



Soils of Great Salt Lake Wetlands: Hydric Indicators and Common Features

Christine Rohal, Karin Kettenring, Rebekah Downard,
and Mark Larese-Casanova

Department of Watershed Sciences, Quinney College of Natural Resources

A casual visitor to Great Salt Lake wetlands might first notice the expansive green vegetation and the many animals that call our wetlands home. But few think about what lies below: soil – the mineral and organic material that supports the life above. Soils are an integral component of a functioning wetland.



What are Soils?

Soil is much more than just dirt. Often called the “living skin of the planet Earth,” soil is a mixture of organic and mineral material, air, and water that is critical for the support of life [1]. Soil provides structure for plant roots, retains water to ensure plants have access long after it rains, and holds nutrients so they are available to organisms over time [1]. Soil is not material devoid of life, but a living ecosystem, home to billions of microorganisms and myriad small animals like worms, crayfish, and snails which combine with the forces of climate and

water to transform the parent material from which it is derived into a rich belowground oasis [2]. Soil is not just a static base for plants to grow on, but a dynamic medium for energy and elements to move through, and be transformed over time.

Organic vs Mineral Soils

There are two main categories of soil that differ in the predominant material from which they are formed: organic and mineral soils. Organic soil contains high amounts of decomposing plant debris while mineral soil is derived primarily from geologic material like rocks and sediments (the parent material) which have been ground into tiny fragments by various chemical and physical forces [3]. Organic soil is often black when wet, porous, and lightweight when dried, while mineral soil can consist of diverse types and sizes of mineral particles making them variable in color and texture [4].

Hydric Wetland Soils

Wetland soils, also known as hydric soils, have unique features due to anaerobic (low oxygen) conditions that are associated with flooding. Microbes (microscopic organisms) found in soil have many physiological responses to these conditions that help scientists identify hydric soil, and learn about its conditions. These features can be seen in the unique wetland soils of Great Salt Lake.



Organic Soil.



Mineral Soil.

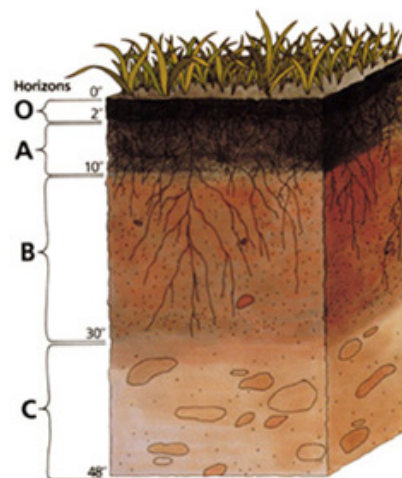
Physical Characteristics of Soils

When wetland scientists excavate a soil sample, they are detectives searching for clues in what they see and feel in order to deduce soil conditions. For example, observing the depths of different layers, or horizons, of the soil can give clues to how much organic matter is present, as well as the soil constituents that make up the parent material. Looking at soil color can indicate whether or not a soil has been saturated with water, and for how long. Feeling the soil textures (e.g., Is the soil sandy or does it contain a lot of clay-sized particles?) can help a scientist understand how much water a soil is likely to hold, and if water is likely to pond in an area based on these textures. Looking at all of these characteristics together can help scientists classify a soil's taxonomy, or soil type. Scientists can also use these observations to determine if a soil is a true wetland (hydic) soil, and to learn about the soil's history of inundation or disturbance. Below is a general description of how scientists classify and describe soil horizons, colors, textures, and taxonomy.

