WETLANDS, Vol. 26, No. 2, June 2006, pp. 385–399

SURFICIAL FEATURES ASSOCIATED WITH PONDED WATER ON PLAYAS OF THE ARID SOUTHWESTERN UNITED STATES: INDICATORS FOR DELINEATING REGULATED AREAS UNDER THE CLEAN WATER ACT

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Abstract: Desert playas can be unambiguously identified in a geological context. However, identifying those portions of desert playas that are defined as either three-parameter wetlands or Waters of the United States (WoUS) in the Clean Water Act (CWA), and thus under the jurisdiction of Federal agencies charged with enforcing the CWA, is sometimes problematic. Although the WoUS definition specifically includes playas, the guidance for playa delineation is not as highly developed as that for wetlands. Delineating WoUS on desert playas involves determining the Ordinary High Water Mark. Field experience has demonstrated that the indicators for Ordinary High Water on desert playas have not been fully identified nor have they been associated with ponding that represents the limits of Ordinary High Water. This report discusses the distribution of indicators above, below, and at the Ordinary High Water Mark. Fifteen playa features are identified for possible delineation use and are rated for reliability and their relationship to the Ordinary High Water position.

Key Words: delineation, playa, dry lake, waters of the united states, indicators, OHW, OHWM, biotic crust

INTRODUCTION

Attempts to identify the extent of United States (U.S.) Federal jurisdictional limits on areas of playas in the deserts of the Southwest have been constrained because certain technical information has been unavailable. In the U.S., the Corps of Engineers and other Federal agencies regulate specific activities in water bodies known as Waters of the United States (WoUS) under Section 404 of the Clean Water Act (CWA). Coastal oceans, rivers, streams, intermittent streams, playas, and wetlands are examples of water bodies included within WoUS. The jurisdiction extent of these aquatic resources is delineated using either the criteria in the *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) (''Corps manual'') for wetlands or the Ordinary High Water Mark (OHWM) for all other WoUS, including playas (33CFR328.3[e]). The OHWM is defined as ''. . . 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.''

Under these criteria, the hydrologic distinction between WoUS and wetlands is that wetland hydrology is specifically defined by a set frequency and duration, while the hydrology of all other WoUS is defined by physical features in the landscape that represent antecedent hydrologic events. For wetlands, the hydrology criteria are defined as the presence of near-surface or surface water for 1–2 wk of the year or 5% of the

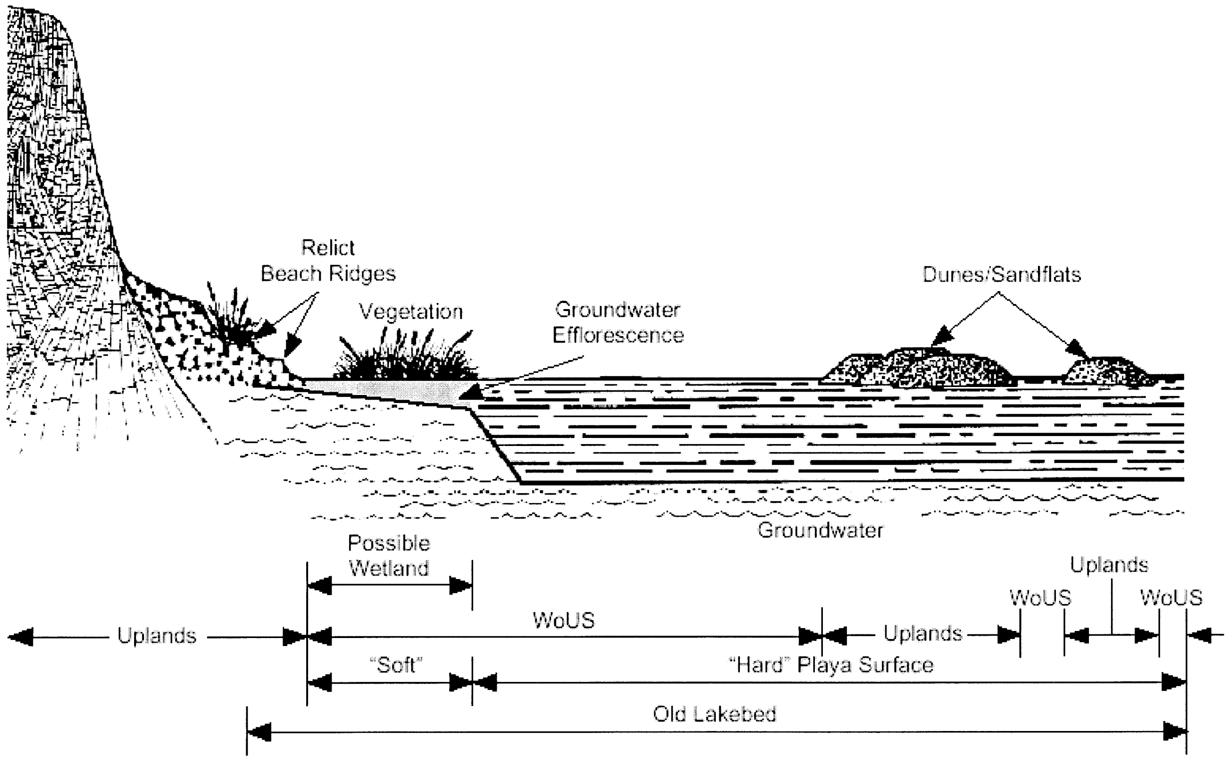

Figure 1. Conceptual diagram of a playa. Note that the area marked ''soft'' would be a wetland only if hydrophytic vegetation, hydric soils, and appropriate hydrology existed; it would be a non-wetland WoUS if it had nonhydrophytic (or no) vegetation and nonhydric soils, but met the hydrology criteria. 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.

growing season [''frequency and duration criteria'' (Office of the Chief of Engineers 1992, 1994)]. For other WoUS, the frequency and duration are not defined but are implied by the concept of ''Ordinary High Water'' (OHW).

