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Research Project

# APPLICATION OF CELLULAR CONFINEMENT SYSTEMS TO MITIGATE SEDIMENT-RELATED ISSUES IN STORMWATER SYSTEMS

By

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## Synopsis

Sediment and erosion control in stormwater systems constitute one issue of great relevance within the State of Alabama, and much research efforts have been placed in devising methods to control channel erosion (ASWCC, 2014). This research has performed an evaluation of the use of cellular confinement systems (CCS) as a means to protect ditches and other stormwater facilities from erosion. While CCS have been used in various contexts for erosion and sediment control, the present research used a new form of CCS deployment. Typically CCS have been applied with some type of media, such as crushed rock or concrete, within the cells. However, the present research considered the use of CCS without any filling or media material. The research hypothesis was that empty cells would create significant amount of energy dissipation that reduce water velocity and shearing near channel beds, thus prevent erosion. If the hypothesis was confirmed, CCS could be a channel lining attractive over rip-rap or vegetated channels.

Following the construction of an apparatus, and after months of deployment, the CCS-lined channel deployed near Cox Rd., in Auburn, AL successfully managed to drain excess rainfall without presenting erosion. Hydrological measurements indicated that flow velocities in over the cells reached peak values in the range of 3.5 ft/s, which is above the permissible velocity for most earthen channels (NRCS, 2007). Samples collected upstream and downstream from the CCS-lined channel did not show increase in turbidity values, but instead a decrease in turbidity along the channel was often reported.

## Report structure

This report is structured as follows: first, the methodology used in the study is presented, followed by results and discussion and final remarks. The end of the report includes the required components of the report, as specified in the guidelines provided by AWRRI.

## Methods, Procedures, and Instrumentation

### Construction and operation of the apparatus

The research involved the construction of a field-scale CCS apparatus in a real stormwater system design. After contacts with the City of Auburn, AL, which supported the implementation of this research, the location made available to our investigation was a drainage channel for in the south side of Cox Road, off from Interstate 85 N Exit 50. Figure 1(A) presents the location of the research site, and shows the main modifications in the location that were created during this investigation. Figure 1(B) shows the initial condition in the research site after the installation of the CCS. The cells had 12-in thickness and came from an in-kind donation from PRESTO Geosystems to this research.

Due to the location and the characteristics of the drainage channel available to our investigation, some changes were needed to be implemented from the initially conceived apparatus to become adequate to the conditions on site. The first change that was implemented was the change of the layout of the channel that was initially proposed. This was motivated by the size of the rip-rap used in the lining (class 2 rip-rap), and the thickness of the rip-rap layer in the range of 2 ft. It was not feasible to remove the rip-rap without heavy equipment and significant disruption in local traffic and in to the ephemeral channel. To minimize the construction impacts it was decided to install the CCS-lining immediately before the rip-rap channel by removing a 24-ft long stretch of vegetation in the channel, as is shown in Figures 1(B) and 1(C).

The size of the cells within the CCS-lined channel, when fully opened, ranged from 9 in to 10 in, with a cells depth of 12 in. However, following the laboratory observations in Simpson et al (2017), cells were not fully opened so that the ratio between the width of the cell normal to the flow and the depth of the cell would be at least 2. It was chosen to open the cells partially, hence having a width normal to flow in the range of 3 to 4 inches. The resulting schematic of the channel is shown in Figure 2, with a resulting width of the CCS-lined channel close to 10.9 ft.

For reference, the cells in the CCS apparatus used in the present research are larger than the related studies presented by He et al. (2014) and He and Marsalek (2014). Another important difference in the tests is that these cells have small orifices in the vertical walls, unlike previous studies. There was thus a degree of uncertainty as to what would be degree of protection of the CCS-lined system in erosion protection, given that this deviated from prior investigations.

