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Soil water balance dynamics on reclaimed mine land in the southwestern United States

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ABSTRACT

Understanding the dynamics of soil water movement in arid and semi-arid environments is critical to successful reclamation of mined lands. Characteristics of applied topsoil impact soil water processes and long-term ecosystem health. The objective of this study was to better understand the soil water balance at a reclaimed mine in the southwestern United States through the investigation of soil hydraulic properties and subsequent one-dimensional water balance modeling. The study was conducted on a mine reclaimed using geomorphic principles. Complementary field and laboratory techniques were used to describe soil properties. Dry bulk density of topsoil at the mine sites increased with depth, while saturated hydraulic conductivity decreased with increasing bulk density. Two discrete one-dimensional models were created to investigate soil water dynamics and results indicate the importance of appropriately describing soil layering to create more accurate model predictions. In addition, results suggest that matric potentials during the study period were often too low for substantial plant growth. Models similar to those created in this study may be helpful in future assessment of seed germination on reclaimed lands as well as the implications that global climate change may have on reclamation strategies in the future.

1. Introduction

The ultimate goal of mine reclamation is to produce a functional and healthy ecosystem similar to the surrounding natural landscape. Perhaps most important to the establishment of such a landscape is the topsoil, here defined as the soil material mining companies often stockpile, store, and later spread over the top of mine spoils during the reclamation process (Hargis and Redente, 1984). Soil properties are important to long-term reclamation goals including vegetation growth, water quality of both surface and ground water, and slope stability and, more specifically, important to infiltration rates, soil water retention, and root water uptake. The topsoil layer is beneficial to the growth of native vegetation types and therefore the success and long-term stability of reclamation efforts (Paschke et al., 2003; Redente et al., 1997). Although application of the topsoil layer is beneficial, revegetation of mined areas in semi-arid portions of the western United States has proven to be difficult possibly due to the lack of sufficient soil moisture at critical times of seed germination (Fehmi et al., 2014; McNearny and Wheeler, 1995). Due to the often extreme unpredictability of rainfall events in arid and semi-arid regions as well as the strong evaporation potential to which soils are exposed, understanding the hydrologic response of the topsoil is crucial to optimizing reclamation efforts in these regions.

Understanding water movement and retention in topsoils at mine sites requires quantification of the physical and hydraulic soil properties. Evaluation of reclamation efforts often focuses on comparisons between disturbed (i.e. mined) and surrounding undisturbed systems, which has shown that mining and reclamation practices often increase soil bulk density (Potter et al., 1988; Shrestha and Lal, 2011). Changes in bulk density may have impacts on soil water retention and soil water movement (Diodato and Parizek, 1994; Vogel, 1987). For example, increased bulk density has been linked to decreased saturated hydraulic conductivities in disturbed soils which may decrease water movement in the topsoil and increase runoff (Potter et al., 1988). As a result, tillage is often used to alleviate concerns regarding compaction by modifying soil properties and water movement within the topsoil (Chong and Cowsert, 1997). Of important consequence, therefore, is any layering formed within the topsoil from possible compaction

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and tillage during the reclamation process. Soil layering may impact both infiltration and evaporation, thus complicating the soil water balance within the soil. With the complicated nature of a water balance within the heavily manipulated topsoil, soil properties alone do not inform temporal conditions at a mine site.

Understanding the temporal dynamics of hydrologic soil conditions is critical in the establishment of a healthy, native ecosystem, especially in arid and semi-arid environments where water availability to plants is scarce. Temporal descriptions of hydraulic properties and hydrologic conditions of the topsoil with field measurements is possible on reclaimed sites and is beneficial to understanding water movement (Diodato and Parizek, 1994). Because mine reclamation sites are often large areas of land, data collection demands can limit spatial and temporal detail and may inhibit the informing of the reclamation process. In such cases, hydrologic modeling of the near surface soils at mine sites may prove to be an effective method for understanding soil moisture conditions. Previously, field data collection and soil moisture modeling have been combined to understand germination potential of grasses in a semi-arid environment (Fehmi et al., 2014). However, in that study the hydrologic model was calibrated to detailed soil moisture data at a long-term study site. Detailed information on historical soil moisture is likely to be unavailable at mine reclamation sites due to the newly constructed landscapes. Therefore, modeling practices based on soil hydraulic properties would be more achievable. The ability to predict soil moisture as a function of time may be an extremely useful tool in optimizing landscape conditions and effectively implementing reclamation.

