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Inundation Patterns and Their Effect on the Physical and Hydraulic Properties of Floodplain Soils in the Middle Rio Grande Floodplain

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Inundation Patterns and Their Effect on the Physical and Hydraulic Properties of Floodplain Soils in the Middle Rio Grande Floodplain

Sophie J. Stauffer

Committee:
Dr. Mark Stone, chair
Ms. Jennifer Schuetz
Dr. Jose Cerrato

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Water Resources Program
The University of New Mexico
Albuquerque, New Mexico
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Abstract

The surface of the floodplain serves as a vadose zone boundary where water infiltrates, evaporates, or returns to the river, and sediments accumulate or are eroded. The discharge of the Middle Rio Grande has been altered by the construction of Cochiti Dam and the implementation of levees. Hydraulic connectivity in the Middle Rio Grande floodplain is perhaps most apparent at a small local wetland and a low-lying trough with a high water table capable of causing seeping floods. The objective of this study was to determine if inundation patterns impact the hydraulic and physical properties of floodplain soils. A study was designed that would test the soil texture, infiltration rates, and hydraulic conductivity at flooding and non-flooding areas within the Middle Rio Grande Floodplain.

The statistical difference among the variables with respect to flooding frequency was determined by non-parametric Mann Whitney U tests. No significant difference was found among saturated hydraulic conductivity values or infiltration rates. A greater distinction among flooding and non-flooding areas was noted between the infiltration rates measured under unsaturated conditions than under saturated conditions. The infiltration rates measured under unsaturated conditions were, in general, greater at the non-flooding areas. The difference in the percent of fine particles in flooding and non-flooding areas was significant, suggesting one way in which inundation patterns affect the physical properties of floodplain soils.
Acknowledgments

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Introduction

The geology of the Rio Grande Rift structurally and constituenty defines the Rio Grande watershed. Over millions of years, sediment carried and deposited by the Rio Grande and other transport mechanisms shaped the local aquifer. Additionally, the Rio Grande flows determine the hydraulic gradient that governs flows between the aquifer and the river (Bartolino and Cole, 2002). Development along the Middle Rio Grande has led to the construction of levees that restrict the river’s flow path and dams (Cochiti Dam in 1975) that reduce the river’s discharge downstream (Ellis, 2003). The frequency of over bank flooding events within the Middle Rio Grande floodplain—known locally as the bosque—has decreased since the settlement of the area. A full understanding of the hydrologic connectivity between the Middle Rio Grande and the riparian floodplain begins with the recognition that river flows are a mechanism for sediment transport, and sediments create a medium for water transport. An important part of the surface and groundwater exchange is the infiltration process that begins at the floodplain surface.

The hydrologic connectivity within the Rio Grande floodplain becomes increasingly complex as one considers the origin of fluvial deposits, as well as their effect on infiltration rates. Bartolino and Cole (2002) suggested that the Santa Fe Group Aquifer is composed in part by sediments deposited by rivers and streams. The sediments of fluvial deposits often vary by grain size. Coarser grained materials are often found along the main water channel, while fine-grained silts are found where overbank flooding occurred (Bartolino and Cole, 2002). Thus, flooding events transport sediment along the floodplain, the size of which could vary. In addition to depositing sediment, flushing floods can remove organic matter and debris that accumulates along the surface of the floodplain.
A decrease in the frequency of overbank flooding in the Middle Rio Grande floodplain has some environmentalists concerned. As of 1993, nitrogen content was limited in cottonwood forests, an indication that nutrient transport has declined (Crawford et al., 1993). Additionally, frequent flushing flooding events could help mitigate the accumulation of organic matter, another concern in the bosque. Molles et al. (1998) introduced flooding to a part of the Middle Rio Grande floodplain that had been disconnected from the river for 50 years. Soil biological activity (dehydrogenase) at the disconnected sites exceeded that at sites with rare to frequent flooding by a factor of two (Molles, et al., 1998). Depending on soil particle size and composition, organic substances, and microbial by-products, and particulate organic matter may coat or intermix with soil particles (Dekker and Ritsema, 1999). Soil may, in fact, become hydrophobic, or water repellent. The infiltration rate of hydrophobic soil will depend upon particle size and pore opening, so infiltration rates may be limited in materials such as sand and clay (Doerr, Shakesby, and Walsh, 2000). Runoff and erosion tend to be greater along water repellant areas (Dekker and Ritsema, 2000).

