Pilot Study on Direct Discharge of Concrete Grinding Residuals to Roadside Shoulders: Part 2 (TAR 2017-2&3)

Prepared by

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INTRODUCTION

Diamond grinding of concrete highway surfaces for pavement preservation generates large volumes of diamond grinding slurry (DGS) containing water and concrete residuals. Disposal or use of the DGS varies according to state regulations with some states allowing land application on the shoulder of the highway and others requiring hauling to a landfill or wastewater treatment plant. The purpose of the Technical Assistance Requests (TAR 2017-2&3) was to conduct a preliminary assessment of the environmental impacts of direct discharge of concrete grinding residuals from the grinding machine to highway shoulders. Field documentation during a diamond grinding project included observing and photographing roadside vegetation, sampling and analyzing soils, and collecting and analyzing samples of runoff. This report summarizes the results of the first and part of the second TAR (2017-2&3).

METHODS

This project was conducted in conjunction with the NCDOT pavement preservation project I-5787 (C 203765) on I-85 just north of the intersection with NC 56 in Granville County to just north of the Vance County line (figure 1). The north and southbound exit ramps along I-85 provided the safest places to set up research equipment and to monitor the diamond grinding operation; therefore, each monitoring site was along the I-85 shoulder within the on and off ramps of an exit. Several sites at exits along I-85 were evaluated for possible inclusion in this pilot study. The sites selected were labelled using the exit number where they were located. Site characteristics such as soil pH, slope and length of the shoulder, and extent of the drainage area were used to evaluate the suitability of the site. The intent was to find a site representing a worst case (narrow and steep shoulder to roadside ditch), a best case (wide shoulder with gentle slope to roadside ditch), and a control that was somewhere in between. The worst case site (Site 206D) was located along the shoulder of I-85 within the southbound on-ramp from US 158 to I-85 (figure 2). The best case site (Site 204C) was located within the southbound off-ramp from I-85 to NC 96 (figure 3). The control was located within the northbound off-ramp from I-85 to NC 96 (figure 4). A vertical tillage tool was used to loosen the soil on the shoulder of I-85 at Site 206D (figure 5). When DGS was applied it tended to accumulate in the furrows left by the tool as shown in figure 5. At site 204C the soil surface on the shoulder was left undisturbed.

At each of the three sites selected, a 0.75 ft flume with a 4 ft approach section was installed in the drainage channel. Plywood wingwalls (figure 3 right) were also installed at the inlet to each flume to direct all of the runoff in the ditch through the flume. An automated sampler with integrated flowmeter was installed next to each flume to record runoff/discharge and collect flow-proportional samples during storm/runoff events. Samples were analyzed for pH, total suspended solids (TSS), total phosphorus (TP), calcium (Ca), magnesium (Mg), and lead (Pb). In-situ Sondes (devices that measured temperature, conductivity, and turbidity in water column of runoff) were installed at two of the sites to analyze the runoff for temperature, conductivity, and turbidity during runoff. In addition, a rain gage was installed at two of the three sites to record rainfall accumulation every 15 minutes.

Samples of diamond grinding slurry (DGS) were obtained from the grinding machines via a 5 gallon bucket. Representative samples for laboratory analysis were obtained by running a large paint stirrer in the bucket via a drill-driver and immediately plunging the lab container into the agitated slurry after several minutes of aggressive stirring to get all of the solids into suspension. Samples were then delivered to the NC Department of Agriculture's (NCDA) Agronomic Analysis Lab and to Waypoint Analytical for analysis. Analysis included calcium carbonate equivalent (CCE), agricultural lime equivalence (ALE), TP, Ca, Mg, pH, and dry matter.

The discharge rate of DGS from the machines was measured by holding a bucket under the discharge hose for a known length of time and then withdrawing it and measuring the volume of DSG. The average speed of the grinding machine was measured by recording the time it took to move down the highway a given length. Speeds were measured by NCDOT and NC State University (NCSU) personnel. The discharge rate and average speed along with the number of passes (3) and application width (5-6 ft) to the shoulder were used to compute the DGS application rate to the shoulder. The application rate and ALE were then used to compute the equivalent lime application rate.

