Pit Reclamation
And
Salt Migration Control

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BEFORE THE OIL CONSERVATION COMMISSION
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Executive Summary

Current techniques in the reclamation of salty materials, such as those found in drilling pits, below-ground tanks and similar facilities from oil and gas drilling operations, have been found sufficient to ensure restoration of natural vegetative covers in New Mexico and other arid areas of North America. Successful reclamation requires proper management of a number of issues on the land surface, including adequate cover, seed bed preparation, seed source, seed mix, proper seeding rates, in some cases amendments to the soils to encourage revegetation, and good post-seeding management practices to maximize vegetative success. A properly reclaimed pit in New Mexico should support an appropriate vegetative community of indigenous or other locally appropriate species.

There is a concern that salts from properly closed drilling pits will migrate to the surface of reclaimed drill sites. Additionally, these salts are thought to negatively affect the success of reclamation. The purpose of this paper is to demonstrate that salts from the closed drilling pits will not migrate to the surface when the surface is properly reclaimed. This paper discusses processes explaining why drilling materials from reclaimed drilling pits placed in deep (1 meter) well drained soils do not migrate to or accumulate at the soil surface. The sciences of soil chemistry and soil physics are used as the basis for an understanding of salt movement. The results of studies and practical experience discussed in this paper support the position that upward salt migration to the surface of a drill pit does not occur when the site is properly reclaimed.

It is generally understood that soil formation occurs in relation to its respective climatic zone. In nearly all cases, soil formation results in salts moving downward; in wet climates to great depths and in dry climates to shallower depths. Salts will move upward to the soil surface only under very specific conditions. This upward migration of salts requires the existence of either a shallow water table or a sustained wetting front to the surface. When soils are dry, common to arid and semi-arid climates, unsaturated flow conditions dominate. Under these conditions, convective flow is essentially eliminated. Therefore, upward migration of salts in the arid and semi-arid climates of New Mexico is not supported.

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The use of appropriate reclamation technology, to close drilling pits, will result in conditions that exclude upward migration of salts to the surface. This fact is demonstrated in a study specifically conducted to evaluate potential upward migration of salts from reclaimed drilling pits. Salts and the sodium were found to migrate 6 to 12 inches upward into the materials placed over the drilling pits. The movement was associated with diffusion not convection and the results compare well to similar studies describing the upward salt migration in coal reclamation.

Vegetation planted on properly reclaimed drilling pits is predicted to be unaffected by the materials present in the drilling pits. In fact, the presence of vegetation will reduce water contents in the root zone lowering the potential for water movement, thus eliminating the potential for upward salt migration. Salts do not migrate upward to a level that will impact vegetation establishment. The use of proper procedures for vegetation establishment can be expected to produce a site of sustainable, productive reclamation.

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Introduction

For most people, soil is no more than "dirt". To some, soil is a nuisance and to others it is the basis for life. To a soil scientist, the word soil describes the unconsolidated weathered layer of the earths' crust that supports the hydrological and biological cycles. In 1941, Hans Jenny (Jenny 1941), a young U.C. Berkeley Professor proposed that soil was the result of five soil-forming factors: parent material; topography; climate; organisms; and time. Today, nearly 70 years later, these same five factors are still recognized as the important mechanisms responsible for the unique characteristics of every soil. As soils form, the weathering processes create an anisotrophic distribution of its properties. This means that the spatial distribution of soil characteristics is not random but depends on direction. Even more simply, soils are not uniform but change with depth. It is well known that soil formation or weathering results in the redistribution of soluble products from the upper part of the soil profile to lower parts. The depth to which salt accumulates is proportional to the amount of precipitation received. For example, in wet climates, soluble salts are often completely removed from the soil profile while in semi-arid and arid climates salts tend to be leached from the surface and accumulate in the subsoil or the lower portion of the profile.

It is generally accepted that soil formation is strongly influenced by climate. In nearly all cases, soil weathering causes salts to move downward in wet climates, to great depths and in dry climates, to shallow depths. Salts rarely move upward to the soil surface and do so only under specific conditions. The upward migration of salts requires the existence of either a shallow water table or a sustained wetting front to the surface; a situation common to irrigated soils. These saturated conditions support convective movement of water toward the surface and the subsequent transport of salt. When unsaturated flow conditions dominate, which is common to arid and semi-arid climates, convective flow in soil is essentially eliminated. Therefore, upward migration of salts in the arid and semi-arid climates of New Mexico is not supported.