In order to come to a greater understanding of the impact of flooding frequency in the bosque, consideration will be given to the hydraulic properties as well as the physical properties of the floodplain soils. A report published by the United States Geological Survey refers to hydraulic conductivity as “perhaps the most important parameter that ground-water scientists use to characterize an aquifer” (Bartolino and Cole, 2002). The effect of soil stratigraphy on the movement of water through the Middle Rio Grande floodplain is a topic of recent study. It was noted that the storage volume as well as flux rates depend upon hydraulic conductivity (Samson, 2012). The Middle Rio Grande study site consisted of alternating layers of silty loam and clay (Samson, 2012). The mean percent fines (particle size 0.75 mm or less) observed in the silty...
loam layers was 30.14% as opposed to 1.92% in sandy layers (Samson, 2012). The hydraulic conductivity varied inversely with percent fines values, as the mean field saturated hydraulic conductivity for silty loam layers was $4.6 \times 10^{-4}$ (cm/sec) and $3.5 \times 10^{-2}$ (cm/sec) in the sand layers (Samson, 2012).

The Bosque Biological Management Plan (1993) recognizes the importance of hydrologic connectivity to ecosystem integrity and biological health within the Middle Rio Grande floodplain (Crawford et al., 1993). In particular the authors emphasize that the Rio Grande flows should mimic the natural hydrograph to the extent possible and that the river should be allowed to move across the floodplain freely (Crawford et al., 1993). Preserving hydraulic connectivity between the river and the floodplain has both physical and biological benefits. Floodplain inundation, either from precipitation events or flooding events is a vital ecosystem service. Thus, the objective of this study is to determine if inundation patterns impact the physical and hydraulic properties of floodplain soils in the Middle Rio Grande floodplain.

Methods

Site Characteristics

Two locations were selected for this study that represented the various inundation patterns within the Middle Rio Grande floodplain. The Bosque Ecosystem Monitoring Program’s (BEMP) Harrison site is located in southern Albuquerque near the return-flow entrance of the municipal water treatment plant. Within this unique area, a wetland has formed where a channel carries water into the floodplain at a low velocity. Cattails thrive in the wetland, but as the surface elevation increases beyond the wetland, saltcedar and willows dominate. The Harrison site was thus chosen for this study due to its adjacent flooding and non-flooding areas.
Figure 1. The wetland within the Harrison BEMP site. Included in the picture is the tension disc infiltrometer.

Conditions at the Harrison site can be compared to the Route 66 site, which also possesses an isolated flooding zone. The Bosque Ecosystem Monitoring Program has reported flooding in a low-lying trough at their Route 66 monitoring station (Eichhorst et al., 2012). The surface on either side of the trough is elevated and creates conditions for seep flooding to occur in the trough (Eichhorst et al., 2012). The isolated wetland (Harrison), trough (Route 66), and the surrounding elevated surfaces were chosen as data collection points for this study.
The low-lying trough and site of flooding measurements at the Route 66 BEMP site.

Soil Characterization

Six inch deep pits were excavated to collect near-surface sediment samples. Once the tension disc infiltration measurements were complete, the disc was lifted from the surface, the contact sand was scraped away, the shallow pit was exacted, and samples were collected. These samples represent the soil conditions where the steady state infiltration rates and hydraulic conductivity were determined. A second soil sample was obtained adjacent to the where tension disc infiltration measurements were measured. Twenty soil samples were analyzed from this study.

Soil samples were transported to the lab where they were analyzed for moisture content and percent fine particles. Approximately 800 grams of each sample was placed in a drying oven at 105 degrees Celsius. The dry samples were re-weighed after several hours. The difference in weight was attributed to moisture. Samples collected from the site of the tension
disc infiltrometer measurements (as opposed to the samples collected from the soil adjacent to the instrument) were analyzed further to determine the percent of fine particles they contained.

