RESEARCH & DEVELOPMENT

Comparing Low-Cost Methods for Stabilizing Diversions and Ditches

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NCDOT Project 2014-21
FHWA/NC/2014-21
July 2018

Comparing Low-Cost Methods for Stabilizing Diversions and Ditches

North Carolina Department of Transportation

PROJECT AUTHORIZATION NO. HWY- 2014-21

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Technical Report Documentation Page

<table>
<tr><td>1. Report No.
????</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Comparing Low-Cost Methods for Stabilizing Diversions and Ditches</td><td>5. Report Date
March 1st, 2018</td></tr>
<tr><td>6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author(s)
Richard A. McLaughlin and Maria A. Polizzi</td><td>8. Performing Organization Report No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Department of Crop & Soil Sciences
North Carolina State University
Campus Box 7620
Raleigh, NC 27695</td><td>10. Work Unit No. (TRAIS)</td></tr>
<tr><td>11. Contract or Grant No.</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
North Carolina Department of Transportation
Research and Analysis Group

1 South Wilmington Street
Raleigh, North Carolina 27601</td><td>13. Type of Report and Period Covered
Final Report
August 2015 – December 2017</td></tr>
<tr><td>14. Sponsoring Agency Code
2014-21</td></tr>
<tr><td colspan="3">Supplementary Notes:</td></tr>
</table>

16. Abstract

Previous studies have demonstrated that a major source of sediment arriving at sediment basins is erosion from unlined water conveyances. While check dams provide some reduction, lining the diversions and ditches can be highly effective. The typical liner is a rolled erosion control blanket (RECB) made of natural fibers, such as excelsior, jute, or coir. Another material, Posi-Shell, consisting of a spray-on mixture of cement and two proprietary products, has potential to be installed much more quickly and easily, but needed to be evaluated. This project provides an evaluation of four potential lining systems for reducing erosion in water conveyances under both controlled, full-scale conditions and on active construction projects. The four systems included jute mesh, jute mesh + polyacrylamide (PAM), excelsior, and Posi-Shell.

The full-scale model study was conducted at the Sediment and Erosion Control Research and Education Facility at the Lake Wheeler Road Field Laboratory in Raleigh, NC. Plywood flumes were constructed with a trapezoidal shape with 2' bottoms and a total length of 16'. Three were constructed to have 4, 8, and 12% slopes, and each was packed with soil to a depth of 1' prior to introducing flows of approximately 0.4, 0.8, and 1.1 cubic feet per second (CFS). Samples were taken at the outlet for turbidity and total suspended solids measurements, and after 10 min the flow was stopped and changes in the channel were measured. At three construction sites, existing diversions were lined with the different materials and samples were obtained during storm events with automatic samplers. Changes in the ditch topography was also measured periodically.

Excelsior performed the best in the flume study, with Posi-Shell and jute+PAM having somewhat more erosion overall. Posi-Shell performance was sensitive to application techniques in both the field and flume. For instance, the hydroseeder used to apply it was unable to produce full power during a field application, resulting in uneven distribution. One application of Posi-Shell to the soil in the flumes did not full cover the soil near the outlet, leading to erosion and failure, which did not occur in all other tests. Jute alone was better than no lining at all, but clearly inferior than the other liners tested. Given the relative ease and speed that Posi-Shell can be applied using standard hydroseeding equipment, and material costs only somewhat higher, this could be a viable option to reduce sediment loading to sediment basins during construction.

17. Key Words Erosion, turbidity, ditch erosion, construction runoff	18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Acknowledgments

This project was a team effort starting with Extension Associate Jacob Wiseman and Technicians Jamie Luther and Chris Niewoehner. Graduate student Maria Polizzi assisted in running the flume tests. Numerous undergraduate students also assisted during the course of the project. Matthew Gonzalez of New Mexico State University collected a great deal of data and provided analyses as part of his summer program here (NSF-funded Research Experience for Undergraduates). We are always grateful for the assistance of the NC DOT Roadside Environmental Unit staff for finding potential sites for us that meet our requirements. We also greatly appreciated the assistance of project staff and contractors to get our test deployed in a timely manner. It is only through this type of cooperation that we can conduct research on “live” construction sites, which is one reason why North Carolina is considered a leader in erosion, sediment, and turbidity control.

Executive Summary

Sediment originating from eroding water conveyances (diversions, ditches) can be a significant portion of the sediment washed into sediment basins. While check dams can help reduce the loading, unlined ditches remain a major sediment source. This project

was an investigation into the effectiveness of different materials for lining ditches to reduce erosion. The current standard excelsior rolled erosion control blanket was compared to jute, jute+polyacrylamide (50 lb/ac under jute), and Posi-Shell. Posi-Shell is a combination of cement and two proprietary products mixed in water and applied with a hydroseeder or similar equipment. Tests were conducted under controlled conditions in large-scale flumes lined with soil and on a number of construction sites. All liners reduced erosion substantially compared to the unlined condition, but jute alone was the least effective as it has large openings between the threads. Excelsior was the most effective overall, with the Posi-Shell and jute+PAM somewhat less effective. The erosion which occurred in the Posi-Shell-lined ditches was primarily due to poor application, either with gaps or uneven application, which produced failures. Most tests with Posi-Shell, however, resulted in little erosion and were comparable to the excelsior results. Not including costs of installation/application, Posi-Shell had a material cost of around 30% more than excelsior. However, we estimate that the time to line a ditch would be reduced by 90% compared to properly stapling in an erosion control blanket. This may offset the material costs or more. Lining diversion ditches to reduce sediment loads in sediment control measures is highly recommended, regardless of the material used.

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Introduction

There has been very little research that relates directly to erosion in water conveyances on construction sites. The majority of erosion and erosion control research has focused on sheet and rill erosion on slopes, with a few studies on farm ditches with little slope. The other categories of ditch research are seepage control (irrigation) and permanent stormwater liners. The have little relevance to temporary construction site diversions. There is good reason to investigate methods to reduce erosion in these conveyances, however. Elliot and Tysdal (1999) demonstrated that the ditches can be the largest source of sediment on unpaved forest roads, with unvegetated ditches generating 5-7 times as much as those with vegetation. They found that 60% of the sediment was generated in the ditch. In a recent NC DOT-funded study measuring sediment loads and erosion on a Piedmont construction project, most of the sediment reaching the basins was from the ditches (Brown, 2012). In fact, when ditch erosion was controlled with a spray-on concrete product, the modeled erosion using RUSLE2, representing slope erosion only, matched the measured sediment load, unlike sites where the ditches were unlined.

An innovative study combining flume tests with computer modeling demonstrated how rolled erosion control products (RECPs) can fail when submerged (Gharabaghi et al., 1999). In reviewing previous studies from Texas DOT, they noted that in unvegetated states, some RECPs began to lose soil at the same rate as bare soil. When vegetated, however, the losses were fairly constant. They studied the behavior of an RECP under flat (highly stapled) and wavy (minimal stapled) conditions and found that the material tended to be buoyant between the staples, allowing considerable erosion under the matting. High flows for short duration and low flows for long durations could produce similar effects. They suggested that liners are more effective when they have low permittivity to reduce soil-water interactions and high stiffness to resist deformation. Smets et al. (2009) tested three geotextiles of relatively open netting (35-59% open space) under shallow sheet flows and found that once flow became relatively turbulent with higher sheer stress, erosion under the blankets increased significantly.

The Gharabaghi et al. study (1999) can be contrasted with an evaluation of three coir matting types for erosion control. Sutherland and Ziegler (2007) tested two open-weave products, probably what we would refer to as 400 g m^{-2} and 700 g m^{-2} coir mesh, and a coir RECP. They conducted tests under rainfall and sheetflow conditions in sequence. The coir RECP, with very little open space, performed much better than either mesh product due to better contact with the soil, less raindrop erosion, and greater flexibility. This was true for both rain and sheetflow conditions. The denser mesh product performed better than the more open product due to both reduced soil exposure and greater "stiffness" to resist deformation. Their findings are both in agreement ("openness" of weave or permittivity; stiffness) and in contrast (flexibility of coir RECP) to Gharabaghi et al. (1999), suggesting that different evaluations are needed for erosion control on slopes versus in water conveyances.

Some research has indicated that PAM could be used to prevent infiltration, in particular in irrigation ponds and canals (Lentz and Kincaid, 2008; Young et al., 2009). Our own research has demonstrated that granular PAM also can inhibit water infiltration into soil (Bhardwaj et al., 2010), but some of the PAM can be washed off the soil surface initially if unprotected (Babcock and McLaughlin, 2011). It has been suggested that erosion in ditches lined with erosion control blankets can be reduced significantly if PAM is applied to the soil surface prior to installing the blanket (Steve Iwinski, Applied Polymer Systems, personal communication). While this makes sense based on previous work, there have been no tests of this system, which could be relatively inexpensive

Materials and Methods

Five treatments were selected for testing the effects of different products as ditch liners. The control was bare soil (or no lining), which is how many temporary construction ditches are treated currently. Jute mesh was selected as an example of an inexpensive rolled erosion control product (RECP) with open netting and flexible fabric. The application of polyacrylamide (PAM) to the soil under the jute was included to determine if applying PAM would improve performance. Excelsior matting (single-net) was included as another low-cost lining material, as it is widely used on NCDOT projects. Lastly, a hydraulically applied concrete product, Posi-Shell (LSC Environmental Products, LLC, Apalachin, NY), was tested. This was applied as a mixture of proprietary fiber and powder along with cement in a ratio of 1.5:20:75, respectively. The mixture was added to water (300 gal) in a hydroseeder and applied to fully cover the soil. Tests were conducted in a simulated ditch with controlled flows and on active NCDOT construction sites.

Simulated Ditch Testing:

Testing of the treatments was conducted at the Sediment and Erosion Control Research and Education Facility (SECREF) in Raleigh, NC. This facility allows water to be gravity fed for many testing designs. For this test water was routed from the facility holding pond, into a 12" PVC plastic piping and then into 8" corrugated pipes before being released into the flumes for testing.

The research flumes were constructed of treated 2x4 lumber, ¼" sheets of treated plywood, and decking screws. After the framing was constructed, a mixture of soil and sand was poured underneath the framing to help support the weight of the soil in the flume. The plywood was then screwed to the frame to form a trapezoid channel.

An impermeable lining material was then stapled to the plywood flume to limit any water loss that might occur during testing.

The three flumes were positioned to achieve slopes of 4%, 8%, and 12%. The flumes were repeatedly surveyed and small changes to the elevations were made using a mixture of soil and sand, until the slopes could be achieved. The flumes were packed with soil to a depth of approximately 20.3 cm (8 inches) (Figure 1). Soil was compacted, by hand using a soil tamp, to a bulk density of between 1.3 g/cm^3 and 1.8 g/cm^3. Two soil cores were taken from randomly selected areas in each flume. Each sample was weighed, dried for 24 hours, and then weighed again to determine water content and bulk density. A local Wake Country, NC Sandy Clay Loam (54% sand, 25% silt and 21% clay) subsoil was used for all tests.

Figure 1. Spreading soil in the flume prior to packing.

After testing, soil was removed from the flumes and then repacked for the next product test. Only soil that had been wetted during the previous test was removed from the flume, soil along the edges of the flume (at the top of the trapezoid) was often unaffected by water flow during the tests and was left in place for the following test (Figure 2). The bottom 3-4" of soil near the liner of the flume was also left in place with new soil to be tested packed on top of it.

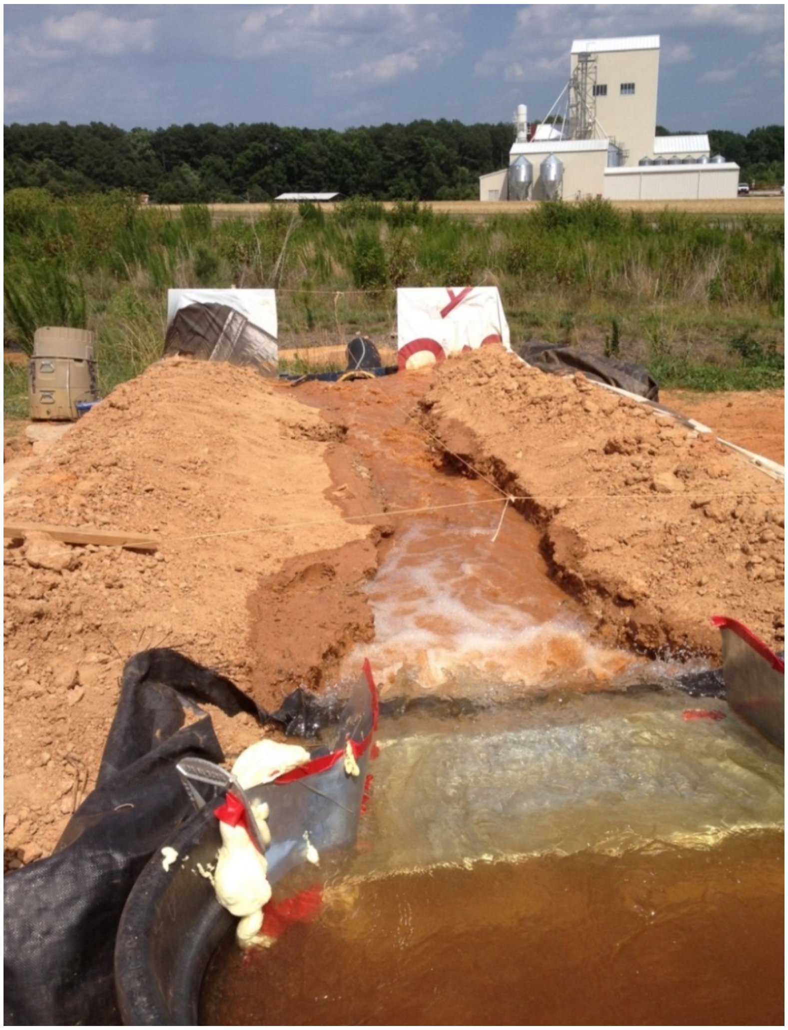

Figure 2. A high flow in the 8% slope flume showing erosion during a bare soil test.