There is a concern with regard to the migration of salts associated with the closure of drilling pits. One position is that salts from drilling pits will migrate to the surface. It is thought these salts will negatively impact successful reclamation of the site. Therefore, reclamation success will not be affected by the upward migration of salt from the pit because the salts do not

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accumulate at the surface. The purpose of this paper is to demonstrate that salts do not migrate or accumulate at the soil surface when drilling pits are properly closed and reclaimed. The sciences of soil chemistry and soil physics provide the basis for an understanding of salt movement. The results of studies and practical experience from these fields of science will be discussed in this paper to support the position that upward salt migration to the surface of a drill pit does not occur when the site is properly reclaimed and, hence, protective vegetation is not likely to be impacted at reclaimed sites.

The Impact of Salinity on Plant Growth and the Physical Characteristics of Soils

Impacts of Salinity on Plant Growth

Salt accumulation in soils is a concern primarily because of its potential impact on plant growth. The accumulation of salts is associated with either natural or manmade conditions. Under natural conditions salts accumulate due to the weathering of mineral rocks in-place or due to the deposition of salts originating from the weathering of rocks from other places in the geological system. Once salts occur in the soils, their impact can have a negative impact on plant growth. High salt levels in the soil solution are characterized with high osmotic potentials that require plants to expend considerable amounts of energy to absorb water. The higher the salt concentrations of the soil solution, the more energy required for a plant to extract water. At some point, the plants are unable to absorb enough water to maintain biochemical functions and the plant dies.

Impact of High Soluble Salt Concentrations on the Hydraulic Properties of Soils

An issue often associated with salt accumulation in a soil profile is the development of high sodium conditions. High levels of sodium can cause significant deterioration in the physical conditions of soils causing imbalances in the water and air regimes. Such conditions can also affect water movement as a deterioration of soil physical conditions, forming a barrier that can support a wetting front or a perched water table. The physical changes result from the flocculation and dispersion conditions caused by the amount of sodium that occupies cation exchange sites. High levels of sodium compared to calcium and magnesium adsorbed to cation exchange sites in the soil can cause soil particle slaking and clay dispersion. This relationship is quantified by the exchangeable sodium percentage, where high exchangeable sodium percentage values are usually associated with problematic soils. Sodium adsorption ratio values, which is the solution levels of sodium compared to calcium and magnesium, are often used in lieu of exchangeable sodium percentage because of ease of collecting the data and the associated cost. The major factors responsible for these chemical reactions include the type of soil colloid materials present and the charge distribution associated with the surfaces of these materials. The flocculation and dispersion reactions are governed by the attractive and repulsive forces associated with the electron double layer resulting from the surface charge of soil colloids. These reactions are significantly influenced by salt levels in the soil as high solution salt levels will prevent soil particle slaking and clay dispersion. An explanation of how sodium can cause dispersion is provided by the Gouy-Chapman Theory (Overbeek, 1952; Bolt, 1955).

It is impossible to estimate the impact of low or high exchangeable sodium percentage values on the physical state of a soil or spoil material without evaluating the electrical conductivity or electrolyte concentration of the system (Shanmuganathan and Oades, 1983; Sumner, et. al., 1998a). Research has shown that extremely high exchangeable sodium percentage values do not cause physical degradation of soil materials if the system also contains high levels of soluble salts. This fact was first demonstrated by research done by Quirk and Schofield (1955). Their work showed that soil materials with an exchangeable sodium percentage of 40% maintained a stable permeability with an electrolyte concentration of about 30 mmol/L (about electrical conductivity = 2.1 dS/m). McNeal and Coleman (1966) reported that typical arid land soils (having clay mineralogy dominated by 2:1 layer silicates with only moderate amount of montmorillonite) can tolerate exchangeable sodium percentage values of 15 or greater before serious reductions in hydraulic conductivity occur, if the salt concentration of the percolating solution exceeds 3 mmol/L (0.2 dS/m). Gardner et al. (1959) came to the same conclusion dealing with unsaturated soils. Similar results were found by Amezketa and Aragues (1995) for calcareous soils from arid environments. These researchers also found that large reductions in hydraulic conductivity occurred in sand clay mixtures where steep concentration gradients developed between the micropores and macropores. They concluded that an "osmotic explosion" effect was responsible for the reduction in hydraulic conductivity. Although interesting, this finding was associated with an artificial system of sand mixed with clay and may not represent conditions occurring in soils.