A partial sieve analysis was performed, as many of the samples dried in large clumps that could have been misinterpreted as large sediment particles rather than clusters of fine-grained particles. The decision was made to wash the samples through the smallest sieve first. The smallest sieve in the sieve stack was the Number 200 sieve that had 0.075 millimeter openings. Washing the samples through this sieve effectively removed sediment with a particle size less than 0.075 millimeters. The sediments remaining after the washing were dried and then weighed in order to receive the dry weight. The amount of fines contained in the sample (that passed through the 0.075 millimeter sieve) was determined from the difference in weight pre and post washing.

*Tension Disc Infiltrometer*

A tension disc infiltrometer was employed to determine the steady rate infiltration rates at each flooding and non-flooding site location. Measurements were taken over bare soil free of organic debris. To prepare the instrument, approximately 70 centimeters of water was poured into the water tower and 30 centimeters of water was poured into the smaller tension tower. A hollow glass rod could be raised and lowered in the tension tower to simulate various pressure head conditions. Infiltration rates were recorded under two pressure head scenarios for this study. The disc must sit on a layer of fine-grained, contact sand spread three millimeters thick over the surface. Once the disc is placed on the contact sand, the disc should not be moved until measurements are complete. Thus, infiltration tests should be repeated in the same location from greatest tension to least.
To conduct the first infiltration test at each site, the tension was established at negative ten centimeters pressure. Once the disc was placed over the contact sand, the valve connecting the disc to the towers was opened. Quickly, two additional valves were opened which allowed air into the tension tower. The vertical downward flow of water into the soil should be dictated by the soil properties. The time was recorded at each moment the water level in the water tower dropped one centimeter. Times were recorded until the time interval between the recordings became constant, indicating steady state was reached.

Pictured here is water from the tension disc infiltrometer flowing laterally across the floodplain. Adjustments were made to the contact sand and disc until water applied to the floodplain surface flowed vertically into the soil.

Ultimately, two steady state infiltration rates were determined (negative ten and zero centimeters pressure) at the flooding and non-flooding areas of the Harrison and Route 66 sites. Tension disc infiltrometer measurements were repeated two to three times per area in order to
verify proper technique and to reduce calculation errors. Twenty tests were conducted. The data collected from the tension disc infiltrometer was critical to understanding the hydraulic properties of the floodplain soils.

*Data Analysis*

The saturated hydraulic conductivity was calculated as a function of the steady flow rate \(q\), the pressure head applied to the soil surface \(h_s\), and the sorptive number \(\alpha\). Steady state infiltration rates were obtained from dozens of time recordings (taken over an average of forty minutes) as the water level dropped one centimeter in the infiltrometer. The inside diameter of the water tower and the inside diameter of the disc were measureable, known constants for the steady state flow rate equation. The observed drop of the water table was established as one centimeter. Of the variables needed to calculate the steady flow rate from the disc, only the time required to drop one centimeter in the water column changed with testing location and pressure head. The steady state flow rate was determined from the following equation:

\[
q = \frac{\Delta h_c}{\Delta t} \left( \frac{d_t^2}{d_s^2} \right)
\]

where \(\Delta h_c\) is the drop in the water column (1 centimeter), \(\Delta t\) is the time required for the water column to drop one centimeter, \(d_t\) is the diameter of the water tower, and \(d_s\) is the diameter of the disc. Two steady state infiltration rates at different pressure heads are needed to determine the sorptive number. Having implemented the tension disc infiltrometer at zero and negative ten centimeters pressure at every study site, two steady state flow rates could be determined easily. An equation for hydraulic conductivity was derived from Wooding’s equation for determining flow rate (Hussin and Warrick, 1995). The equation was rearranged so the saturated hydraulic conductivity was expressed as a function of the circular disc, steady state flow rate, and sorptive number, and pressure head:
\[ k_s = \left( \frac{q}{1 + \frac{4}{\pi 10} \alpha} \right) \exp (\alpha h_s) \]

where \( q \) is a steady state infiltration rate, \( h_s \) is the pressure head applied to the soil surface

\[ h_s = h_t + h_c \]

where \( h_t \) is the pressure head established by the water column and \( h_c \) is the pressure offset due to the contact sand,

and \( \alpha \) is the sorptive number

\[ \alpha = \frac{\ln \frac{q_1}{q_2}}{h_{t1} - h_{t2}} \]

where \( q_1 \) and \( q_2 \) are the steady state infiltration rates and \( h_1 \) and \( h_2 \) are the pressure heads established through the water tower settings. The hydraulic conductivity measured at negative ten centimeters pressure was evaluated from (a modification of) Gardner’s equation (Hussen and Warrick, 1995).

