurrence of halophytic and xerophytic vegetation. Barbour and Major (1990) report succulent chenopods such as *Allenrolfea occidentalis*, *Nitrophila occidentalis*, *Salicornia subterminalis*, *Suaeda* spp., and *Sarcobatus vermiculatus* as representatives of playa edges. They also report that, farther away from the playa edge, other species of xerophytes increase in occurrence until eventually the halophytic shrub zone is replaced by xerophytes or whatever other community occurs in the region around playas. For Mojave Desert playas, Thompson (1929) observed what he called a characteristic vegetation around the border of

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playas in instances where the water table was high; where the water table was low, the nearest vegetation to the playa was on alluvial slopes. Lichvar et al. (1999) reported a narrow seasonal band of "pseudohalophytes" composed of annual vegetation from Deadman Dry Lake, Twentynine Palms, California.

The causal factor in the apparent negative association between many species of desert plants and flooding is problematic; further, the degree to which desert vegetation provides information helpful in identifying inundated areas is unknown. Dobrowolski et al. (1990) reviewed plant responses to soil saturation and flooding in desert systems. They cited studies of plants such as creosote bush, big sagebrush (*Artemisia tridentata*), and green rabbitbrush (*Crysothamnus nauseosus* ssp. *viridulus*), which quickly succumbed to experimental flooding and to elevation of the water table to a 10-cm (4-in.) depth, presumably because of anoxia adversely affecting their roots. They noted other species tolerant of flooding: *Atriplex torreyi* and greasewood (*Sarcobatus vermiculatus*). While the latter could not survive six-month or longer inundation, the former pair could. The authors of the review expressed surprise at these results since greasewood is commonly considered to be a phreatophyte and tolerant of high water tables, whereas saltbush and rabbitbrush are thought to have more xeric-adapted ancestry.

In perhaps the work of most direct application to playa delineation, Ganskopp (1986) followed population responses (big sagebrush, green rabbitbrush, and greasewood) to inundation and groundwater level at varying elevations above the water level. Leaves of all three species perished immediately upon inundation. Big sagebrush and green rabbitbrush were intolerant of either any inundation or water tables within 10 cm (3.93 in.) of the surface. The former died soon after surface inundation, the latter tolerated surface flooding for up to one week. Greasewood tolerated surface flooding for 40 days. In a study of vegetation patterns on an Owens Lake playa (California), Dahlgren et al. (1997) reported that the ultimate limitation to plant distribution is shallow anoxic groundwater restricting rooting depth.

The vegetation of playas under consideration here differs markedly from that of other areas; the playa lakes of western Texas have suites of characteristic vegetation, some species of which may not be found elsewhere (e.g., Reed 1930).

BIOTIC SOIL CRUSTS

Much as variations in the species abundance and diversity of macrophytic vegetation may be used as indicators of certain environmental conditions, microbial communities can as well. Distinct small-scale surface zonation of desert bacterial and algal species has been documented across moisture and other environmental gradients in some field studies and in laboratory studies. Surface films of *Microcoleus* sp. (a crust-forming blue-green alga) have been reported on the mud at Racetrack Playa, California (references cited in Stone 1956), and several related species have been reported on other playas (Brostoff et al. 1996, Brostoff 1998). Further, the presence of microalgae remnants such as Phacotus in cores is associated with the presence of standing water in the recent geologic history of playas (Enzel et al. 1992).

Biotic crusts have been used as possible positive and negative indicators for WoUS (Lichvar and Sprecher 1996) in southern California, and crust types and presence have been shown to be related to inundation cycles in Canadian playas (Renaut 1993). Further, for vernal pools in California, Riefner and Pryor (1996) report concentric distribution of the same crusts as occur in many playas, and speculate that the organisms and crusts they produce would be useful for delineation.