Most of the measurement operations described below are illustrated in Figure 3. For each test, water samples were taken manually at the inlet and outlet of the test ditch at one minute intervals. After 10 minutes, flow was stopped and erosion measured using a pin device at set intervals of 60 cm (24 in) along the flume (see below). After that, the test was resumed at the next higher flow rate until all three rates were completed. Flow was affected by the water level in the source pond but the three rates were 0.3-0.5 cubic feet per second (cfs), 0.7-0.8, and 0.9-1.2 cfs. Water samples were analyzed for turbidity and total suspend solids (TSS) in the laboratory. In addition, for a few tests the ditch surface changes were recorded photographically and a program was used to generate a three-dimensional image, and a ground-based LiDAR system also recorded the surfaces. These latter two systems were used just to determine their utility for this type of surface analysis as part of the summer intern project. An ISCO

6712 automated sampler (TELEDYNE Isco, Lincoln, NE, USA) was positioned at the exit of the research flume, where a square-notch weir was attached. The sampler was programed to record ditch flow (cfs) during each test.

Figure 3. Measuring erosion with a pin device (background) and testing bare soil in the medium (8%) slope. Surveys were also conducted via georeferenced photographs and a LiDAR unit, shown at the end of the closer flume, for several tests. Manual collection of inlet and outlet samples is also occurring in this ditch.

An ISCO 1670 automated sampler was positioned at the exit of the research flume. The sampler was programed to record ditch flow (cfs) and collect samples at 500 gal intervals. These samples were then analyzed for turbidity and TSS.

Before and after each test a detailed survey of the flume was produced using the Ditch Pin Measuring Apparatus (DPMA). The DPMA contained 13 individual “pins” (spaced 6” apart) that are able to slide up and down within the device. The DPMA was placed at known points and elevations along the ditch (spaced at 2’ intervals) and the pins were allowed to slide down until they came in contact with the flume soil. Measurements were taken for each pin and compared with the before measurements to determine soil loss at each pin.

Examples of the Posi-Shell application and testing are shown in Figures 4 and 5.

Figure 4. Posi-Shell being applied to the simulated ditch at SECREF.

Figure 5. Testing the hydraulically applied concrete product with a 1 cfs test flow.

NCDOT Active Construction Sites:

Greensboro

The first suitable site was on the I-840 Urban Loop extension around Greensboro, NC, between US 70 and US 29 (STIP # U-2525B), just north of US 70. Two ditches were lined with a series of liners (jute, jute + PAM, excelsior, Posi-Shell). On one set, we installed weirs and samplers at the end of each section in order to measure sediment in runoff from that section. For both ditches, we established three locations where we measured the contours of the ditch after a number of storm events to detection erosion. The ditch with the water quality monitoring included a V-notch flume after each check dam, which marked the change to a different liner, and an automatic sampler to obtain flow and samples (Figure 6).

Three cross-sections were measured in each section of ditch that had been treated and compared with the initial measurements that were taken at the site. Figure 7 shows the cross-section pin measurement device being used to record changes in a bare soil (control) treatment ditch at the site. After placing the device on permanently installed stakes along each ditch and pushing the individual pins down until they contact the soil, each of the pin lengths above the cross-member were measured and recorded. More views of the Greensboro site are shown in Figures 8-9.

A second site was established on the same project but construction activities destroyed the weirs and disrupted the liners beyond repair, so no data was collected.

Figure 6. Measuring the slope of each ditch section. Note V-notch weir and sampler placed to measure flow and sediment loss.

Figure 7. Using the cross-section pin measurement device in a bare soil (control) treatment section of the ditch.

Figure 8. The rolled erosion control blanket (excelsior) treated section of Ditch 2 shows very few signs of erosion.

Figure 9. Automated sampler and V-notch weir for collecting water quality and quantity data.

Apex

A second site was located at the construction of an interchange on I-540 at Old Holly Springs Apex Road. Ditches lined with excelsior, Posi-Shell, jute+PAM, and an unlined ditch was also monitored. However, grading activities often reduced or eliminated flows in the diversion ditches and eventually most were no longer receiving runoff or obliterated by grading (Figure 10). The hydroseeder with which we applied the Posi-Shell had mechanical difficulties and could not produce enough pressure to make a good application anyway, and that lining did show evidence of erosion (Figure 11).

Figure 10. Excelsior-lined ditch at the Apex site after flow was cut off to it during grading. Stakes along each side are level across the ditch so the pin tool could be laid on them to measure changes in the cross-section.

Figure 11. Posi-Shell-lined ditch at the Apex site showing erosion due to poor distribution of the material as a result of inadequate pressure in the hydroseeder.

Durham

The third and last active site was located on the Durham East End Connector project (STIP # U-0071). With the assistance of the project staff, we were able to locate four ditches running roughly parallel on one portion of the project. We applied four treatments: jute, jute + PAM (on soil under jute), excelsior, and Posi-Shell. These were applied to the upper portion of each ditch. V-notch weirs were installed to measure flow and obtain exit samples using automatic samplers. Polyacrylamide was being applied to the check dams by the contractor. An example of a Posi-Shell lined ditch at this site is shown in Figure 12.

We also applied Posi-Shell to a second site on the same project. This site had two diversion ditches which discharged into a sediment basin. The site had just been seeded and straw applied when we selected it, so the straw was removed from the ditches manually before applying the Posi-Shell. Weeds and grass grew through the lining over the course of monitoring these ditches (Figures 13-14). Although no monitoring occurred on the adjacent basin, we did observe the conditions in the unlined ditches there (Figure 15). Water quality (turbidity) was monitored with automatic samplers at a ditch outlet and basin outlet. The basin with Posi-Shell diversion ditches (Figure 16) was monitored for water quality and level, while the adjacent standard basin was observed for contrast in water quality (Figure 17).

Figure 12. Diversion ditch lined with Posi-Shell after several flow events.

Figure 13. Posi-Shell-lined ditch in May 2017, one month after application.

Figure 14. Second Posi-Shell-lined ditch in September 2017, also showing considerable volunteer vegetation.

Figure 15. Unlined ditch in September 2017, showing no vegetation and eroding side walls.

Figure 16. Sediment basin which has Posi-Shell applied to the two diversion ditches leading to its inlet.

Figure 17. Posi-Shell-lined basin on left and unlined inlet basin on right illustrating potential effects on turbidity.

Results

Simulated Ditch Testing:

Turbidity in the water exiting the flumes represents the erosion of the ditch and was measured in samples taken every two minutes for the ten minute test runs. Most combinations of slope (4, 8, or 12%) and flow (0.3-0.5, 0.7-0.8, and 9.0-1.2 cfs) produced similar results, with turbidity from the jute lined ditch being somewhere between the bare soil and the remaining three linings (Figures 18-26). There were some exceptions, such as the 4% slope, high flow testing in which the Posi-Shell turbidity was higher than the bare soil for one time point. This was likely the result of the Posi-Shell eroding in one of the tests (Figure 27) due to some combination of poor application and susceptibility at the weir exit.

Another approach to evaluating the test results is determine the number of tests in which the exit turbidity was within a certain range (Table 1). Excelsior has the most tests in the lowest (<50 NTU) turbidity range and no tests with turbidities exceeding 100 NTU. Posi-Shell and jute+PAM had a similar distribution of tests in the four ranges, but with most test results falling into the lower two ranges. Jute alone had roughly the same number of tests in the highest and lowest turbidity ranges, while most of the bare soil test results were in the highest turbidity range. This analysis provides a clearer separation among the liners, with the excelsior being the highest performer and the Posi-Shell and jute+PAM with slightly lower performance. Jute alone resisted erosion better than bare soil but not as well as the other liners.

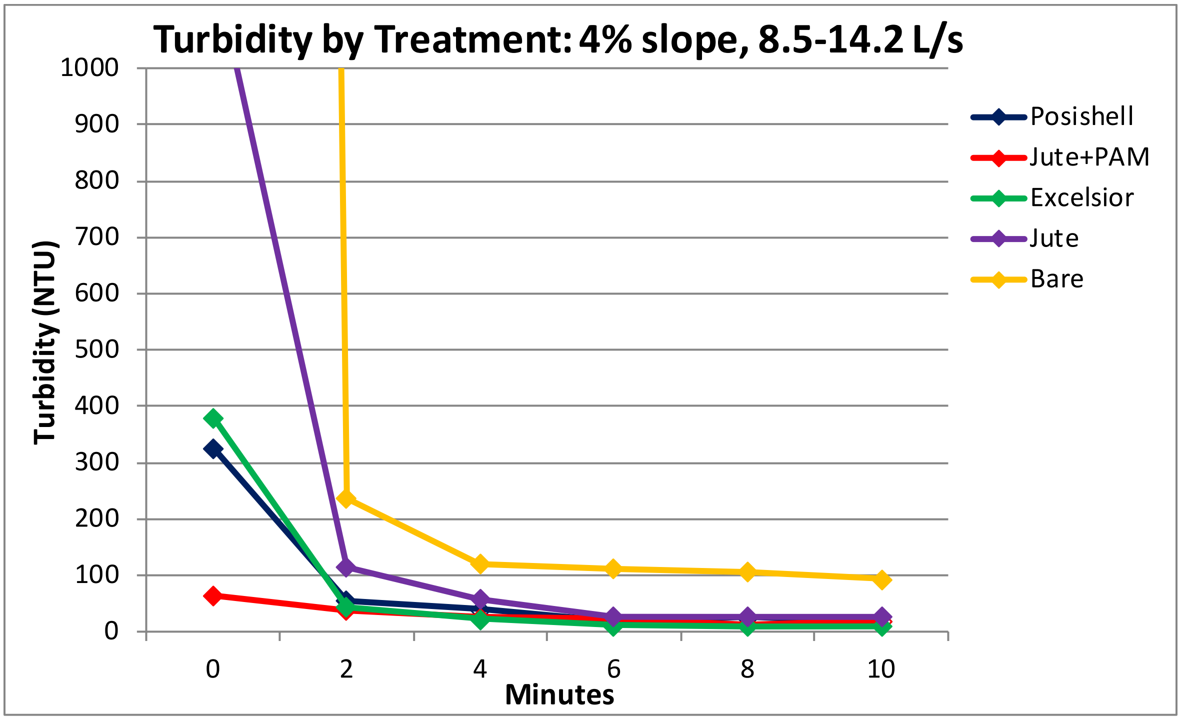

Figure 18. Average turbidity for bare and lined conditions for the 4% slope and low flow.

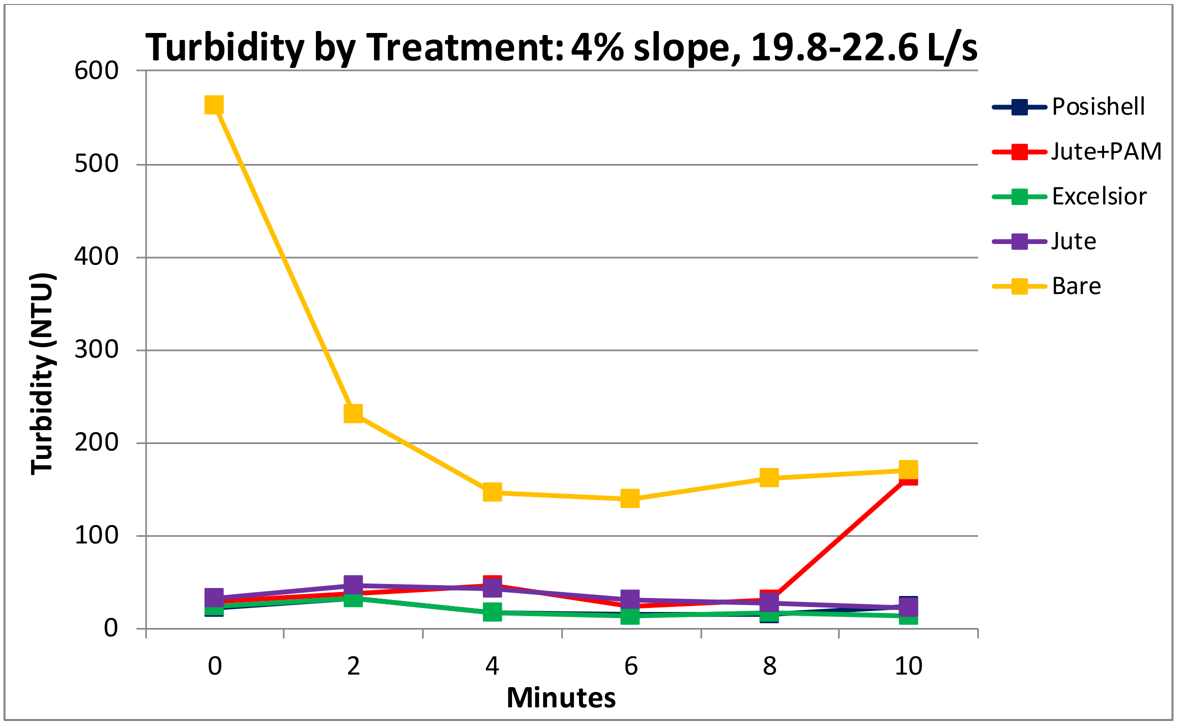

Figure 19. Average turbidity for bare and lined conditions for the 4% slope and medium flow.

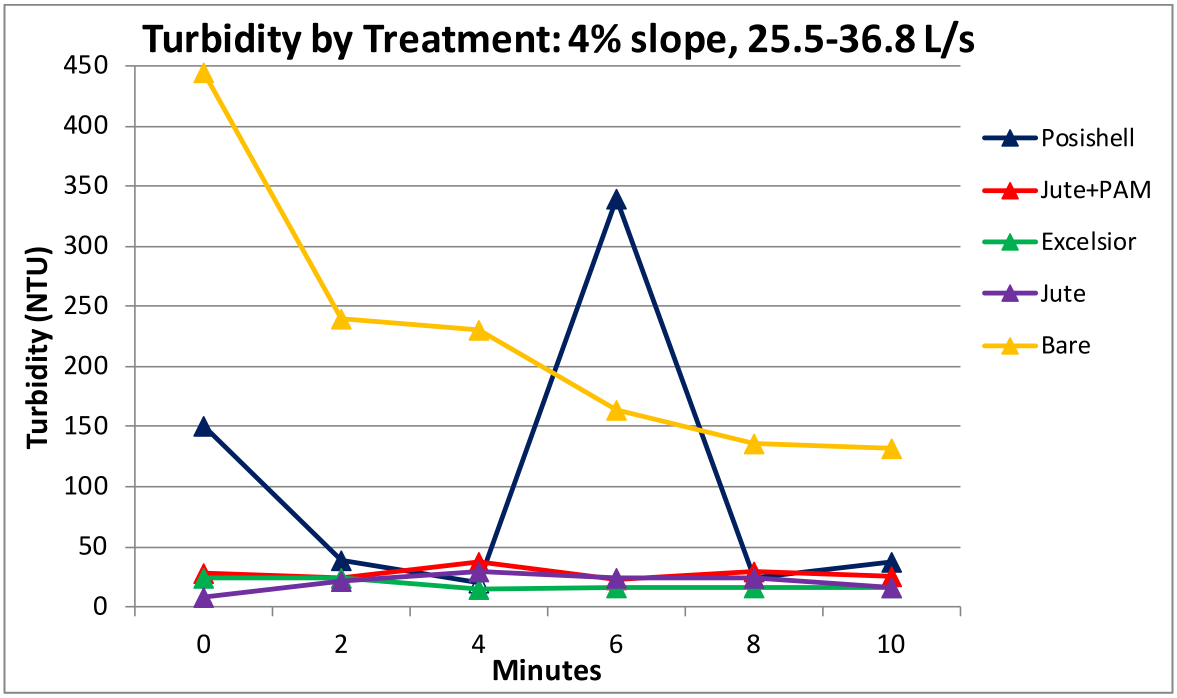

Figure 20. Average turbidity for bare and lined conditions for the 4% slope and high flow.