Soil samples were collected from the top 2 inches of the soil layer on shoulders and exit ramps along I-85 prior to DGS application . Soil samples were also collected from the top 2 inches of the shoulders after DGS application (figure 6). These samples were collected 3-4 ft out perpendicular from the edge of the road surface at 2-3 locations along about a 50 ft section of the shoulder and combined to make 1 sample for analysis. This was repeated along another 50 ft section of the shoulder where DGS was applied in the pilot sites. Samples were collected directly below the aforementioned sample sites at a depth of greater than 2 inches. Particular care was taken to prevent observed DGS solids from being collected as part of the soil sample. Soil samples were also collected about 8 ft directly downslope from the shoulder samples, but not in roadside ditch bottom itself. All soil samples were sent to the Waypoint lab for analysis. Photodocumentation and observation of vegetation on the shoulder will also be conducted.

RESULTS and DISCUSSION

DGS Characteristics and Application Rate:

Sample analysis results for the four samples analyzed by the NCDA Laboratory are shown in columns 1, 3, 4, and 5 of Table 1. In addition, one duplicate was analyzed by the NCSU Biological and Agricultural Engineering (BAE) laboratory (column 2) and another duplicate by the Waypoint laboratory in Virginia (column 3). Analysis results were highly variable, except for the pH, which ranged from 10.9 to 11.6 well below the level considered hazardous waste. The CCE ranged from 6.3 to 26.3%. A duplicate sample of DGS from the 206 bulk sample was sent to the Waypoint lab had a CCE of 38%, which, given the variability of the slurry and difficulty in getting a duplicate sample, was not that different from the high end of the range (26.3%) provided by the NCDA lab.

The DGS application rate was computed from the DGS discharge rate from the grinding machine, the speed of the machine, and the width of the application swath (6 ft). The discharge rate from the grinding machine ranged from 20 to 36 gpm. The speed of the machine was 18.3

ft/min as measured by NCDOT personnel and 18.5 ft/min as measured by NCSU personnel just north of exit 206. The width of the application swath was somewhat variable depending on the operators and how far some of the DGS flowed, but generally averaged 6 ft wide. Using these numbers the average DGS application rate was computed as 0.73 gal/ft^2 or 31,696 gal/ac (range=23,170 to 42,770 gal/ac). The mean ALE for the four DGS samples was 3,000 gal DGS/ton lime, which is considerably less than for DGS samples collected in the previous NCSU project (RP2013-4). Dividing the application rate by the ALE yields an average liming rate was 10.7 ton/ac (range= 7.8 to 14.5 ton/ac). Soil samples collected from three locations (near Exits 191 and 204) along the shoulder of I-85 had a soil pH of 5.8 or 5.9. Recommended lime application rates to correct soil acidity for growing fescue on these soils (4 samples) was 0.7 tons/acre (0.5 to 1.3 tons/ac). Given these conditions, the average DGS application rate was more than 14 times (range = 6 to 29 times) the recommended rate to correct soil acidity.

At least two assumptions must be considered with these results. The first is that the NCDA assumed that the density of the DGS was 8.34 lb/gal based on agricultural wastes, whereas the actual density of the DGS was unknown. Secondly, the Waypoint Analytical lab's target soil pH of 6.2 was near the midpoint of the range of soil pHs considered optimum for growing fescue. Thus, some additional lime would not be detrimental to the growth of vegetation. In fact, there was no visual evidence of vegetation dying or suffering (wilting, turning brown or yellow on leaf tips, etc.).

A final consideration is that the DGS was applied to the land surface and it is unclear how it affected the soil pH through the soil profile, especially in the root zone. The pHs of soil samples collected after the DGS application on shoulders ranged from 6.0 to 7.7 (figure 7) with the pH at greater than 2 inches deep (range = 6.0 to 7.1) being less than those at less than 2 inches. This indicates that most of the effect of the DGS at raising the soil pH was only near the surface of the soil. Recalling that the soil pH for samples collected prior to or without DGS application ranged from 5.8 to 6.0, shows that the soil pH did increase with DGS application; however, the increase was inconsistent and relatively small. Due to the variability and the few samples, it is not possible to determine if the increase was statistically significant or if it was simply the result of natural variability. All but one of the soil samples had a pH>6.2, which was the target pH for recommending lime application. These soil samples data show that while there was an increase in soil pH following DGS application, it does not appear to be too great or as yet to have negatively affected plant growth. However, it is possible that soil pH could increase with time deeper in the soil profile to a level that may negatively affect plant growth.

These vegetation and soil data must be interpreted with caution as they are extremely limited. The soils in this project appeared to have significant clay content. For soils with more sand and/or gravel the effect of the DGS may be greater and occur more quickly as slurry would likely infiltrate more deeply into the soil profile. In addition, plants which are more sensitive to high pH, such as Centipede grass, may be harmed by DGS application.