Soil Horizons

When observing areas where a vertical section of soil is exposed, as in an eroded stream bank, you can often observe many distinct layers of different

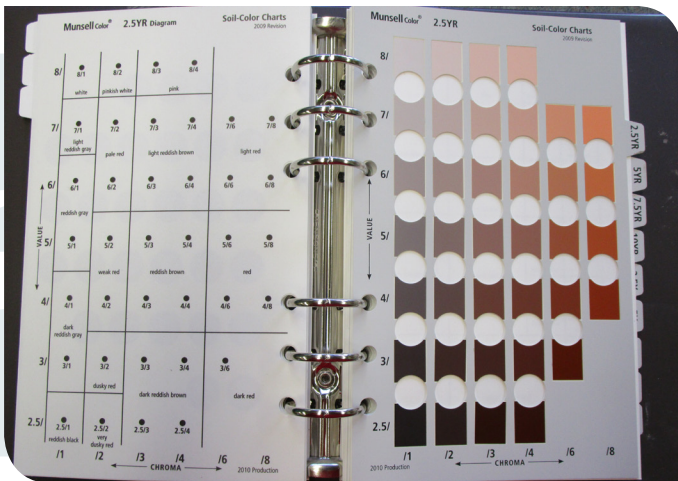
types of soil. The “soil profile” is made up of different soil layers (called horizons), which are differentiated from each other by differences such as organic material contents, mineralogy (the minerals from which they are made), color, aggregate (soil clump) size and shape, and chemistry [4]. There are four primary soil horizons. The top horizon is the O-horizon, formed of organic material from dead plants and animals. The A-horizon, often called the “topsoil,” is the topmost mineral horizon, which contains a mixture of organic material and mineral material, and is often darker than the lower horizons. The B-Horizon is the subsurface horizon where weathered soil material is gradually deposited from upper layers and accumulates in a process called illuviation. The C-Horizon is made up of the underlying parent material (i.e., sediments, glacial deposits or rock debris), and is often outside the zone of major biological activity [5].



Soil Colors

One of the first things we notice when looking at a soil is its color. Soils can be a wide range of colors, from reds, to yellows, to greys and blacks, even greens. But color is often hard to describe clearly and in a repeatable way. The Munsell Soil Color Charts are a standardized tool to help soil scientists be as exact as possible about the color of the soil in question.

Munsell charts separate color into three categories – hue, value, and chroma. Hue, or spectral color, identifies the quality of pigmentation; value addresses the lightness or darkness; and chroma refers to the richness of the pigmentation (from pale to bright) [4]. Being able to clearly describe soil color helps scientists identify differences in horizons, differences in the make-up of soils, and different conditions that the soil is experiencing.

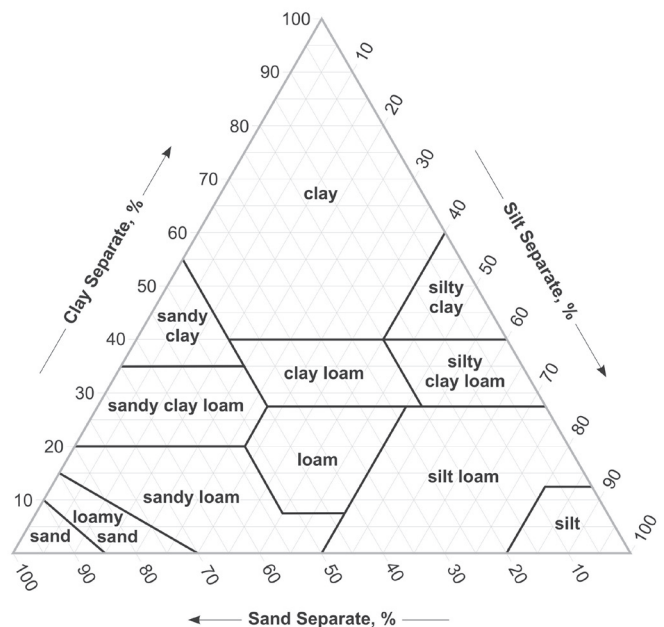


Sample page from a Munsell Soil Color Chart. Colors are organized by hue, value, and chroma.