\[ k_{-10} = k_s \exp(h_{s-10} \alpha) \]

To determine whether the difference in data collected from flooding locations and the data from non-flooding locations was statistically significant, Mann Whitney U tests were performed. A Mann Whitney U test is a non-parametric test that can be conducted whether or not data is normally distributed (Sheskin, 1997). This test was appropriate for this study since there were only ten study locations, or data points. The results of each field and laboratory test were ranked by magnitude in ascending order and given a value from 1 to 10. For every Mann Whitney U test conducted there were two groups: flooding sites and non-flooding sites. The ranks from the flooding sites were totaled, and a separate total was found for the non-flooding locations.
sites. Two U values were calculated for each variable from the flooding and non-flooding groups based on the sum of the ranks (R) and the number of the points in each group (n) (Sheskin, 1997):

\[ U_1 = (n_1 \times n_2) + \left( \frac{n_1 \times (n_1 + 1)}{2} \right) - R_1 \]

\[ U_2 = (n_1 \times n_2) + \left( \frac{n_2 \times (n_2 + 1)}{2} \right) - R_2 \]

The sum of ranks (R) varied with each Mann Whitney U test, but the number of data points in the non-flooding group \( (n_1 = 4) \) and in the flooding group \( (n_2 = 6) \) were constant. The significant difference in the two groups is determined by comparing the lesser U value \( (U_1) \) to the critical U value. After referencing a table of critical U values, it was found that when \( n_1 = 4 \) and \( n_2 = 6 \), the critical U value equals 2 (site). The lesser of the calculated U values \( (U_1) \) must be less than the critical U value for there to be a statistically significant difference within the data set. Finally, the Mann Whitney U tests were conducted in the R Programing language in order to obtain the P values.

**Results**

Data collected at the Harrison wetland and the Route 66 low-lying trough were considered to represent flooding conditions in the Middle Rio Grande floodplain. Just beyond the wetland and trough, where the surface elevation increases, data was collected that represents the non-flooding conditions of the bosque. In order to assess the impact of inundation patterns on the physical properties of floodplain soils, particle size was considered. Upon first observation, a greater quantity of sand was noted in samples from the non-flooding areas. It appeared that the
dried samples collected from the flooding areas of the Middle Rio Grande floodplain were composed primarily of fine particles. Soil samples collected from the flooding areas consistently contained a greater percentage of fine particles than samples collected from non-flooding areas of the floodplain. A sample collected from the Harrison wetland was 99% fine particles by weight, and all samples from flooding areas contained at least 82% fines (figure 1). The mean soil sample collected from a non-flooding area was 31% fines by weight. Greater variation was found among non-flooding soil samples, as samples ranged from 9% fine particles to 46%. After performing the Mann Whitney U test, it was determined that the soils collected from the frequently flooding areas were composed of a significantly higher percentage of fine particles than non-flooding soils. Soil in the non-flooding area of the floodplain was statistically coarser than soil in the flooding area with a P value of 0.0095.

Figure 4. Percent of Fine Particles (less than 0.075 mm) by Site. Soil samples from flooding location contained a higher percentage of fine particles, having a P value equal to 0.0095.
Under the tension disc infiltration method, the time required for the water in the column of the tension disc infiltrometer to drop one centimeter, should become constant after an initial period of fluctuation. One must simply wait until the time interval becomes constant. Tests were conducted for up to ninety minutes in the bosque before steady state was reached. An infiltration test at the Route 66 non-flooding area was terminated after it required sixteen minutes for the water in the column to drop one centimeter (appendix figure A-1). Thus, the time required to confidently obtain a steady state infiltration rate with the tension disc infiltrometer was one of the challenges of this study.