<u>Runoff Volume and Quality</u>:

Rainfall and runoff/discharge data for the three sites are shown in Tables 2, 3, and 4. Rainfall characteristics for each site were nearly the same, which was expected given their close proximity. Storms at the three sites varied in depth, intensity, and duration; however, there were relatively few storms occurring during the monitoring period so there are relatively few data. For a comprehensive evaluation of runoff, storms with varying intensities, durations, and overall depths are needed during monitoring. While there was a relatively wide range of events monitored during the pre-DGS application period at the exit 204 site, there were few during the post-DGS application period. The opposite was true for the exit 206 site. Storms of a range of intensities, especially high intensity (> 0.5 in. in 30 minutes) because the dried DGS is not easily transported by rainfall/runoff, are needed to evaluate potential effects on adjacent surface waters.

The quality of runoff from the control site, Site 204A (no DGS application), was relatively consistent (figure 8) as expected given that there were no significant changes in the drainage area during monitoring. There was repaving of the highway shoulder during monitoring; however, this did not appear to be substantial enough to affect runoff. For Site 204C (DGS application with no tillage), concentrations of Ca and Mg increased considerably from pre-DGS period to the post-DGS period (figure 9). The increases in concentrations during the post-DGS application period were likely not the result of natural variability or differences in rainfall as we did not see a similar increase in concentrations in runoff from the control site (Site 204A). However, there was not enough data to determine this using statistics. Changes in the TP, Pb, and pH levels were generally so small that they likely could not be distinguished from natural variability (Table 3). The post-DGS concentrations of TSS are quite low compared to many storm-event levels and hence are not a concern. While it is clear there was an increase in Ca and Mg concentrations from pre- to post-DGS application, it is unclear if such increases have any detrimental effects on the quality of adjacent surface water resources.

Runoff volume and quality for Site 206D are shown in Table 4. Only 1 storm occurred prior to DGS application so there is no pre- to post-DGS comparison. Runoff from the first storm after DGS application (#2 in figure 10) had the highest concentrations of Ca and Mg. Subsequent storms had elevated concentrations of Ca and Mg in runoff compared to the runoff from the pre-DGS application storm, but not nearly as great as the first event. The first storm after DGS application was intense (Peak 30-min. rain= 0.5 in/hr), but had relatively low overall runoff (Table 4), which combined to produce the highest concentrations of Ca and Mg in runoff. The first storm after DGS application has lots of available DGS on vegetation and other surfaces which is easily transported in runoff. Observation documented that most of the DGS was in the small furrows left by the vertical tillage tool on the contour of the shoulder. The TSS concentration in runoff was relatively low, which was unexpected as the tillage disturbed the soil surface. However, the disturbance was not enough to break up the root mass of the vegetation which held the soil in place.

When comparing sites, the average concentrations of Ca and Mg in runoff during the post-DGS application period at 206D were less than those for Site 204C; however, the pre-DGS Ca and Mg concentrations at Site 204C were somewhat elevated, so direct comparisons with those at Site 206D are not possible. Concentrations for the first storm after DGS application were similar to the mean post-DGS period at Site 204C, but concentrations in runoff from subsequent storms decreased considerably resulting in a lower overall post-DGS mean. The reason for these lower post-DGS average concentrations after the first storm is unknown, but may be related to differences in soils, topography, and or the tillage conducted on the shoulder at Site 206D. Although these initial results look favorably to the use of the tillage tool, there is too few storm data and the differences (between runoff from Site 206D and Site 204C) in data that has been collected are relatively small, so making a definitive statement as to the effectiveness of the tillage is not possible.

Observations:

The DGS analysis and application data show that direct application of DGS to the I-85 shoulder resulted in application at rates greater than those recommended to correct soil acidity (recommended lime application rate). However, even with the heavy application of DGS, there appeared to be no significant detrimental effect on the vegetation growing on the shoulder. The reason for this is that most of the increase in soil pH resulting from DGS application was confined to the top 2 inches of the soil column and not to the full root zone. This may change over time as typically it takes some time for surface-applied liming agents to increase the pH of soil in the root zone and deeper.