Applying the concept of OHW to ''desert playas'' is sometimes problematic (Doub and Colberg 1996) because hydrologic inputs are low, very localized, and more variable on an annual basis than in mesic situations where it is otherwise applied (Lichvar et al. 2004). Further, field indicators used in the delineation of playas in arid areas are further confused by geomorphically effective hydrologic events (Lichvar and Sprecher 1996) that leave physical features lacking any information about their intensity, duration, or frequency.

We have reviewed the literature and combined it with our experience to provide a list of the most reliable field indicators. In the absence of a formal regional definition of ''Ordinary'' that recognizes either the rainfall patterns or actual ponding duration to aid in delineations, we developed a list of OHW indicators.

PLAYAS

''Playa'' is the Spanish word for shore or beach, but in English-speaking countries, it is generally defined as the flat, lower portions of an arid basin that has internal drainage and periodically floods and accumulates sediment (Neal 1975) (Figure 1). The definition was further refined by Neal and Motts (1967) and Shaw and Thomas (1989) to include a surface that is covered with water less than 25% of the time, has evaporite accumulations or lacustrine activity or both, and has a negative hydrologic balance 75% of the year (Briere 2000). Implicit or stated in these definitions is that playas lack macrophytic vegetation and are composed of Pleistocene lacustrine sediments covered with Holocene deposits (Orme 2004).

The playas covered in this review (Figure 2) mostly originated as Pleistocene lakes (e.g., Kerr and Langer 1965). In the older literature, Stone (1956) referred to desert playas that contain water as ''playas,'' those that are dry as ''dry lakes,'' those white with a conspicuous salt crust as ''salt flats,'' and those wet from seepage as ''salinas.'' On United States Geological Survey (USGS) topographic maps, playas are denoted

Figure 2. Distribution of western desert playas. (After Stone 1956 and Motts 1970.)

as intermittent lakes. The term ''playa'' also refers to pluvial lakes in the southern high plains of the U.S. (e.g., parts of Texas and Oklahoma). However, the characteristic vegetation (Reed 1930), soils, hydrology, landscape position, and geologic origin of these pluvial lakes differ from those under consideration (Hall et al. 2004), and in most instances, the standard wetland delineation protocols are applicable.

LANDSCAPE SETTING OF PLAYAS

Desert playas represent about 1.1% of the land-surface area of the Mojave and Sonoran Deserts in California, Arizona, and Nevada and similar proportions of the Sahara, Libyan, and Arabian Deserts (Stone 1956). Although playas are a distinct part of the landscape, portions of the relict lakebed surface may be covered with alluvial material (Motts 1970) (Figure 1). Frequently, small playas occur near the margins of larger playas, in depressions within overlying dunes, behind relict beach ridges on the edges of playas, or in irregularities in alluvial fans that are removed from larger playas (Stone 1956).

PLAYA HYDROLOGY

Although there is some information available on the factors involved with the presence of water on the playa surface, few reports document the areal extent of inundation (Rosen 1994, Lichvar et al. 2004) and the relationship to OHWM for delineation purposes. Surface water may accumulate on playas from runoff, precipitation, or ground-water discharge. A particular playa may or may not pond at all during a particular year, or it may remain ponded for up to three years due, in part, to the frequency distribution of precipitation in the desert (Cooke et al. 1993). In an examination of 45 California playas over three consecutive years, Kubly (1982) reported that during 1978, 65% of playas ponded water, while only 45% and 30% ponded water in 1979 and 1980, respectively. The inundation period is influenced by many variables, including climatic, geomorphic, edaphic, and biotic characteristics, as well as water salinity and the geometry of the water body itself. Some playa surfaces are impervious to infiltration of surface water, whereas others have enormous capacity for absorbing and transporting moisture (Neal 1965). Where ground water is the predominant source of surface water, the water level may be more stable than for playas largely dependent on precipitation.

Wind can have an important effect on desert playa hydrology, particularly the areal extent of inundation. Stone (1956) described instances where water may shift considerable distances or be driven toward one end of a playa during a windstorm. Malek et al. (1990) reported that the area ponded with water in the playa in Pilot Valley, Utah may move several kilometers 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). Dinehart and McPherson (1998) reported wind-induced changes in water depth of more than 0.3 m on Rogers Lake Playa, California. The shifting of water back and forth by wind may smooth out irregularities and other features in the surface, eliminating the surface evidence of previously ponded water (Langer and Kerr 1966, Neal and Motts 1967) and further complicate the WoUS delineation process.

INDICATORS OF ANTECEDENT HYDROLOGIC CONDITIONS

Once standing water has evaporated from the surface or percolated into the substratum, a range of characteristic features remain or develop that indicate the areal extent and/or upper limit of ponded water (OHWM). Characteristics of desert playas that might provide information on antecedent hydrology include surface morphology, patterns associated with evaporites, other surface phenomena, soils, and other biotic indicators.

Surface Morphology

Background. The surface morphology of most playas is related to several factors, the most important being the ratio of surface-water flooding to capillary discharge from ground water (Motts 1970). Playas influenced by capillary discharge from ground water are classified as soft playas. A playa lacking capillary discharge is classified as a hard playa. A single playa may have spatially separate features of more than one type and can change between types over long periods of time (Neal 1965).

Potential Indicators. Hard playas have dry, compact, generally smooth surfaces because their hydrologic input is limited to rainfall and surface runoff (Stone 1956, Motts 1970, 1972, Stevens 1988). They have little microrelief except for surface crusts, mud cracks, or polygons. Since ground-water depths greater than 5 m preclude discharge to the surface and favor the development of a hard, dry, compact surface, they do not contain a zone of saturation (capillary fringe) near the surface; consequently, there is little or no evaporite accumulation, which would be diagnostic of soft playas (Motts 1970). Some degree of shine or glaze is also characteristic of hard playa surfaces, related to fine-particle orientation. Because they generally lack vegetation, hydric soils, and a hydrologic frequency and duration to meet wetland criteria, hard playas are not wetlands as defined by the CWA.