The objective of this study was to improve understanding of water balance dynamics on a reclaimed mine site in the southwestern United States. This was achieved through field and laboratory data collection and analysis and the application of a one-dimensional, numerical water balance model. Physical and hydraulic properties of the soil were investigated with a focus on soil layering. The properties were then applied to the numerical model. Soil moisture measurements were also collected to assess the performance of the numerical model through time with measured meteorological inputs. With a model capable of predicting field-measured water contents in the unsaturated zone of the reclaimed sites, we discuss the implications that the topsoil hydrologic processes may have on the reclamation process.

This research was conducted on a reclaimed mine in the southwestern United States. The reclamation was conducted using geomorphic reclamation principles. Geomorphic reclamation applies fluvial geomorphic processes to design a more natural hydrologically functioning landscape (Eckels and Bugosh, 2010). Characteristics include heterogeneous slopes and aspects, sinuous channels, and complex drainage patterns. The total mine area was 12.5 km^2 at an elevation of approximately 1850 m. Reclamation included reapplication of stockpiled topsoil to the hillslopes with a depth between 20 and 30 cm above mine spoils. After both the regrade with spoil and application of topsoil, the layers were disked to alleviate soil compaction in the topsoil and topsoil-spoil interface and to prepare the soil for seeding. Four types of native seed mix were dispersed across portions of the reclaimed hillslopes and straw was spread across the seeded landscape. Straw was crimped into the topsoil with the goal of reducing runoff and soil erosion.

2. Materials and methods

2.1. Soil properties

2.1.1. Laboratory measurements

2.1.1.1. Soil sampling. Soil samples were obtained from two watersheds separated by 2 km at the reclaimed mine site. These watersheds, designated as watersheds A and B, were each about 0.5 ha (Fig. 1). Sampling locations at each watershed were found by first dividing the watershed into quadrants defined by ridge lines or changes in slope aspect. Next, coordinates of three sampling locations within each quadrant were determined by random number generators.

Both disturbed and undisturbed soil samples were collected. Undisturbed samples were collected from one location within each quadrant using a split spoon sampler with a diameter of 5 cm and a length of 15 cm. So-called "top" samples were collected within 15 cm of the surface and "bottom" samples were collected from a depth of 15 cm–30 cm. Disturbed samples were also collected from these different depths. Two undisturbed samples were also collected from the top of a reclaimed channel, locations where topsoil was not applied, to determine properties of the spoil materials.

2.1.1.2. Determination of physical properties. Grain size distributions of the disturbed samples were determined following ASTM D422. Sieve analyses were conducted for materials retained on #200 sieve after washing. Hydrometer analyses were conducted on soil that passed the #200 sieve. Specific gravity tests were conducted according to ASTM D854. The densities of the undisturbed samples were obtained following ASTM D2937. The density values measured from "top" samples represented cumulative average densities for the top 15 cm of soils where the values from "bottom" samples represented cumulative average densities for 15–30 cm depths of soils. Gravimetric moisture contents were determined for the undisturbed samples collected from each location following ASTM D2216.

2.1.1.3. Determination of hydraulic properties. Falling head permeability tests were conducted for the measurement of saturated hydraulic conductivity (K_{sat}) of undisturbed samples (method B of ASTM D5084, constant tailwater pressure). Falling head

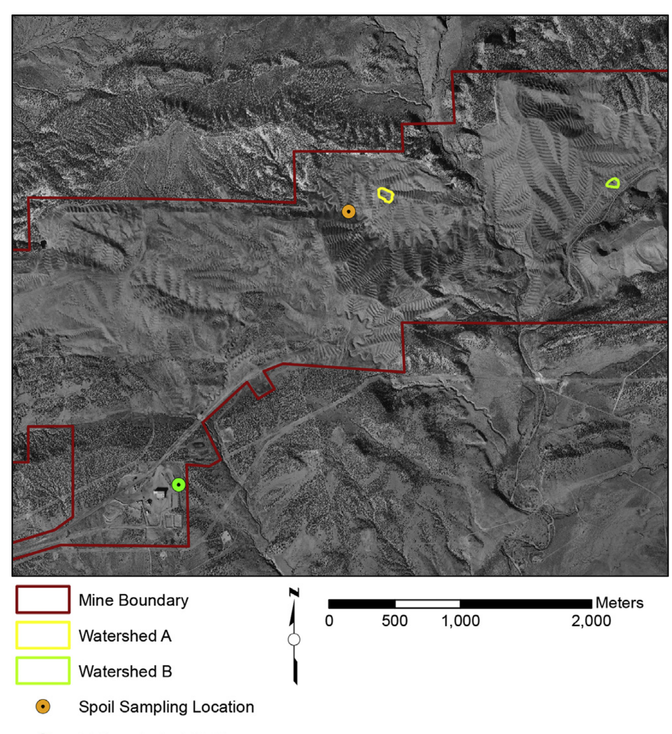

Fig. 1. Locations of sampling sites within the mine boundary.