Although biologically induced soil crusting has been documented in the technical literature for nearly 100 years, only in the past few years, with a recognition of the importance of their ecological function, has it been given attention (Johansen 1993). These crusts, which in very arid areas may replace macrophytes as dominants, are referred to as cryptobiotic, cryptogamic, algal, microphytic, cyanobacterial, microfloral, or biological crusts. Cryptobiotic crusts are water-stable soil aggregates held together by algae, fungi, lichens or mosses, and the substances they produce. As a group they are characterized by generally darker coloration and greater adhesion than crusts formed strictly by physical and chemical processes. Johansen (1993), in a review article, mentions three common forms of cryptobiotic crusts: 1) smooth and flat forms dominated by algae, 2) rough, uneven crusts dominated by lichen, and 3) pedicled algal and algal–lichen crusts. The first form is found typically in areas of ephemeral ponding and may or may not develop into the other two forms; the lichen crusts usually occur on silty, often saline soils; the last form is common in pinyon–juniper and sagebrush communities. Among the organisms comprising these crusts are blue-green algae, green algae, diatoms, euglenas, lichens, fungi, mosses, liverworts, and bacteria. They are a biologically diverse assemblage showing high spatial and temporal variation. Several species of cyanophytes are common in these crusts, but they are most often dominated by the filamentous blue-green alga *Microcoleus vaginatus*. Other typical genera include *Phormidium*, *Plectonema*, *Schizothrix*, *Nostoc*, *Tolypothrix*, and *Scytonema*. In some soils with a high concentration of gypsum, diatoms may dominate.

Crust types have been broadly classified into two

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ecological groups, “upland” and “aquatic remnant” crusts (Brostoff 1998). The upland crusts (corresponding to the rough, uneven crusts and pedicled crust types of Johansen) occur predominantly on dunes, alluvial slopes, and other areas that do not pond water. The dominant constituent species (*Microcoleus*, lichens, mosses) of these crusts are often destroyed or at a competitive disadvantage when submerged even for short periods. However, these crusts are frequently most abundant on nonponded areas adjacent to areas that do pond based on a study of a playa–dune system in California (Brostoff 1998). Thus, based on both documented biology and empirical evidence, the upland crusts may be used as negative evidence for protracted periods of standing water.

The aquatic remnant crusts form in areas of previously standing water (Fig. 5). Although relatively little attention has been paid to them, they may be dominated either by bacteria or by one or more species of algae—usually the same ones that are found in the upland crusts (Brostoff et al. 1996, Brostoff 1998). These crusts range from beige or brown to red in color, sometimes with a distinct green cast on their underside. The darker colored crusts are more often dominated by algae; based on very preliminary laboratory results, it is thought this darkening is an extracellular algal product (an extracellular polysaccharide or possibly a pigment). The crusts range from 1 to 2 cm (0.39 to 0.78 in.) up to 15 cm (6 in.) across and from <1 mm (0.039 in.) to a few mm thick. The thinner crusts characteristically show upturned edges. The surface may be smooth, or show rosette or mesh-like patterns with units roughly 100 μm (0.0039 in.) wide by 1 mm (0.039 in.) long. These patterns may appear as impressions in the surface, old algal sheath material, or algal filaments. Based on laboratory observations (Brostoff and Rundel 1998), the patterns, when present, are evidence of ponding; however, smooth-surfaced crusts are not necessarily negative evidence. Crust formation has been followed for two wet–dry cycles at Edwards Air Force Base, California (EAFB), and there is good correspondence between areas of flooding during the wet season and presence of aquatic remnant crusts during the dry season (Brostoff 1998, and unpublished observations). During the season, the crusts may decrease in width (i.e., fracture into smaller pieces) and, during dry periods, blow away (Fig. 5b, c). This wind erosion is exacerbated by anthropogenic disturbance (Brostoff 1998). Some crusts (predominantly the algal rather than bacterial-dominated ones) appeared to remain stable for several years. Although formal laboratory comparisons were not performed, there were no apparent macroscopic differences between recently formed crusts and those which remained dry over one inundation period.