Soft playas are differentiated from uplands and hard playas by a soft, often moist, friable, puffy surface that develops from capillary input of ground water (≤5 m) and subsequent deposition of evaporite minerals (Motts 1970, Neal 1975). Microrelief is 5–7.5 cm or greater, giving the surface a lumpy appearance. Noticeable swelling may occur after precipitation, demonstrating a property called ''self-rising'' ground (Kerr and Langer 1965). Many soft playas are sparsely vegetated and may meet the hydrophytic vegetation criteria for wetlands. They occasionally have hydric soil redoximorphic features definitive of wetlands but typically lack wetland hydrology criteria because the depth of ground water is deeper than the criteria set for wetlands and ponding usually does not occur because of rapid infiltration.

Several surface characteristics of both hard and soft playas, 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 during diurnal heating and cooling, freeze–thaw cycles, or chemical changes. For Death Valley, Hunt (1975) stated that ''patterned ground'' varies in an ''orderly fashion that faithfully reflects differences in the hydrologic regimen of the ground.'' Stone (1956) identified and discussed the occurrence of several types of mud cracks/polygons based on size, shape, and thickness for playas in the southwestern United States.

Surface polygonal mudcracks are found only on portions of the playa that were previously inundated. Closed polygonal mudcracks, which are either domed and multi-layered, are the most reliable indicators of ponded water. However, polygonal mudcracks that are

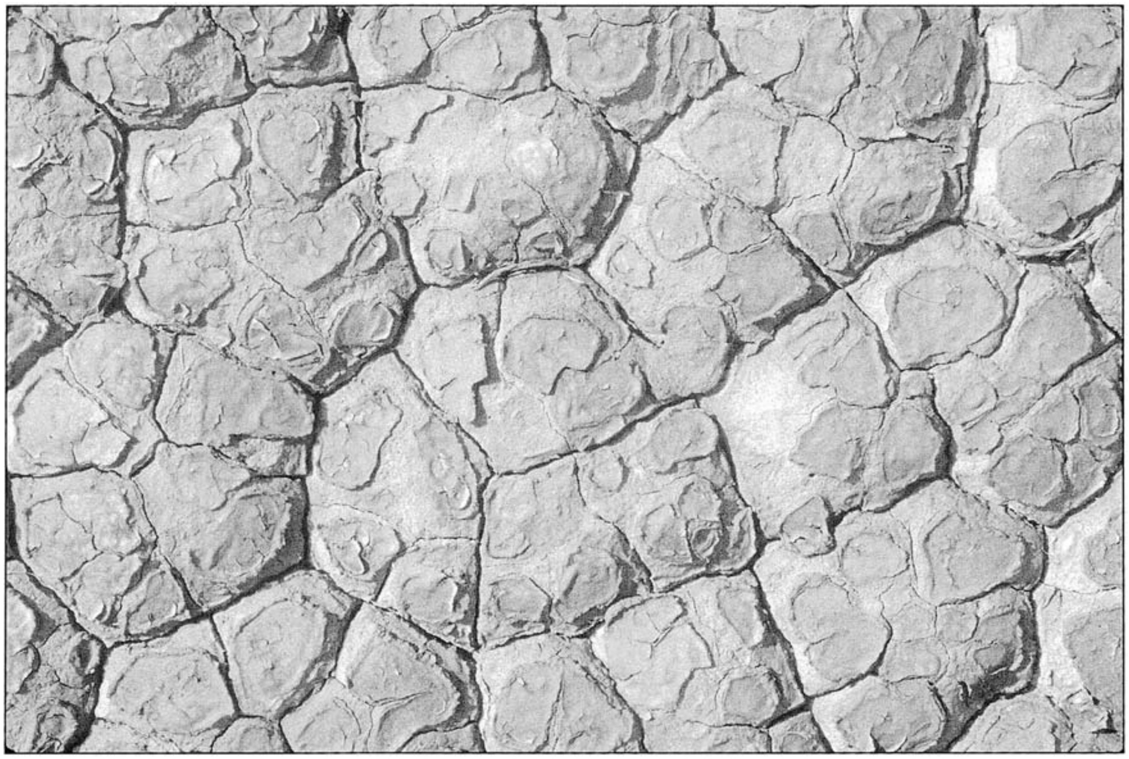

Figure 3. Domed mudcracks covered with algal crusts.

neither layered nor domed are also indicators. The diameters of the typical polygons range from 5 to 40 cm; the vertical dimensions of the domed feature range from 5 to 50 mm (Figure 3). In contrast, nearly closed (open-sided polygons) are upland indicators (Lichvar and Sprecher 1996).

A crust is a surface layer that is generally more compact, harder, and more brittle than the soil beneath (Souirji 1991). Crusts can form for a range of reasons: (1) rearrangement of the soil fabric as a result of wetting and drying, (2) biological factors (e.g., action of microbial species), or (3) externally applied mechanical pressures (e.g., raindrop impacts). The occurrence of crusts, cracks, and polygons on playas was reviewed by Stone (1956) and is discussed below.

Patterns Associated with Evaporites

Background. Conspicuous accumulations of mineral deposits develop on hard and soft playas during the evaporative process. Initially, a smooth flat crust is laid down, and with further evaporation, other characteristic features are formed (Lines 1979).