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Many studies have shown the relationship between clay mineralogy and the relationship between salinity and sodicity (Velasco-Molina, et al., 1971; Frenkel et al., 1978). In general, the research indicates that clay dispersion becomes very important for soil management decisions when electrolyte concentrations are low even at low sodium adsorption ratio values. This was found for the 2:1 clay minerals and to a lesser degree in the 1:1 kaolinitic clays (Velasco-Molina, et al., 1971; Miller et al. 1990). Sumner et al. (1998a) provides a thorough discussion of the sodium adsorption ratio/electrical conductivity relationship in their publication titled "Sodic Soils: Distribution, Properties, Management, and Environmental Consequences."

The data show that if soluble salts are maintained at or above a threshold electrolyte concentration value for a specific material, the physical condition of the material will be maintained in a flocculated state no matter how high the sodium adsorption ratio. The only caveat to this situation is that some materials that have high sodium adsorption ratios and high electrical conductivities can become dispersed at the surface if impacted with water containing low levels of electrolytes from irrigation or rainfall. However, the dissolution of unstable minerals due to weathering often results in solution salt levels above the threshold electrolyte concentration and therefore swelling and dispersion do not occur. This is especially true for the unstable minerals usually found in soils of the arid to semi-arid regions of the country. In addition, mechanical forces resulting from raindrop impact, the flow of water at the surface or the use of farm equipment could cause clay dispersion. However, if measures are taken to eliminate these potential impacts to the system, the high sodium adsorption ratio, low electrical conductivity soil/spoil material will usually be maintained in good physical condition. One method of doing this is to treat the surface with an amendment such as gypsum. The application of gypsum at the surface would result in electrolyte concentrations from 5 to 15 mol Ca/m^3 and would be sufficient to ensure flocculation of the soil clays, reducing dispersion-induced sealing and erosion. These measures are not expected to be needed for pit closures. Another method of protecting the surface against the mechanical forces that can initiate slaking and dispersion is to cover such materials with topdressing material. Thus the placement of plant growth material over salty material would help prevent physical property issues.

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Soil Water Movement and Its Impact on Salt Movement

The physiochemical condition of soil water is characterized in terms of its potential. Soil water potential is made up of three components: gravity, matric (capillarity), and osmotic (salt concentrations). The per mass or per volume fraction of water in the soil is expressed in terms of soil wetness. Soil wetness and matric potential are functionally related to each other. Therefore, the amount of water in a soil and the energy state of the water are important factors affecting the availability of water for plant growth and the movement of water in the soil environment. Difference in potential energy over distance is the moving force causing water flow in soils. Simply, water moves along a gradient.

The water movement in well-drained soils is primarily associated with unsaturated flow where the mechanisms of flow are associated with gravity and matric potential (Hillel, 1998). Gravity pulls water downward in the soil profile. Water also moves from one area to another within the soil dependent on the matric potential differences or gradient between various sites in the soil. Water will tend to move from areas characterized with higher water content characterized with less negative matric potentials to areas with low water content or with more negative matric potentials. In other words, water moves from wetter places in the soil to drier places in the soil. Water held in small voids or capillaries and on the soil particle surfaces can also move as a vapor to other locations in the soil. This mechanism usually accounts for very small amounts of water movement and does not influence salt movement.

Osmotic potential, which is dependent on the amount of salt in solution, is primarily associated with the migration of salts within the water phase due to diffusion resulting from concentration gradients. Solution salt levels tend to move from areas of high concentration to areas of low concentration. This movement of salt is governed by diffusion mechanisms, which result in limited potential for salt movement. Solutions high in salts, characterized with high osmotic potentials, will also have some influence on matric potential by decreasing (more negative values increasing the suction) the matric potential. However, this mechanism is often negligible and does not significantly influence water movement in soils.