On rare occasions the crust types intergrade. Crusts with characteristics of both upland and aquatic remnant types have been reported on soft pans between dunes situated on a larger playa at Edwards Air Force Base (Brostoff 1998). The crusts in question were smooth and thin and had upturned edges and conspicuous black areas on a light gray background. Normally, these pans do not become inundated, but may remain moist for protracted periods of time because of discharge of water from surrounding dunes (possibly analogous to groundwater seepage). During periods of heavy rainfall they do pond. Similar crusts have also been seen in Utah and New Mexico, and have been produced under laboratory conditions (Brostoff, personal observations).

Along playa/dune isoclines, the crust types may be either adjacent or disjunct in distribution (Brostoff 1998) (as in the transition shown in Fig. 3b). Locations where upland and aquatic remnant crust types were found adjacent were those where water levels were adjacent to dunes. Those locations with disjunct distributions represent instances where maximal water levels were well below the level of dunes. Further, the most conspicuous upland crust formation was adjacent to areas that ponded for the longest periods of time.

The use of crusts for retrospectively determining the OHW mark is promising. Current work at ERDC and EL on both restoration and modeling crust-dominated ecosystems will yield results applicable to delineation in two areas: (1) understanding the relationship between moisture and crust formation and (2) differentiating causal factors in algal-dominated vs. bacteria-dominated aquatic remnant crusts. At least at present, because the relation between crust characteristics and inundation is probably site specific, conservative predictions of OHW from crust presence should be based on local knowledge. Ideally, some local crust formation should be observed such that it can be unambiguously linked with the presence of water. Another caveat is that crusts may blow away, so the absence of the aquatic remnant crusts should not be used as negative evidence for OHW.

Diatoms, in addition to being a crust component, may be found among playa sediments (Busch and Kubly 1980). Because of the high turbidity, diatoms are not able to live in playa waters. Two other potential habitats for diatoms exist around playas: (1) the aerial habitat, or “dry soil,” which is populated by ubiquitous soil diatoms such as *Navicula* and *Hantzschia*, and (2) moist to wet areas around the margins of standing water populated by a group of diatoms often found around lake edges, including *Achnathes*, *Denticula*, *Epithemia*, *Gomphonema*, and *Meridion* (Busch and Kubly 1980). However, using species assemblages to demarcate the border between inundated and non-inundated areas

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a. Typical algal crust on a hard playa. The first algal crust formed after evaporation of surface water (dark gray) is one coincident with the polygons subtended by the larger cracks (black) below. With time, the first-formed algal crust breaks down into smaller crusts ("flakes") as evident above.

b. Closeup of algal crusts. The crust has broken into smaller flakes and been removed.

c. Algal crusts in 5-ha hard playa. Note the conspicuous curling and layering (darker upper/ inner surface), both of which indicate previous inundation.

Figure 5. Algal crusts.

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may be complicated first by the fact that the dry soil assemblage is stimulated by moist conditions, and second, that wind can blow diatoms in and out of areas, potentially causing unrepresentative assemblages in the sediment. Further, although Busch and Kubly (1980) examined the diatom flora of 10 playas from around southern California and found from three to twenty species in each, in algal floristic work that included playas of Edwards Air Force Base, only a single diatom was found (Brostoff et al. 1996, Brostoff 1998). Thus, there is a potential technical basis for using diatom species assemblages to delineate WoUS on playas (based on identifying previously moist areas); however, some effort would need to be devoted to development of protocols.