Observation of DGS application to shoulders showed that, for the most part, the DGS stayed on the shoulder and did not run down into the ditches or offsite immediately after application. The fact that the ground was relatively dry and the shoulders well vegetated during the application certainly helped. This also helped prevent the DGS from being transported in runoff. However, there were places where the DGS flowed a considerable distance immediately after application. One such place is shown in figure 10. At this location, the vegetation was relatively light and the shoulder to the median narrow so that during application DGS flowed into and down the roadside ditch and was observed flowing into the woods. This location was in the median and there was a wooded buffer so it is unlikely the DGS reached and surface water; however, certainly runoff from subsequent storms could wash a considerable amount of the DGS into an adjacent stream. There were several other places where the DGS flowed 1-3ft down the slope of the vegetated shoulder, but then stopped. It is uncertain how far solids in this DGS would be transported by runoff. Hence, there may be project locations where collecting and hauling, at least some, of the DGS may be necessary. For this section of I-85, several locations within the exit and on ramps appeared to be suitable for land application of DGS, so hauling distances could be reduced. A set of conditions for highway shoulders (i.e. slope steepness and length of shoulder, proximity to stream, density of vegetation, soil type, and area of shoulder compared to drainage area), could be developed as a Best Management Practice (BMP) which would determine the potential for direct-discharge of DGS with the rest of the generated DGS being hauled to a nearby area for land application.

Further, the effect of DGS application on storm runoff from the I-85 shoulder was shown to be rather minimal and short-lived with regard to TSS, TP, Mg, Ca, and Pb concentrations and pH. However, the storm runoff data is extremely limited; thus, additional storm data is needed to confirm these initial observations.

SUMMARY AND CONCLUSIONS

Several sites along I-85 in Granville County were visited and assessed for possible land application of DGS and inclusion in a pilot study of direct application of DGS to the shoulder of the highway. After soil samples were collected and analyzed and other factors such as slope, drainage area and accessibility were assessed, three sites were chosen for inclusion in the pilot study. The mean DGS application rate was computed from the measured DGS discharge rate, application area, and the grinding machine’s speed. This application rate combined with the equivalent lime content, obtained from analysis of DGS samples, was used to determine an equivalent lime application rate of 10.7 ton/ac, which was more than 14 times the recommended rate for growing fescue on the soils of the highway shoulder. Nevertheless, the DGS application appeared to have no short-term (< 3 months) detrimental effect on the vegetation grown on the shoulders. The reason for this may have been that the DGS was applied to the surface and its effect on soil pH confined mainly to the top 2 inches of the soil profile. Analysis of soil samples collected from the shoulders confirmed that the pH of soil at greater than 2 inches was less than at less than 2 inches. In addition, concentrations of Ca and Mg in runoff from well-vegetated shoulders with DGS application were somewhat greater than without, but the increase appears to be temporary suggesting that the effects on adjacent surface waters would be negligible. However, observations at some locations with less vegetation and narrow shoulders showed that direct application of DGS to shoulders resulted in the flow of DGS into and down roadside ditches thereby raising concerns about a considerable amount of DGS reaching adjacent surface waters during storm events. In conclusion, the data from the three pilot sites show that direct application of DGS to the I-85 shoulder had a minimal effect on the vegetation, soil, and surface water quality, but that the potential for a much greater effect at less optimal sites is significant.

Because this was a preliminary project and limited in scope and extent, conclusions must also be limited. Given this the following conclusions can be made from the data:

- The cumulative impact of DGS application was not estimated as the drainage area to each station must be determined and additional runoff monitoring conducted before areal loading can be estimated/computed.

- Developing a set of site conditions or BMP to screen NCDOT sites for direct discharge to highway shoulders and other areas within NCDOT right-of-ways is recommended. Conditions and observations from this project can be used to start this BMP after the I-85 shoulders have been surveyed.

- While the direct discharge of DGS from the grinding machine resulted in application rates that exceeded the recommended agronomic rates, there did not appear to be any short-term (< 3 months) adverse impacts to the soils, vegetation, or surface runoff (as measured by concentrations of TSS, TP, Ca, Mg, Pb, and pH) from the sites.

- The effectiveness of using a vertical tillage tool to loosen the soil surface of the highway shoulder prior to DGS application could not be determined. While the tool appeared to limit the movement of DGS downslope from the shoulder, additional monitoring of these sites and other sites is needed to adequately determine the effectiveness of this tool.

- Monitoring of additional sites with different soils, topography, and moisture conditions are needed to adequately establish the environmental impacts of widespread use of direct discharge of DGS to highway shoulders.

Table 1. Analysis of DGS Samples.