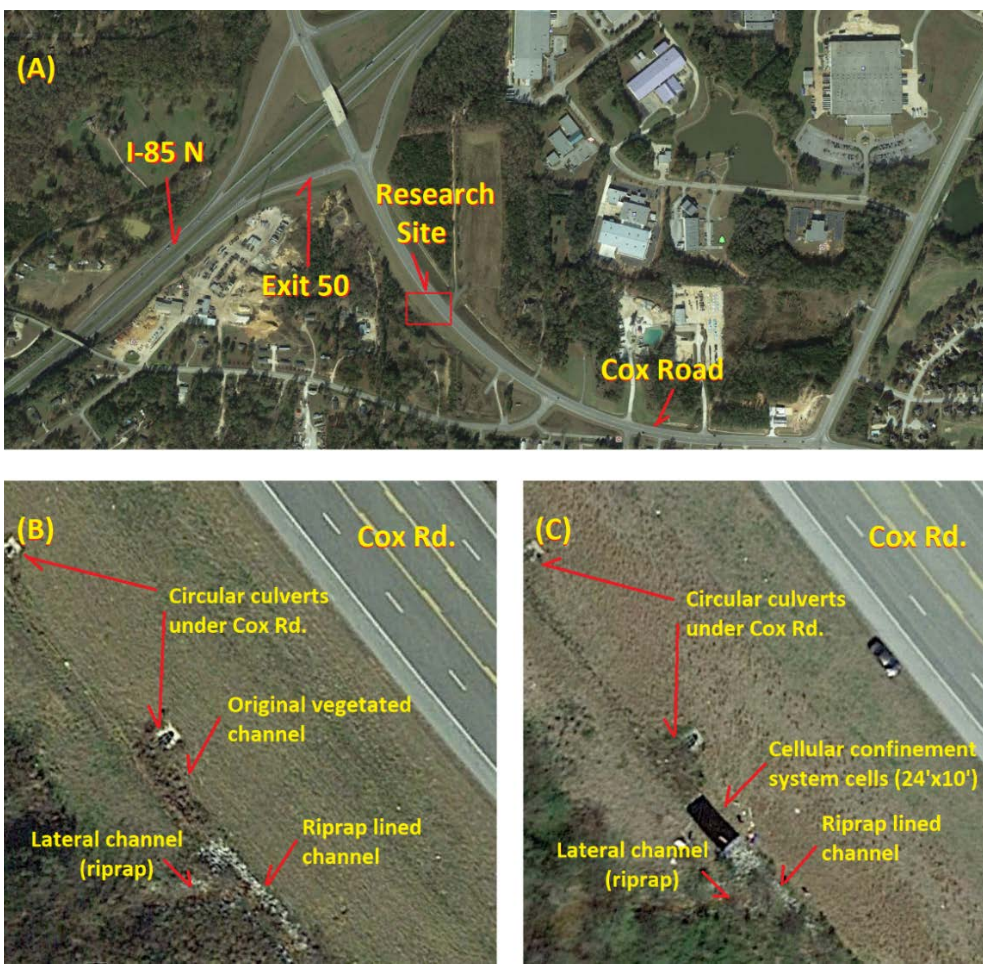


*Figure 1 – Location of the research site (A), initial condition in the drainage ditch (B) and after the installation of the cellular confinement system (C)*

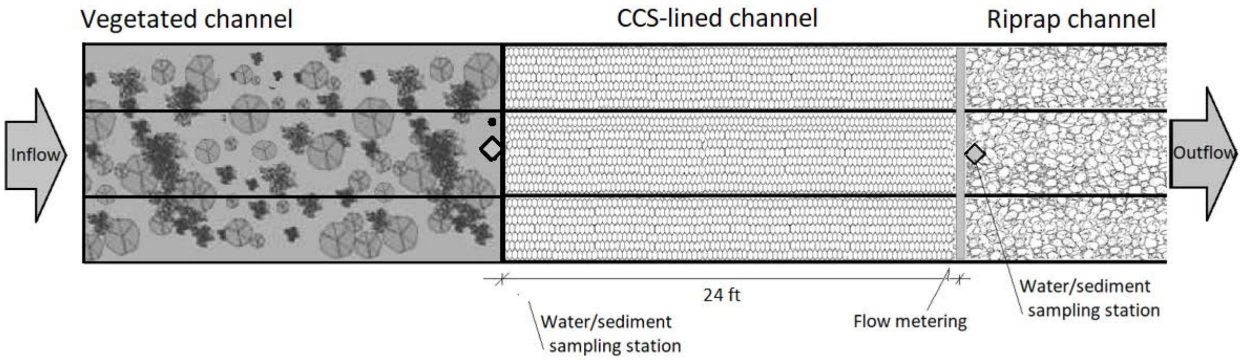


*Figure 2 – Schematic of the field apparatus that was used in the evaluation of the CCS for stormwater drainage systems*

Over time, minor modifications were introduced in the apparatus to have it better attached to the surface of the ditch. The CCS cells are constructed with high density polyethylene (HDPE), which is slightly less dense than water (SG=0.93-0.97). Thus cables were used to anchor it across the width of the cells at various places and reinforcing bars were bent helped to anchor the CCS into the bottom of the ditch, as shown in Figure 3. These all ensured the stability of the CCS deployment.