OTHER BIOTIC INDICATORS

The presence of desert shrimp remnant adults or eggs has potential for being an indicator of previously standing water. Several species of desert shrimp (branchiopod crustaceans) are characteristic of playa habitats in playas in the southwestern United States. Two factors make them potentially useful for delineation. First, their eggs remain viable just below the surface, usually in the top 5–10 mm (0.195–0.39 in.) of surface crust (Brown and Carpelan 1971), for at least several decades, but hatch and complete their life cycles quickly after inundation. The presence of eggs can be determined quickly and easily by immersing a small quantity of substratum into water and counting hatchlings after a few days or by sieving suspect substratum (e.g., Brown and Carpelan 1971). This method has been used to compile species lists and quantitatively estimate abundance in particular areas (e.g., Sassaman 1998). Many species of these organisms are characteristic of playa habitats throughout the arid areas of the western United States (Eng et al. 1990; Belk and Brtek 1995, 1997; Eriksen and Belk 1999). The species composition of collections made in a particular location is dependent on a suite of factors (e.g., duration of inundation, water temperature, water chemistry) that are of potential use in establishing the extent and duration of inundation as might be useful for performing delineations (Gallagher 1996, Hathaway and Simovich 1996).

In a delineation of WoUS at the Marine Corps Air–Ground Combat Center, Twentynine Palms, California, shrimp were found outside the area classified as WoUS in only one instance (Lichvar and Pringle 1993). It has not been established whether eggs have been found in areas that do not pond water. Second, the remains of adults or their impressions may remain in the surface after drying. In a detailed survey of 0.25 km^2 (2.69 ft^2) of mixed playa–dune habitat near Buckhorn Playa, California, Brostoff (1998) encountered a few square meters with distinct desert shrimp remnants in the surface crusts (Fig. 6). At the same site, desert shrimp hatched in the laboratory from virtually all collections of playa surface material (Sassaman 1998).

Figure 6. Desert shrimp remnants embedded in soil algal crusts from a small playa at EAFB (larger tic marks are cm).

REMOTE SENSING

Very little remote sensing work has been published specific to playas. Drake and Bryant (1994) used Advanced Very High Resolution Radiometer (AVHRR) imagery to determine the flooding frequency of a set of Tunisian playas. Henley (1988) reports some success in estimating relative moisture conditions using reflectance spectra from remote sensing. On dry playas, the reflectance in the 2100-nm band is equal to or greater than the reflectance in the 1650-nm band. For permanently or intermittently wet playas, the 2100-nm band reflectance is lower than the 1650-nm band. Kokaly et al. (1994) discussed the application of AVIRIS (Airborne Visible Infrared Imaging Spectrometer) to mapping cryptobiotic crusts and the advantages of this method over others (e.g., NDVI [Normalized Difference Vegetation Index]) in arid areas. Because of the probable spectral differences between aquatic remnant crusts—both algal- and bacterial-dominated and adjacent substratum types—it is possible that remote sensing protocols could be developed.

CURRENT PRACTICE BY CORPS DISTRICTS AND OTHER FEDERAL AGENCIES

A telephone survey of Corps District and field offices with playas that might include WoUS was conducted during July and August 1998. The personnel with responsibility for delineations were identified in Los Angeles, Albuquerque, Fort Worth, Sacramento, and Portland Districts, as well as other Federal agencies with

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jurisdiction (Bureau of Land Management [BLM], NRCS). To the extent possible, all relied on the presence of water as a primary indicator, and best professional judgement incorporating drift lines, aerial photographs, USGS maps, and anecdotal evidence by local experts. Albuquerque district used crusts (presumably both biotic and non-biotic) as well. Sacramento district incorporated evidence of wildlife use as well as a transition from *Salicornia* and other halophytes to unvegetated surfaces.

CASE STUDIES

Edwards Air Force Base, California

Major playas include Rosamond, Buckhorn, and Rogers (Lichvar and Sprecher 1996, Brostoff et al. 1996).

A stepwise process was used to distinguish between wetland, non-wetland WoUS, and unregulated areas: 1) determine if the area had one or more primary indicators of OHW developed for the area; 2) areas lacking a primary indicator were eliminated from further consideration as a WoUS; 3) areas having a primary indicator were evaluated for indicators of a three-parameter wetland. If not, the area was determined to be a WoUS. The delineation also involved development of a range of evidence for indications of OHW described below.