Potential Indicators. Salt crusts remain on the surface unless they are dissolved by winter rains or other inundation or are eroded by blowing sand (Malek et al. 1990). Microrelief of salt crust (Neal 1965) ranges from a few to 30 cm. Salt polygons (Stone 1956, Neal 1975) are common on soft playas that contain brine concentrations near the surface. The polygons are generally five-sided, 1.8–12 m in width, and bounded by ridges, sometimes called pressure ridges (Lines 1979), of salt from 0.3 to 0.9 m high.

Some highly saline areas form pressure ridges of salt crust, where freestanding salt crusts may form ''blisters'' that rise above the surface to heights of 5 cm. 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). Their surface extent is greater 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.

Other Surface Phenomena

Background. Ponded water from seasonal or intermittent events causes several other identifiable surface features, such as water-flowing debris, freeze–thaw cycles, and erosion. The occurrence, frequency, and spatial location of these other surface features vary across playas based on climatic conditions and orientation of wind patterns.

Potential Indicators. ''Rosette impressions'' (Motts and Carpenter 1970) are distinctive markings produced on flooded playas by ice movement or ice crystal formation across mud surfaces. In the playa lakes of Canada, similar freeze–thaw cycles produce a characteristic granularity in the soil (Renaut 1993). ''Desert flowers'' are characteristic dendritic patterns 5–7 cm deep left by the erosive forces of water flowing into desiccation fissures (Motts and Carpenter 1970). ''Sticky-wet surfaces'' are continuously wet regardless of season and are composed of salt, silt, and clay (Kerr and Langer 1965). ''Gas pit/gas holes'' are conical basins 0.3–0.9 m in diameter and 15–90 cm deep, with a smaller vent hole (Stone 1956). The pits are formed while the surface is under water and are the result of escaping gas.

Although not considered in the technical literature, litter and drift material may also provide good evidence for the extent of recent inundation. Drift lines on playas may occur as continuous concentric patterns centered around the greatest depth of previously ponded water, or they are found only on the downwind sides of previously ponded areas. Drift lines are specifically mentioned in the CWA as an indicator of OHWM. However, they may not accurately reflect the OHW, as they represent the level of the previous inundation, which may be either lower or higher than ''ordinary'' high water.

Soils

Background. Federal regulations recommend using soil morphology as a tool to help delineate the areal extent of wetlands (Environmental Laboratory 1987, USDA–National Resource Conservation Service 2003) and of the OHWM location (Code of Federal Regulations 33 CFR 329.11[a][1]). For playas, the ''changes in the character of the soil'' that are potentially useful for identifying the OHWM elevation include accumulations of organic matter, iron segregations, and salt crystals.

Neither the hydric soil field indicator lists of the USDA-NRCS (2003) nor the 1987 Manual (Environmental Laboratory 1987) have been useful for identifying regulatory boundaries on playas (Lichvar and Sprecher 1996, 1998, Clausnitzer et al. 2003). When developing their list of field indicators of hydric soils, the USDA-NRCS found it necessary to define a separate indicator for playa rims of the arid West (TA1, Playa Rim Stratified Layers) because the other hydric soil field indicators were not found there (USDA-NRCS 2003).

Organic Matter Accumulations. Lines (1979) and Lichvar and Sprecher (1998) found thin black layers at or within a few centimeters of the soil surface in playas at Bonneville Salt Flats, Utah, and White Sands Missile Range, New Mexico, respectively. Those at White Sands Missile Range were found in soft playas or ground-water-discharge points adjacent to hard playas. The organic-rich layers had a greasy feel and H_2S odor when wet and were <1 cm (Lichvar and Sprecher 1998). The black layers appeared to have a very large abundance of heterotrophic bacteria, based on light microscopy, compared to other playa substrata (Brostoff, personal observation). We have also observed green, presumably chlorophyllous, matter within the surficial black layer at White Sands Missile Range (Lichvar and Sprecher 1998). Akili and Torrance (1981) reported a similar layering of fine-grained, wind-blown sand and cemented gray mud for continental sabkhas on the Arabian Peninsula.

The USDA-NRCS (2003) proposed for testing a hydric soil indicator ''TA1, Playa Rim Stratified Layers.'' This testing indicator includes the morphology of thin strata darkened (Munsell value/chroma of 3/1 or darker) by organic matter within the surface 15 cm of the soil. The USDA-NRCS stipulated no threshold of organic matter content. They based their proposal on the field experience of the National Technical Committee on Hydric Soils and soil scientists practicing in the region (Steven Sprecher, personal communication, 2002).

These independent observations of organic-rich layers in the surface soils of playas and playa-like landforms from different parts of the world show their utility for identifying seasonally wet areas in arid regions. Since hot, dry climates in the arid West promote rapid decomposition of organic matter (Oades 1988), an accumulation of organic-rich layers should be a reliable indicator of landscape positions that are frequently saturated with water in the soil surface layers.

Iron Segregations. Most hydric soil determinations for wetlands in the U.S. are based on the morphology of iron segregation (Environmental Laboratory 1987, USDA-NRCS 2003). In such hydric soils, iron segregates into areas of iron depletion and concentration under fluctuating water tables and redox conditions (Vepraskas 1994). However, it is unlikely that these indicators would be useful in playas of the arid western U.S. because the organic matter content is too low and the soil pH too high for significant amounts of iron reduction to occur on these playas (Boettinger and Richardson 2001, Clausnitzer et al. 2003). Boettinger (1997) reviewed the soil series descriptions of Aquisalids (salt-enriched desert soils with wetness problems) and found that iron concentrations are present in several soil series but at the bottoms of the profiles rather than the tops. Clausnitzer et al. (2003) found that iron segregations, when present in playa soils, were less abundant than required for most non-playa hydric soils; they concluded that organic matter contents of soils in their studies were too low to support microbially mediated iron reduction sufficient to generate traditional wetland indicators.