Water Movement in Soils: Saturated and Unsaturated Flow Conditions

The flow of water under saturated and unsaturated conditions is much different. The hydraulic conductivity changes significantly as saturated flow supports high hydraulic conductivity resulting in movement of large volumes of water compared to unsaturated flow conditions, which is characterized by lower hydraulic conductivity. Under saturated flow conditions, the hydrostatic pressure is positive and the large and small soil pores transmit water. The water phase is continuous and the water movement through the profile is at a maximum. As the water content decreases below saturation, soil pores become filled with air and the pores available for water flow decrease. Air filled pores tend to conduct water as if they were solid material. The water is characterized by a pressure lower than atmospheric and is referred to as matric potential. As the soil becomes less saturated, the matric potential becomes more negative and the water present is held tighter. Therefore, in unsaturated flow conditions, water tends to move slowly as the path of water movement becomes very tortuous. As the soil becomes drier, water movement decreases.

As water enters the soil, it tends to flow downward due to both gravity and the matric potential of the drier material located beneath the recently wetted surface soil. The wetting front will move downward initially as a pulse. When the addition of water is stopped, the pulse or front continues to move down leaving a less saturated condition behind the pulse. Soluble salts move with the water front. In time, as the waterfront moves downward it dissipates. A portion of the water is left behind in an unsaturated condition and a portion of the water moves ahead also in an unsaturated condition. At some depth, the water front "stops". Unsaturated flow conditions now exist throughout the soil profile. In effect, there is no significant movement of salt.

The establishment of a wet zone (saturation) characterized by positive pressure below the surface may result from the impedance of water flow due to the existence of impermeable layers or from a water table. The presence of a saturated zone can promote upward movement of water above the front. The extent of upward movement is dependent on the extent of the saturated zone. Capillary movement of water above a water table can be significant.

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The Influence of Plant Evapotranspiration on Water Movement

Evapotranspiration or the uptake of water by plants is another factor that will influence water movement to the soil surface. Without the presence of a water table near the surface, water is removed from the rootzone by plants enhancing unsaturated water flow conditions. In other words, the root zone becomes drier and the resulting negative potentials further reduce water movement. As a result, salts tend to experience limited upward migration.

Limitations to Salt Migration in Unsaturated Water Flow Conditions Associated with Reclaimed Drilling Pits

The reclaimed drilling fluid pits are primarily associated with unsaturated conditions and therefore any fluids that migrate from such structures will do so through the mechanisms associated with unsaturated flow. The proposed reclamation of drilling pits consists of thoroughly mixing soil materials with the drilling fluids/solids. Following the mixing, the material has approximately 50% water content and is geotechnically stable as to support vehicle traffic. This material is covered with 48 inches of plant growth medium that will support plant growth. The pit material and the material placed on the surface are characterized with water levels much below saturation and support water movement under unsaturated flow conditions. Therefore, water conditions in this system do not promote the establishment of wetting fronts that support upward movement of water and salts.

Salt Distribution in Native and Reclaimed Soils

Under typical conditions, water applied to the surface of either native or reclaimed soils moves downward; thus salts are leached to lower levels in the profile. This fact has been seen at numerous locations representing native soil development, the reclamation of mine sites, and the reclamation of drilling pad sites.

Native Soils

In my experience over the last 35 years in San Juan County, I have looked at over 6000 soil profiles. In this semi-arid region of New Mexico, I have repeatedly noted that salts have been leached from the upper portions of the soil profile and if they are present, they will be deposited at levels below the root zone. Generally, it is common to find grass roots extending to depths of

24 inches and shrub roots to depths of 60 inches. The soluble salts are typically leached to layers below the root zones. The less soluble salts like calcium carbonate, when they accumulate, occur at depths above the soluble salts. It is common to find these calcic horizons at depths of 24 to 30 inches. The vast majority of the deep, well drained soils in northwestern New Mexico can be characterized as being well-developed with distinct horizons and relatively free of salt. Two profiles have been selected to characterize this concept of a typifying pedon for the region. The soils were sampled as part of soil surveys conducted in 1998 and 2006. Both soils are Coarse-loamy, mixed, mesic, Typic Haplargids. The soils are derived from alluvium deposited on an ancient stream terraces with slopes from 1 to 3%. The dominant vegetation on these soils is alkali sacaton and galleta grasses and shadscale, a salt tolerant shrub. A partial soil description follows:

<u>1998 Soil</u>

A	0 to 5 inches; sandy loam, electrical conductivity = 0.60 mmhos/cm.	
Bt	5 to 17 inches; sandy loam, electrical conductivity = 0.58 mmhos/cm.	
Btk	17 to 31 inches; sandy loam, electrical conductivity = 1.39 mmhos/cm.	"calcic"
Ck	31 to 51 inches; sandy loam, electrical conductivity = 3.53 mmhos/cm.	