Identification and calibration of surficial indicators was predicated on analysis of precipitation records from 1941 to 1995 and aerial photographs from April and August 1992. The former set of photos corresponded to a rainfall history at the 95th percentile level, the latter to a 50th percentile level. OHW determinations were made by compiling and then evaluating the surface characteristics of the playas and dry washes. Ponded water and the potential indicators that developed after drying were followed over several months. Indicators were then assigned a rating of primary, one that is consistently reliable for assessing the location of OHW in the field at EAFB; and secondary, for those indicators that were either less reliable or found occasionally in upland landscape positions. Traditional indicators, such as drift lines, were used in addition to unconventional indicators. These included features that had been documented in the geomorphic literature as indication of previously standing water: mud crack styles, reddish-brown stains, and biotic crusts. Considerable attention was paid to the nature of soil crusts; while a few specific crust types were consistently associated with standing water, both bacterial- and algal-dominated crusts occurred in previously inundated areas. The black, pedicled, cryptobiotic crusts were negatively associated with standing water. (Note that in later work Brostoff and Rundel [1998] and Lichvar [personal observation] found rare occurrences of black crusts in areas that ponded water only during exceptional years, such as the El Niño period of 1998.)

Dugway Proving Ground, Dugway, Utah

Because areas of the playa (Lichvar et al. 1995) known to become inundated generally lacked one or more of the three parameters of a wetland, the OHW line was used to determine jurisdictional limits. OHW was determined by ponded water or combinations of other indicators, including mud cracks; drift lines; phreatophytic vegetation; topography; salt crusts; and color, bulk density, and texture of the soil.

Primary indicators

- Ponded water was used as a primary indicator.
- Drift lines composed of various types of debris material, which were generally observed only in localized areas and not as a continuous feature around the playa boundary, were also used as evidence of previously ponded water and thus the OHW boundary.
- The landscape in pre-defined sampling areas was evaluated for its potential to pond water; those zones that were flat and not drained by intermittent channels were assumed to pond water. This was broadly verified by the observation that ponded water was frequently observed in flat areas with a hard, gray aspect. Similarly, because surface water was observed inside drainage areas on the playa, these drainage areas and depressions were rated as reliable indicators. Sloped and highly eroded areas at the edge of or within the playa itself were excluded.
- Soils with moist matrix colors of 10YR 7/1 to 8/2 and high silt contents were found only in the playa.
- Low bulk density soils were found only on soft playas and thus used as a negative indicator of inundation.

Secondary indicators

(1) Mud cracks ranging from polygonal to open and lined were common. The former type was observed in the presence of ponded water and soil mottles; the latter type was interpreted as occurring near the edge of the OHW. (2) The unvegetated areas between mounds of phreatophytic vegetation (*Allenrolfia occidentalis*) were assumed to pond water. (3) Because the origin of salt crusting is ambiguous it was rated as a secondary indicator. (4) Soil texture is a negative indicator in that soils with high sand content (>50%) were not found on the playa except as nonjurisdictional sand dunes.

Twentynine Palms

The largest playas on the base at the U.S. Marine

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Corps Air–Ground Combat Center [MCAGCC], Twentynine Palms, California (Lichvar and Pringle 1993), are Deadman Lake, Dry Lake, Emerson Lake, Lavic Lake, and Mesquite Lake. They range in size from about 70.82 to 1092.65 hectares (175 to 2700 acres).

None of the playas on the MCAGCC were three-parameter wetlands, so the OHW line was used to determine the limits of jurisdiction. Ponded water and other indicators, including mud cracks, drift lines, vegetation, topography, and soil texture, were used to establish the OHW line. Other indicators included ruts made by off-road vehicles (ORV) during previous wet periods. The latter indicators were observed at the edge of ponded water and were applied elsewhere after the water had receded. Interestingly, the soft playas (nonjurisdictional) were found neither to pond water nor to have groundwater closer than 1 m (3.28 ft) from the surface.

