Final Report

ASSESSMENT OF HYDRODEMOLITION RUNOFF WATER TREATMENT OPTIONS

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16. Abstract

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SUMMARY

Large volumes of hydrodemolition runoff/reuse water (HRW) are being generated in NC annually during highway bridge resurfacing projects. Currently most of the HRW is being dumped at wastewater treatment plants or landfills. However, preliminary analysis of the HRW has indicated that it may be useful as a liming agent. The purpose of this project was to characterize HRW from several bridges by sampling the HRW and assess the effects of land applying it on soil, vegetation, and runoff via greenhouse and field trials. Results of sampling HRW in holding tanks at 2 sites showed that most of the solids settled out of the HRW within 1 or 2 days. Further, samples collected with solids (raw from truck) and without solids (after settling or filtering) showed that the inclusion of solids greatly increased turbidity, TSS, TP, Ca, and Mg compared to HRW for which solids had settled or been filtered out. In contrast, pH, TKN, NH_3-N, and NO_3-N were similar with or without solids. Analysis results of HRW samples from 4 sites showed that, from a surface water quality perspective, land application of HRW slurry presents little if any concern related to volatile organics or heavy metals, but has some potential concerns mostly related to elevated pH, TSS, BOD_5, and TP concentrations in the HRW: however, because the solids settle relatively quickly, the probability of transport in runoff from application areas would seem to be low. A field trial, begun during this project, will provide data on how easily the HRW solids are transported by runoff from plots of bermudagrass. The greenhouse trial showed that HRW applications are a viable alternative to correcting soil acidity constraints to fescue growth and that application HRW at up to 2 times the recommended rate for correcting acid soil conditions had no detrimental effect on fescue growth.

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INTRODUCTION

Hydrodemolition or waterjetting is the process of removing unwanted concrete or asphalt by directing a jet of high pressure water onto the surface of the concrete to break up and/or dislodge it. Hydrodemolition is quickly becoming the most common methods of removing deteriorating concrete on bridge decks for subsequent resurfacing. Some of the advantages of hydrodemolition over chipping or cutting are that it is faster, is highly controllable, creates no dust, does not damage steel reinforcing rods, and does not produce vibrations throughout the structure which often cause micro fractures in the rest of the structure (Nasvik, 2001). The reduced time and absence of micro fractures are particularly important for bridge deck resurfacing on highways; thus, hydrodemolition has become increasingly more common in North Carolina as well as many other states. The hydrodemolition process generates a large volume of slurry (concrete-water mixture) that will be referred to as hydrodemolition reuse or runoff water (HRW).

While there have been a considerable number of published reports on the use and economics of hydrodemolition of bridge decks, there is very little, if any, published reports on the handling and/or reuse of the runoff or wastewater. Hawk (2001) identified disposal of hydrodemolition water as a concern and presented several contractors' disposal methods, but none mentioned land application as a method or presented sampling results. Common methods of disposing of HRW are to haul it to a nearby wastewater treatment plant and/or a landfill and pay a dumping fee. However, a more cost-effective alternative for disposal of HRW would be to apply it to selected grassed areas in NC DOT's right-of-ways. This application may even be beneficial as there is some evidence that the HRW may improve growing conditions by raising the pH of the soil.

Thus, the purpose of this project was to begin to characterize HRW and assess the effects of land applying it on soil, vegetation, and runoff.

METHODOLOGY AND PROCEDURES

The purpose of this project was to assess the potential for applying hydrodemolition reclaimed water (HRW) in NC DOT right-or-ways by sampling and analyzing HRW from several sites; conducting a greenhouse trial where HRW was applied under controlled conditions; and conducting a field trial where HRW was applied under more natural conditions.

Sampling and analyzing HRW: Collecting a representative sample of HRW can be difficult due to several factors including the often large volume of HRW, the inconsistency of solids in the HRW; and the solids in the HRW tended to settle out of the slurry/solution very quickly. As an example, the volume of HRW generated for three bridges was estimated by measuring the depth of water in the tank at the access hole and computing the volume of the tank based on the tank dimensions and slope. For two of the bridges monitored in this study the volume of HRW generated was 9,000 and 14,000 gallons, which was between 1.1 and 1.6 gallons of HRW/ft^2 of bridge. Ideally, at least 3-4 samples would be collected and analyzed from this volume of HRW and then the results averaged; however, due to the cost of some analyses, the samples may be combined into one composite sample for analysis.

Samples of HRW collected from a large tank can be problematic due to the settling of the solids and floating material. Hence, sampling of two holding tanks was conducted to document how holding time and depth of sample collection effects sampling results. A clean plastic 2-liter bottle with a controlled air release tube (figure 1a) was used to collect samples of HRW at desired depths in two large tanks (figure 1b). The sample bottle was plunged into the water at a place where there was no observable floating layer of material (if floating material was there it was cleared back prior to sample collection). For the top of the water column (TWC) samples, the bottle was held 2-3 inches under the surface of the water and then the air tube was opened to allow the bottle to fill with HRW, while for the bottom of the water column (BWC) samples, the bottle was held on the bottom of the tank and allowed to fill. Finally, a sample (MOT) was obtained by simply plunging the sample bottle into the HRW with the top off to simulate how most people might obtain a sample. These test samples were analyzed for turbidity, solids, and pH.