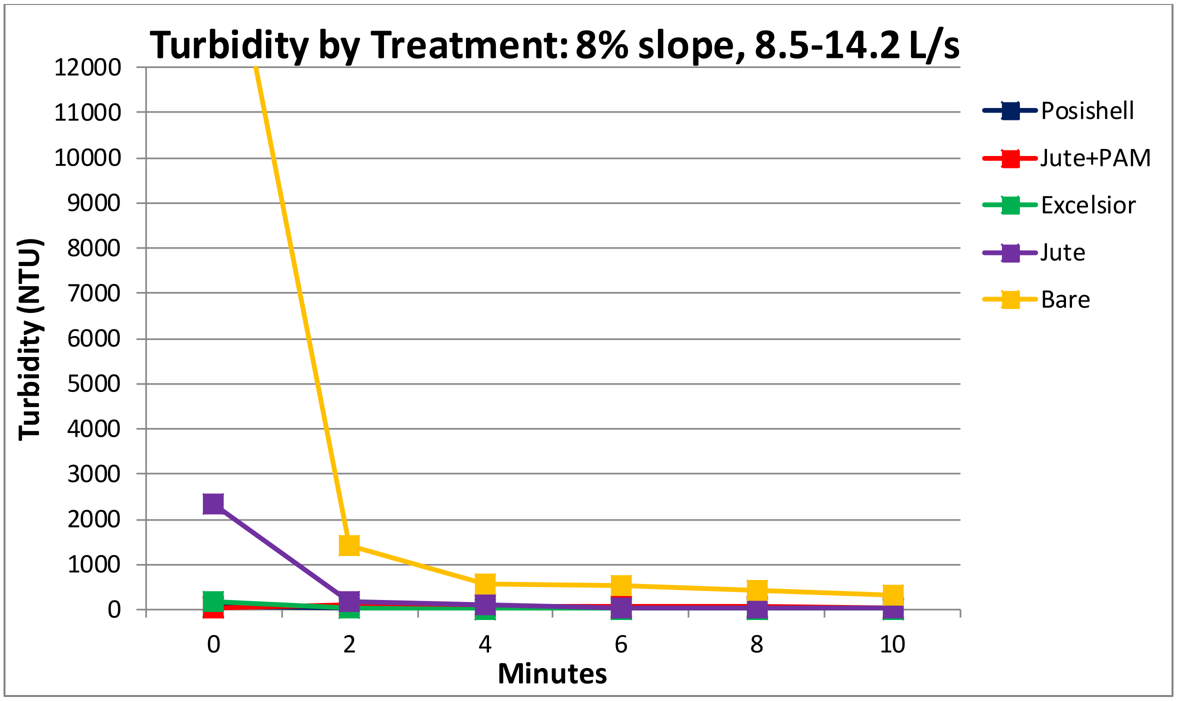

Figure 21. Average turbidity for bare and lined conditions for the 8% slope and low flow.

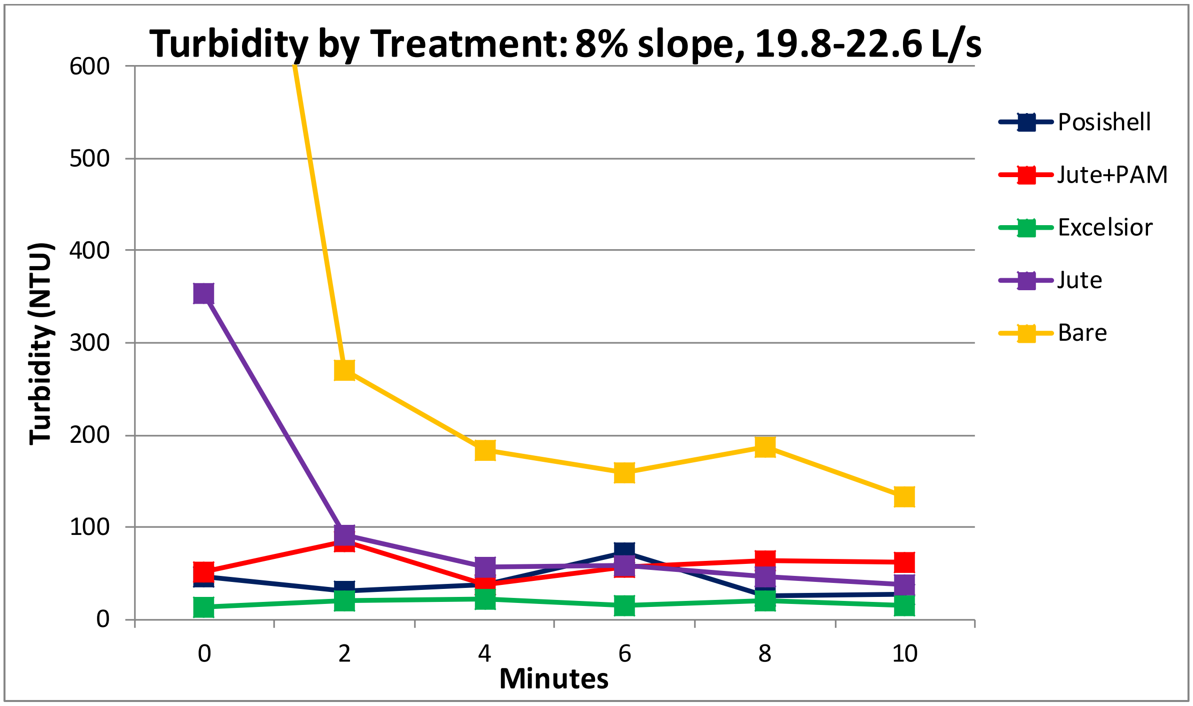

Figure 22. Average turbidity for bare and lined conditions for the 8% slope and medium flow.

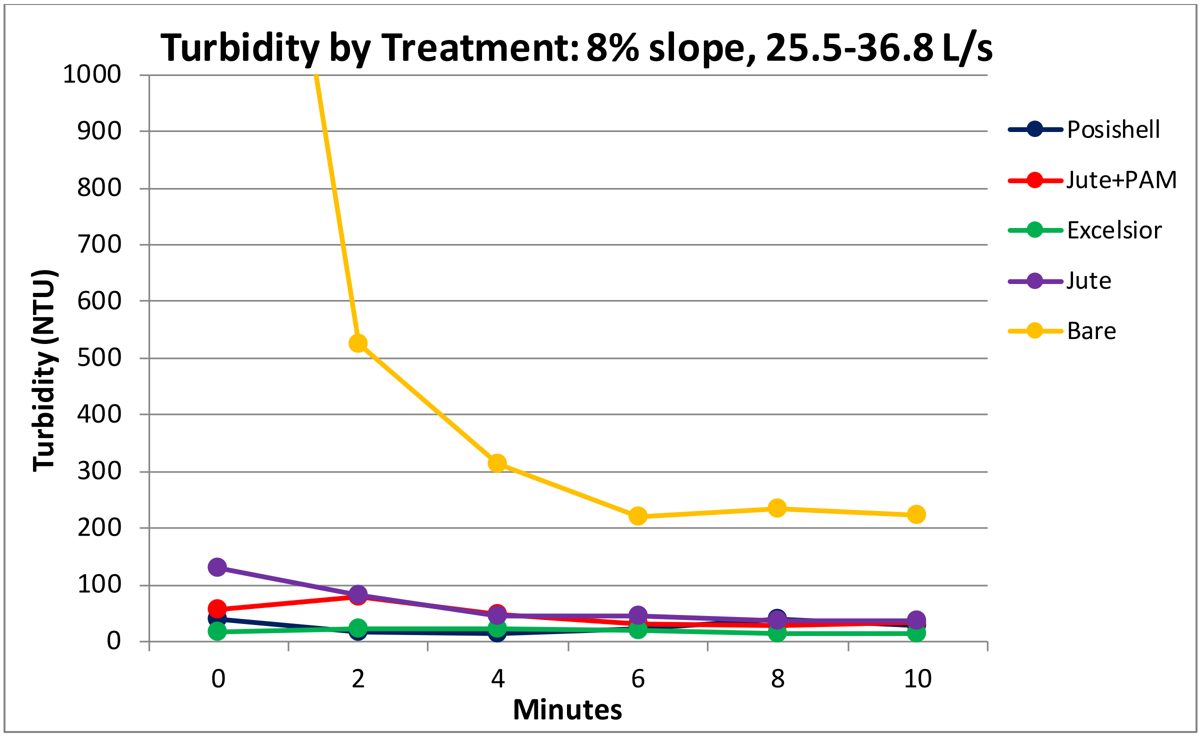

Figure 23. Average turbidity for bare and lined conditions for the 8% slope and high flow.

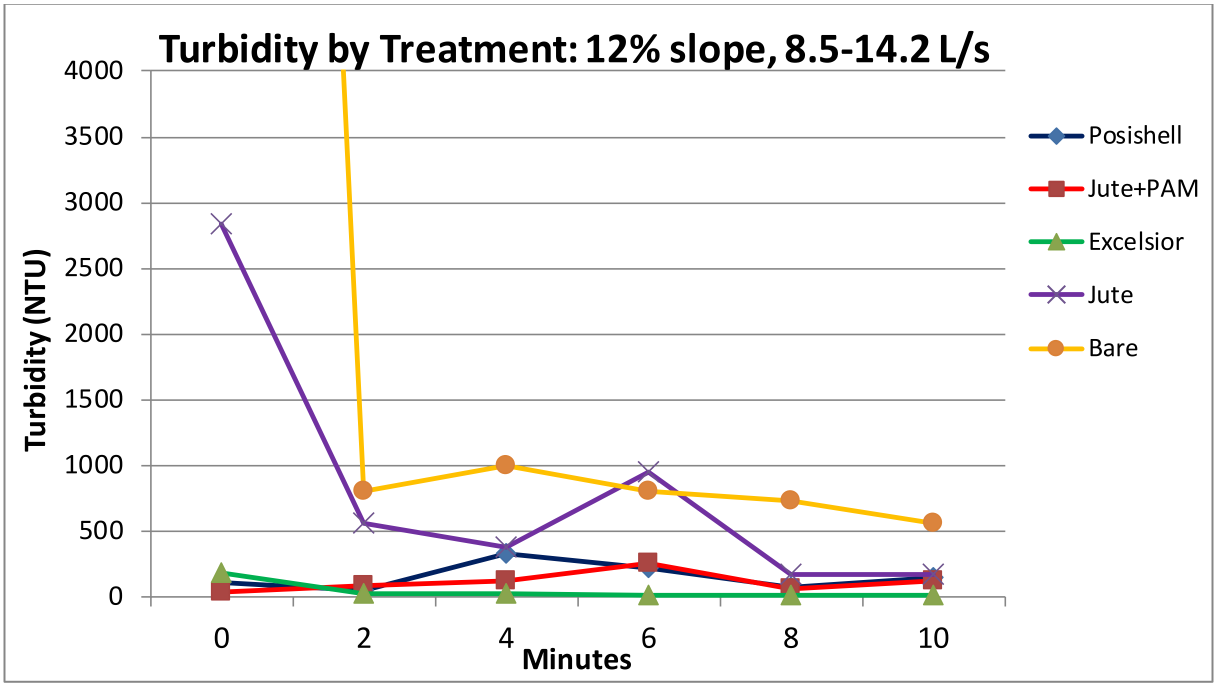

Figure 24. Average turbidity for bare and lined conditions for the 12% slope and low flow.

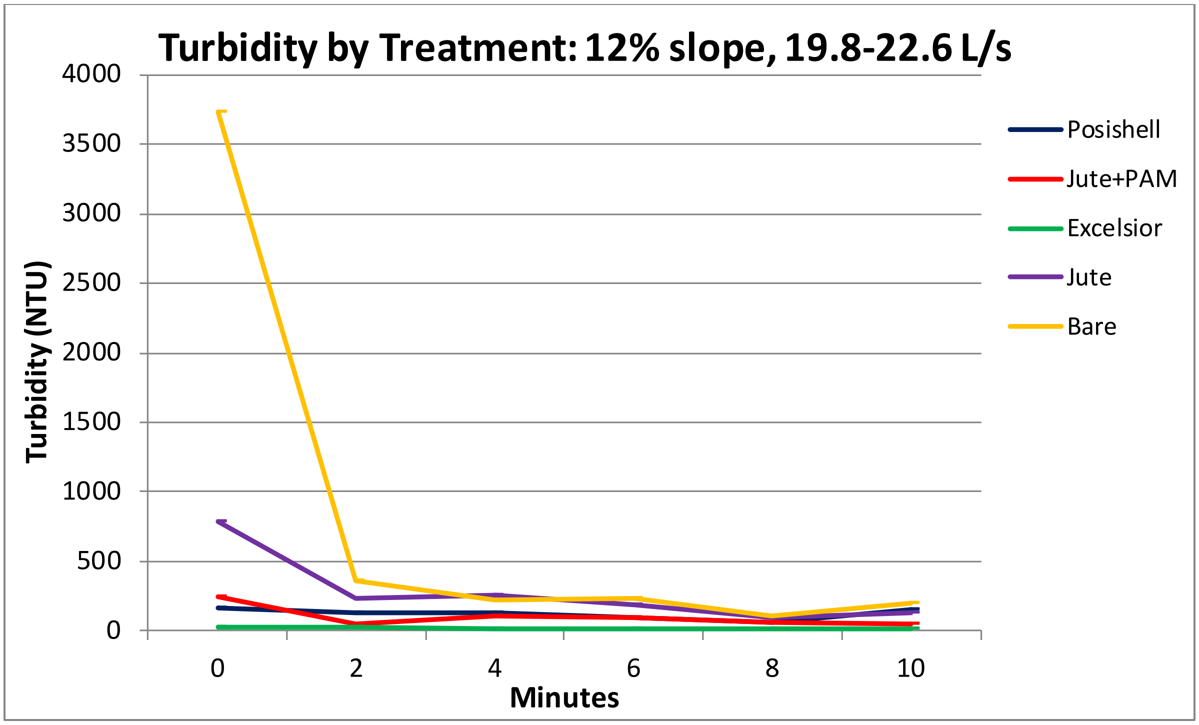

Figure 25. Average turbidity for bare and lined conditions for the 12% slope and medium flow.