Fort Bliss, Texas, and New Mexico (FBA)

The playas at FBA (Lichvar and Sprecher 1998) generally lacked one or more of the three parameters of a wetland; consequently the OHW line was used to determine the limits of jurisdiction. Ponded water and other indicators of hydrology were used to establish the OHW line; other indicators included mud cracks, drift lines, algal crusts, and soil surface features. Secondary indicators included hummocks, which develop as a result of moist soil processes; and the presence of Cow Pan Daisy (*Verbesina encelioides*), which is common on the pans. Gas holes (a surface collapse feature described by Stone [1956]) were located on the surface of the playas along with other indicators of ponded water. These were typically 0.3048–0.4572 m (1–1.5 ft) across and 15.24–30.48 cm (6–12 in.) deep. They are reportedly found on other playas in the southwest as well.

White Sands Missile Range (WSMR), New Mexico

A number of site-specific indicators for OHW were developed (Lichvar and Sprecher 1999). Ponded water and other indicators (mud cracks, drift lines, algal flakes, soil surface features, flow channels, sulfur stained surfaces, and bed and bank morphology) were used to determine OHW. Primary indicators were as follows:

- Surface colors or blotches of black, green, or gray, often accompanied by an odor of H_2S. Some of the pans and playas have a high content of gypsiferous material; as a result of shallow ponding, it is assumed sulfur is being reduced and creating colored streaks or blotches.
- Iron segregation. Redoximorphic segregation features develop under aquic conditions because of chemical reactions in the soils; while the segregation of iron was not prominent, the authors felt it represented strongly reducing conditions.
- Domed mudcracks with algal flakes. This feature was observed at WSMR and other areas of the desert southwest with prolonged water ponding.
- Oxidized rhizospheres in sparsely vegetated areas.
- Ponded water (in OHW definition).
- Drift lines (in OHW definition).
- Smooth, gray, level surface on playa or pan. A smooth level surface is associated with ponded surfaces. The gray tone is associated with reduced surface conditions resulting from ponded water.
- Mud cracks filled with wicked salt (on alkali flats). In areas where water ponds the longest, zones of mud cracks with salt crystals protrude about 1 to 2 cm (0.39 to 0.78 in.) above the surface.
- Polygonal patterns in salt pan surfaces filled with protruding salt crystals to heights of 1 to 3 cm (0.39 to 1.18 in.).
- Rubberized surface (on alkali flats). In depressional landscape positions within the alkali flats, cryptobiotic soil surfaces have a rubberized texture.

Secondary indicators included

- Thematic Mapper (TM) satellite image with areas of ponded water combined with a level, smooth surface.
- Sloped pans. Sloped, flat surfaces located downslope of dune fields had pans that were unvegetated and lacked hydric soil indicators, but were moist in the upper 15.24 cm (6 in.) of the soil without immediately preceding rains.
- Unvegetated landform (on dry lakes). The dry lakes scattered throughout stabilized dune areas were a depressional landform feature typically devoid of vegetation due to high salt content soils and seasonal ponding.
- Patterned ground (on salt pans). Large mudcrack polygons scattered across the salt pan surface.
- 10YR 5/3 streaks and blotching on salt pans. In these high-salt-content soils, these faint iron segregations indicated seasonal fluctuation of near-surface groundwater.
- Large salt crystals (restricted areas). Soil profiles with salt crystals greater than 2 mm (0.08 in.) at an occurrence of 5% or more have been observed at sites with saturated soils during wet seasons.
- Raised and mounded rings (on alkali flats).