Soil Textures

Making mud pies in the back yard, kids quickly notice that not all soil feels the same. Some soils are gritty and rough while others are smooth and soft. The texture of a soil is very important for soil func-

tion – it influences pore size which determines how fast water moves through the soil. Coarser materials allow water to pass through quickly, while finer materials hold more water for a much longer time. Soil texture is defined as the relative percentage of particles of different sizes. These particles are organized into three particle sizes: sand (0.05-2.0 mm), silt (0.002-0.05 mm), and clay (<0.002 mm) [4]. Sand feels gritty when rubbed between fingers; silt feels somewhat like flour when rubbed; clay feels sticky [4]. In most soil horizons, you find some mixture of sand, silt, and clay. The ratios of each of these three ingredients determine a specific textural class, such as a loam (a mixture of primarily sand and silt, with a smaller amount of clay). Even though organic matter can make soils feel spongier, it doesn't change the texture of the soil, which is only determined by mineral particle size distribution. Many scientists use a soil texture triangle to determine the textural class of a soil.



A soil texture triangle defines soil texture based on different ratios of three sizes of particles: sand, silt, and clay.

Soil Taxonomy

Soils have names, just like plants and animals do. Soils are classified most broadly into one of twelve orders, which are based on differences in the manner in which the soil was formed and the stage of development or weathering (i.e., soil genesis). After dividing further into group and family, which are divided based on differences in moisture regime and mineralogy, soil scientists identify the soil's "series," a name comparable to species in plant taxonomy. Approximately 20,000 soil series have been identified in the United States [4]. Soils are in many ways as diverse as the ecosystems they support.

Hydric Soils

Hydric soils are associated with wetland hydrology and wetland vegetation. They are characterized by wetness or saturation, particularly during the plant growing season, and anaerobic conditions in the root zone of plants [6]. The dominance of these anaerobic conditions leads to a series of chemical reactions that change the character of the soil.

This section will describe the chemical processes that occur under the anaerobic conditions of hydric soils and the physical changes to the soil as a result of these unique conditions.

Why Look at Hydric Soils?

Digging soil pits can help scientists learn a lot about the ecological conditions of a certain area.

The most common reason for digging soil pits in and around wetlands is for wetland delineation.

Because of rules associated with the Clean Water Act that regulate development in wetlands, developers must carefully determine the boundaries of wetlands. Hydric soil is one of three key indicators for determining where a wetland lies (the other two are hydrology and the presence of wetland vegetation).

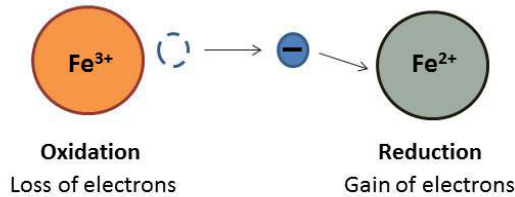
Determining whether a soil is hydric can also help identify potential wetland restoration opportunities [8]. Even when an area does not currently have wetland vegetation and hydrology, looking at the soil can give a window into the past, as hydric features can last long after hydrology changes.

Oxidation and Reduction (Redox)

Soil is teeming with billions of microbes that consume organic compounds in order to obtain energy to grow. In non-flooded soil exposed to fresh air, also called aerobic or oxidized soil, most microbes require oxygen to consume and therefore decompose organic material. When soil becomes flooded, oxygen is used more quickly than it can be replenished from the atmosphere through the water and thus becomes depleted, leaving soil in an anaerobic or reduced state. In this reduced environment, specialized soil microbes must use compounds other than oxygen in the chemical process of decomposing organic material [7].

The chemical reactions involved in the microbial consumption of organic matter can be quite complicated, but the important thing to note is that they always involve the transfer of electrons. When organic matter is consumed by microbes, electrons are released or lost from atoms in a process called oxidation. These electrons must go somewhere, so whenever an electron is lost by one atom it is gained by another, in a process called reduction [7]. Coupled together, these processes are called oxidation-reduction reactions, or redox reactions. In oxidized soil, oxygen is the "electron acceptor" in this process. In anaerobic soil, other compounds like nitrate and iron must be used as electron acceptors. When an atom gains an electron in redox reactions, it can completely change the character