The statistical significance of the infiltration rates with respect to flooding frequency was evaluated with a Mann Whitney U test. When grouped in terms of flooding or non-flooding location, the lesser U value generated by the infiltration rates under saturated conditions was 11. The critical U value for a data set of this study size is two, thus the test did not depict a statistically significant difference in the infiltration rates measured at zero centimeters pressure. Infiltration rates at negative ten centimeters, however, showed a stronger correlation to flooding frequency with a U value of 4 and a P value equal to 0.1143. Although the infiltration rates at all other flooding locations were lower than the non-flooding areas, the greatest infiltration rate measured at negative ten centimeters pressure was found at the first Harrison flooding location (figure 2). The infiltration rates measured under unsaturated conditions at the other five flooding areas were less than from the non-flooding areas, but there appeared to be no statistical difference between the infiltration rates at flooding and non-flooding areas.
Figure 5. Infiltration Rates by Site: The P value for infiltration rates under unsaturated conditions (-10 centimeters pressure) with respect to flooding frequency was equal to 0.1143. The P value for infiltration rates under saturated conditions (0 centimeters pressure) was equal to 0.9143.

Saturated hydraulic conductivity values were derived from the infiltration rates. In order to perform the Mann Whitney U test, the hydraulic conductivities were ranked by magnitude. No significant difference in saturated hydraulic conductivity between the flooding and the non-flooding areas was found from the Mann Whitney U Test, as the P value was equal to 0.9143. Of the ten values, both the greatest and the least saturated hydraulic conductivity were found at frequently flooded areas (figure 3). The saturated hydraulic conductivity seemed to vary to a greater extent at the frequently flooded areas than the non-flooding areas. The mean saturated hydraulic conductivity of the flooding sites was greater than the mean at non-flooding sites. Thus, based on the rank sum test performed, no significant difference was found between the hydraulic conductivities of the representative flooding and non-flooding locations of the Middle Rio Grande floodplain.
Figure 6. Saturated Hydraulic Conductivity by Site: The P value for saturated hydraulic conductivity by flooding frequency was equal to 0.9143.

The results of the Mann Whitney U test suggest an incongruity between the percent of fine particles in soil samples and saturated hydraulic conductivity. Saturated hydraulic conductivity values were not significantly different—rather they varied among the flooding and non-flooding sites. Soil samples from the flooding areas possessed a higher percentage of fine particles than soil from the non-flooding areas, thus revealing that the difference in particle size between flooding and non-flooding areas was significant. If the hydraulic conductivity is compared to soil particle size, study samples with the greatest particle size did not necessarily correspond to samples with greatest hydraulic conductivity.

The purpose of the Mann Whitney U test was to indicate a statistically significant difference in data collected from flooding and non-flooding areas. Each variable (hydraulic conductivity, soil particle size, and infiltration rates) was represented as a unique data set containing measurements from the ten sample locations. Despite having the same Mann Whitney U value, the saturated hydraulic conductivity values did not correspond to the infiltration rates.
under saturated conditions (zero centimeters pressure from the tension disc infiltrometer). The study site with the lowest saturated hydraulic conductivity was one of the Harrison flooding locations, but a Route 66 flooding location had the lowest infiltration rate under saturated conditions. The Mann Whitney U test compares each variable to the flooding frequency (flooding vs non-flooding). Thus, in order to compare the saturated hydraulic conductivity, soil particle size, and infiltration rates using the Mann Whitney U Test, one compares the relationship of these variables to flooding frequency rather than comparing the variables themselves.

Saturated hydraulic conductivity, soil particle size, and infiltration rates were studied and compared among flooding and non-flooding locations within the Middle Rio Grande floodplain. The difference in soil particle size and soil moisture between the flooding and non-flooding areas was statistically significant. Although the differences in hydraulic conductivity and infiltration rates with respect to flooding frequency were not significant, differences between the flooding and non-flooding locations are apparent. The percent of fine soil particles present in the soil samples at each study site are perhaps better distinguishing features of the flooding and non-flooding areas. A statistical test evaluating the relationship between hydraulic conductivity and soil characteristics was not conducted in this study. Next, it was determined whether the results of this study were consistent with the principles of groundwater hydrology.