The sample obtained for laboratory analyses was collected from the tank after bridge deck demolition was completed. The sample was obtained from the midpoint of the water column in the tank using the bottle described above. The sample bottle was refilled three times and a composite sample was made and poured into the lab containers. The sample bottle was inverted 3-5 times just prior to pouring into the lab containers in order to suspended any sediment in the bottle. Once filled, the lab containers were then placed on ice and delivered to the lab personnel within 2 hours. A chain-of-custody form accompanied the samples from collection to lab analysis. Analyses were conducted by state certified labs using standard methods.

Greenhouse trial: Soils were collected from three different NC DOT right-of-way sites, one each in the Coastal Plain (Bertie County), the Piedmont (Wake County), and the Mountain (Wilkes County) physiographic regions of NC. Approximately 40 L of soil was removed from within 150-mm of the surface of a 20-m long grassed area along the highway using a shovel (figure 2a). The soil was obtained from 5-6 locations along the area some of which were near the road surface and some were near the roadside drainage. After removing the large organic material, the soil was air-dried and sieved using a 4-mm mesh. After thorough mixing, subsamples were obtained and sent for analysis by the Soil Testing Laboratory of NC Department of Agronomic & Consumer Services (NCDA&CS). The NCDA&CS recommended agricultural lime application rates for growing fescue grass based on the pH and buffer acidity values of each soil ranged from 896 to 2912 kg/ha (0.4 to 1.3 tons/ac). The lime application rates were converted into equivalent gallons of HRW based on the slurry's agricultural lime equivalent (ALE) values, which was 81,600 L of HRW/metric ton of agricultural lime or 19,600 gallons/ton. The HRW was obtained from a bridge reclamation job in Greensboro, NC on 5/17/12 during transfer from a tank truck to a large storage tank. A sample of the HRW was analyzed raw to determine the volume of HRW to add to each pot of soil. The raw HRW was also filtered and the liquid and solids analyzed separately to characterize each.

Greenhouse treatments for each soil consisted of the HRW slurry application rate equivalent to the NCDA&CS lime recommendation for fescue, and three additional rates above and below the recommended rate. Two additional reference treatments were included for each soil, a control without lime or HRW and agricultural lime applied at the NCDA&CS recommended level. Thus, comparisons between soils are based on multiples of the recommended lime rates, instead of absolute quantities of HRW. Lime and HRW were thoroughly mixed with 1L of soil and then placed in each pot. There were three replicates of each soil-treatment combination arranged in a randomized complete block design.

An equal volume of tall fescue variety 'Spartan II' was sown on the soil surface of each pot. Soil in the pots was maintained at 90% water-holding capacity from June 11, 2012 to October, 15, 2012 to facilitate growth. Aboveground fescue biomass (figure 2b) was harvested, dried in air-forced ovens at 65 degrees C, weighed, ground and analyzed for nutrients by the Plant Analysis Lab of NCDA&CS. After harvesting the fescue, soil samples were obtained from each pot and analyzed by the Soil Testing Laboratory of NCDA&CS.

Field trial: In order to assess potential effects on vegetation and surface water runoff under natural conditions, 6 plots (nominally 0.61 x 0.91 m; 2ft x 3ft) were established on an area of a NC State University field laboratory or farm in Raleigh, NC. The soil was mapped as Cecil sandy loam, but observation indicated that the surface layer (<100 mm) of soil contained more clay than sand. The soil was likely altered as there was considerable construction in the area including construction of a stream channel immediately next to the area. Analysis of soil samples from the area documented a soil pH of 5.0-5.2. There was an established, although relatively thin, stand of bermudagrass on the area with other vegetation mixed in (figure 3a). The plots were delineated with the longer dimension up and down the slope with the average slopes ranging from 4-8%, while the cross slope was less than 1%. Plastic landscape edging was installed around the perimeter of 3 plots and a runoff collection system was added to the downslope end in order to collect samples of storm-event runoff (figure 3b). One replicate of each treatment (no HRW, recommended rate, and 1.5 x recommended rate) was included in the 3 plots with runoff collection systems. The collection system consisted of a conduit sealed to the downslope end of the landscape edging, which conveyed runoff to a 19-L bucket placed inside a shelter. The plots and collection system were installed on 6/17/14 and then not used for monitoring until 7/9/14 to allow time for the soil and vegetation around borders to stabilize or recover and to see how the system was working. A recording raingage was installed on-site on 7/9/14 to monitor rainfall.

Rainfall on and runoff from the instrumented plots was collected and analyzed from 7/9/14 to 8/12/14. All the runoff from each of the storms occurring during the period was collected and measured. Samples of the runoff were obtained within 24 hours and transported immediately to the laboratory for analysis of total suspended solids (TSS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate+nitrite nitrogen (NOx-N), lead (Pb), zinc (Zn), manganese (Mn), and copper (Cu) as shown in Table 1. Vegetation was cut to the same height on 7/28/14. Photos were taken to document the condition of the plots at this time (example in figure 3a).

About 56 L of HRW slurry from an I40 overpass bridge was obtained from a transfer truck as it dumped its load into a holding tank. More specifically, the HRW slurry was obtained by pointing the end of the hose that was being used to transfer the HRW from the truck to the holding tank at the top of each of 3, 19-liter buckets. A sample from each of the two buckets was obtained by mixing the HRW with a large paint stirrer spun by an electric drill until the HRW was swirling in the bucket and then immediately plunging a clean lab bottle into the HRW to obtain a sufficient volume of sample for laboratory analysis.