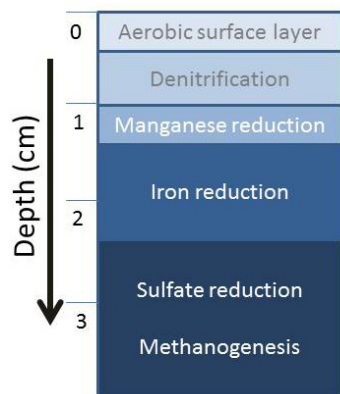
of that element. For instance, when oxidized, ferric, iron (Fe^{3+}) gains an electron it is reduced into ferrous iron (Fe^{2+}). This specific change can be seen in the conversion of soil from a reddish-brown “rust” color, rich in ferric iron to a greenish-grey color, dominated by ferrous iron (the reduced state) [9].



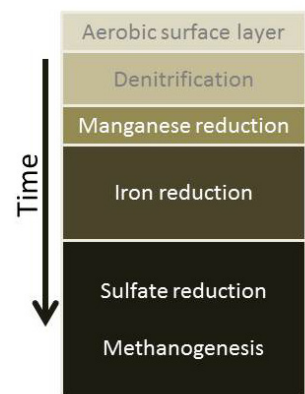
Redox, or oxidation-reduction reactions, involve the transfer of electrons between atoms. Losing and gaining electrons changes the character of an atom. For example, when an iron atom gains an electron, it transforms from a rust color (left circle) to a greenish grey color (right circle).

There are many compounds in the soil, besides oxygen, which microbes can use as electron acceptors in the process of consuming organic material. But when oxygen is present, the microbes that use oxygen as electron acceptors dominate. Oxygen-specialist microbes dominate because using compounds other than oxygen is not very energy efficient. For example, in oxidized conditions, at the cellular level, one unit of glucose consumed by oxygen-loving microbes can produce 38 units of ATP, a measure of cellular energy. In contrast, fermentation bacteria which are common microbes that use anaerobic decomposition, get far different results. The same unit of glucose when consumed by these anaerobic bacteria can only produce two units of ATP [10]. The microbes that use oxygen as electron acceptors can easily outcompete microbes that use other compounds when oxygen is present – they can produce a lot more energy, grow faster, and reproduce more.

However, when soil becomes flooded and the oxygen is depleted, microbes that use other compounds as electron acceptors have the upper hand. These anaerobic decomposers use compounds in a predictable order, so long as all the alternative compounds are present in the soil. This order is determined, in part, by the energy yield (amount of ATP) per unit of glucose consumed. As oxygen is depleted, microbes that specialize in the use of nitrate take over, because they have the next-best energy yield per unit of glucose. Then, as all available nitrate is depleted, new microbes that specialize in the use of manganese and iron take over, followed by sulfate-loving microbes and finally carbon-dioxide specialists [10]. This predictable order of soil processes happens over both space and time.



Generalized diagram showing the depth (cm) where different microbial processes dominate. Figure adapted from Craft, 2001.



Generalized diagram showing that different microbial processes dominate as the length of flooding increases. Figure adapted from Craft, 2001.

Denitrification

When oxygen is no longer available in flooded soil, the first microbes to take over are those that use nitrate (NO_3^-) to consume organic material. In this process, these bacteria reduce nitrate to nitrogen gas, a transformation called denitrification. This

reaction is a very important part of the nitrogen cycle, enabling the return of nitrogen that was fixed from the atmosphere, back to the atmosphere [7]. This process is also very important for removing excess nitrate that enters wetlands as runoff from nutrient rich areas [10].



Excess nitrate, which can cause algal blooms and low oxygen in water bodies, can be partially mitigated by the process of denitrification in wetlands.

Manganese and Iron Reduction

After the nitrate-specialist bacteria use up most of the available nitrate in the soil, microbes that use manganese and iron to consume organic carbon take over. This process converts iron and manganese into their reduced states [10]. Manganese and iron reduction is responsible for many of the physical features associated with hydric soils, particularly soil color. Redoximorphic features are formed by the reduction, oxidation, and movement of iron and manganese compounds [11].