**Discussion**

An attempt was made through this study to collect soil and hydraulic data that represents the varied inundation patterns along the Middle Rio Grande floodplain. Factors such as forest clearing and fire can potentially influence surface characteristics as well. The partial sieve analysis, tension disc infiltometer tests, and hydraulic conductivity calculations effectively measured some of the potential hydraulic impacts along the floodplain surface, although others
may exist. The most significant difference between the flooding and non-flooding areas was in the percent of fine particles. A greater percentage of fine particles was detected at the wetland and low-lying trough where flooding occurs more regularly. Despite the emphasis and concern placed on hydrologic connectivity within the Middle Rio Grande floodplain by the Bosque Biological Management Plan (Crawford et al., 1993), a strong statistical relationship between inundation patterns and hydraulic conductivity was rate was not found. Inconsistencies among the infiltration rates under different pressure heads were detected, that may have been due to the chosen testing method.

A stronger correlation was found between flooding frequency and unsaturated infiltration rates ($P=0.1143$) than between flooding frequency and saturated infiltration rates ($P=0.9143$). The difference in the statistical significance between flooding frequency and infiltration rates measured under different pressure heads was unlikely due to soil structure. Despite best efforts to measure infiltration rates as a function of soil structure, soil moisture content could have influenced the data. The time required to reach steady state infiltration rates was a complicating factor of this study. Two infiltration rates (from each location) measured under different pressure heads were required to calculate the hydraulic conductivity, so due to time restraints each tension disc infiltrometer test was terminated after ninety minute. Five of the six flooding locations showed lower infiltration rates at zero centimeters pressure than the non-flooding sites—a strong (but not significant) difference. Under saturated conditions, however, the infiltration rates at half of the flooding sites exceeded those at non-flooding sites. Caution was taken during field tests not to disturb the soil between tension disc infiltrometer measurements. Infiltration tests under negative ten centimeters pressure and zero centimeters pressure were performed in quick succession without moving the instrument. Thus, the most challenging aspect of the tension disc
infiltrometer method was the ensuring the full time required to reach steady state infiltration. Some tests, may have been terminated before the soil had become saturated, which could affect both the infiltration rates under saturated conditions and the saturated hydraulic conductivity values.

Tension disc infiltration tests are intended to demonstrate the relationship between hydraulic conductivity and soil structure (Simunek et al., 2009). When calculating the infiltration rates under saturated conditions, soil saturation was assumed. During the infiltration process, water will begin to occupy pore spaces within an aquifer (Hornberger et al., 1998). The relationship between soil-water tensions and pore opening governs both infiltration and hydraulic conductivity. Hornberger et al. (1998) explain that under saturated conditions, the hydraulic conductivity of gravel will most likely exceed the hydraulic conductivity of sand (Hornberger et al., 1998). Hornberger et al. (1998) explain that under unsaturated conditions gravel’s large pore spaces will be filled with air that will “essentially stop the transport of water.” Except under largely negative capillary pressures the pore spaces of sand will contain water and will encourage infiltration (Hornberger et al., 1998).

Based upon the soil samples collected in the bosque, it would be reasonable to expect saturated hydraulic conductivity to be statistically greater at the non-flooding sites where soil samples contained less fine particles. In general hydraulic conductivity will increase with the coarseness of the medium (Hornberger et al., 1998). Hydraulic conductivity is a key variable in Darcy’s equation for determining the flux of water through a porous medium, and may be considered a “function of the properties of a medium and a fluid” (Sperry and Pierce, 1995). If fluid properties remain constant, hydraulic conductivity will depend upon the porous medium (Hornberger et al., 1998). Hydraulic conductivity may range several orders of magnitude
(Bartolino and Cole, 2002). In this study, the range of hydraulic conductivity values was only two orders of magnitude \((3.88 \times 10^{-5} - 4.73 \times 10^{-3})\).

The Hazen method was developed a century ago to predict hydraulic conductivity from a single soil particle size (Carrier, 2003). Although the total percentage of fine particles varied with flood frequency, the particle size for which 10% of the soil was finer was similar at every site in this study. By running the soil samples through a 0.075 millimeter sieve it was determined that each sample was at least 9% fine particles by mass. The sample collected from the second Route 66 non-flooding study location was 9% fine particles, while samples from two of the Harrison flooding locations were 99% fine particles. The Hazen Formula is written

\[
k = C_H D_{10}^2
\]

where \(C_H\) is the Hazen Empirical Coefficient and \(D_{10}\) is the particle size for which 10% of the soil is finer (Carrier, 2003). Opinions regarding the accepted value of the Hazen Empirical Coefficient vary. The assigned value of \(C_H\) is typically 100, although published values range from 1 to 1,000 (Carrier, 2003). To accept a standard coefficient suggests that the hydraulic conductivity can be predicted from the \(D_{10}\) particle size alone. The similar \(D_{10}\) value found at all study sites could help explain the lack of a significant difference in hydraulic conductivity found within the two Rio Grande floodplain locations.