<u>2006 Soil</u>

A	0 to 2 inches; sandy loam, electrical conductivity = 0.50 mmhos/cm	
Bw	2 to 8 inches; sandy loam, electrical conductivity = 0.50 mmhos/cm	
Btk	8 to 24 inches; sandy loam, electrical conductivity = 0.48 mmhos/cm	
Bk	24 to 32 inches; sandy loam, electrical conductivity = 1.22 mmhos/cm	"calcic"
C	32 to 60 inches; loamy sand, electrical conductivity = 5.56 mmhos/cm	

It has been my experience that soils as described above are representative of the soil types common to well site locations in the San Juan Basin. Even where a variety of soils are found at the well sites, ranging in parent material, topographic position, climate, vegetation and age, the one common denominator that persists is the fact that salts have not accumulated in the surfaces of these profiles but rather have been leached to lower depths of the soil profile.

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Reclaimed Soils

A study conducted by Stutz and Buchanan (1987) on reclaimed sites demonstrates that materials characterized with high salt levels at or near the surface were significantly altered by natural rainfall. Salts were leached from the surface materials and deposited at lower levels in the profile. This study included sampling of fourteen sites, four with topsoil and 10 without topsoil. The sites had been reclaimed 9 to 12 years prior to sampling. These sites were deep, well-drained, and dominated with fourwing saltbrush on slopes ranging from 0 to 15%. About 50% of the fourwing saltbrush roots were found in the upper 40 inches of the profile and 90% were found in the upper 100 inches. The electrical conductivity data in each case show declines at the surface (0 to 10 inches) with accumulation zones lower in the profile (near 30 inches). For example, an average electrical conductivity value for the surface 10 inches was 3.11 mmhos/cm and the average from 10 inches to 30 inches was 7.53 mmhos/cm. This sequence of salt distribution is seen for both the topsoiled and non-topsoiled sites. It was obvious that water was infiltrating the spoil material and leaching salts to lower levels in the profile. There was no evidence of the salt moving from lower levels in the profile to the surface. The study demonstrates that saline-sodic materials containing relatively high levels of salt had leached the soluble salts from the surface to levels deeper in the profile over a 9 to 12 year period.

A study conducted by Buchanan Consultants (1998) on a reclaimed site after four growing seasons at the San Juan Mine in New Mexico demonstrated downward salt migration under irrigation conditions. The 0 to 8 inch depth increment in the topdressing appeared to be a zone of depletion with salt deposition at lower levels in the profile.

A similar evaluation was conducted by Brown (2006) at several drill pad reclamation sites located near Sheridan Wyoming, which is a semi-arid environment. The sites were successfully reclaimed with grass and were influenced with very high evapotranspiration demand. Following reclamation, the electrical conductivity values found at the surface were in the 3 to 6 mmhos/cm range. Three years later, the sites were sampled and the resulting electrical conductivity data showed substantial decreases. These results show a large reduction in salt levels of the surface materials after a relatively short time period. The salts were leached to lower levels in the reclaimed materials and did not accumulate near the surface.