Analyte	Units	206S[1]	206Sb[2]	206Sc[3]	203S[1]	206M[5]	204M[5]	Mean
		--------- Sample Identification ---------						
P	ppm	246	104	na	224	53	71	148
Potassium (K)	ppm	2720	na	na	3080	707	776	1821
Ca	ppm	115000	54648	na	98800	24100	27200	66275
Mg	ppm	4250	1665	na	3820	1070	1130	2568
Sulphur (S)	ppm	2660	na	na	2200	594	662	1529
Iron (Fe)	ppm	9590	na	na	8735	2320	2360	5751
Manganese (Mn)	ppm	147	na	na	149	40.4	37.6	93.5
Zinc (Zn)	ppm	113	na	na	53.6	18.1	29.2	53.5
Copper (Cu)	ppm	39.5	na	na	14.3	6.2	9.4	17.3
Boron (B)	ppm	9.17	na	na	6.40	1.66	2.16	4.8
Sodium (Na)	ppm	2000	na	na	2410	556	725	1423
pH	s.u.	11.0	na	na	10.9	11.6	11.5	11.2
Dry Matter	%	38.4	39.4	na	31.3	na	na	na
CCE	%	26.3	na	38	24.3	6.3	6.3	15.8
ALE	tons	8.94	na	na	11.9	na	na	na
ALE	gallons	2144	na	na	2854	3420	3400	2954

[1] Collected from shoulder near exit 206 and 203.
[2] Duplicate of 206S analyzed by BAE lab.
[3] Duplicate of 206S analyzed by Waypoint Analytical lab.
[4] Collected from median near exit 206 and 204.

Table 2. Runoff from Shoulder of I-85 at Northbound Exit 204 Ramp (Site 204A).

Date	------ Rainfall ------- Depth in	Peak 30min in	Dur hr	-- Runoff/discharge -- Volume gal	Peak gpm	Dur hr	TSS	TP	Ca	Mg	Pb	pH
							---------------- mg/L ----------------					
7/30/16	0.54	0.54	0.3	140	1.1	4						
8/6/16	0.41	0.20	3.5	430	6	5						
8/8/16	0.82	0.51	1.2	7354	112	5.2	5.26	0.49	8.92	1.21	0.00	7.3
8/19/16	0.71	0.65	0.8	96	9.5	2						
8/20/16	0.13	0.11	3	30	0.6	5						
8/21/16	0.55	0.54	0.8	2486	75	2	3.08	0.83	12.30	1.31	0.04	7.5
9/2/16	0.66	0.06	9	556	0.9	14						
9/18/16	0.80	0.52	5	284	1.1	8						
9/19/16	0.63	0.21	3	2357	24	6	7.69	0.78	10.88	1.18	0.00	7.6
9/22/16	0.74	0.19	28	3255	43	18						
9/27/16	0.44	0.37	1.5	547	10.6	2.5	10.53	1.21	14.49	2.09	0.00	6.6
9/29/16	0.87	0.35	5	8653	47	11	8.00	1.54	14.43	3.02	0.03	6.6
10/7/16	4.48	0.22	36	127,500	250	36	10.53	0.88	9.76	2.32	0.11	6.4
Pre 9/22/16 mean							5.34	0.70	10.70	1.23	0.01	7.5
Post 9/22/16 mean							9.68	1.21	12.89	2.48	0.05	6.5

Table 3. Runoff from Shoulder of I-85 at Southbound Exit 204 Ramp (Site 204C).

Date	------ Rainfall ------ Depth in	Peak 30min in	Dur hr	- Runoff/discharge - Runoff gal	Peak gpm	Dur hr	TSS	TP	Ca	Mg	Pb	pH
							---------------- mg/L ---------------					
7/30/16	0.54	0.54	0.3	77	4.5	1.5						
8/6/16	0.37	0.20	3.5	1002	7	8						
8/8/16	0.85	0.51	1.2	10056	145	7	10.0	0.22	7.93	0.76	0.00	6.8
8/19/16	0.72	0.61	1	381	11	5						
8/20/16	0.33	0.30	4	906	12	8						
8/21/16	0.51	0.50	1	3487	95	8	2.73	0.51	9.09	0.78	0.04	8.1
9/2/16	0.68	0.06	8	1215	6.5	14	3.12	0.60	6.44	0.44	0.10	8.7
9/18/16	0.92	0.67	6	489	7.5	8						
9/19/16	0.67	0.26	4	4773	32	10	5.33	0.27	7.00	0.83	0.00	7.0
9/22/16	0.79	0.20	20	5751	45	22						
9/27/16	0.51	0.42	1.2	1845	28	4	16.84	0.31	19.62	3.17	0.00	6.7
9/29/16	0.86	0.34	5	8247	43	11	5.60	0.74	31.78	7.19	0.04	6.6
10/7/16	5.10	0.24	36	84167	165	72	12.22	0.30	13.60	1.76	0.03	6.3
Pre-DGS period							5.3	0.4	7.6	0.7	0.03	7.6
Post-DGS period							11.6	0.5	21.7	4.0	0.02	6.5

Table 4. Runoff from Shoulder of I-85 at Southbound Exit 206 On-ramp (Site 206D).