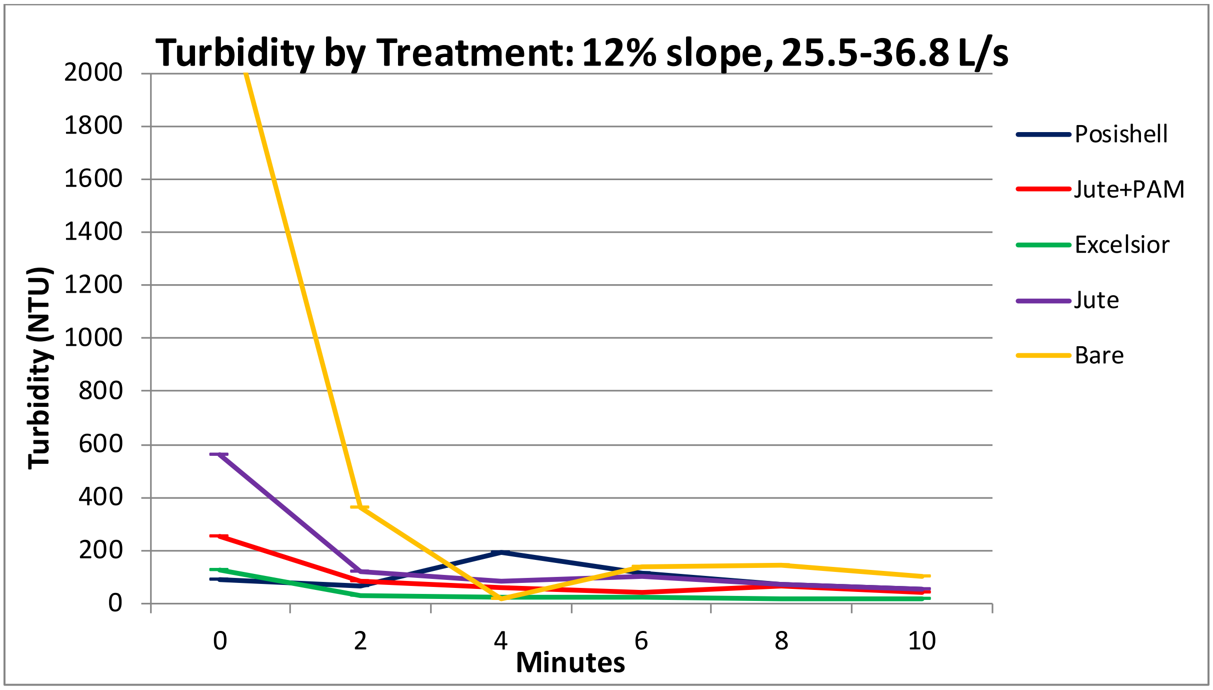

Figure 26. Average exit turbidity for bare and lined conditions for the 12% slope and high flow.

Figure 27. Failures, and resulting erosion, in the hydraulically applied concrete product after poor application to a test ditch.

Table 1. Proportion of tests with exit turbidities in different ranges, by treatment.

	Number of Tests with Average Exit Turbidities in Each Range			
Treatment	**<50 NTU**	**50 -100 NTU**	**100 -200 NTU**	**>200 NTU**
Bare	0	0	1 (8.3%)	11 (91.7%)
Jute	8 (29.6%)	5 (18.5%)	5 (18.5%)	9 (33.3%)

Jute+PAM	11 (39.3%)	7 (25%)	5 (17.9%)	5 (17.9%)
Excelsior	24 (88.9%)	3 (11.1%)	0	0
Posi-Shell	13 (41.9%)	10 (32.3%)	3 (9.7%)	5 (16.1%)

The net effect of each different liner under the various slope and flow conditions can also be measured by the average turbidity at the exit (Figure 28). Because of the manner in which tests were conducted, starting with the lowest flow and increasing the flow in the same ditch, the first test always generated the highest turbidity. Even with packing the soil before the first test, there is always loose soil that generates high turbidity. As in previous tests, bare soil resulted in much higher turbidity than any liner, and the jute tended to be the highest of the liners.

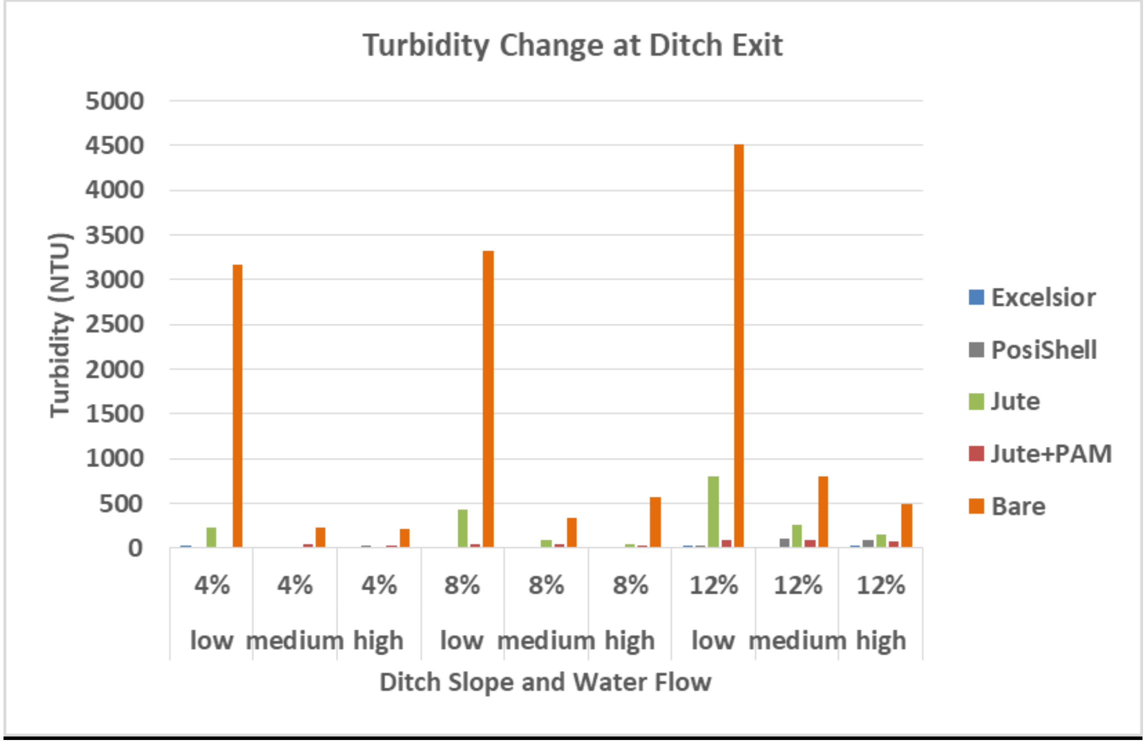

Figure 28. Turbidity change as water passed through the three simulated ditches at three flow rates. Note that tests within a ditch slope were tested consecutively, so the first test (low flow) had the highest turbidity as loose soil was washed out.

The total sediment lost in the ditches had a somewhat different pattern than turbidity. Excelsior was consistently the best at reducing sediment, but the other liners performed differently depending on the test conditions (Figure 29). For instance, under low slope and medium flow conditions, the jute+PAM lining generated nearly as much sediment as the bare soil. At the steepest slope, the Posi-Shell liner had the highest sediment load at the low and high flow rates. This was the result of one of the three replications having far more sediment than the other two. If that replication was removed, the high slope, high flow sediment loading would drop from 8 kg to 0.27 kg. This illustrate the sensitivity of Posi-Shell to application techniques, as it is likely the high-sediment replication failed due to an error in application (Figure 30).

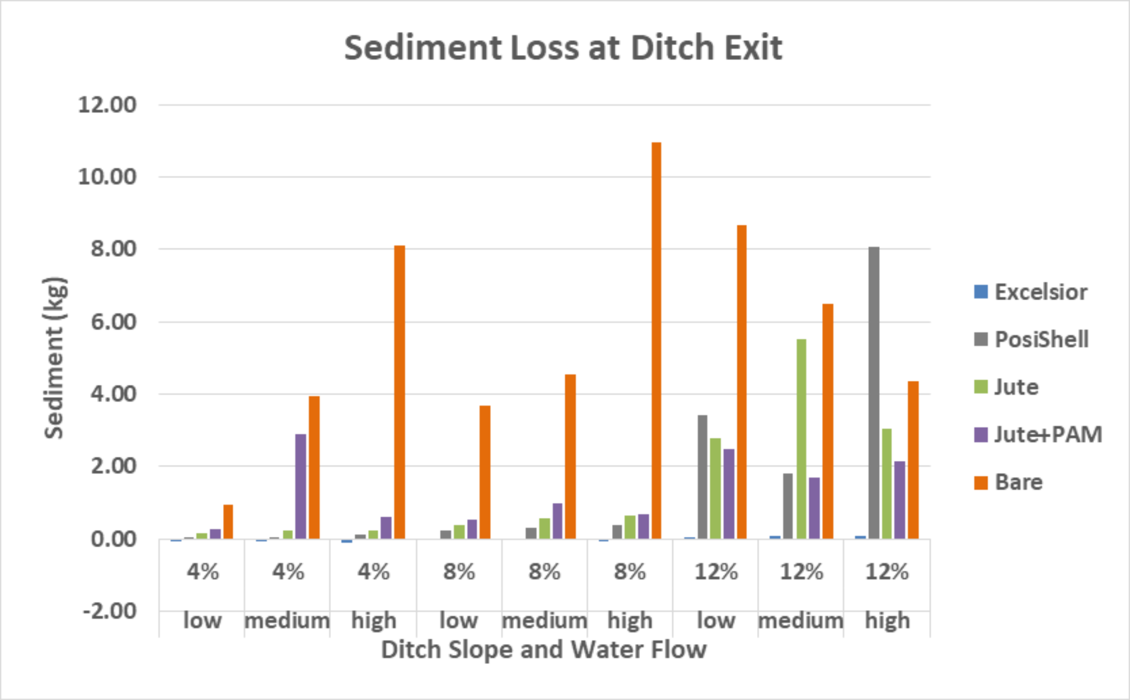

Figure 29. Sediment lost at the ditch exit for each of the three simulated ditches at each flow rate.

Figure 30. Failure of the Posi-Shell at the steepest (12%) slope. This may have been an artifact due to the high turbulence at the point where the liner meets the weir – notice how it started at the bottom.

Active Construction Site Installations

Greensboro Site:

Elevation changes in the two ditches were measured nine times during the monitoring period. In Ditch 1, most of the measurements suggested relatively little erosion and some deposition for all treatments (Figure 31). Most of the changes were <2 cm, which is probably the level of accuracy for the pin system we used. While this ditch had a relatively steep slope, it received very little runoff during the monitoring period and flows rarely exceeded 0.1 cfs. Ditch 2 also had relatively small changes in elevation, with the exception of apparent erosion in the bare soil section toward the end of the monitoring period (Figure 32).

Weirs and samplers were installed after each treatment section in Ditch 1, but usually only a few produced samples (Figure 33). In most cases, however, the TSS values were relatively low, reflecting the low erosion rates found with the pin measurements. The June 12 event was an exception, with high sediment concentrations in the jute section, and high sediment removal in the jute+PAM section. This may be a calculation artifact, since the TSS concentration leaving one section is subtracted from the TSS concentration leaving the next one downslope. No samples were obtained from the Posi-Shell section during the monitoring period due to malfunctions of the sampler, possibly related to the shady location preventing adequate battery charging.

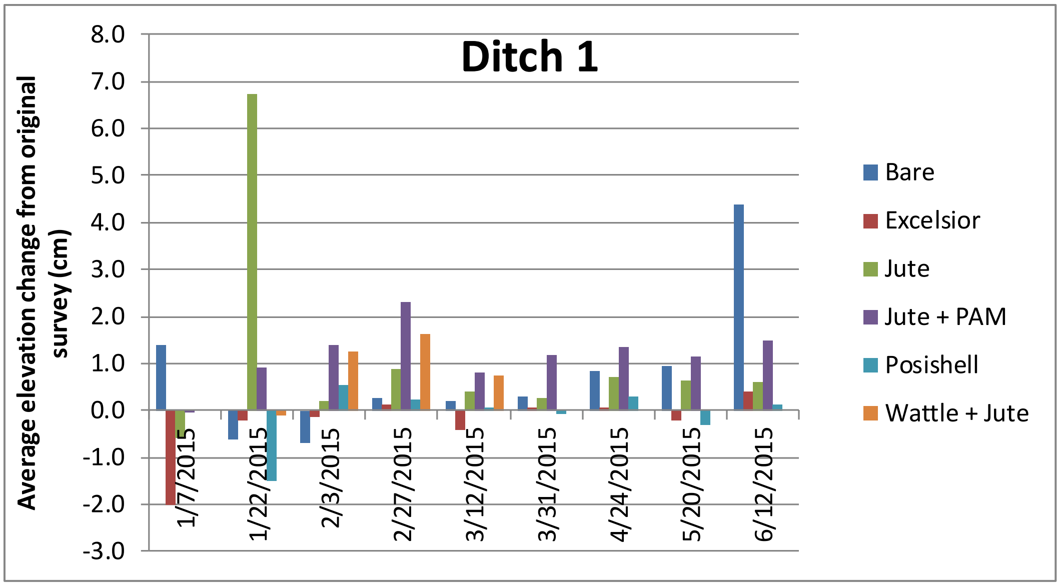

Figure 31. Average difference in cross-section measurements from the initial measurements in Ditch 1. Note that negative values indicate soil loss and positive values indicate deposition.