We found relatively few iron concentrations near the soil surface of hard, unvegetated playas of the arid western U.S. (Lichvar and Sprecher 1998). The gypsiferous playas of White Sands Missile Range occasionally had 2.5Y to 10YR 5/3 matrixes with 7.5YR 5/4 to 5/6 iron concentrations, but the redox mottles were more often lacking than present. We rarely found iron concentrations or depletions in the hard playas of Utah and California. Clausnitzer et al. (2003) quantified the hydrology and redox regimes of vegetated vernal pools of eastern Oregon and found that, although iron segregation was occurring in their pools, it was insufficient to develop any of the Federally recognized hydric soil indicators. They recommended pedogenic interpretations of soils with iron concentrations on a case-by-case basis.

Salt Crystals. Salt crystals can be used to infer relative durations of inundation on hard playas because of relative solubilities of the various minerals that precipitate out of playa brines (Hunt 1966, Lines 1979). These authors reported that, in general, in playa brine, solubility increases in the sequence of chlorides > sulfates > carbonates. The specific salts that precipitate out of playa brines depend on the proportions of the various ions in solution, so certain predictable precipitation sequences are to be found in natural playas (Hardie and Eugster 1970).

Applying Hardie and Eugster's (1970) analysis to hydric soils, Boettinger and Richardson (2001) concluded that hydric soils can be indicated by the presence of either salts more soluble than gypsum within the upper 30 cm of the soil or salt crusts on top of the playa surface. Our experience is that visually conspicuous concentric rings of salt crystals are found in the lowest areas of hard playas where water had ponded the longest. We considered them to be positive indicators that the particular playa had held standing water recently. These salt crusts are relatively fragile and can be obliterated by wind-blown sands or subsequent inundation (Neal 1975).

Two other kinds of evidence for ponded water are thin, horizontal layers of mud in the upper part of the soil profile, and solution cavities (Lowenstein and Hardie 1985). Mud layers are formed when inundating waters carry fine silts and clays with them from the surrounding landscape. These fines deposit as thin layers with each inundation event, with thicknesses on the order of millimeters rather than centimeters or decimeters.

Solution cavities form when individual crystals are dissolved by water entering from either below or above the ground (Lowenstein and Hardie 1985). In soils that inundate periodically, individual crystals have rounded rather than sharp edges, and horizontal truncation surfaces can be seen where crystal morphology changes abruptly. When these soils are viewed in thin section or by hand lens, one can also see millimeter-size cavities (vughes) that result from dissolution of the halite mass.

These solution cavities should not be confused with the vesicular porosity that is found in the surface crusts of desert soils wherever vegetation is sparse and stone or pebble content is high (Nettleton and Peterson 1983). These nearly ubiquitous vesicular pores in the soil surface crust form from air trapped in the soil crust during and after rainstorms and develop in most areas where soils crusts are present, even upslope of wetlands or playas.

VEGETATION

Background

The relation between vegetation, OHWM, and areas that undergo inundation on playas is tenuous and confounded by many factors. Although the occurrence and abundance of certain species of macrophytes is one of the three parameters used for delineating wetlands, this is problematic for playas because of the usual (if not defining) absence of vegetation. The criteria for hydrophytic vegetation (Tiner 1991) for wetland delineation are specifically defined in the Corps manual (Environmental Laboratory 1987) and guidance from the Office of the Chief of Engineers (1992, 1994). A list of wetland species is provided by the U.S. Fish and Wildlife Service (Reed 1988) to determine if hydrophytic vegetation is present after applying the formal delineation protocols.

However, the utility of using plants for establishing the OHWM on playas is limited by being frequently absent, their response to environmental factors other than inundation, or ''status ratings'' that do not recognize the unique nature of playas. Field experience has shown that the reliability of the status ratings of wetland plant species as indicators along playa edges is compromised by halophytes and phreatophytes responding to saline soils and ground water at depths greater rather than just surface or near-surface hydrology as defined in the criteria for wetland delineation. For example, Lichvar et al. (1995) discussed problems with iodinebush [*Allenrolfea occidentalis* (S. Watson) Kuntze], rated Facultative Wetland (FACW), 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.

Potential Indicators

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) that restrict the occurrence of vegetation from playa surfaces. However, 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 with fine silts, phreatophyte mounds, and dunes on the playa surface. When vegetation is present along the edge of a playa, it is often on phreatophytic mounds (see below) (Blank et al. 1992), varies from less than 1 to 25% areal coverage (Barbour and Billings 1988), and has a low species diversity.

The macrophyte species composition of soft and hard playas differs greatly, although the central portions of both are devoid of vegetation. In general, plant communities on hard playas vary from xerophytic, which is stunted and shrubby compared to conspecific upland counterparts, to halophytic species of the ''alkaline sink scrub'' vegetation type. Thorne (1976) classified this type as consisting of scattered scrubs of halophytic plants mostly in the Chenopodiaceae. On occasion, representatives of the Asteraceae, Brassicaeae, Fabaceae, and Poaceae are found (Barbour and Billings 1988). In contrast, soft playas are more typically vegetated with succulent chenopodes (e.g., iodinebush) (Stone 1956, Lichvar et al. 1995) of the ''alkaline sink scrub.''

Phreatophyte mounds, 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 and having a 2- to 10-m circumference. They are formed when wind-blown sand and silt accumulate around a phreatophyte growing at the level of the playa surface and build successively upward. Concentric cracks, or ring fissures (Cooke et al. 1993), similar to cracks in the playa surface resulting from ponded water, may form around these mounds after desiccation or lowering of the ground-water level from plant processes. Lines (1979) similarly reported that, on otherwise puffy ground, hard, compact areas may form around iodinebush because of the reduction of groundwater level. Further, the location of the wetland boundary is distorted by the occurrence of phreatophytes, many of which have an FACW rating; these plants typically seeking out ground water from up to 1 m or more in depth (Hunt 1966, West 1983), which exceeds the criteria for depth of regulated ground water for wetlands in the U.S.