Date	------ Rainfall ------ Depth in	Peak 30min in	Dur hr	- Runoff/discharge -- Runoff gal	Peak gpm	Dur hr	TSS	TP	Ca	Mg	Pb	pH
							--------------- mg/L ----------------					
7/30/16	0.54	0.54	0.3	na								
8/6/16	0.37	0.20	3.5	2806	65	6						
8/8/16	0.85	0.51	1.2	9654	200	6	130.7	0.10	1.95	0.25	0.13	6.8
8/19/16	0.72	0.61	1	199	10	1.5						
8/20/16	0.33	0.30	4	0	0	0						
8/21/16	0.51	0.50	1	1750	40	5	16.0	0.25	17.8	5.61	0.00	6.7
9/2/16	0.68	0.06	8	0	0	0						
9/18/16	0.92	0.67	6	1124	13	6						
9/19/16	0.67	0.26	4	14186	310	7	7.57	0.17	4.18	0.69	0.00	6.7
9/22/16	0.79	0.20	20	3947	55	8						
9/27/16	0.51	0.42	1.2	1964	32	4	10.0	0.12	5.12	0.92	0.00	6.8
9/29/16	0.86	0.34	5	5937	47	11	22.6	0.14	5.70	1.17	0.07	6.6
10/7/16	5.10	0.24	36	45902	105	36	7.8	0.13	5.68	1.06	0.06	6.7
Post-DGS period							12.8	0.16	7.69	1.89	0.03	6.7

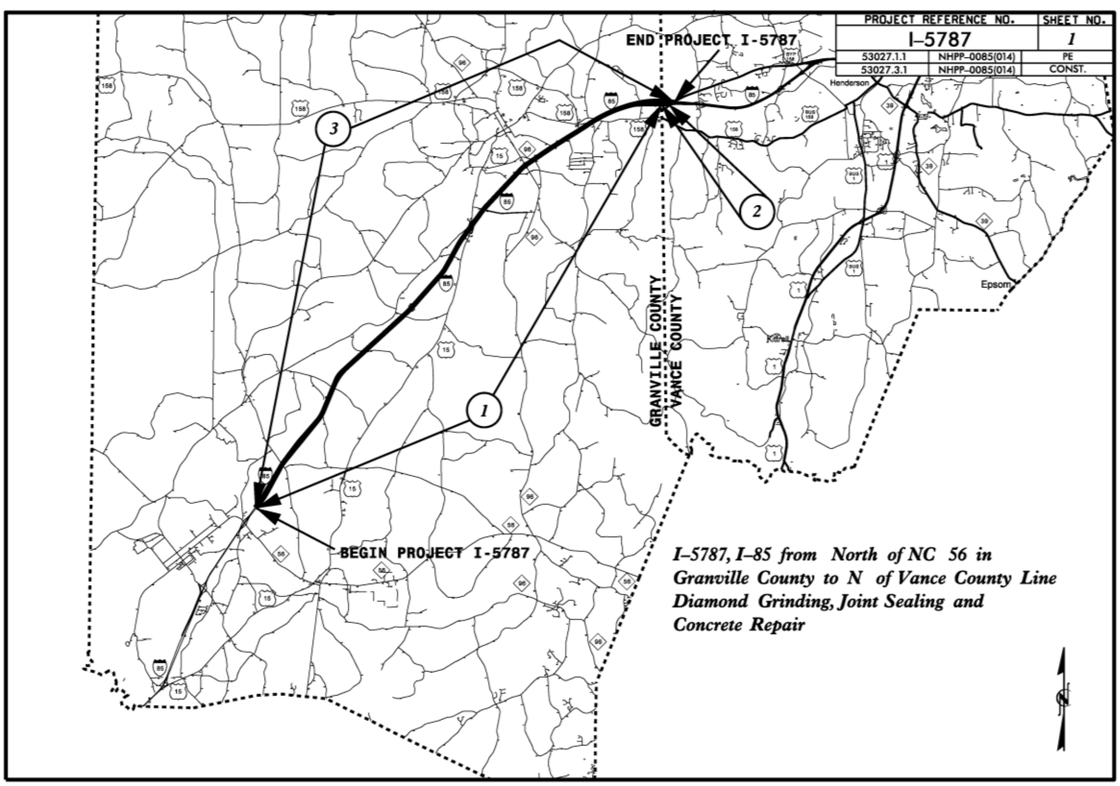

Figure 1. Map of NCDOT pavement preservation project area.