Sulfate Reduction

Sulfate is the next compound to be utilized by specialized microbes when iron and manganese are

sufficiently reduced. In this process, sulfate is reduced to hydrogen sulfide, which gives off a characteristic “rotten egg” smell that many would recognize, particularly when visiting a coastal wetland. This process is more common in estuarine soils than freshwater wetlands [10]. Great Salt Lake, having a similar chemical composition to the ocean, has more sulfate than other inland areas, and thus sulfate reduction is relatively common in our soils [14].



Oxidized iron visible in wetland soil.

Methanogenesis

Once all other reducible substrates in the soil have been consumed, new specialized microbes use carbon dioxide as the electron acceptor in chemical reactions for cell metabolism, a process which produces methane. Methanogenesis yields much less energy than other reducing reactions, so it is not a competitive process unless all other compounds have been reduced [10]. In other words, microbes that use other compounds as electron acceptors can produce more energy from the same unit of glucose (they don't have to work as hard), so they will always win, unless their compounds are used up. The production of methane in some wetland soil is a concern to many, as methane is a potent greenhouse gas.

Physical Characteristics of Hydric Soils

There are distinct features in the organic and mineral soil that are associated with hydric, “reduced” soil. These features are a direct result of the microbial activity, discussed above, that occurs under anaerobic conditions. These features are used to delineate, or demarcate, where wetlands are located, most importantly, for legal purposes associated with the Clean Water Act.

Organic Soil in Wetlands

Soil microbes use organic carbon from decomposing plant material as an energy source. However, the rate at which the microbes can consume this energy source is considerably lower under anaerobic conditions. This reduced rate is because, as mentioned in the above section, microbial consumption of organic material is much less energy efficient in anaerobic conditions than aerobic conditions. Thus, in saturated soils, organic matter from animal waste and dead plant leaves, shoots and roots degrades very slowly and often accumulates - a key indicator of hydric conditions in some wetlands [12]. The accumulation of organic matter is often used to identify a hydric soil in wetland delineation.

Organic matter accumulates best under cold temperatures and in areas with frequent rainfall which enables the growth of large amounts of plant material [13]. This accumulation occurs because microbial consumption of organic material is even less efficient under extreme cold or extensive flooding periods. The thickness and state of decomposition of organic horizons must be considered when using the organic soil layer to identify a hydric soil [11]. Organic horizons that are greater than 20 centimeters (cm) are in most cases found in areas that are periodically flooded [11]. Organic

horizons that are 40 cm or more are classified as “histosols” which are a unique wetland soil order [12]. Organic soils are rare and take long time periods to form, making them important resources to study and preserve [13].

In Great Salt Lake wetlands, organic horizons are thickest under vegetation like cattail and *Phragmites* that produce large amounts of organic material in emergent wetlands that are frequently flooded. Soil organic matter has chemical properties that allow it to adsorb nutrients and contaminants. Accumulation of soil organic material in Great Salt Lake wetlands is one way that these wetlands retain sediments, nutrients, and pollutants, improving downstream water quality [14].



Organic matter in Great Salt Lake wetland soil.

Mineral Soil in Wetlands

Mineral soils in wetlands, by definition, have less organic matter than organic soils, less than 20-35% [9]. Mineral soils have a higher dry weight per unit volume (bulk density) and a lower amount of airspace (porosity) than organic soils, making their water holding capacity comparatively low. Mineral soils, when flooded for extended periods of time, develop characteristic features that can be used in

their identification. Most of these features are redoximorphic, formed by the reduction and oxidation of iron and manganese compounds [11]. Below are three key redoximorphic features common in Great Salt Lake wetlands that are used in the identification of wetland soils.

Redox Concentrations

Redox concentrations are orange/ reddish brown or black spots seen throughout an otherwise greyish (gleyed) soil matrix [9]. These colorful spots are concentrations of iron (orange) or manganese (black) oxides that have accumulated at a point or around a pore, like a root channel, where oxygen is present [11]. These features are often present when an area is intermittently flooded and then dried. The fluctuating oxygen conditions associated with these conditions give rise to distinct patches of reduced versus oxidized soil minerals. Redox concentrations are relatively insoluble, remaining long after soils have been drained, a characteristic that makes them a vital clue in deciphering a region's hydrologic history [9].