The literature on plant taxonomy, biogeography, and physiological ecology is of little use in locating the OHWM. Some anecdotal information does exist on the relationship between vegetation and areas that flood periodically. For example, Went and Westergaard (1949) and West (1983) provided mutually exclusive species lists of plants in ''lowland'' (free water table at least occasionally present at the surface) and ''upland'' (water table less than 1 m below surface) salt-desert habitats. In contrast to playa surfaces, the areas around playas are often vegetated. Sometimes, this vegetation can be characteristic of playa edges. However, a gradient does exist between halophytic and xerophytic vegetation. Barbour and Major (1990) reported succulent chenopods such as iodinebush, nitrophila [*Nitrophila occidentalis* (Nutt.) Moq.)], pickleweed (*Salicornia subterminalis*), seablite (*Suaeda* Scop.), and greasewood [*Sarcobatus vermiculatus* (Hook.) Torrey] as representatives of playa edges. They also reported that, 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 the playas. For Mojave Desert playas, Thompson (1929) observed what he called characteristic vegetation around the border of 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 band of ''pseudohalophytes'' of annuals composed of mostly FACW plant species from Deadman Dry Lake, Twentynine Palms, California.

OTHER BIOTIC INDICATORS

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 be used as well. Distinct small-scale surface zonation in the species and abundance of desert bacteria and algae, which often form soil crusts, has been documented across moisture and other environmental gradients in field and laboratory studies (Brostoff et al. 1996, Brostoff 2002).

Biotic crusts are water-stable soil aggregates held together by algae, fungi, lichens, or mosses and the substances they produce (Johansen 1993). Algae are common in these crusts found on and around desert playas, but they are most often dominated by the filamentous blue-green alga (cyanobacteria) *Microcoleus vaginatus* (Vauch.) Gom. Other typical genera include

Phormidium, *Plectonema*, *Schizothrix*, *Nostoc*, *Tolypothrix*, and *Scytonema*. In soils with a high concentration of gypsum, diatoms may dominate.

Crusts have been classified into two ecological groups, ''upland'' and ''aquatic remnant,'' in part based on factors associated with inundation or lack thereof (note that the term upland is not used in any reference to wetland jurisdictional issues) (Brostoff 1998). The upland crusts occur predominantly on dunes, alluvial slopes, and other areas that do not pond water. The dominant constituent taxa (*Microcoleus*, lichens, mosses) and the physical structure of these crusts are often destroyed when submerged for short periods (Brostoff et al. 2002). However, a very high soil moisture content, or inundation on the order of millimeters, will give these crusts a characteristic wavy texture. These upland crusts are frequently most abundant on non-ponded areas adjacent to areas that do pond in a playa–dune system in California (Brostoff 2002). Thus, based on both documented biology and empirical evidence, the upland crusts may be used as evidence that there have not been protracted periods of standing water.

Aquatic remnant crusts develop in areas that were previously ponded and are indicators of inundation. They are usually dominated either by heterotrophic bacteria or by one or more species of algae (Brostoff et al. 1996, Brostoff 2002). These crusts range from beige or brown to red, sometimes with a distinct green cast on their underside or with rosette or reticulate patterns or both. The darker-colored crusts and the patterned crusts are dominated by algae and, based on laboratory observations (Brostoff 1998, Brostoff 2002), are better evidence of ponding than crusts lacking these characteristics. Crust formation has been followed for several wet–dry cycles at Edwards Air Force Base, California, and there is good correspondence between areas of flooding during the wet season and the presence of aquatic remnant crusts during the dry season (Brostoff 2002, and unpublished observations). During the dry season, the crusts may decrease in width (i.e., fracture into smaller pieces) and during dry periods, blow away. Some crusts remain stable for several years.

Biotic soil crusts have been used as possible positive and negative indicators for WoUS (Lichvar and Sprecher 1996) in southern California and elsewhere. Further, for vernal pools in California, Riefner and Pryor (1996) reported 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.

Desert Shrimp

Several species of fairy, tadpole, and clam shrimp (branchiopod crustaceans) are characteristic of desert playas in the United States (Eng et al. 1990, Belk and Brtek 1995, 1997, Eriksen and Belk 1999).

The presence of desert shrimp, remnant adults or eggs, has potential for being an indicator of previously ponded water. Two factors make them potentially useful for delineation. First, their eggs remain viable in the top 5–10 mm of the surface crust (Brown and Carpelan 1971) for at least several decades, but they hatch and complete their life cycles quickly after inundation. Second, the presence of eggs can be determined quickly by immersing a small quantity of substratum into water and counting hatchlings after a few days or by sieving suspect substratum for eggs (e.g., Brown and Carpelan 1971). The species composition in a particular location depends 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 (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).

REMOTE SENSING

Very little remote sensing work has been published specific to playas. Drake and Bryant (1994) and Bryant and Rainey (2002) used Advanced Very High Resolution Radiometer (AVHRR) imagery to determine the flooding frequency of a set of Tunisian playas. Henley (1988) reported success in estimating relative moisture conditions using reflectance spectra from remote sensing. 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. Lichvar et al. (2004) used 20 years of archived LANDSAT and TM (Thematic Mapper) imagery to establish periods of duration and frequency of ponded water on playas in the Mojave Desert, CA. Remotely sensed data can't be used as a field indicator per se, but they could be very useful in establishing periodicities associated with ponded water and features on the ground.

FIELD EXPERIENCE IN DELINEATING PLAYAS

The authors have performed delineations of desert playas on over 1,000,000 ha in the southwestern U.S. (e.g., Lichvar and Sprecher 1996, Lichvar and Sprecher 1998). Based on the literature and this field experience, we have found that indicators of previously ponded water represent two groups: OHWM indicators

Table 1. Potential strength of certain surface features as indicators for playa delineation rated for presence/absence, playa type, and spatial relationship to OHW. Strong indicators are rated as ++, weaker as +; − indicates either that it is absent or not an indicator. Indicators are rated as stronger or weaker for areas above, at, and below the OHWM. These surface features that are present in other landscape positions and not restricted to playas are listed for non-playas areas.