The recommended application rate of agricultural lime was computed from soil sample analysis results as 1880 kg/ha or 0.84 ton/ac using the average soil pH of 5.1 and the buffer acidity of 1.4. The recommended HRW application rate was then computed using the average ALE of the 2 samples of HRW slurry analyzed (7,015 L/metric ton or 1685 gal/ton) and the lime application rate from the soil analysis. On 8/11/14 two plots each received no HRW application, recommended rate of HRW, and 1.5 x recommended rate of HRW. The 1.5 times the recommended rate was used because it is difficult to apply the HRW uniformly; hence, it is likely that up to 1.5 times the target rate would often be applied. The HRW was applied by a custom-made flange device (figure 4a) to the plots on 8/11/14 which was during the time Bermudagrass is rapidly growing. The soil moisture was replenished from recent rains; thus, soil moisture should, at least initially, not be a limiting factor. Application at this rate did not appear to be heavy as observation showed that none of the grass was matted or there was little evidence of solids on the ground (figure 4b).

After 2-3 months soil and grass samples will be collected from each plot and analyzed at the NCDA lab. The grass will clipped to the same height as at the start of the trial and samples of grass from a known area will be dried and weighed to determine growth during the period. Observations and mass of Bermudagrass clippings from plots with no HRW application will be compared to those with HRW application to document HRW effects on plant growth. Soil sample analysis results from plots with no HRW application will be compared to those with HRW application to document changes resulting from HRW application.

RESULTS

Sample collection and analysis: Analysis results for samples collected from two HRW on-site storage tanks are shown in Tables 2 and 3. Samples were collected the morning after overnight demolition work of one lane of the Glen Eden Road bridge (4/26/11) and for the following 2 days (Table 2). The turbidity of the top of the water column (TWC) and bottom of the water column (BWC) samples decreased considerably from 4/26/11 to 4/27/11 and then remained about the same to 4/28/11. The BWC samples varied less consistently because collecting a sample of HRW near the bottom of the water column involved disturbing what felt like sediment on the bottom of the tank. Like turbidity, the TSS in samples also decreased considerably from 4/26/11 to 4/27/11. The similar decreases in TSS and turbidity suggested that the turbidity is caused by the solids and that most of the solids settled out of the water column in about 1 day.

The pH of the water column samples was relatively consistent varying between 12.5 and 12.6 as measured by an YSI EcoSense pH/Temperature Pen.

Turbidity and TSS for the grab near the middle of the tank (MOT) sample were considerably greater than the water column samples. This was likely due to this sample incorporating the floating material on top of the water, which diminished over time but some still remained on the top of the water column after 3 days. When the lid was added to the sample bottle on 4/28/11 to restrict influx of the surface material the turbidity of the middle of the tank sample decreased to a level more similar to the water column samples. These data indicate that the floating material contained a much higher concentration of solids than the liquid. Inclusion of the floating material into the sample did not affect the pH of the sample. Results of HRW from the Ridge Road bridge are shown in Table 3. Turbidity decreased considerably 5/12/11 to 5/13/11. The pH of the HRW samples from the Ridge Road bridge was similar to those from the Glen Eden bridge. These data show that samples of HRW drawn from a holding tank must be obtained within hours after the HRW is put in the tank or the HRW must be agitated to entrain the solids into the water. This doesn't seem to be needed for pH measurement, but certainly for TSS, turbidity, and likely many of the constituents.

The importance of having a representative mass of solids in the sample is shown in Table 4. Analysis results for the HRW slurry obtained from Greensboro, NC (GO) are shown in row 1 while analysis results for the liquid and solid (in mg/kg) portions of the slurry, which were separated by filtering, are shown in rows 2 and 3, respectively. For all constituents, concentrations in the slurry were much greater than those in the liquid phase, except for Na, pH, and the ALE. This indicates that most of the constituents analyzed for were associated with the solids. Also, the ALE indicated that 7.3 gallons of liquid were equal to the lime value of 1 gallon of slurry. Hence, these data show that most of the lime value and the pollution potential are associated with the solids. Sieving the solids from this sample revealed that 94% of the solids were less than 0.5 mm (0.02 inches) in diameter. This percentage may be higher because at least some of the larger diameter solids were aggregates of small particles as they broke up easily when rolled between 2 fingers. As a comparison, soil particles from 2 mm to 0.05 mm are classified as sand-sized soil particles.

Sample results collected from four bridge hydrodemolitions during this project along with data from Hydro-tech's self-monitoring are shown in Table 5. The Glen Eden Road and Ridge Road samples were collected after several days of settling and the Wilkes sample was collected after filtering, while the GO sample was raw slurry. It is unknown how or of exactly what the HT samples were collected from, but given the relatively low turbidity and TSS, they likely were not samples of raw slurry, but were collected after solids had settled out. Turbidity and TSS concentrations of HRW after settling or filtering were relatively low and thus would likely represent a minimal potential threat to surface water quality when applied to vegetation along highways. However, the raw HRW with its much higher TSS concentration might be a threat to surface water quality depending on how easily the solids were transported in runoff. The total dissolved solids (TDS) concentrations were high being greater than the NC regulatory limit for groundwater (1000 mg/L) and water supply (500 mg/L), but the concentrations were similar to those reported by HT. The pH of the HRW was relatively unaffected by the amount of solids as all of the values were similar. It is unknown how much application of HRW to grassed areas would increase the pH of runoff considering that most NC soils are acidic and would likely reduce the pH in surface water and certainly in any infiltrating water.