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Results of a simulated weathering study (Musslewhite et al., 2007) conducted using minesoil materials collected from mine sites located in northwestern New Mexico and Northeastern Arizona support the results found in the field studies discussed. Ten columns were constructed with materials collected from four mines located in New Mexico and Arizona. The columns were constructed with 6 inches of coversoil over 12 inches of minesoil compacted at levels simulating field conditions. Water was applied to the columns simulating irrigation schedules, which consisted of applications of 0.3 inch of water over a four hour period every 4 days over a 28 day period. Ten combinations of minesoil were used with electrical conductivity values from 0 to 4 mmhos/cm, 4 to 8 mmhos/cm and 8 to 18 mmhos/cm with corresponding sodium adsorption ratio levels of 15 to 25, 25 to 40 and greater than 40. The results of this study showed that the weathering process including leaching resulted in a reduction in soluble salts, primarily sodium and sulfate and lower electrical conductivity and sodium adsorption ratio values. For example, Minesoil #6 was characterized with a baseline electrical conductivity value of 7.42 mmhos/cm. After the simulation, electrical conductivity values of the minesoil were 1.41 mmhos/cm in the 0 to 2 inch depth increment, 1.31 mmhos/cm in the 2 to 4 inch depth increment, 1.73 mmhos/cm in the 4 to 8 inch increment, and 3.33 mmhos/cm in the 8 to 12 mmhos/cm. Compared to the baseline value considerable amounts of soluble salts were leached from the minesoil during the weathering study.

The studies briefly outlined, demonstrate that natural climatic conditions move salts downward in native and reclaimed soils with time. In native soils, the parent material weathers and soluble constituents are leached and accumulate lower in the soil profile. Reclaimed soils experience the same type of reaction to the soil forming processes. The presence of zones in the mine soil containing elevated soluble salts does not influence the direction of salt movement. Salts do not remain at the surface or migrate upward to the surface even under the high evapotranspiration demand of the plants occupying the reclaimed sites.

Upward Salt Migration at Reclaimed Sites

An issue associated with pit closure is if the salts in the drilling pit will migrate to the surface. Information in this paper supports the downward movement of both water and salt for sites in arid and semi-arid climates. Water is expected to move downward under most conditions, viz.

where a water front is not established near the soil surface either from a water barrier or a water table. The research and observations indicate that salt will move downward in the soil profile from salty materials located at the surface under vegetation cover. Now it is important to review research efforts that have specifically evaluated upward sodium migration from materials placed near the surface. Such information is available dealing with coal mine reclamation projects, covering heap leach facilities associated with mineral mining operations and the conventional surface disposal of drilling fluid wastes, which is the topic addressed in this report.

Some twenty years ago, a major issue with coal mine land reclamation was the migration of sodium from sodic spoil material into the overlying topsoil. A number of studies were undertaken in the Northern Great Plains (semiarid climate) during the 1970's using wedge plots to determine how much topsoil was needed over sodic materials to assure successful reclamation. These plots were also used by various researchers to assess the movement of sodium from the spoil into the overlying topsoil material. Dollhopf et al. (1980) initially found no upward movement of sodium in soils two years after construction with a sandy loam topsoil (27.6 inches in depth) overlying a spoil material characterized by kaolinitic clay mineralogy. Then, eleven years later Dollhopf et al. (1992) reported sodium migrated in the lower 9 inches of the topsoil. The actual level of upward migration can not be specifically determined since the 9 inch zone was sampled as a single sample. In other words, the migration could have been limited to some level less than 9 inches. These findings are similar to reconstructed soil profiles at sites in the northern Great Plains by Bailey (2001), which showed an increase of sodium in the 6 inches of topdressing material directly above the spoil interface 16 years after soil profile construction. The constructed profiles consisted of 6 inches of clay loam topsoil over either 22 inches or 37 inches of subsoil above the sodic spoil material. These studies were associated with topsoil materials overlying sodic spoils containing smectitic clays. The researchers reported there to be less influence from upward sodium migration in the 37 inch subsoil profile compared to the 22 inch subsoil profile. Similar findings were demonstrated by Merrill et al. (1983) using reconstructed profiles consisting of 12 inches of topsoil materials over sodic spoils (sodium adsorption ratio = 25, electrical conductivity = 3.3 dS/m) with about 30% smectitic clays (sandy clay loam texture) that had been reclaimed for 4 years. This study noted that the greatest upward migration of sodium occurred during the first two years of the study to levels 4 to 6 inches above the spoil interface. Barth and Martin (1984) found similar results in their study of wedge plots located in Wyoming, Montana and North Dakota where 60 inches of topsoil was placed over sodic spoil material. After 5 years, these sites showed sodium migration from 3 to 6 inches into the topsoil overlying sodic spoil materials. These studies were all conducted where topsoil was placed over sodic spoil materials. The interesting result of these studies is that upward sodium migration reaches an "equilibrium" state of about 6 inches under the conditions studied. In all cases, the upward migration apparently resulted from diffusion rather than convective means.