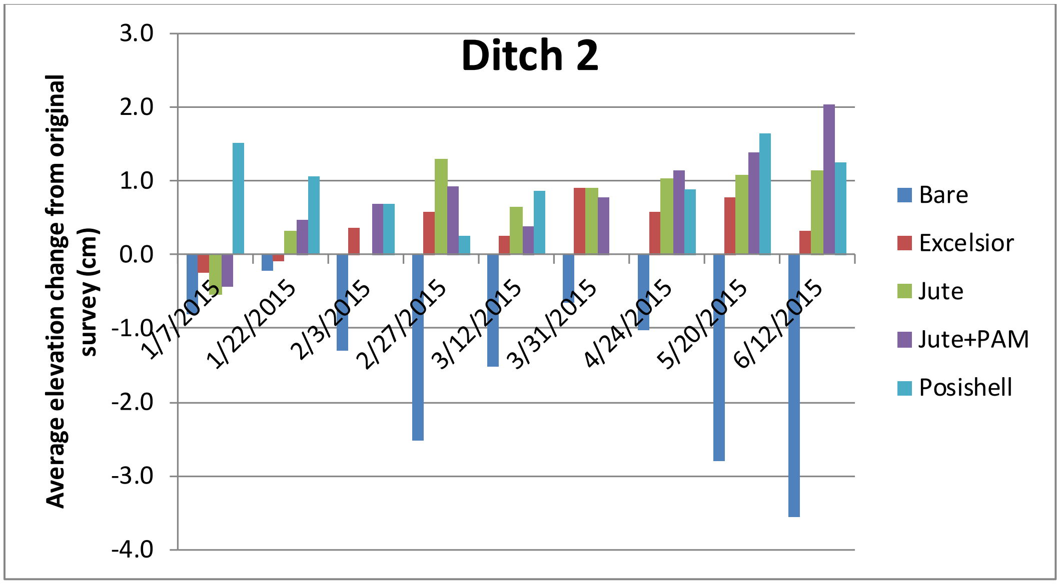

Figure 32. Average difference in cross-section measurements from the initial measurements in Ditch 2. Note that negative values indicate soil loss and positive values indicate deposition.

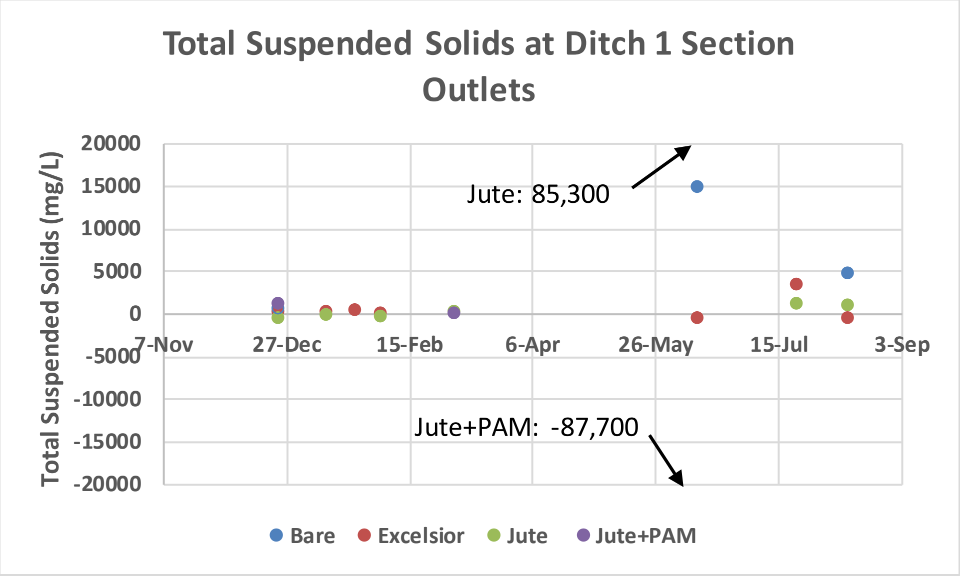

Figure 33. Total suspended solids in runoff exiting Ditch 1 sections with different liners. For most events, samples were not obtained at each outlet. The scale was reduced to allow better viewing of the data points, with the June 12 event producing very high and low values. Note that a negative value indicates removal of sediment in that section compare to the uphill section.

Apex Site:

The I-540 interchange site in Apex had relatively flat ditches resulting in more deposition than erosion and often very little change (Figure 34). In addition, grading activities regularly cut through the ditches, diverting flow so that the ditches carried little storm flow. For that reason monitoring was limited to a little more than a month. Some examples of erosion pin data are presented to illustrate these points. The excelsior+PAM, excelsior, and Posi-Shell ditches had little evidence of erosion or deposition, with the possible exception of the excelsior ditch right bank (Figures 35-37). The bare soil ditch showed evidence of both erosion and deposition as measurements were made down the slope (Figures 38-41). Almost 20 cm of deposition was evident in that ditch at station 7, suggesting that a check dam was adjacent. For various reasons, there was only one storm which generated flow in all four ditches (Figure 42). Turbidity was high in the Posi-Shell and bare ditches, but with relatively little erosion evident the turbidity likely originated from the surrounding areas. There were too few samples to draw any conclusion for the excelsior and excelsior+PAM ditches.

Figure 34. Excelsior-lined ditch in Apex showing the pin stations (stakes) and the V-notch weir at the outlet. Picture was taken July 6, 2016.

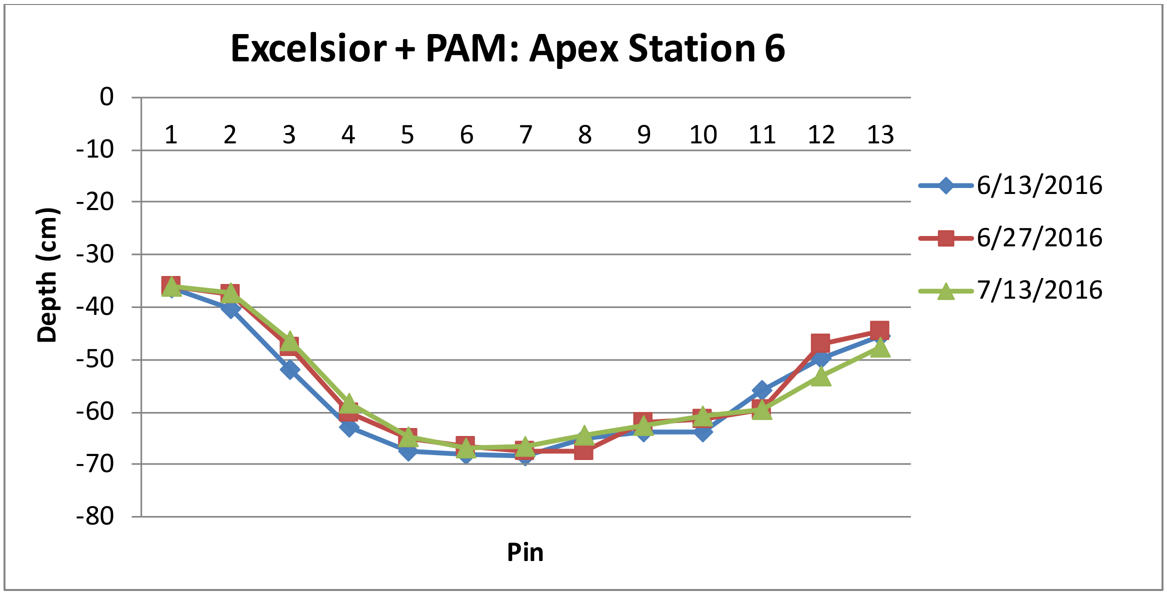

Figure 35. Elevation changes at the 6th station in the ditch lined with excelsior and PAM on June 13th, June 27th and July 13th, 2016 at the Apex DOT site.

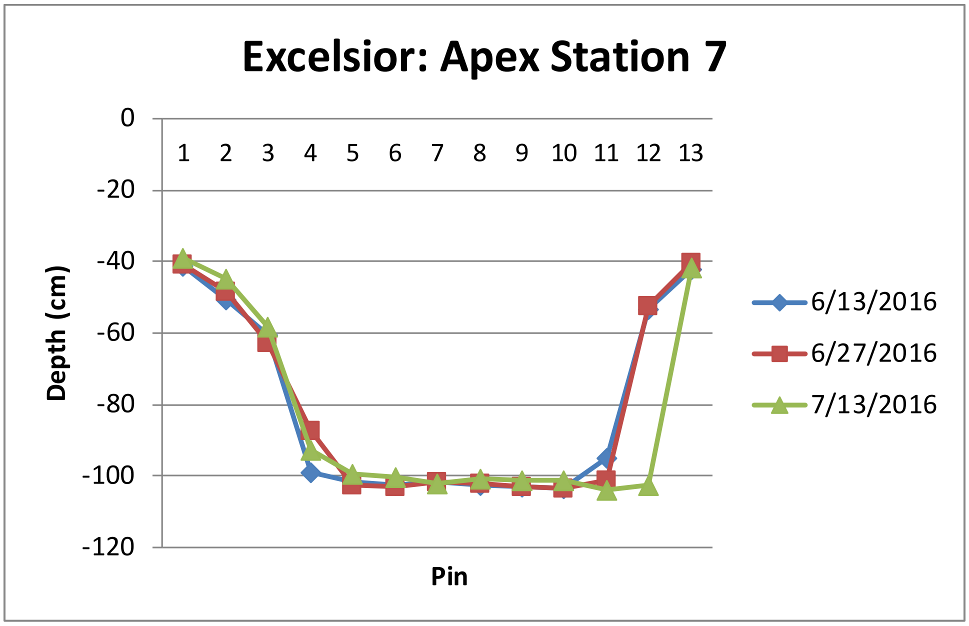

Figure 36. Elevation changes at the 7th station in the ditch lined with excelsior on June 13th, June 27th and July 13th, 2016 at the Apex DOT site.

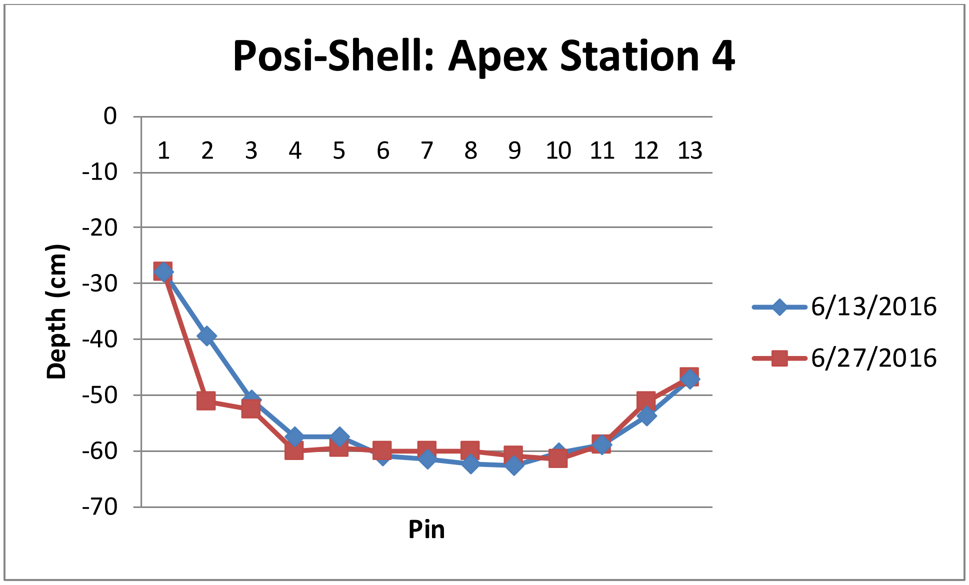

Figure 37. Elevation changes at the 4th station in the ditch lined with Posi-Shell on June 13th and June 27th, 2016 at the Apex DOT site.

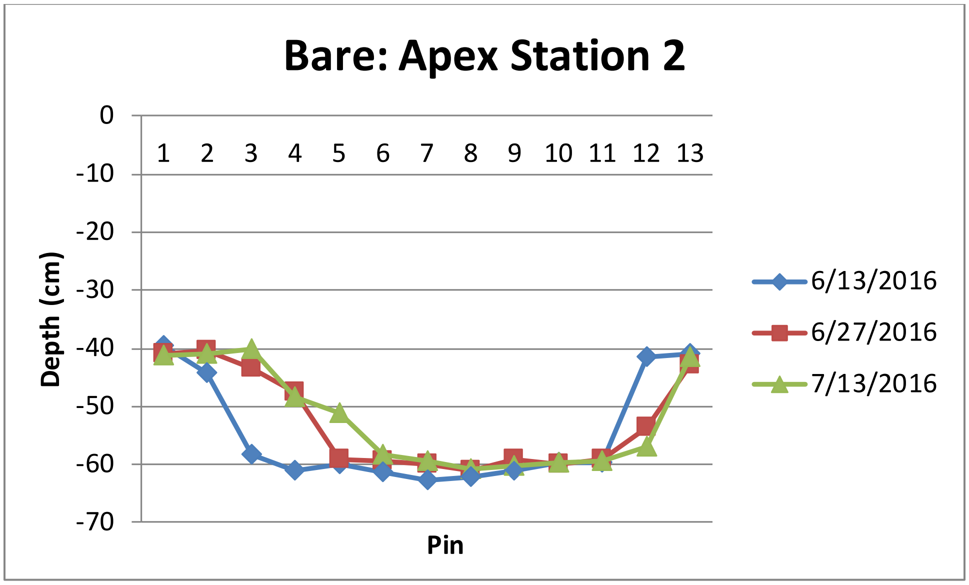

Figure 38. Elevation changes at the 2nd station of the bare ditch on June 13th, June 27th and July 13th, 2016 at the Apex DOT site.

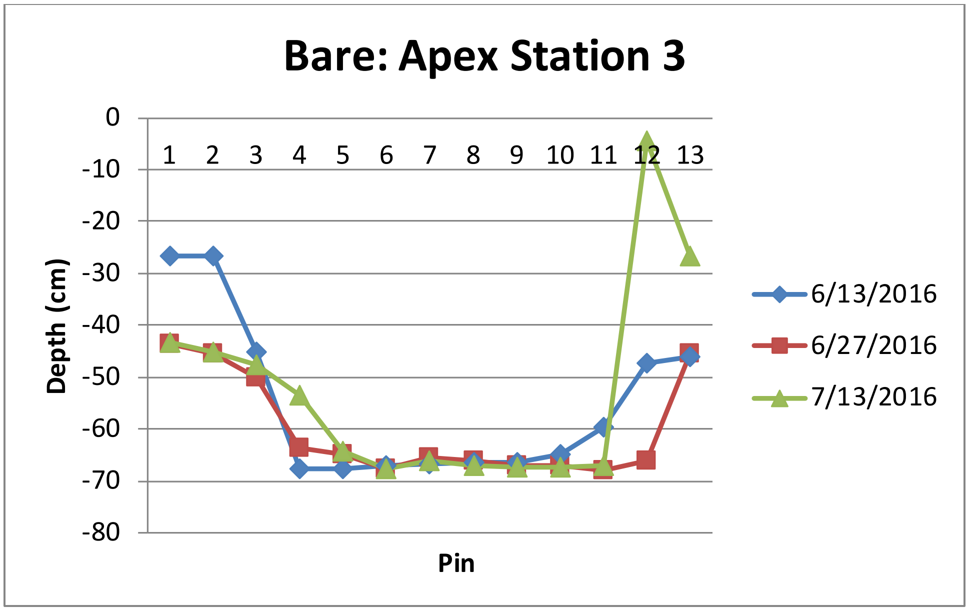

Figure 39. Elevation changes at the 3rd station of the bare ditch on June 13th, June 27th and July 13th, 2016 at the Apex DOT site.