Sample analysis results for BOD_5, and fecal coliform are also shown in Table 5. The levels of BOD_5 in samples from three bridges' HRW were more than 2 times higher than the NC limit for most surface water (daily maximum of 15 mg/L). The relatively high levels of BOD_5 were unexpected as there is no apparent significant source of organic material for which to cause elevated BOD_5. However, the total organic carbon (TOC) concentration indicated there was sufficient organic carbon in the water, the source of which is unknown. It is also unknown why the BOD_5 and the TOC in the HT samples were much less than those of this study. A check of the source water used in hydrodemolition of the three bridges involved in this study revealed low BOD_5. The elevated BOD_5 may result from treatment of the water by the hydrodemolition equipment or from oxidation of reduced forms of nitrogen in the HRW, although the concentrations of these in the samples are not high. Fecal coliform levels were low, which was expected given that there was no observable source of bacteria on the bridges. In addition, the sodium adsorption ratio (SAR) was less than 2 for all samples indicating there should be no restrictions on the application.

Concentrations of the three most common forms of nitrogen in surface waters were relatively low. The NH_3-N concentrations in the three samples as well as the HT samples were well below the daily maximum (6 mg/L) limit for reclaimed wastewater (RWE) as well as for many wastewater treatment plant discharges into surface waters. The NO_3-N concentrations were below NC groundwater (10 mg/L) and freshwater (6 mg/L) regulatory limits. Finally, the TKN concentrations were relatively low. Results for samples collected with solids (i.e GO bridge) and without solids (after settling or filtering) were similar for TKN, NH_3-N, and NO_3-N indicating that the inclusion of solids likely would not significantly affect the concentrations of these parameters.

The phosphorus (TP) concentrations of the 3 HRWs for which solids were removed were relatively low; however, the raw HRW (GO) had a relatively high TP concentration. Because phosphorus is often bound to solids such as soil particles, it is unknown how much of the phosphorus would be available for transport in runoff. Concentrations of chloride (Cl) were somewhat high with 2 of the 3 samples exceeding the NC regulatory limit for water supply (250 mg/L), freshwater (230 mg/L), and groundwater (250 mg/L).

Of the metals, calcium (Ca) and sodium (Na) were found in the highest concentrations; however, there are no regulatory limits on calcium with respect to surface or ground waters. Magnesium (Mg) was also found in all samples, although at relatively low levels for samples which had most of the solids removed. The CA and Mg concentrations appear to be highly correlated to solids concentration, while the Na does not. Lead (Pb) and barium (Ba) were the only other metals found in samples of HRW, although both were found at relatively low concentrations.

Few other compounds were found above detection or reportable limits and none consistently between all samples. Hence, it appears that these compounds are either not found in HRW or that their concentrations are very low.

With respect to solids in samples, the very limited data reported here suggested that the inclusion of solids greatly increased turbidity, TSS, TP, Ca, and Mg compared to HRW for which solids had settled or been filtered out. In contrast, pH, TKN, NH_3-N, and NO_3-N were similar with or without solids. Thus, if the HRW will be applied as a slurry, it will be important to collect and analyze samples that have a representative amount of solids in them. This means that the slurry should be agitated in some way to suspend the solids and then be sampled immediately. Having all of the HRW in a large tank and then agitating and sampling it has the advantage being a composite sample of all of the HRW, but sampling the outflow from a truck is much easier and if it is done immediately after the truck has stopped the HRW should be have been agitated during transport; however, HRW will likely vary between truckloads.

Greenhouse trial results: Assessment of the effects of HRW application on soil properties and the growth of fescue grass was conducted under controlled conditions via a greenhouse trial. Although in actual cases HRW would likely be applied to the surface of established grass, in this trial it was thoroughly mixed throughout the soil to simulate maximum effect. The reasoning was that if the fescue germinated and became established when the HRW was mixed into the soil, then it should not hinder the growth of established fescue when surface applied.

There were significant differences in fescue dry matter when averaged across soils or treatments, as well as the soil-treatment interaction (Table 6). Fescue dry matter in the Wake soil was especially low with similar yields in all treatments. Dry matter in the Bertie and Wilkes soils were 5- to 10-fold greater than in the Wake soil with significant growth responses to agricultural lime and/or HRW treatments. Dry matter produced with the recommended agricultural lime rate and the equivalent lime application with the '1 HRW' treatment were statistically identical in both the Bertie and Wilkes soils. Furthermore, there was a significant dry matter increase with HRW applications relative to the unlimed control treatment in both soils.

One of the experiment objectives was to investigate how much HRW could be applied to soils without detrimental effects on growth. In both soils (Bertie and Wilkes) which presented a fescue growth response to lime and HRW, yields were depressed with HRW application rates equivalent to 3 times the recommended lime equivalent rate (3 HRW treatment). These data would suggest that HRW applications equivalent to twice the recommended lime equivalent could be used without detrimental effects on tall fescue growth (Table 6).

The liming effect from applied HRW was apparent from soil analytical data at harvest of the fescue (Table 7). Lime and HRW applications increased soil pH and Ca levels, and decreased soil acidity as measured by the Mehlich buffer solution. The reduced fescue growth with the high HRW application rate in the Bertie and Wilkes soils coincides with soil pH values of 7.6. Potential detrimental consequences of liming soils to such high pH values are the reduction in plant availability of essential micronutrients in the soil.

The Wake soil contained appreciably lower levels of Mehlich-3 extractable Zn (Table 8). Mean soil Zn values averaged across treatments were 2.8 mg dm^{-3} for the Wake soil versus 10.8 and 33.2 mg dm^{-3} for the Bertie and Wilkes soils, respectively (Table 8). In addition to the limited amounts of soil acidity and the high pH values in most treatments, poor fescue growth in the Wake soil (Table 6) may have been associated with reduced availability of Zn; however, further testing would be needed to confirm this. Soil levels of P, S, Mn and Cu were suitable for fescue growth in all treatments and soils.