Bright orange mottles, called redox concentrations, are locations where an anoxic soil becomes oxidized by an intrusion of oxygen into the soil.

Depleted Matrices

In depleted matrices, the iron and manganese in loamy and clayey material in mineral soil is chemically reduced. With this feature, we see the color

of the soil transformed from a red, brown, yellow or orange color typical of unsaturated soils containing iron and manganese to a soil where the iron and manganese that create these colors have been reduced and leached out. Thus, in depleted matrices, we see the natural color of the parent material, typically greyish colors that are low in chroma and high in value [12].



This depleted matrix shows color loss due to the reduction and leaching of substances like iron and manganese in the subsoil.

Gley Soil Colors

“Gley” is a specific range of hues, or spectral colors, described in the Munsell Color Charts that is associated with flooded soil. The gley hues are often described as greyish, but are sometimes greenish or blue-grey. Gleying occurs when iron has been reduced, in the process changing soil from red, brown or black to a unique gley hue [11].



Gley, or blue-grey, color in soil occurs with the chemical reduction of iron.

Wetland Soils of the Great Salt Lake Region

Great Salt Lake soils are notable for their high concentrations of salts and other dissolved minerals. These minerals built up over geologic time as rocks were weathered and sediment was transported from the surrounding region [15]. Since Great Salt Lake is a terminal lake, there is no place for these minerals to go. And as lake water evaporates, dissolved minerals become more concentrated in lake water and sediments, leading to the unique mineral composition of Great Salt Lake wetland soils [15].

Great Salt Lake soils are composed of dense, fine grained sediments originally deposited in the glacial Lake Bonneville that once covered the entire region [16]. These lake-formed, or “lacustrine deposits,” are the parent materials for the three dominant soil series in the wetlands of Great Salt Lake: Playa, Eimarsh, and Pintallake. These soil types differ in salinity, accumulated organic material, and the types of vegetation with which they are associated.

Playa Soil Series

The Playa series are intermittently flooded soils where the water is prevented from percolating through by an impermeable soil horizon and is thus left to evaporate [19]. When the water evaporates it often leaves behind salt crusts inhospitable to plant life. Few plants can survive on playa soils, which typically only support less than 10 percent plant cover. The plants that can survive on playa soil are very salt tolerant species, such as pickleweed (*Salicornia rubra*) [19].



Playa soil profile.



Playa vegetation community.

Typical profile: 0-150 cm, stratified fine sandy loam to silty clay
Salinity: Strongly saline (32-100 mmhos/cm)
Available water capacity: Very low (approx. 3 cm)
(NRCS Web Soil Survey)

Eimarsh Soil Series

Eimarsh soils are often found in close proximity to Playa soils, but experience more moisture during the growing season. They are typically wet during fall and winter and during the early part of the critical vegetation growing season [20]. These soils are often associated with saline wet meadow vegetation communities dominated by salt grass (*Distichlis spicata*) or Nebraska sedge (*Carex nebrascensis*) [20]. The organic material produced by these communities does not result in a large O-horizon – rather, it is integrated into the first 0-13 cm in the A-horizon, accounting for the loamy texture in this layer [21]. These soils can be strongly saline but do not reach the high salinity levels that are found in playas.



Eimarsh soil profile.



Eimarsh vegetation community.

Typical profile: 0-13 cm silty clay loam, 13-150 cm silty clay
Salinity: Strongly saline (30-80 mmhos/cm)
Available water capacity: Very low (approx. 6 cm)
(NRCS Web Soil Survey)

Pintailake Soil Series

Pintailake soils are less saline than Eimarsh and Playa soils. Pintailake soils can also hold more water, thus supporting more productive vegetation communities. Emergent plants like threesquare bulrush (*Schoenoplectus americanus*) and hard-stem bulrush (*Schoenoplectus acutus*) are common on these soils [20]. These soils have a larger O-horizon than the other soils due to the accumulation of decaying plant material [21].