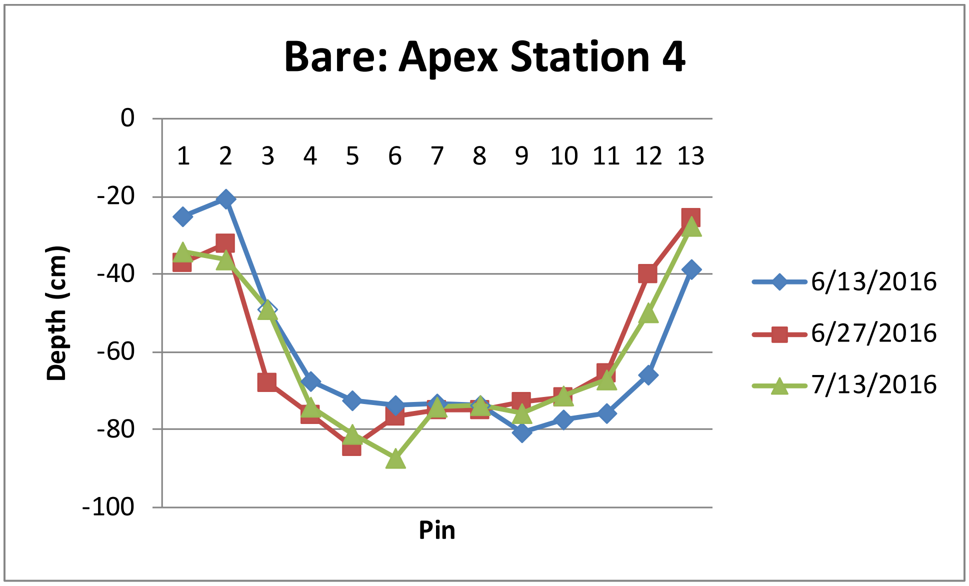

Figure 40. Elevation changes at the 4th station of the bare ditch on June 13th, June 27th and July 13th, 2016 at the Apex DOT site.

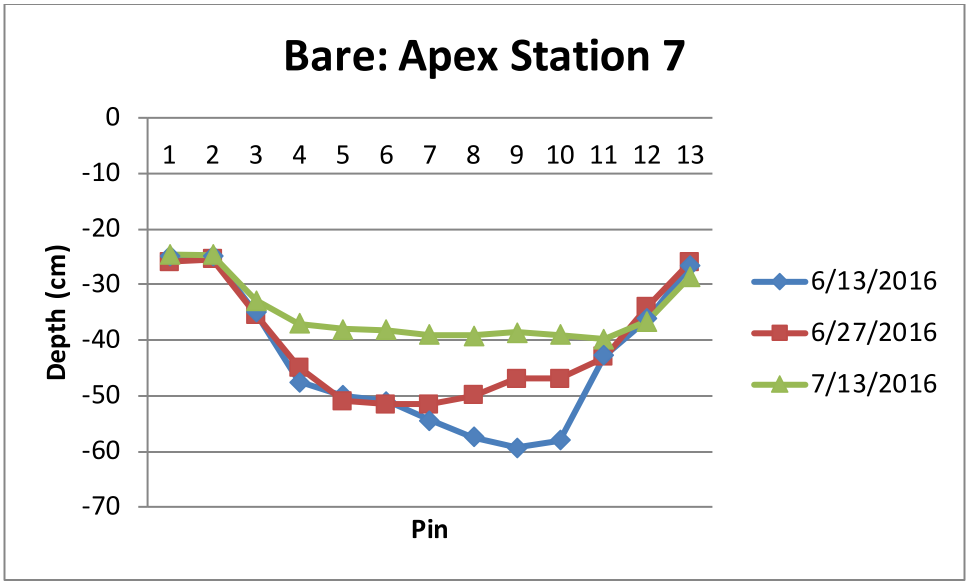

Figure 41. Elevation changes at the 7th station of the bare ditch on June 13th, June 27th and July 13th, 2016 at the Apex DOT site.

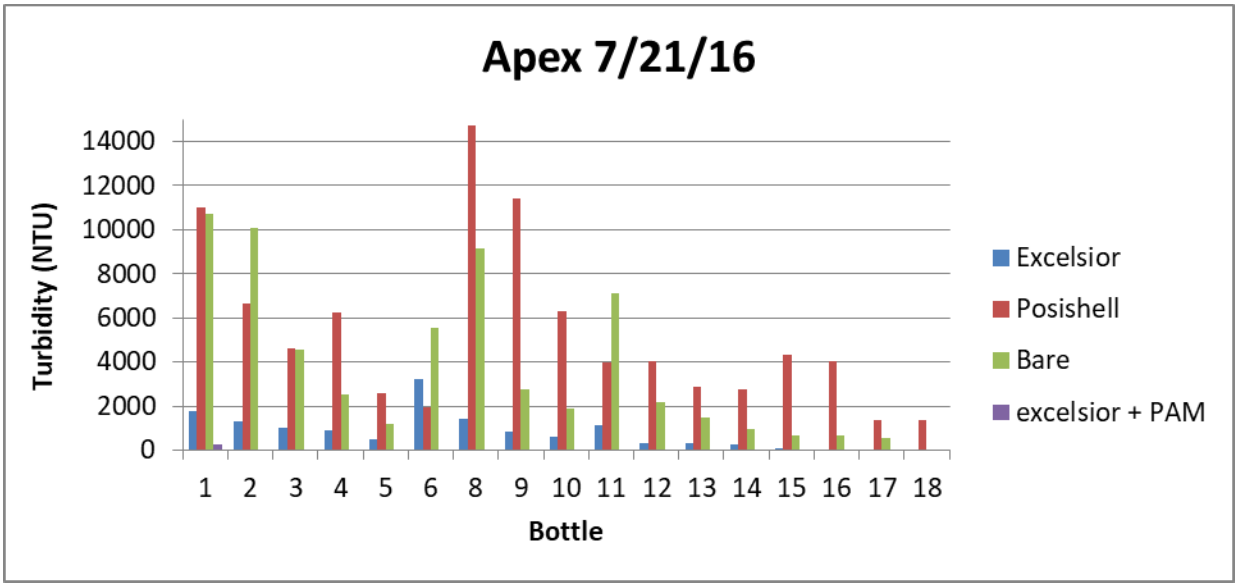

Figure 42. Turbidity in samples collected in ditches with different lining treatments. This was the only storm in which samples were generated for all for treatments.

Durham Site:

The jute-lined ditch had somewhat varied performance depending on the location. Deposition was evident at station 3 (Figure 43), with an decrease in depth over time, while erosion was evident at station 8 (Figure 44) with increasing depth over time. The jute+PAM ditch did not have areas of erosion but remained relatively unchanged over time (Figure 45) or had deposition (Figure 46). The Posi-Shell ditch had both areas of erosion (Figure 47) and deposition (Figure 48), however, the first and last surveys in Figure 47 showed little elevation change. There was not clear evidence of major erosion in this ditch, suggesting there was a systematic error in the intermediate surveys, which were all in agreement, or a large deposition event occurred in the last month.

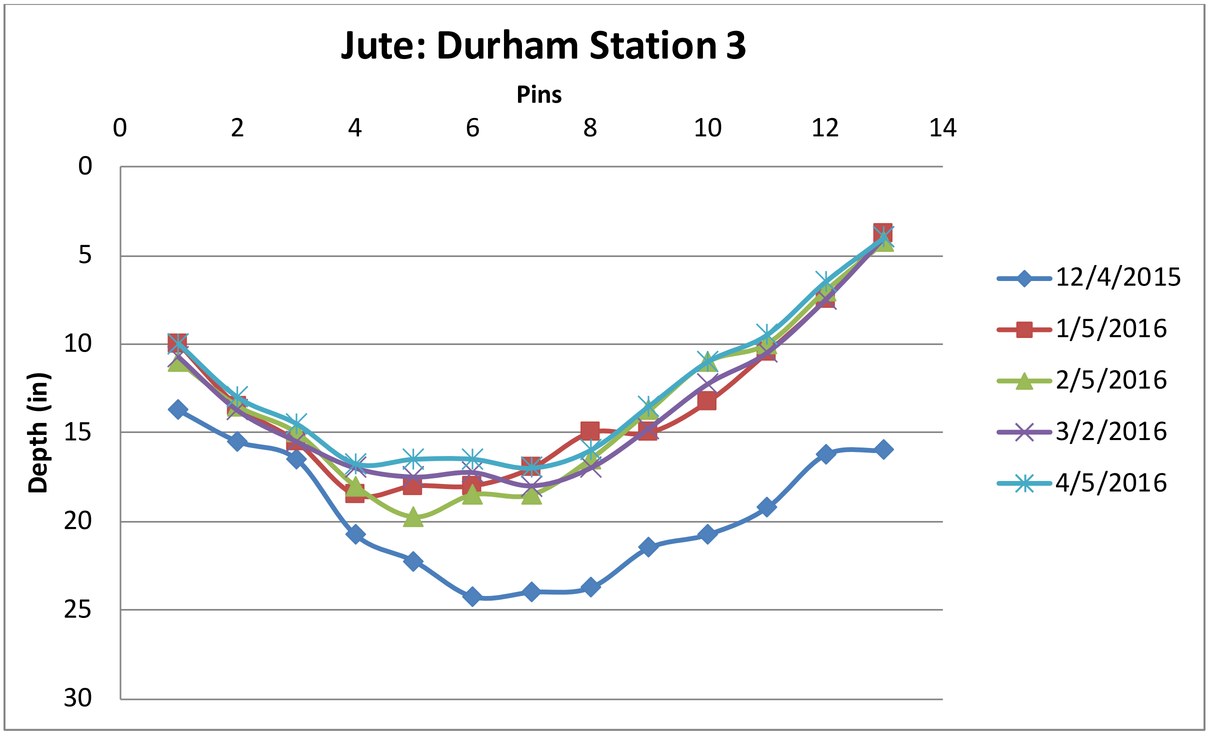

Figure 43. Elevation changes at the 3rd station in the ditch lined with jute on 5 separate dates at the Durham DOT site.

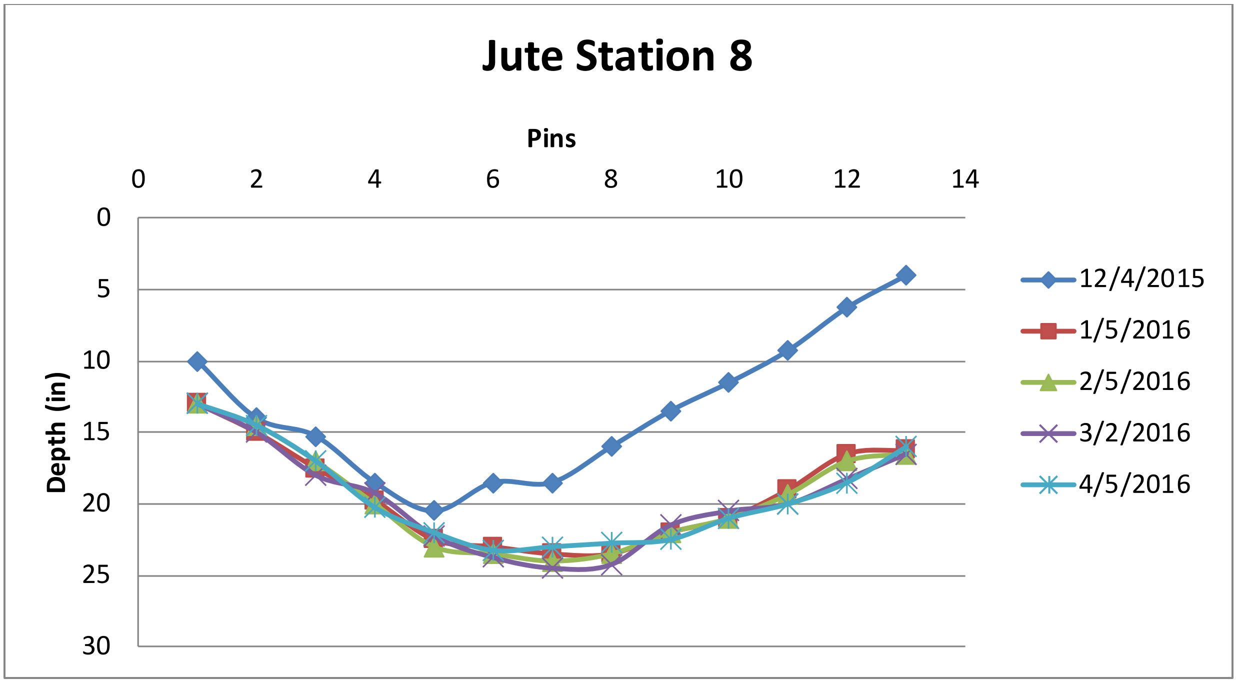

Figure 44. Elevation changes at the 8th station in the ditch lined with jute on 5 separate dates at the Durham DOT site.