Mehlich-3 extractable As, Cd, Ni and Pb were also measured in all pots, but lime and HRW applications did not significantly impact their soil levels. There were significant differences in levels of these metals between soils, reflecting inherent differences between soils.

In summary, these data indicated that HRW applications are a viable alternative to correcting soil acidity constraints to fescue growth. Application to acid soils based on the HRW's agricultural lime equivalent (as determined by the NCDA&CS soil analysis lab) had no detrimental effect on fescue growth when applied up to twice the recommended lime application rate.

Field trial results: Results of analysis of HRW for use in the field trial are shown in Table 9. As shown, the concentrations of P, Mg, Mn, and Zn were 2 times greater in bucket 1 compared to bucket 2. The concentrations of the other parameters are greater in bucket 1, although to a lesser extent. The fact that the buckets were collected immediately after one another with the samples collected in the same manner and there were still relatively large differences concentrations reflects the difficulty in obtaining representative samples of HRW. However, the pH and ALE were relatively similar, in fact, bucket 1 ALE was only ~27% less than the bucket 2 ALE meaning that 1.5 times the bucket 1 ALE would be more than the bucket 2 ALE.

Table 10 contains preliminary results for runoff volume and pH. Plot 1 had no HRW application, while plots 2 and 4 had the recommended rate and 1.5 times the recommended rate of HRW applied on 8/11. As shown runoff volumes vary considerably by storm and by plot. The storm on 8/12 was large and relatively intense resulting in the most runoff for any storm during the monitoring period. The fact that the storm occurred the day after HRW application made this almost a 'worst case scenario' with respect to runoff. The pH of runoff varied from 6.5 to 7.2 prior to HRW application, while the range increased to 7.8 to 8.8 after HRW application. The fact that the pH of the runoff from plot 1 increased considerably for the 8/12 storm, even though it had no HRW applied, indicated that the increased pH might not have resulted from HRW application. Analysis of runoff from additional storms will help confirm the effects of HRW application on the pH of runoff. All of these values are within regulatory limits for NC freshwater (6.0 to 9.0), but two are slightly higher than the limits for groundwater (6.5 to 8.5). Results of analysis for nitrogen, phosphorus, TSS, and metals are not yet available. Runoff collection and analysis will continue for several more weeks under RP 2013-14 and will be included in the final report for that project.

SUMMARY AND CONCLUSIONS

In summary, HRW from hydrodemolition of four highway bridges was sampled and analyzed, the effects of HRW on fescue growth was documented in a greenhouse trial, and the effects of HRW application on bermudagrass growth and runoff from plots was documented in a field application trial. Analysis of samples of HRW obtained from holding tanks on-site showed that most of the solids settled out of the HRW within 1 or 2 days. Although there were only four samples total, samples collected with solids (raw from truck) and without solids (after settling or filtering) showed that the inclusion of solids greatly increased turbidity, TSS, TP, Ca, and Mg compared to HRW for which solids had settled or been filtered out. In contrast, pH, TKN, NH_3-N, and NO_3-N were similar with or without solids. Analysis results of four HRW samples showed that, from a surface water quality perspective, land application of HRW slurry presents little if any concern related to volatile organics or heavy metals, but has some potential concerns mostly related to elevated pH, TSS, BOD_5, and TP concentrations in the HRW: however, because the solids settle relatively quickly, the probability of transport in runoff from application areas would seem to be low. The field trial, begun during this project, will provide data on how easily the HRW solids are transported by runoff from plots of bermudagrass. The greenhouse trial showed that HRW applications are a viable alternative to correcting soil acidity constraints to fescue growth and that application HRW at up to 2 times the recommended rate for correcting acid soil conditions had no detrimental effect on fescue growth. From the data the following conclusions can be made:

- Collecting a representative sample of HRW was difficult as the slurry is highly variable and contains high concentrations of solids which settle quickly. Sampling HRW slurry as it is transferred from a truck to a holding tank is likely not the best method of obtaining the sample. Likely the most representative sample can be obtained from a holding tank in which the HRW is agitated vigorously.
- Land application of HRW at up to 2 times the NCDA&CS recommended rate to correct soil acidity had no significant effect on fescue growth for the 3 soils tested in a greenhouse trial
- Collecting a representative sampling of HRW slurry must be done immediately after agitation as the solids settle out relatively quickly and much of the TSS, TP, Ca, Mg concentrations and liming potential appear to be associated with the solids
- From concentrations in HRW samples, surface water quality concerns should be focused on pH, TSS, BOD_5, and TP as these were the only parameters with concentrations that exceeded NC surface or groundwater standards; however, no data exists on how much of the applied HRW would be transported in runoff.
- Concentrations of volatile organics and heavy metals (Cd, Pb, Hg) in the HRW from four bridges were low or below reportable limits

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LIST OF TABLES

Table 1. Methods of Sample Analysis.

Parameter	Method	Source
TSS	2540D	Eaton et al. (1995)
TP	4500-P E	Eaton et al. (1995)
TKN	351.2	EPA Method
NH_3-N	4500 NH_3 H	Eaton et al. (1995)
NO_x-N	353.2	EPA Method
Metals	200.7	EPA Method
Volatiles & semi-volatiles	various	EPA Method
Turbidity	Hach 2100P turbidimeter	

Table 2. Sample Analysis Results for HRW from the Glen Eden Road Bridge.