*Figure 3 – Photograph of the experimental apparatus, looking toward the upstream end.*

At the leading edge of the CCS-lined channel and at the downstream end there were some additional features that were used in the construction. To prevent damage from the direct impact of debris to the cells, a line of rocks was placed immediately upstream from the cells, where there was the transition with the vegetated channel. At the downstream end, a line of cinder blocks was placed to create a broad-crested weir to enable calculation of the flows over the CCS. A tarp enclosed the cinder blocks to reduce flows between the blocks. These features are shown in Figure 4. Both these locations were used to collect the samples for water quality analysis.

Figure 4 – Details of the upstream (Left) and downstream (Right) ends of the experimental apparatus, including the weir locations at the downstream end to gauge flow depth and calculate flow rates over the weir.

The cross section of the channel was approximately parabolic, but not exactly regular. And symmetric. The finished cross section of the flow measurement weir was surveyed and to help in the development of a head-discharge relationship to quantify flow rates based on the water level above the crest of the cinder blocks. The resulting cross section survey is presented in Figure 5. Due to the configuration of the apparatus, it was determined that flow rate would not change significantly across the CCS system, so a single flow metering location was used. Also, during research, sediment accumulation at the CCS was too small to be accurately quantified. This indicates that there were no significant sources of sediments the drainage catchment where tests were performed.

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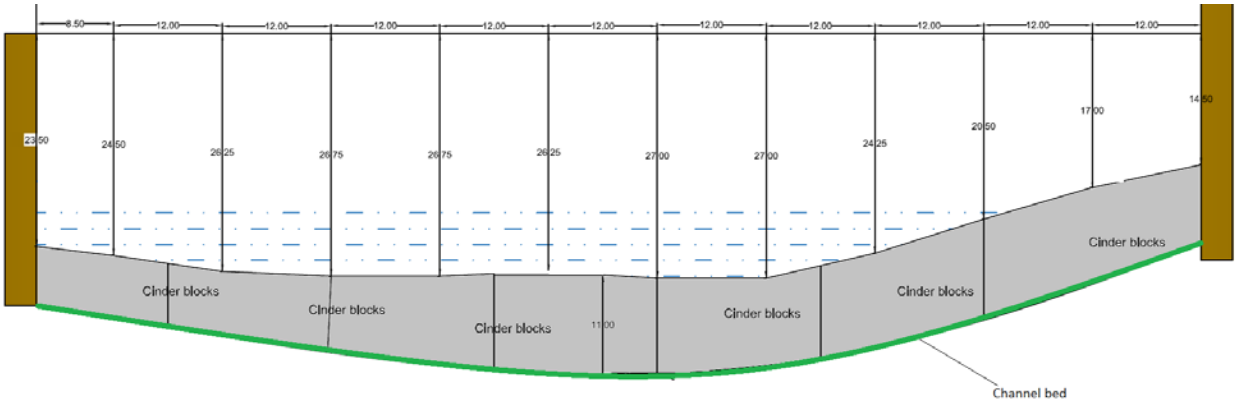


*Figure 5 – Cross section of the channel at the location where weir was installed.*

In addition to the installation of the cells, the following sensors and instruments were placed or deployed at the research site for gathering data on the performance of the system:

- Two level loggers HOBO U20L-04, with 13-ft pressure head range, and accuracy of 0.013 ft of water level, sampling every 15-30 minutes. One was used to gauge atmospheric pressure, the second to measure water level upstream from the cinder blocks, at the location where the CCS discharged into the rip-rap lined channel.
- One rain gauge HOBO RG3, continuously measuring rainfall, with accuracy of 0.01 inch.
- Portable current meter Global Water FP311, to measure water velocity in the apparatus with accuracy of 0.1 ft/s, and range up to 19.9 ft/s.