Pintailake soil profile.



Pintailake vegetation community.

Unique Features of Great Salt Lake Soils

When digging a soil pit around the Great Salt Lake, you might come across a few unique features to the region. You may find a layer of what looks like perfectly round, shiny sand grains. Called oolites, these “grains” are actually brine shrimp fecal pellets or other mineral fragments, which over time have become coated with concentric layers of calcium carbonate (from the open water portions of Great Salt Lake).[17].



Calcium carbonate can also form a caliche layer, as mineral elements move throughout the soil profile with wetting and drying and become concentrated at the wet-dry interface [18]. These caliche layers are hard, rock-like formations that are occasionally found deep in the soil.



Typical profile: 0-8 cm slightly decomposed plant material, 8-25 cm silt loam, 25-80 cm silty clay loam

Salinity: Moderately saline (10-33 mmhos/cm)
Available water capacity: Moderate (approx. 18 cm)

(NRCS Web Soil Survey)

Is That Snow on the Ground?

Some may ask this question on their first visit to Great Salt Lake wetlands seeing white crust covering the ground. The expansive open ground with little vegetation is actually covered with a thin layer of minerals -- soluble salts, carbonates, and gypsum -- that accumulate on the soil surface [22].



As water evaporates from the soil, large amounts of salt and other minerals are moved to the surface [16]. When evapotranspiration exceeds yearly precipitation, these minerals become concentrated at the surface, resulting in the salt crusts seen throughout Great Salt Lake wetlands [22].

Final Remarks

Using information in this booklet, the physical features of a wetland soil can be observed to tell a story about a soil's history, its characteristics, the wetland in which it is found, and the plant life it supports. Hydric soils have unique characteristics, due to anaerobic conditions, that distinguish them from other soil types. Great Salt Lake wetland soils display many of these hydric characteristics. The many functions that Great Salt Lake wetland soils provide, from transforming nutrients, to filtering toxins and accumulating loose sediments, make them an important resource worth protecting. The diversity of soil types and soil features in this region both support and reflect the dynamic diversity of plants and animals that visitors admire.



References

1. Hartemink, A. E., Nortcliff, S., & Dent, D. L. (2008). *Soil – The living skin of planet Earth [Brochure]*. Wageningen, The Netherlands: International Union of Soil Sciences.
2. Soil Science Society of America. (2008). *Glossary of soil science terms*. Madison, Wisconsin: Soil Science Society of America.
3. Soil Survey Division Staff. (1993). *Soil survey manual*. (U.S. Department of Agriculture Handbook 18). Washington, DC: Soil Conservation Service.
4. Sprecher, S. W. (2001). *Basic concepts of soil science*. In J. L. Richardson & M. J. Vepraskas (Eds.), *Wetland soils; genesis, hydrology, landscapes, and classification (3-18)*. Boca Raton, Florida: Lewis Publishers.
5. U.S. Department of the Interior. (2003). *Riparian area management: Riparian-wetland soils*. (Technical Reference 1737-19). Denver, CO: Bureau of Land Management.
6. Mausbach, M. J. & Parker, W. B. (2001). *Background and history of the concept of hydric soils*. In J. L. Richardson & M. J. Vepraskas (Eds.), *Wetland soils; genesis, hydrology, landscapes, and classification (19-33)*. Boca Raton, Florida: Lewis Publishers.

7. Vepraskas, M. J., & Faulkner, S. P. (2001). Redox chemistry of hydric soils. In J. L. Richardson & M. J. Vepraskas (Eds.), *Wetland soils; genesis, hydrology, landscapes, and classification* (85-105). Boca Raton, Florida: Lewis Publishers.

8. Sumner, R., Schubauer-Berigan, J., Mulcahy, T., Minter, J., Dyson, B., Godfrey, C., & Blue, J. (2010). *Alternative futures analysis of Farmington Bay wetlands in the Great Salt Lake ecosystem*. (EPA/6--/R-10/032). Cincinnati, OH: U.S. Environmental Protection Agency.