Figure 2. Site 206D aerial view (left) and flume (right).

Figure 3. Site 204C aerial view (left) and monitoring station (right).

Figure 4. Site 204A aerial view (left) and monitoring station (right).


Figure 5. DGS on furrowed shoulder (left) and DGS discharge from grinding machine (right).

Figure 6. Soil sampling location on shoulder (left) and sampling hole with DGS cleared (right).

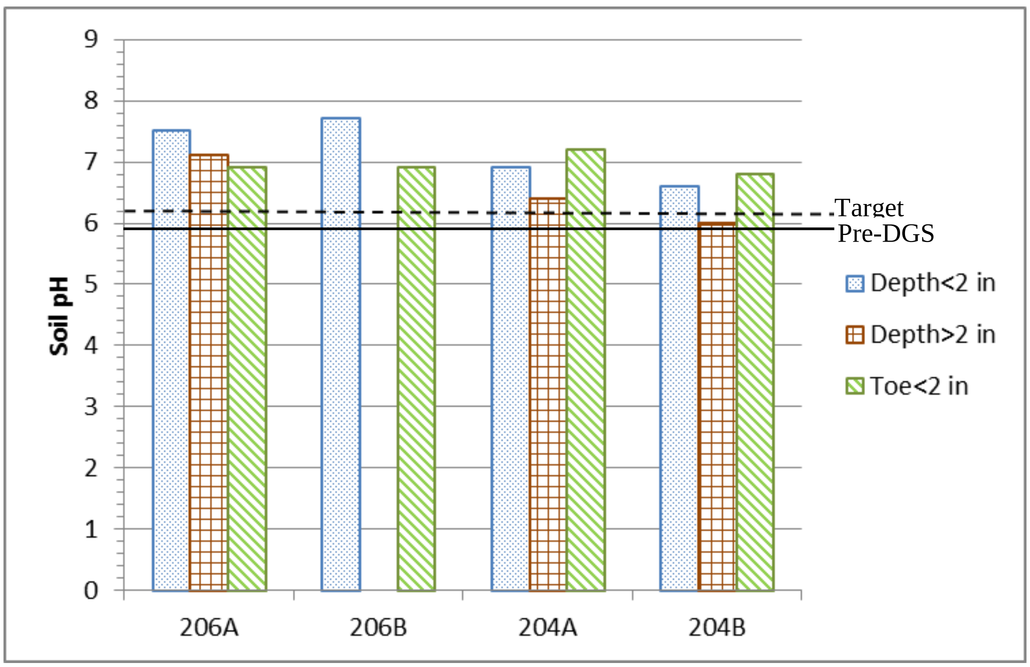

Figure 7. The pH of soil samples collected from the shoulder of I-85 at exits 206 and 204 after DGS application.