With time, the upward migration and the downward percolation of sodium will reach equilibrium in constructed soil profiles consisting of topsoil materials overlying sodic spoil materials. These constructed profiles are expected to develop characteristics of a natric soil with time. Bailey (2001) speculated that these profiles will develop with the displacement of sodium by divalent cations resulting from the soil weathering processes and leaching of sodium from the profile with time. The massive spoil materials will evolve with more structured development as aggregation develop due to wet-dry and freeze thaw cycles resulting in a well drained material.

Research conducted by McFarland et al. (1992) at reclaimed drilling pits in arid and semi-arid rangelands in Texas showed very similar salt movement results for drill fluid burial sites compared to those discussed previously. These authors studied the effect that depth of suitable plant growth material over drill fluids and cuttings had on upward salt migration. The drilling fluids contained very high levels of sodium and chloride. The study was conducted over a 20 month period. The study showed that soluble salts did migrate from 6 to 12 inches upward into the cover material. The exchangeable sodium percentage values did not increase at levels greater than 2 inches above the drilling fluids. Elements such as barium, chromium, copper, nickel, and zinc did not migrate into the overlying material. The migration of sodium was reported to be associated with diffusion rather than convective flow mechanisms. Vegetation growing on the sites that included four wing saltbush and buffalo grass was not affected by the drilling fluids.

Research conducted on revegetation of neutralized heap leach materials also provides insight into upward salt movement. Cellan et al. (1999) evaluated upward salt migration in the Santa Fe/Calvada heap material. The Santa Fe/Calvada Mine is located near Hawthorne Nevada in a precipitation zone of 4 to 6 inches per year. The company involved was concerned with the expense of covering the heap material with plant growth material and if sodium and soluble salts would migrate upward thus leaving the plant growth material toxic to plant growth. The study was conducted using 6 and 12 inches of plant growth material directly applied over the heap materials. The heap materials consisted of 4 inches of very salty material (EC=62 mmhos/cm; sodium = 2760 ppm or 120 meq/L) resulting from evaporation of excess barren solutions over heap materials characterized with electrical conductivity values of 10 mmhos/cm and sodium concentrations of 1702 ppm (74 meq/L). The project was conducted using a meteoric/climatic cycle simulation column test, which consisted of water applied at rates simulating meteoric conditions; Winter application rates = 2.57 inches, Spring = 1.11 inches, Summer 0.76 inches and Fall = 1.56 inches for a total of 6 inches. Temperatures were modified to simulate seasonal temperatures. A total of 70 days was required to simulate two annual climatic cycles. Soluble salts, sodium and nitrates were found to be vulnerable to the leaching process for both the 6 inch and 12 inch growth medium cover. Results for tests conducted on Pad 1 materials with 6 inches of cover, sodium decreased an average of 57%, electrical conductivity decreased 50% and nitrates decreased 83% in the cover soil. The levels of the three constituents found in the surface salt layer decreased, ranging from 92% to 99%. The constituents in the heap material leached, ranging from 14% to 62%. Leaching associated with the application of 12 inches of plant growth material resulted in a decrease in sodium by an average of 61%, electrical conductivity an average of 57% and nitrate 61% in the growth medium layer. The three constituents decreased, ranging from 91% to 99% in the surface salt layer. The three constituents in the heap material decreased, ranging between 22% and 74%. Similar results were found for tests conducted for combinations of other materials. The results demonstrate that the application of 6 inches and 12 inches of suitable plant growth material over the high salt heap material is protected from upward salt migration.

The related upward salt migration research data show that salts tend to migrate upward to a limit of about 6 inches above the high salt materials under arid and semi-arid environments where water tables do not exist near the surface. If salt movement upward does occur, movement is limited by diffusion to about 6 inches and does not represent a problem for the growth of vegetation.