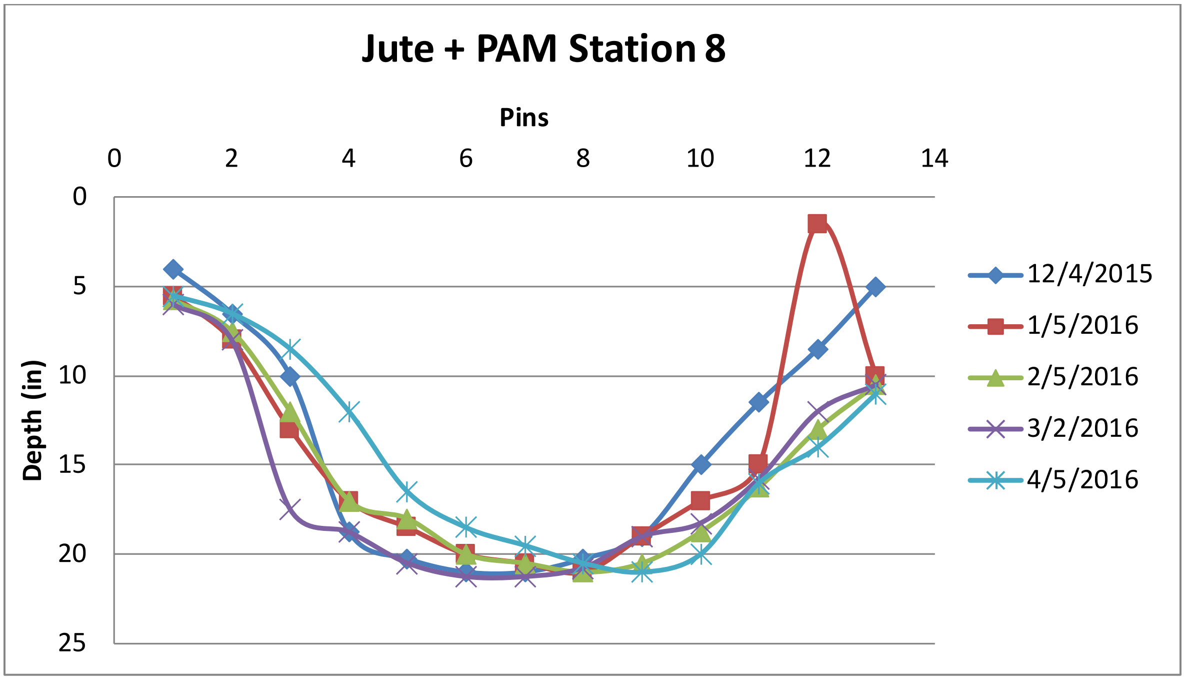

Figure 45. Elevation changes at the 8th station in the ditch lined with jute + PAM on 5 separate dates at the Durham DOT site.

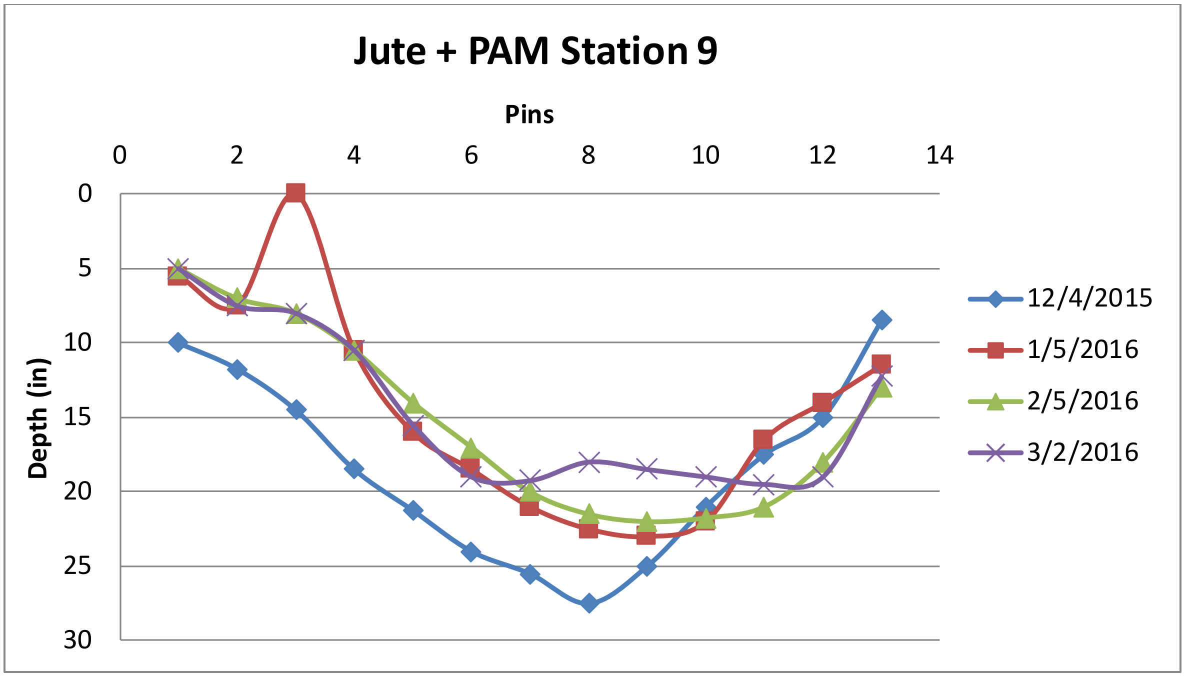

Figure 46. Elevation changes at the 9th station in the ditch lined with jute + PAM on 4 separate dates at the Durham DOT site.

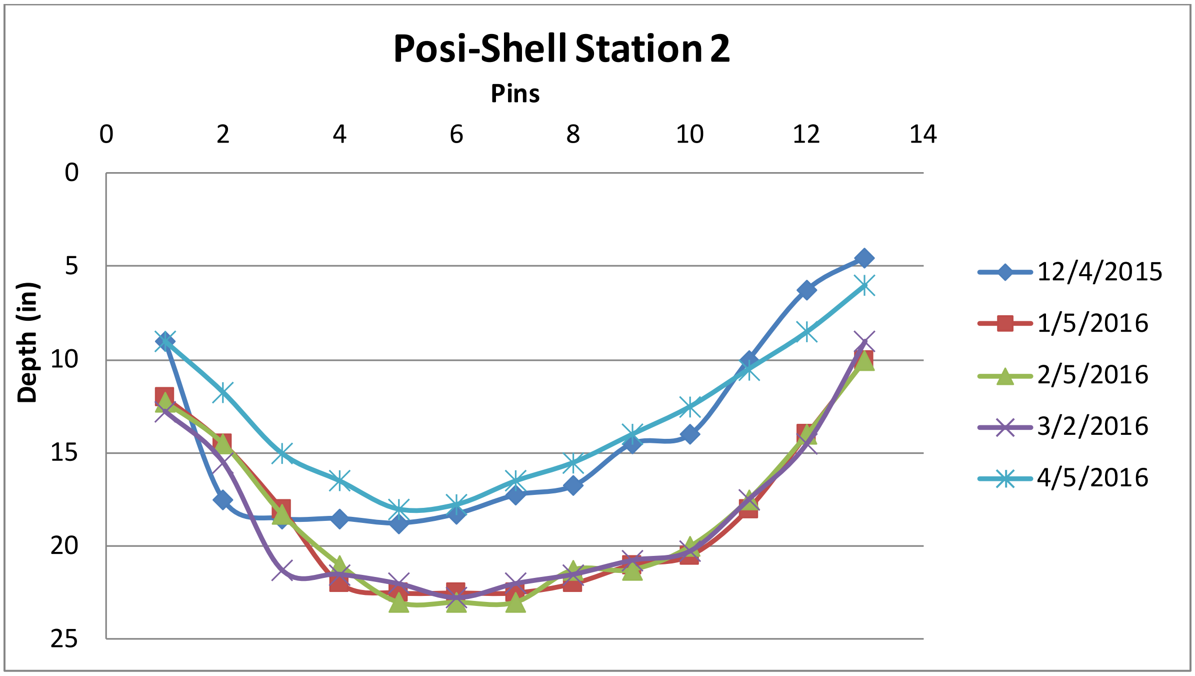

Figure 47. Elevation changes at the 2nd station in the ditch lined with Posi-Shell on 5 separate dates at the Durham DOT site.

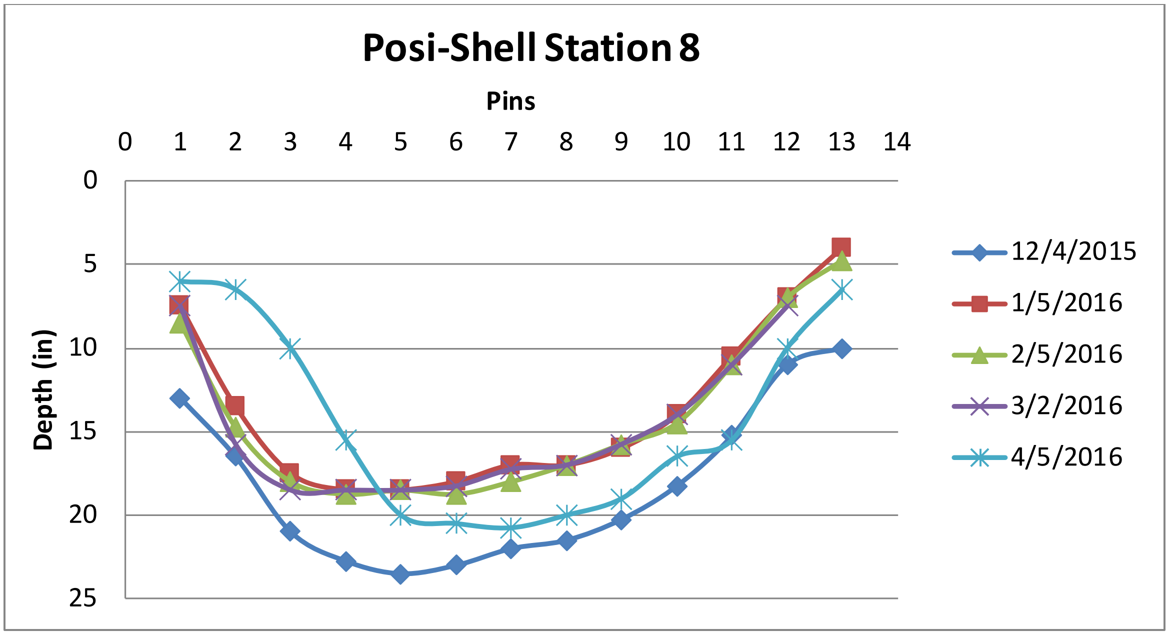

Figure 48. Elevation changes at the 8th station in the ditch lined with Posi-Shell on 5 separate dates at the Durham DOT site.

The excelsior-lined ditch had sections that surveys suggested had both deposition and erosion (Figure 49), no changed (Figure 50), deposition (Figure 51), and erosion (Figure 52). Often, however, most or all of the monthly surveys after the first one suggested little change. This could be because most of the change occurred in the first month. The turbidity could be high in the ditch discharges (Figure 53) and there were large differences in flows. For instance, runoff total volume during the storms that generated the samples in Figure 53 ranged from around 1,000 cu ft for the jute ditch to 4,500 (jute+PAM) and 4,900 (Posi-Shell) cu ft. No flow was measured in the excelsior-line ditch. In contrast, March 13 runoff volumes were only 230 cu ft in the Posi-Shell-lined ditch but 1,700 (jute) and 3,300 (jute+PAM) cu ft with turbidity continuing to be highest in the jute+PAM ditch (Figure 54). Since the jute+PAM ditch did not appear to be eroding significantly but mostly aggrading (Figures 45-46), the high turbidity is likely due to activities and runoff entering this ditch. This illustrates why it is important to conduct studies under controlled conditions in order to determine the effects of a treatment.

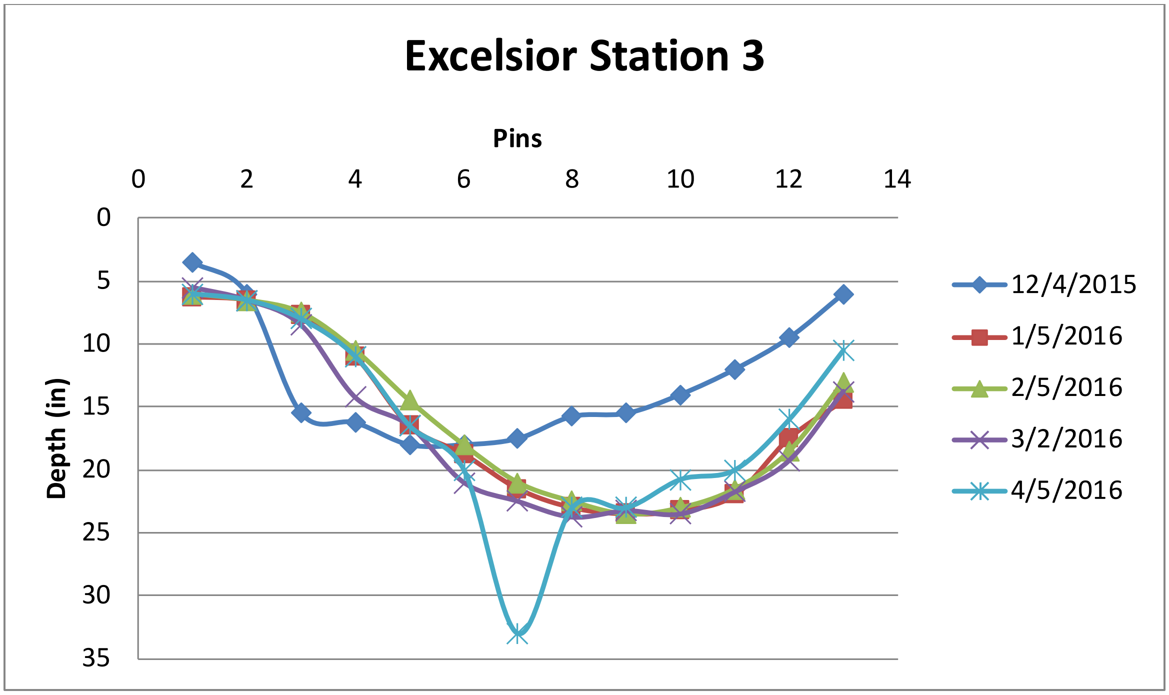

Figure 49. Elevation changes at the 3rd station in the ditch lined with excelsior on 5 separate dates at the Durham DOT site.