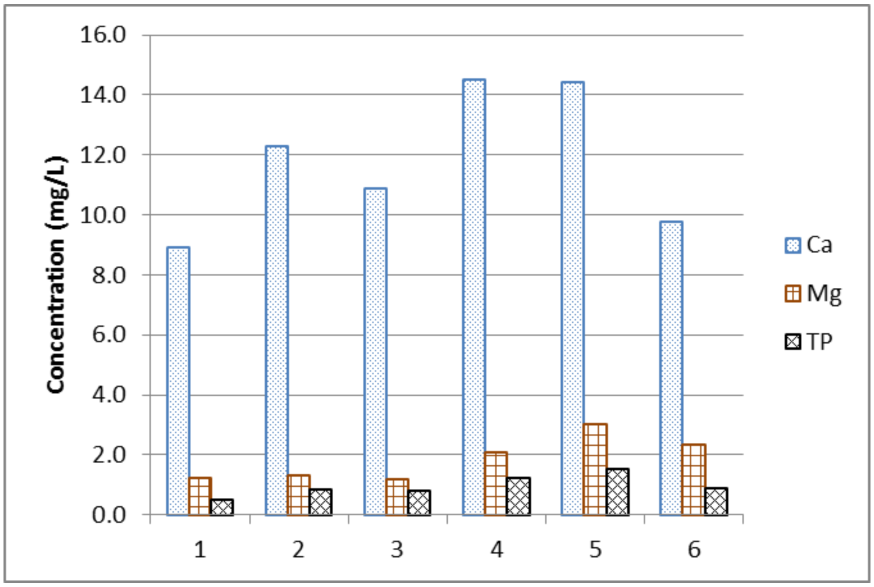

Figure 8. Concentrations of Ca, Mg, and TP in runoff samples from site 204A.

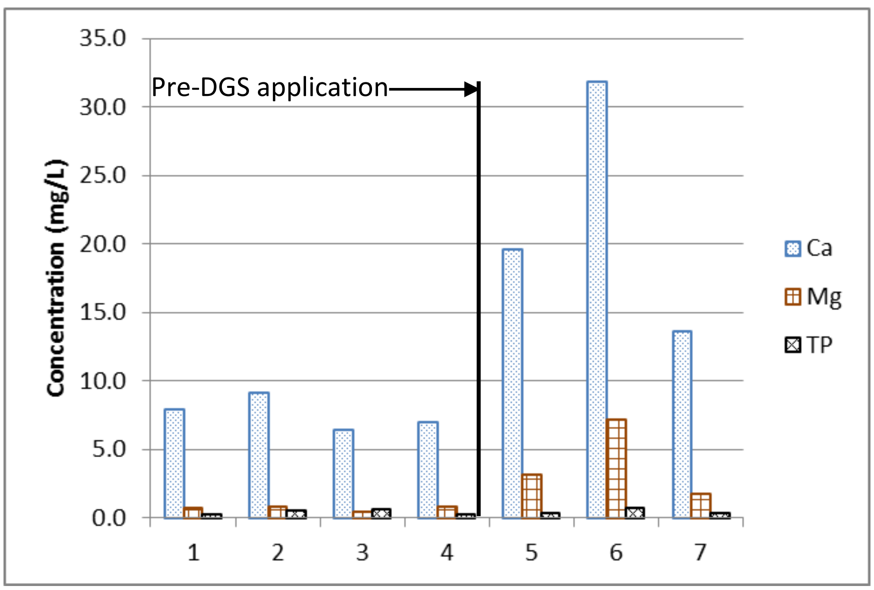

Figure 9. Concentrations of Ca, Mg, and TP in runoff samples from site 204C.

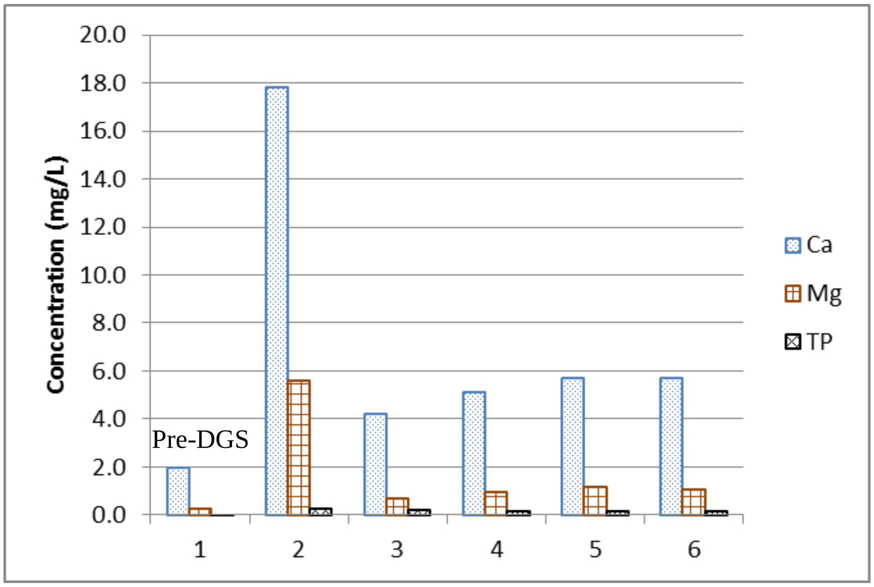

Figure 10. Concentrations of Ca, Mg, and TP in runoff samples from site 206D.

Figure 10. DGS in roadside ditch flowing towards woods.