The flooding experienced in the Harrison wetland and the Route 66 trough should not be confused with overbank flooding. Overbank flooding (flushing floods) may redistribute both organic matter and sediment. The tension disc infiltration measurements did not account for the presence of wood chips and other organic matter present along the surface of the floodplain, since it must be placed on bare soil. Organic matter content comprised a very small portion of the soil samples collected in this site, since bare soil was sought for the infiltration tests. The
statistical significance of organic matter content and particle size may vary at other flooding and non-flooding locations that have been impacted by fire or overbank flooding.

Despite the significant difference in the percent of fine particles in the soils collected from the flooding and non-flooding areas, particles less than 0.075 millimeters comprised at least ten percent of each sample. It should not be forgotten that the Middle Rio Grande floodplain is one system. If hydraulic conductivity were to be estimated from the Hazen method \( k = C_H D_{10}^2 \) then there may appear to be no significant difference in the hydraulic conductivities within the flooding and non-flooding areas (Carrier, 2003). Obtaining steady state infiltration rates under saturated condition was met with difficulty. Understanding the differences in the physical and hydraulic properties of floodplain soils within flooding and non-flooding areas of the Middle Rio Grande floodplain has just begun, and future work may reveal even greater significances.

**Conclusions**

Hydraulic connectivity is necessary for the sustained ecological health of Middle Rio Grande floodplain, or bosque. The river—which historically meandered freely throughout the floodplain—and the aquifer sustain life in the bosque. This study focused on the impacts of inundation pattern on the physical and hydraulic properties of floodplain soils, through the completion of partial sieve analysis, tension disc infiltrometer tests, and hydraulic conductivity calculations based on two steady-state infiltration rates. The statistical difference between the physical and hydraulic properties of flooding and non-flooding surfaces was determined through a Mann Whitney U test. Particle size was found to be statistically different (\( P = .0095 \)), as flooding locations showed a greater percent of fine particles. Although, not significantly different, infiltration rates under unsaturated conditions were generally greater at non-flooding
sites. The hydraulic conductivity values were not statistically significant and only ranged only two orders of magnitude ($3.88 \times 10^{-5} - 4.73 \times 10^{-3} \text{ cm/sec}$).

The spatial and ecological variability of the Middle Rio Grande bosque could not be fully represented with only the four chosen study areas. Due to the limited number of study locations, the wetland at the Harrison Bosque Ecosystem Monitoring Program (BEMP) and the low-lying trough at the Route 66 BEMP site were placed in a single group (flooding group) for statistical analysis. Understanding the physical and hydraulic impacts of inundation patterns and hydrologic connectivity as a whole could help efforts to strengthen the ecological diversity within the Middle Rio Grande floodplain. Although the soil particle size was greater at non-flooding locations, the particle size for which ten percent of the soil was finer ($D_{10}$) was constant for all of the study locations. The soils and sediments transported by the river and comprising the aquifer help define the Middle Rio Grande floodplain as one, ever-changing system.
References


Appendix

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>% clay by weight (%)</th>
<th>ksat (cm/sec)</th>
<th>Infiltration at -10 cm (cm/sec)</th>
<th>Infiltration at 0 cm (cm/sec) (%)</th>
<th>% moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harrison Flooding 1</td>
<td>95.76</td>
<td>3.88E-05</td>
<td>1.55E-03</td>
<td>1.60E-03</td>
<td>30.09</td>
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<tr>
<td>Harrison Flooding 2</td>
<td>99.15</td>
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<td>1.58E-04</td>
<td>7.07E-03</td>
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<td>1.51E-03</td>
<td>1.25E-04</td>
<td>2.36E-03</td>
<td>40.48</td>
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Table A-1 Complete Field and Lab Data

Figure A-1 Infiltration Times: Route 66 Flooding Site
Figure A-2. Infiltration Times: Route 66 Non-Flooding Site