Date	Time	Type	Turbidity NTU	TSS mg/L	pH
4/26/11	9:45	Top of water column (TWC)	101	116	12.5
	9:40	Bottom of water column (BWC)	100	na	12.5
	9:55	Grab near middle of tank w/o lid (MOT)	>1000	1096	12.5
4/27/11	11:30	Top of water column (TWC)	18	35	12.5
	11:35	Middle of water column	12	na	12.5
	11:40	Bottom of water column (BWC)	7	22	12.5
	11:04	Grab near middle of tank w/o lid (MOT)	>1000	na	12.5
4/28/11	11:40	Top of water column (TWC)	15	na	12.6
	11:45	Bottom of water column (BWC)	23	na	12.5
	11:50	Grab near middle of tank with lid on bottle	80	na	12.5

Table 3. Sample Analysis Results for HRW from the Ridge Road Bridge.

Date	Time	Type	Turbidity NTU	TSS mg/L	pH
5/11/11	12:30	Top of water column (TWC)	59	92	12.5
	12:40	Bottom of water column (BWC)	>1000	na	12.6
5/12/11	11:00	Top of water column (TWC)	61	53	12.6
	11:15	Mid of water column	51	na	12.6
	11:20	Bottom of water column (BWC)	>1000	>5000	12.6
5/13/11	11:50	Top of water column (TWC)	21	na	12.5
	12:00	Bottom of water column (BWC)	26	na	12.5
	12:10	Grab near middle of tank with lid on bottle	28	na	12.5
5/24/11	1:13	Grab near middle of tank	<1	na	Na

Table 4. Analysis Results for Solid and Liquid Parts of HRW Slurry From Greensboro Bridge.

Description	P ppm	K ppm	Ca ppm	Mg ppm	Na ppm	Fe ppm	Mn ppm	Zn ppm	Cu ppm	DM[2] %	pH	ALE[2] Kgal
GOSlurry[1]	26.8	86.2	5131	167	79	317	4.07	1.69	0.72	3.7	11.5	19.6
GOLiquid[1]	5.7	53.7	799	14	75	0.89	0.03	0.28	0.20	0.7	11.6	144
GOSolids[1]	787	1159	122463	5374	182	8659	140	46.7	19.6	58	11.5	na

[1] HRW from back of hammer/robot vacuum truck bridge in Greensboro. Slurry=raw water; Solids=slurry filtered using glass-fiber filter; Liquid=liquid left after solids filtered out.

[2] DM=dry matter and ALE=agricultural lime equivalent.

Table 5. Analysis Results for HRW Samples.

Parameter	Units	Glen Eden Road[1]	Ridge Road[1]	Wilkes Bridge[2]	GO Bridge[3]	HT[3]
Turbidity	NTU	15	51	1	>1000	7-35
Suspended Solids (TSS)	mg/L	31	70	<10	20000	9-40
Dissolved solids (TDS)	mg/L	2050	2010	1640	na	1800-2500
pH	s.u.	12.5	12.5	12.4	12.0	11.1-12.2
BOD_5	mg/L	114	36	38	na	5.0-14.0
Total Organic Carbon (TOC)	mg/L	42.1	30.6	33.2	na	6.8-11.9
Fecal Coliform	cfu/100ml	<1	<1	<1	na	<10
Sodium Absorb. Ratio (SAR)		1.60	1.53	1.71	0.02	0.39-0.69
NH_3-N	mg/L	0.1	0.7	<0.10	0.28	0.12-0.80
NO_3-N	mg/L	0.79	1.23	0.63	0.68	0.3-0.68
TKN	mg/L	1.22	1.38	1.40	1.2	<0.5-1.4
TP	mg/L	<0.05	0.09	0.08	5.4	<0.05-2.4
Chloride	mg/L	572	1100	227	na	88-1200
Metals						
Calcium	mg/L	498	649	547	4600	660-770
Sodium	mg/L	130	142	146	73	39-70
Magnesium	mg/L	0.20	0.49	1.59	120	<0.1-0.5
Barium	mg/L	na	na	1.3	<0.15	0.32-0.45
Cadmium	mg/L	na	na	<0.005	<0.05	<0.001
Lead	mg/L	<0.005	<0.005	0.037	0.069	<0.005
Mercury	mg/L	<0.2	<0.2	<0.0002	<0.0002	<0.0002
Silver	mg/L	na	na	<0.025	<0.05	<0.005
Chromium	mg/L	<0.01	<0.01	<0.01	<0.05	<0.005
Other compounds						
Arsenic	mg/L	na	na	<0.025	<0.05	<0.010
Phenols	mg/L	0.042	0.050	0.112	na	<0.05
Benzene	mg/L	<0.005	<0.005	<0.005	<0.05	<0.001
Carbon tetrachloride	mg/L	<0.005	<0.005	<0.005	<0.05	<0.002
Chlordane	mg/L	na	na	na	<0.005	na
Chlorobenzene	mg/L	<0.005	<0.005	<0.005	<0.05	na
Chloroform	mg/L	<0.005	0.04	<0.005	<0.25	<0.001-1.5
m-Cresol (4-Methylphenol)	mg/L	na	na	<0.05	na	na
o-Cresol (2-Methylphenol)	mg/L	na	na	<0.05	na	na
p-Cresol (4-Methylphenol)	mg/L	na	na	<0.05	na	na
Cresol	mg/L	na	na	na	na	na
2,4-D	mg/L	na	na	na	<0.002	na
1,4 Dichlorobenzene	mg/L	<0.005	<0.005	<0.005	<0.1	na
1,2-Dichloroethane	mg/L	<0.005	<0.005	<0.005	<0.05	na