Indicator Class	Non-Playas	Playas: Above OHW		Playas: OHWM Line		Playas: Below OHWM		Citation
		Hard	Soft	Hard	Soft	Hard	Soft	
POSSIBLE INDICATORS OF HYDROLOGY								
Surface ponding	++	++	+	++	−	++	−	Stone 1956, Neal 1965, Langer and Kerr 1966, Neal and Motts 1967, Lines 1979, Kubly 1982, Stevens 1988, Shaw and Thomas 1989, Malek et al. 1990, Cooke et al. 1993, Rosen 1994, Dinehart and McPherson 1998, Lichvar and Sprecher 1998, Briere 2000, Lichvar et al. 2004
Groundwater	++	−	++	−	−	−	−	Stone 1956, Neal 1965, 1975, Motts 1970
Surface discharge	++	+	++	−	−	−	−	Stone 1956, Neal 1965, 1975, Motts 1970, 1972, Lines 1979, Lichvar and Sprecher 1998
POSSIBLE INDICATORS OF ANTECEDENT HYDROLOGY								
Surface Morphology								
Self rising/puffy surface	−	−	++	−	−	−	−	Kerr and Langer 1965, Motts 1970, Neal 1975
Porous (low bulk density)	++	+	++	−	−	−	−	Lichvar and Sprecher 1998
Patterned Ground associated with Evaporites								
Salt crusts	−	++	++	++	++	++	++	Hardie and Eugster 1970, Neal 1975, Malek et al. 1990, Boettinger and Richardson 2001
Salt polygons	−	++	++	+	++	+	++	Stone 1956, Neal 1975, Lichvar and Sprecher 1998
Pressure ridges	−	−	++	−	++	−	++	Lines 1979
Other Surface Phenomena								
Rosette impressions	−	++	+	++	+	++	+	Motts and Carpenter 1970
Desert flowers	−	++	+	−	−	−	−	Motts and Carpenter 1970
Drift lines/water marks	−	−	−	++	−	++	−	Lichvar and Sprecher 1998, Regulations (33 CFR 329.11[a][1])
Sticky-wet	+	+	−	+	−	+	−	Kerr and Langer 1965
Gas holes	−	−	−	−	−	++	−	Stone 1956
Piping	+	++	−	−	−	−	−	Orme 2004
Microtopographic	++	++	+	++	−	++	−	Kerr and Langer 1965, Neal 1965, Motts 1970
Solution cavities	−	−	++	−	+	−	+	Nettleton and Peterson 1983, Lowenstein and Hardie 1985, Lichvar and Sprecher 1998
Thin horizontal layers of mud	−	+	++	+	++	+	++	Lowenstein and Hardie 1985
Blisters	−	−	++	−	−	−	−	Lines 1979, Hunt 1966

Table 1. Continued.

Indicator Class	Non-Playas	Playas: Above OHW Hard	Playas: Above OHW Soft	Playas: OHWM Line Hard	Playas: OHWM Line Soft	Playas: Below OHWM Hard	Playas: Below OHWM Soft	Citation
Mudcracks								
Closed								
Flat	–	–	–	++	–	++	–	Neal 1975
Domed	–	–	–	+	–	++	–	Lichvar and Sprecher 1998
Open	++	++	–	–	–	–	–	Lichvar and Sprecher 1998
Soils								
Soil character changes	++	++	++	–	–	–	–	Regulations (33 CFR 329.11[a][1])
Stratified layers NRCS (TA1)	++	+	+	–	–	–	–	Akili and Torrance 1981, Lichvar and Sprecher 1998, USDA-NRCS 2003
Thin black layers/greasy	+	+	+	–	–	–	–	Lines 1979, Akili and Torrance 1981, Lichvar and Sprecher 1998, William Brostoff, personal observation
Chlorophyllous material	+	++	–	–	–	–	–	Akili and Torrance 1981, Lichvar and Sprecher 1998
Gray mottles or matrix	–	+	–	+	–	+	–	Environmental Laboratory 1987, Lichvar and Sprecher 1998
Fe segregations	–	–	+	+	–	+	–	Environmental Laboratory 1987, Vepraskas 1994, Boettinger 1997, Lichvar and Sprecher 1998, Boettinger and Richardson 2001, Clausnitzer et al. 2003
Gypsiferous playas with 2.5Y to 10YR 5/3 matrix with 7.5 to 10YR 5/4 to 5/6 concentrations	–	++	–	++	–	++	–	Lichvar and Sprecher 1998, Clausnitzer et al. 2003
Concentric bands of $CaCO_3$	–	++	+	++	–	++	–	Neal 1975, Lichvar and Sprecher 1998
Gypsiferous minerals	++	++	–	++	–	++	–	Lichvar and Sprecher 1998
Halite minerals	+	–	++	+	+	++	–	Lichvar and Sprecher 1998
Vegetation								
Sparse cover	++	–	++	–	–	–	–	Nettleton and Peterson 1983
Devoid cover	+	+	–	++	–	++	–	Thorne 1976, Lichvar et al. 1995
Xerophytic	++	++	–	–	–	–	–	Thorne 1976, Barbour and Major 1990
Stunted growth form	++	++	–	–	–	–	–	Thorne 1976
Halophytic	++	++	++	–	–	–	–	Thorne 1976, Barbour and Billings 1988, Barbour and Major 1990, Lichvar et al. 1999

Table 1. Continued.