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Drilling Pit Reclamation Techniques

Drilling pits are sometimes characterized as areas that do not support vegetation. The existence of these bare sites that are either characterized by the presence of surface salts are assumed to result from the upward migration of salts from the drill pits. However the presumed salt problems are not likely due to salt migration but to some other explanation. Upward migration is not likely to have occurred at the site for the reasons outlined previously in this report. Drilling pits are commonly six to eight feet below the surface. Migration is limited to layers of 6 inches above the drilling fluids and if the site is well drained the surface 30 inches is expected to be leached. When these problems do exist they are likely associated with the following conditions: (1) the drilling pit extended to the surface and was not covered or was covered with a few inches of plant growth material; (2) the drill pit was covered with a plant growth material originally containing a high salt content, and then the material was compacted where water could not penetrate the compacted and salt movement was prohibited; and (3) the drill pit materials were mixed with the plant growth medium during pit reclamation resulting in a material that contains high salt levels eliminating plant establishment and the leaching of salts at the site.

The use of proper reclamation techniques will eliminate problems as described above. Reclamation techniques used to properly close drill pits in New Mexico should assure the sustainable establishment of vegetation communities. The reclamation should include stabilization of the fluids left in the drilling pit. Mixing it with soil materials removed from the pit will dry the sludge leaving it at an unsaturated water content condition thus restricting water flow characteristics as noted previously for unsaturated flow conditions. The stabilized drill pit materials are than covered with a minimum of 36 to 48 inches of good quality material free of salts.

When proper reclamation conditions are applied there will be no substantial upward migration of water or salts. As discussed previously, even if the drill pit is not covered with a liner material, the salts would be expected to move upward a maximum of about 6 inches. Properly reclaimed, vegetation is expected to establish and provide sustainable plant production and conditions simulating native soil formation.

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Conclusions

1. The principles of soil physics demonstrate that water movement in native soil and reclaimed soil profiles is dominated by unsaturated flow conditions if a water table is not present near the surface. The uptake of water by plants often decreases water levels significantly reducing water movement. Under such conditions, salts are leached to lower levels in the soil profile as demonstrated by data collected at field sites described in this report and will not migrate to the surface.

2. The data show that if soluble salts are maintained at or above a threshold electrolyte concentration value for a specific material, the physical condition of the material will be maintained in a flocculated state no matter how high the sodium adsorption ratio.

3. Unsaturated water flow conditions will prevent significant upward migration of salts if water table conditions do not exist near the surface. Upward migration of salts is dominated by diffusion as upward convective water movement is limited in unsaturated flow conditions.

4. There are a variety of soils found at well sites, ranging in parent material, topographic position, climate, vegetation and age. In spite of the range of characteristics, the one common denominator that persists is the fact that salts have not accumulated in the surfaces of these profiles but rather have been leached to lower depths of the soil profile.

5. Spoil materials containing relatively high levels of salt will tend to leach deeper into the profile with time and will not accumulate at the surface.

6. In coal mined reclaimed sites, where plant growth materials are placed over materials characterized by high salt and high sodium content, upward salt migration appears to reach a maximum at about 6 inches. The studies reviewed provide a consistent result, which supports the conclusion that in arid and semi-arid climates the upward migration of salts is limited to 6 inches above the interface with the high salt and/or high sodium materials. The primary mechanism responsible is diffusion.

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7. Plant growth materials placed over heap leached materials containing high levels of salts and sodium did not change due to upward migration of salts. In fact, salts were leached to lower depths in the profile. A discussion of this study is presented.

8. The use of appropriate reclamation techniques to close drilling pits will result in conditions that will not support upward migration of salts to the surface. This fact is demonstrated in a study specifically conducted to evaluate potential upward migration of salts from reclaimed drilling pits. Salts were found to migrate upward 6 to 12 inches and sodium was found to move about 6 inches upward into the materials placed over the drilling pits. The movement was associated with diffusion and the results compare well to those found for the upward salt migration in coal mined reclaimed areas.

9. Vegetation planted on properly reclaimed drilling pits should not be negatively impacted by the materials present in the drilling pits. Salts will not migrate upward to a level that will impact vegetation establishment. Vegetation establishment will provide significant habitat for wildlife and domestic livestock.

Recommendations

1. Stabilize drilling materials with soil
2. Apply 4 feet of cover soil;
    a. Sufficient to prevent salt migration to the surface.
    b. Sufficient to establish a sustainable native vegetation.
    c. Sufficient to maintain a community similar to conditions prior to oil and gas operations.
3. Reclaim with site-specific native species

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