1,1-Dichloroethelyne	mg/L	na	na	na	<0.05	na
2,4-Dinitrotoluene	mg/L	na	na	<0.05	<0.10	na
Endrin	mg/L	na	na	na	<0.005	na
Hexachlorobenzene	mg/L	na	na	<0.05	<0.10	na
Heptachlor & hydroxide	mg/L	na	na	<0.05	<0.005	na
Hexachloro-1,3-butadiene	mg/L	<0.005	0.006	<0.05	<0.10	na
Hexachloroethane	mg/L	<0.005	<0.005	<0.05	<0.10	na
Lindane	mg/L	na	na	na	<0.005	na
Methoxychlor	mg/L	na	na	na	<0.005	na
Methyl ethyl ketone	mg/L	na	na	na	na	na
Nitrobenzene	mg/L	na	na	<0.05	<0.10	na
Pentachlorophenol	mg/L	na	na	<0.1	<0.10	na
Pyridine	mg/L	na	na	<0.05	<0.10	na
Selenium	mg/L	na	na	<0.1	<0.10	na
Tetrachloroethylene	mg/L	na	na	na	na	na
Toxaphene	mg/L	na	na	na	<0.01	na
Trichloroethylene	mg/L	na	na	na	<0.05	na
2,4,5-Trichlorophenol	mg/L	na	na	<0.05	<0.10	na
2,4,6-Trichlorophenol	mg/L	na	na	<0.05	<0.10	na
2,4,5-TP (Silvex)	mg/L	na	na	na	<0.002	na
Vinyl chloride	mg/L	<0.005	<0.005	<0.005	<0.05	na
Bromodichloromethane	ug/L	**<0.5**	**<0.5**	**<0.5**	na	na
Dibromochloromethane	ug/L	**<0.5**	**<0.5**	**<0.5**	na	na
Bromoform	ug/L	**<0.5**	**<0.5**	**<0.5**	na	na
o-Xylene	ug/L	0.75	**<0.5**	**<0.5**	na	na
Total Xylenes	ug/L	0.75	**<0.5**	**<0.5**	na	na
1,2,3 Trichloropropane	ug/L	0.70	**<0.5**	**<0.5**	na	na
1,2,4 Trimethylbenzene	ug/L	0.80	**<0.5**	2.84	na	na
1,2 Dibromo-3-chloropropane	ug/L	9.2	**<0.5**	**<0.5**	na	na
Naphthalene	ug/L	4.9	**<0.5**	16.53	na	na
1,2,3 Trichlorobenzene	ug/L	0.70	**<0.5**	8.46	na	na

[1] Raw HRW prior to treatment, but after most of the solids settled out of the HRW.
[2] HRW was filtered prior to analysis.
[3] HRW was obtained from bridge in Greensboro, NC.
[4] Data was obtained from Hydro-Tech monitoring of HRW from 7 bridges in NC.

Table 6. Fescue dry matter yield as a function of recommended lime and variable HRW application rates to soils from three NC counties.

Treatment	Soil: Bertie	Soil: Wake	Soil: Wilkes	Treatment Mean
	-------------------- plant top dry weight (g/pot) --------------------			
Control	1.86	0.48	2.38	1.57
Ag Lime	2.19	0.47	4.40	2.36
0.5 HRW	2.00	0.45	3.65	2.03
1 HRW	2.41	0.28	4.64	2.44
2 HRW	2.99	0.51	5.28	2.93
3 HRW	2.65	0.33	3.90	2.29
Soil Mean	2.35	0.42	4.04	
$LSD_{0.05}$:[a]				
Soil		0.35		
Treatment		0.50		
Soil x Treatment		0.86		

[a] F-test protected Least Significant Different at the 0.05 probability level.

Table 7. Effect of lime and HRW application rates on soil acidity and exchangeable cation parameters of soils from NC DOT right-of-ways in three NC counties.

Soil	**Treatment**	**pH**	**Buffer Acidity**	**Ca**	**Mg**	**K**	**CEC**
			------------------ meq/100 cm^3 soil --------------------				
Bertie	Control	5.5	1.80	3.16	1.21	0.12	6.30
	Ag Lime	6.2	1.10	4.92	1.16	0.13	7.30
	0.5 HRW	6.0	1.27	4.58	1.16	0.11	7.10
	1 HRW	6.4	0.93	5.64	1.12	0.10	7.80
	2 HRW	7.0	0.43	7.25	1.03	0.10	8.83
	3 HRW	7.6	0.00	9.77	1.03	0.12	10.87
	Mean	*6.5*	*0.92*	*5.89*	*1.12*	*0.11*	*8.03*
Wake	Control	6.7	0.70	11.98	4.83	0.39	17.77
	Ag Lime	7.1	0.43	13.12	4.56	0.39	18.40
	0.5 HRW	7.1	0.43	12.92	4.53	0.39	18.17
	1 HRW	7.1	0.47	13.25	4.42	0.39	18.53
	2 HRW	7.3	0.33	13.68	4.34	0.39	18.67
	3 HRW	7.5	0.10	14.35	3.90	0.40	18.70
	Mean	*7.2*	*0.41*	*13.22*	*4.44*	*0.39*	*18.37*
Wilkes	Control	4.6	2.13	2.11	0.98	0.20	5.40
	Ag Lime	5.7	1.30	4.44	0.88	0.21	6.80
	0.5 HRW	5.4	1.50	3.79	0.94	0.20	6.43
	1 HRW	5.9	1.07	5.25	0.90	0.20	7.40
	2 HRW	6.8	0.50	7.60	0.84	0.21	9.10
	3 HRW	7.6	0.00	10.53	0.71	0.22	11.43
	Mean	*6.0*	*1.08*	*5.62*	*0.87*	*0.21*	*7.76*
$LSD_{0.05}$	*Soil*	*0.1*	*0.07*	*0.31*	*0.07*	*0.01*	*0.32*
	SoilxTmt	*0.2*	*0.18*	*0.77*	*0.17*	*NS*[a]	*0.77*
			---------- Treatment Means Averaged Across Soils ----------				
	Control	5.6	1.54	5.75	2.34	0.23	9.82
	Ag Lime	6.4	0.94	7.50	2.20	0.24	10.83
	0.5 HRW	6.2	1.07	7.09	2.21	0.24	10.57
	1 HRW	6.5	0.82	8.05	2.18	0.23	11.24
	2 HRW	7.0	0.42	9.51	2.07	0.23	12.20
	3 HRW	7.6	0.03	11.55	1.88	0.25	13.67
$LSD_{0.05}$	*Treatment*	*0.1*	*0.10*	*0.44*	*0.10*	*NS*	*0.45*