Sierra Army Depot, Nevada

Basic assumptions for indicators were made as follows (Doub and Colberg 1996): For vegetation, salt grass was regarded as “facultative” for playa edge—growing inside and outside of playa boundaries. *Atriplex* spp. were considered “facultative upland,” rarely grow-

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ing inside playa boundaries but common in uplands close to playas. For soils, playa soils from the Lassen County Soil Survey were described as “deep, somewhat poorly drained soils that form a hard, vesicular, crusted surface layer when dry.” For hydrology, the most reliable field indicators during dry times of the year were the presence of deep soil cracks and a thin salt encrustation on the soil surface.

Using these criteria, five types of playas were delineated:

1) Playas: Isolated topographic depressions (0.30–0.91 m [1–3 ft] lower than surrounding uplands) lacking vegetation and with salt-encrusted, cracked surfaces.

2) Riverine playas: Similar to playas, but single, narrow, linear, meandering depressions with a possible directional water flow.

3) Playa complexes: Playa-like areas dotted with numerous upland mounds supporting upland vegetation. To be included in this classification, the playa-like surface represented 50% or more of the total area.

4) Uplands containing playettes: These areas resemble playa complexes, except that the playa-like surface represents less than 50% (and typically less than 20%) of the area.

5) Playa-like uplands: These are nonvegetated areas, but without distinct playa soils. They are generally sandier than playa soils, and the surface cracking and salt encrustation are not as pronounced. A further distinguishing feature is that the upland mounds are not as distinctly steep as in the playa complexes. It is thought that these areas may pond briefly, but drain quickly.

The Sacramento District of the Corps assumes jurisdiction over types 1–3.

CONCLUSION

A review of the technical literature on playas has identified unambiguous morphological features associated with inundation and/or shallow saturation. However, none of this material addresses sequential episodes of inundation for use in establishing the duration or frequency of flooding needed to establish OHW. Further, the longevity of these features is questionable; there are no data to suggest that the absence of such features may be used as evidence for the absence of inundation or saturation, and some features may be greatly confounded by factors such as soil chemistry. Consequently the delineation of playas is currently based on a mixture of meager technical data, best professional judgement, and site-specific inferential study.

While some site-specific work will probably always be required because of the inherent variability among playas, productive lines of research that would contribute greatly to the consistency and cost effectiveness of playa delineation do exist. Laboratory work on playa sediments specifically investigating the relation between hydrology and (1) surface crack formation, (2) crust formation (both biotic and abiotic), and (3) possible layering phenomena, would produce readily usable information for playa delineation in the field. Further laboratory work on the chemical and microstructural responses of playa sediment to inundation and saturation would yield tools for instances in which other indicators were unreliable. Studies on the effect on vegetation of the relationship between salt accumulation and hydrology would also produce useful indicators.

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14. ABSTRACT

Playas of the arid Southwest can be unambiguously identified in a geologic context. However, identifying those portions of playas that are defined as "Waters of the United States" (WoUS) in the Clean Water Act (CWA) and thus under the jurisdiction of the Corps of Engineers (Corps) and other Federal agencies charged with enforcing the CWA is sometimes problematic. While the WoUS definition specifically includes playas, the guidance for playa delineation is not as highly developed as for wetlands. Delineating WoUS, as performed by the Corps or by others to comply with Corps regulations, involves determining "Ordinary High Water" (OHW). However, under certain circumstances, the indicators provided in Federal regulations and available technical information for determining OHW have been found to be insufficient when applied to playas. Consequently, some delineations performed to date have involved the development of local indicators by integrating observational data obtained during cyclical inundation, information available for delineating wetlands, and inference based on technical knowledge. Examples of local indicators include small-scale cracks in the soil surface, soil algal crusts, and phreatophyte mounds. This report summarizes the pertinent literature and provides examples of case studies in delineating playas. This review, however, is not intended to provide protocols for delineating playas or to be interpreted as guidance provided by any Corps District or Headquarters, U.S. Army Corps of Engineers. Rather, the scientific background and technical application needed for performing specific delineations are reviewed.

15. SUBJECT TERMS

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"Waters of the United States"

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