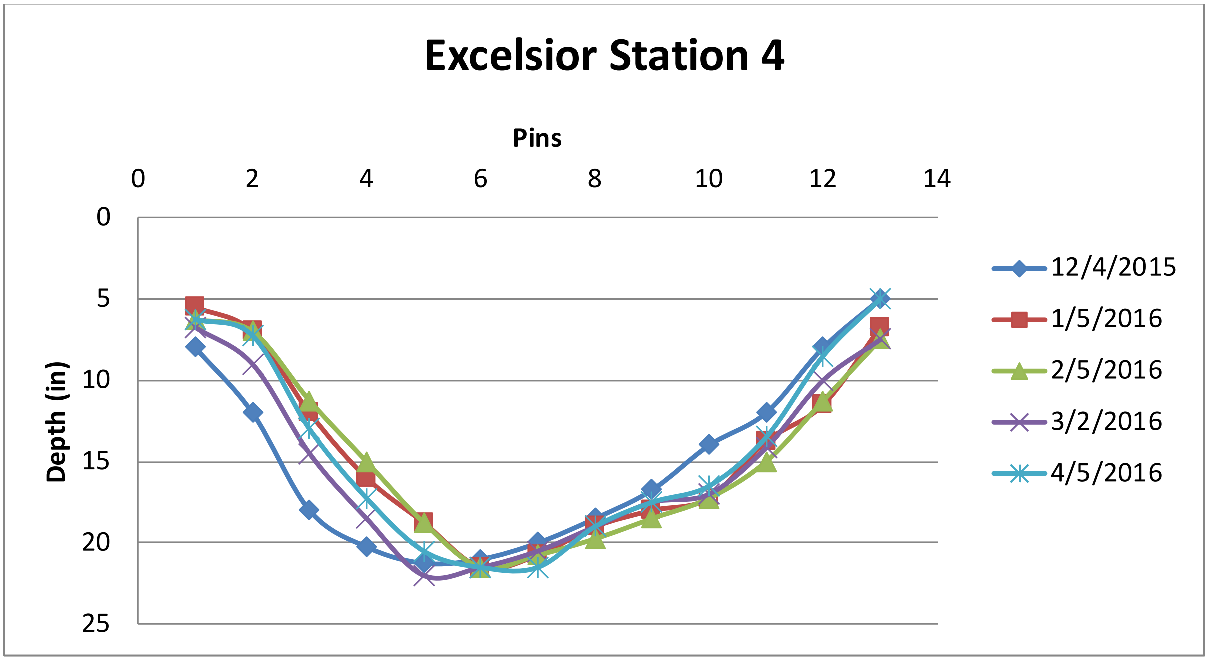

Figure 50. Elevation changes at the 4th station in the ditch lined with excelsior on 5 separate dates at the Durham DOT site.

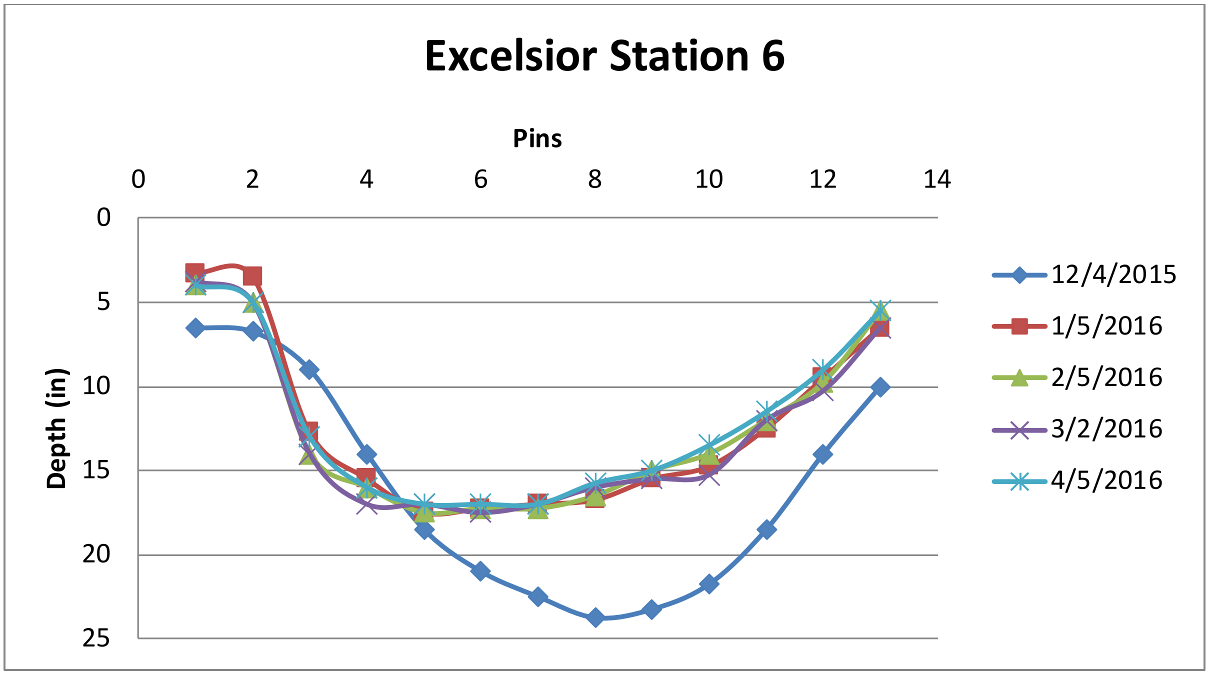

Figure 51. Elevation changes at the 6th station in the ditch lined with excelsior on 5 separate dates at the Durham DOT site.

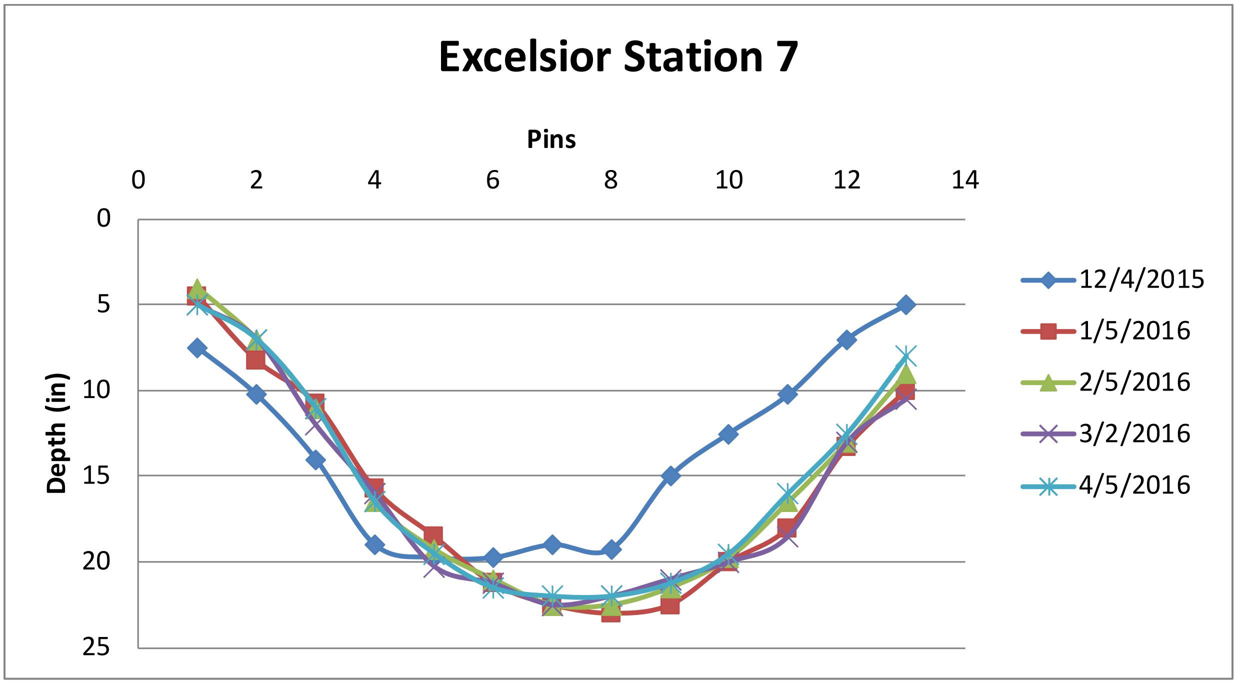

Figure 52. Elevation changes at the 7th station in the ditch lined with excelsior on 5 separate dates at the Durham DOT site.

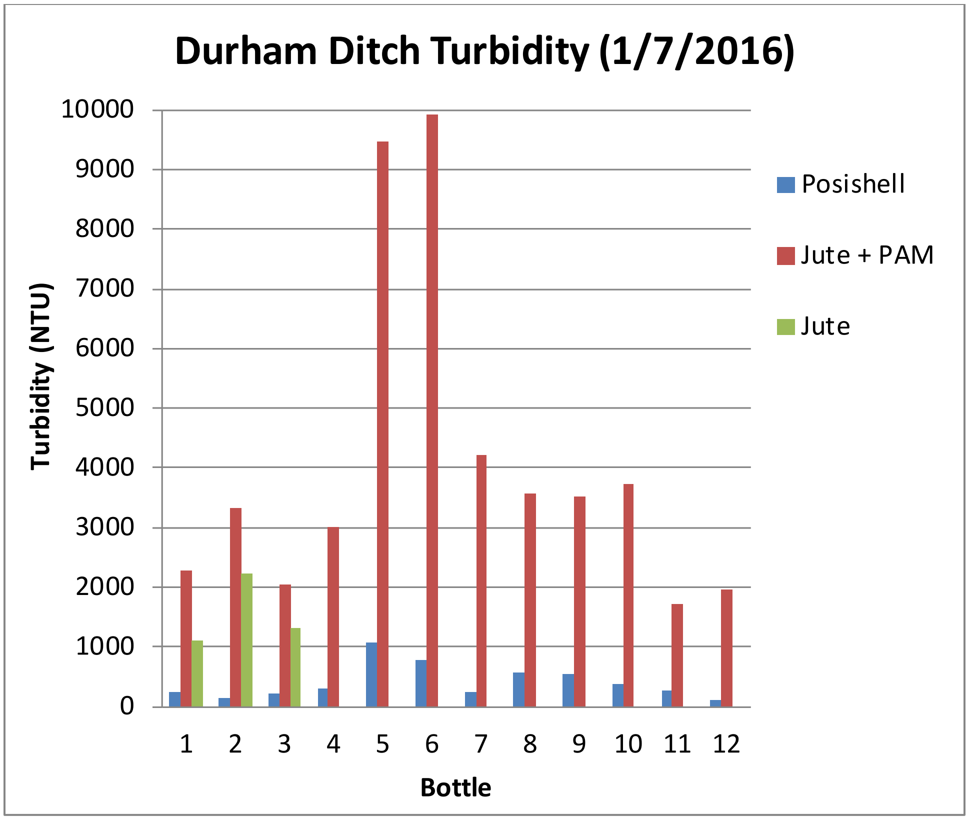

Figure 53. Turbidity in discharges from ditches with three different liners at the Durham site, January 7, 2016. No discharge from the excelsior-lined ditch was detected.

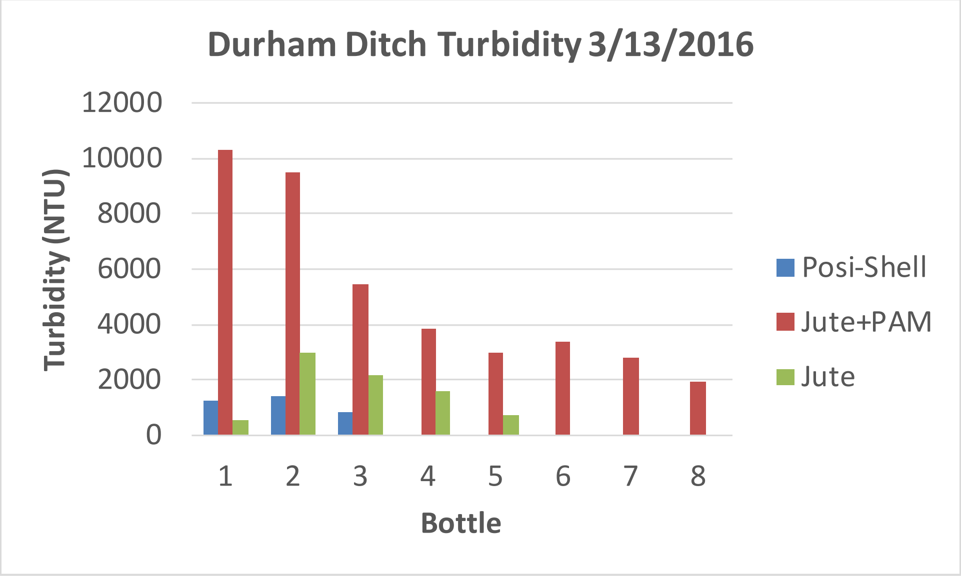

Figure 54. Turbidity in discharges from ditches with three different liners at the Durham site, March 13, 2016. No discharge from the excelsior-lined ditch was detected.

Figure 55. Vegetation establishment around the jute-lined ditch at the Durham location, at the time of the March 2 survey.

Overall, the ditches lined with different materials had substantially different “stresses” during the 5 month period of monitoring. The jute+PAM-lined ditch had the highest peak flow, while the jute-lined ditch had the highest discharge volume (Table 2). Due to topography and site activities, the excelsior-lined ditch received very little runoff. As mentioned above, this illustrates the need to closely monitor field-installed systems and devices to ensure fair comparisons, and to conduct studies under controlled conditions.

Table 2. Peak flow and total discharge from the four ditches monitored at the Durham site from December 2015 to April 2016.

Lining	Peak Flow (cu ft/sec)	Total Volume (cu ft)
Jute	1.4	29,500
Jute + PAM	3.8	16,100
Excelsior	0.01	287
Posi-Shell	1.1	9,400

Product costs are important in the evaluation of the best options for ditch lining. The material costs are estimated for all of the systems tested plus excelsior+PAM in Table 2. Excelsior would appear to be the most cost-effective product based on material costs, since it is the lowest cost and also the best at reducing erosion. The installation costs are less easily estimated. For the rolled products, an experienced person might be able to properly staple in a blanket at a rate of about 100' per hour, as an example. It would take about five minutes for an experience Posi-Shell applicator to cover that same length. However, there is also the mixing/loading time and the cost of owning and operating the hydroseeder, and possibly a water truck to fill the tank. Whether those costs would full offset the 30-35% increased material costs would depend on many factors. Finally, there may be some reluctance for owners of hydroseeders to have cement poured into their tank and pumped through their hoses. These need to be rinsed within 30-60 minutes of completion of application.

Table 3. Product cost for each of the liners tested plus excelsior+PAM. Installation costs are not included.

Liner	Cost per Roll with 8" staples	Cost per ft^2
Jute	$ 93.75	$ 0.104
Jute + PAM (50lbs/acre)	$ 99.15	$ 0.111
excelsior	$ 60.30	$ 0.075
excelsior + PAM (50lbs/acre)	$ 65.15	$ 0.082
Posi-Shell	- ------	$ 0.115
Staples installed 1.5/ft^2	Estimates do not include labor costs.	

Conclusions

- Lining diversion ditches reduces erosion substantially compared to unlined ditches.
- The excelsior, jute+PAM, and Posi-Shell linings performed similarly in many cases, but excelsior was the most consistent across all tests.
- The higher material cost of Posi-Shell, 30-35% more than excelsior blankets, may be offset by the much shorter time needed to install it.

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