[a] Non-significant effect at 0.05 probability level.

Table 8. Effect of lime and HRW application rates on Mehlich-3 extractable soil P, S, Mn and Zn from NC DOT right-of-ways in three NC counties.

Soil	Treatment	P	S	Mn	Zn
		------------------------ mg/dm^3 soil ------------------------			
Bertie	Control	25.0	17.7	30.6	3.3
	Ag Lime	25.0	15.7	27.0	10.8
	0.5 HRW	25.0	15.0	23.7	11.3
	1 HRW	24.0	16.0	25.0	10.0
	2 HRW	25.7	20.7	30.0	9.6
	3 HRW	34.3	47.3	33.2	9.6
	Mean	*26.5*	*22.0*	*28.2*	*10.8*
Wake	Control	35.0	28.7	29.4	2.2
	Ag Lime	36.0	30.0	32.1	3.1
	0.5 HRW	38.3	37.3	31.8	2.8
	1 HRW	36.7	42.7	30.5	2.6
	2 HRW	37.3	33.7	31.3	3.0
	3 HRW	40.3	50.7	32.4	3.3
	Mean	*37.3*	*37.2*	*31.3*	*2.8*
Wilkes	Control	26.3	20.3	66.3	50.9
	Ag Lime	28.3	17.0	44.8	35.5
	0.5 HRW	26.7	20.7	45.9	35.8
	1 HRW	27.3	25.3	45.5	29.5
	2 HRW	29.7	38.0	52.6	24.1
	3 HRW	37.3	56.0	54.4	23.0
	Mean	*29.3*	*29.6*	*51.6*	*33.2*
LSD $_{0.05}$	*Soil*	*1.3*	*6.6*	*2.0*	*1.1*
	SoilxTmt	*NS*[a]	*NS*	*NS*	*2.7*
		---------- Treatment Means Averaged Across Soils ----------			
	Control	28.8	22.2	42.1	22.1
	Ag Lime	29.8	20.9	34.6	16.5
	0.5 HRW	30.0	24.3	33.8	16.6
	1 HRW	29.3	28.0	33.7	14.0
	2 HRW	30.9	30.8	38.0	12.2
	3 HRW	37.4	51.3	40.0	12.0
LSD $_{0.05}$	*Treatment*	*1.9*	*9.3*	*2.8*	*1.5*

[a] Non-significant effect at 0.05 probability level.

Table 9. Analysis of Two Samples of HRW From the Same Truckload.

Parameter	Units	Bucket 1	Bucket 2
pH		11.6	11.4
TKN	ppm	69.5	65.3
P	ppm	144	71.7
Ca	ppm	30,900	21,100
Mg	ppm	1,220	591
Fe	ppm	1,710	1,640
Mn	ppm	55.3	27.6
Zn	ppm	27.0	13.0
Cu	ppm	6.7	3.4
Na	ppm	156	150
ALE	gal	1,420	1,950

Note: analysis of HRW slurry by NC DA&CS laboratory.

Table 10. Rainfall, Runoff Volume, and pH of Runoff from Field Trial Plots.

Storm Date	Storm Rain mm	Plot 1 Runoff ml	Plot 1 pH	Plot 2 Runoff ml	Plot 2 pH	Plot 4 Runoff ml	Plot 4 pH
7/21/14	5.1	165	na	10	na	0	na
7/24/14	48.8	5000	6.9	10	na	2100	7.2
7/27/14	5.6	10	na	0	na	0	na
8/2/14	38.6	13250	6.5	750	na	1750	6.7
8/9/14	34.8	20	na	0	na	0	na
8/12/14[1]	43.7	18930	8.0	18930	7.8	18930	8.8

[1] Post HRW application on plots 2 and 4; none on plot 1.

LIST OF FIGURES

(1a) (1b)

Figure 1. Sampling bottle (a) and truck unloading HRW into tank (b).

(2a) (2b)

Figure 2. Bucket of Wake soil (a) and greenhouse pots with above ground vegetation shown (b).

(3a) (3b)

Figure 3. Field plot vegetation (a) and runoff collection system (b).

(4a) (4b)

Figure 4. HRW applicator (a) and HRW on grass in plot after application (b).