9. Mitsch, W. J., & Gosselink, J. C. (2007). *Wetlands*. Hoboken, New Jersey: John Wiley and Sons.

10. Craft, C. B. (2001). Biology of wetland soils. In J. L. Richardson & M. J. Vepraskas (Eds.), *Wetland soils; genesis, hydrology, landscapes, and classification* (107-135). Boca Raton, Florida: Lewis Publishers.

11. Vepraskas, M. J. (2001). Morphological features of seasonally reduced soils. In J. L. Richardson & M. J. Vepraskas (Eds.), *Wetland soils; genesis, hydrology, landscapes, and classification* (163-182). Boca Raton, Florida: Lewis Publishers.

12. U.S. Department of Agriculture, Natural Resources Conservation Service. (2010). *Field Indicators of Hydric Soils in the United States, Version 7.0*. L. M. Vasilas, G. W. Hurt, and C. V. Noble (Eds.). USDA, NRCS, in cooperation with the National Technical Committee for Hydric Soils.

13. Collins, M. E., & Kuehl, R. J. (2001). Organic matter accumulation and organic soils. In J. L. Richardson & M. J. Vepraskas (Eds.), *Wetland soils; genesis, hydrology, landscapes, and classification* (137-162). Boca Raton, Florida: Lewis Publishers.

14. Interview with Toby Hooker, PhD, wetland scientist, Utah Division of Water Quality.

15. Boettinger, J. L., & Richardson, J. L. (2001). *Saline and*

wet soils of wetlands in dry climates. In J. L. Richardson & M. J. Vepraskas (Eds.), *Wetland soils; genesis, hydrology, landscapes, and classification* (383-390). Boca Raton, Florida: Lewis Publishers.

16. Kadlec, J. A. (1982). Mechanisms affecting salinity of Great Salt Lake marshes. *American Midland Naturalist*, 107(1), 82-94.

17. Gwynn, J. W. & Murphy, P. J. (1980). Recent sediments of the Great Salt Lake basin. In J. W. Gwynn (Ed.), *Great Salt Lake: a scientific, historical and economic overview* (83-96). Salt Lake City, Utah: Utah Geologic and Mineral Survey.

18. Laubhan, M. K. (2004). Variation in hydrology, soils and vegetation of natural plustrine wetlands along geologic provinces. In M. C. McKinstry, W. A. Hubert & S. H. Anderson (Eds.), *Wetland and riparian areas of the intermountain West: Ecology and management* (23-51). Austin, Texas: University of Texas Press.

19. Rocchio, J. (2006). *Intermountain basins playa ecological system: Ecological integrity assessment*. Fort Collins, CO: Colorado Natural Heritage Program, Colorado State University.

20. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. (n.d.) *Official Soil Series Descriptions*. Retrieved from http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/home/?cid=nrcs142p2_053587

21. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. *Web Soil Survey*. (n.d.) Retrieved from <http://websoilsurvey.nrcs.usda.gov/>

22. Boettinger, J. L. (1997). Aquisalids (Salorthids) and other wet saline and alkaline soils: problems identifying aquic conditions and hydric soils. In M. J. Vepraskas & S. W. Sprecher (Eds.), *Aquic conditions and hydric soils: the problem soils* (79-97). Madison, Wisconsin: Soil Science Society of America.

Utah State University is committed to providing an environment free from harassment and other forms of illegal discrimination based on race, color, religion, sex, national origin, age (40 and older), disability, and veteran's status. USU's policy also prohibits discrimination on the basis of sexual orientation in employment and academic related practices and decisions. Utah State University employees and students cannot, because of race, color, religion, sex, national origin, age, disability, or veteran's status, refuse to hire; discharge; promote; demote; terminate; discriminate in compensation; or discriminate regarding terms, privileges, or conditions of employment, against any person otherwise qualified. Employees and students also cannot discriminate in the classroom, residence halls, or in on/off campus, USU-sponsored events and activities. This publication is issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Kenneth L. White, Vice President for Extension and Agriculture, Utah State University.