Indicator Class	Non-Playas	Playas: Above OHW Hard	Above OHW Soft	OHWM Line Hard	OHWM Line Soft	Below OHWM Hard	Below OHWM Soft	Citation
Succulent chenopods	++	+	++	–	–	–	–	Barbour and Major 1990
Phreatophytic mounds	+	++	–	–	–	–	–	West 1983, Hunt 1966, Neal and Motts 1967, Blank et al. 1992, Lichvar et al. 1995
Hydrophytic	+	+	++	–	–	–	–	Environmental Laboratory 1987, Tiner 1991, Lichvar et al. 1995
Line of annual forbs	–	++	–	–	–	–	–	Lichvar et al. 1999
Biotic Soil Crusts								
Upland crusts	++	++	–	–	–	–	–	Brostoff 2002
Aquatic remnant	–	–	–	++	–	++	–	Lichvar and Sprecher 1996, 1998, Brostoff 2002
Shrimp								
Shrimp eggs	++	++	–	++	–	++	–	Brown and Carpelan 1971, Eng et al. 1990, Belk and Brtek 1995, 1997, Eriksen and Belk 1999
Remnant shrimp	++	++	–	++	–	++	–	Lichvar and Pringle 1993, Brostoff 1998

and inundation indicators. By combining these, the OHW can be reliably determined. One or more OHWM indicators (e.g., drift lines, breaks in topography) may provide an adequate OHW determination. Reliability in establishing the extent of OHW also increases with the presence of several inundation indicators (e.g., domed polygons, algal crusts, closed polygonal mud cracks with overlying algal crusts, salt crystals). In the absence of OHWM indicators, inundation indicators alone, even when more than one type is found, may not establish the extent of OHW but, rather, the area of inundation contained within the OHW.

CONCLUSION

A review of the technical literature, together with field observations on playas, has identified a variety of features that represent surface antecedent hydrology on desert playas. Based on our field delineation experience with playas, we have identified differences in the protocols for establishing regulated boundaries between soft and hard playas. In the case of soft playas, the soils are modified and have low bulk density with high porosity, allowing for infiltration of surface water and thus precluding ponding due to high infiltration rates. Also, these soft playas tend to have FACW phreatophytic species that have the ability to go to greater depths to obtain soil moisture. Thus, delineation decisions when dealing with soft playas are more appropriately handled by wetland delineation protocols.

In contrast, hard playas are impermeable and mostly unvegetated, and they pond water on the flattened surfaces. For making delineation decisions with hard playas, it is necessary to use the OHWM indicators summarized in Table 1. Typically, the entire hard playa does not pond water. Consequently, the OHWM must be determined by the presence of specific OHWM indicators and playa-specific inundation and upland indicators.

Fifteen possible OHWM features have been identified for establishing regulated boundaries on hard playas (Table 1). Of these, four features are more consistent and reliable for establishing the OHW boundary: drift, microtopography, closed polygonal mudcracks, and aquatic remnant algal crusts. They can occur either individually or in some combination. The domed-style closed polygonal mudcrack type and aquatic remnant algal crust more typically indicate inundation than the OHW boundary. However, since they occasionally extend out to the boundary, they are useful as OHWM indicators. All four of these OHWM indicators are present and diagnostic throughout the year and can be used for delineation purposes. In contrast, features such as ponded water and salt crust are ephemeral and are related to changes in surface ponding and groundwater influences.

Determining OHW using any of these features must consider long-term climatic conditions. Since all these features develop as a result of ponded water, they may represent the most recent precipitation event and not ''ordinary.'' To establish what may be ordinary, we suggest using local precipitation records or gauging stations and a series of aerial or satellite images for the preceding 5–20 yr (Lichvar et al. 2004).

However, for specifically delineating the extent of OHW by use of untested OHWM indicators, these surface features may be insufficient for the following reasons: 1) Various elevation levels on the playa surface can be associated with different inundation indicators resulting from their different periods of ponding; however, these indicators may not correspond directly with OHW (e.g., some inundation indicators occur at the lowest elevation point on the playa surface but may still be located downslope and not necessarily coincident with the OHW boundary). 2) Other physical factors such as wind conditions distort the physical evidence about long-term water levels since the wind may cause some indicators to be mobile during windy conditions and then become fixed in misrepresentative locations upon drying. 3) In certain landscapes, some inundation and OHWM indicators can develop or occur in drier locations than defined by OHWM, which may require that some level of combining indicators be necessary under certain conditions.

Lacking a demonstrated relationship between climatic data and the ability to make statements that an indicator implies some level of ''ordinary'' ponded events, none of the indicators are useful in establishing the duration or frequency of ponding OHWM. These indicators can sometimes be eliminated from the system the same year as drying occurs (Brostoff 2002); therefore, the absence of such features is not necessarily evidence for the absence of inundation or saturation. Consequently, the delineation of playas is currently based on a mixture of meager technical data, best professional judgment, 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) formation of biotic and abiotic crusts, 3) mud crack layering phenomena, 4) and the longevity of indicators, would produce readily usable information. 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 or unavailable. Studies on the response of desert playa vegetation and its relationship to salt accumulation and hydrology would also produce useful information leading to vegetation indicators useful for determining OHW.

ACKNOWLEDGMENTS

The authors extend their great appreciation to their sponsors for providing the opportunity to delineate ''Waters of the United States'' on military installations in the desert Southwest and for related projects. Support for this work was provided by U.S. Army Dugway Proving Ground, Utah; U.S. Army White Sands Missile Range, New Mexico; U.S. Marine Corps, Marine Corps Air–Ground Combat Center, Twentynine Palms, California; and Edwards Air Force Base, California. Bill Sipple, EPA, and Jim Wakeley, Environmental Laboratory, ERDC, generously provided comments on the manuscript and critical insights into wetland delineation protocols.

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Manuscript received 29 November 2004; revisions received 14 November 2005; accepted 27 January 2006.