# Results and discussion

## Hydrological CCS performance characterization

Following the installation of the CCS at the drainage channel in the south side of Cox Rd the monitoring process initiated with the collection of rainfall in the site. Results of the rainfall data, collected from Mid-October 2018 until the Mid-June, 2019 are shown in Figure 6, with a total accumulated rainfall depth exceeding 34 inches in the period.

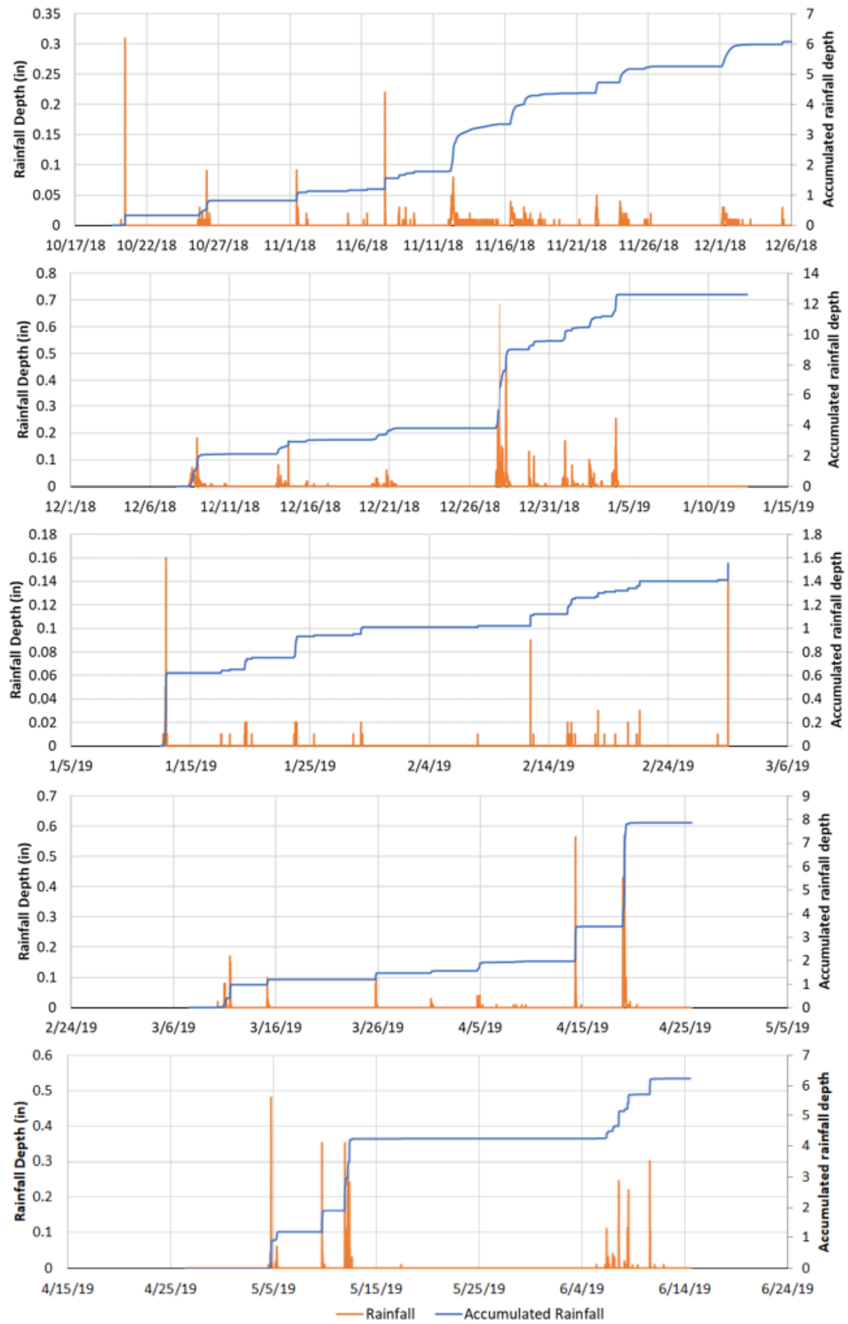


*Figure 6 – Rainfall measurements performed in the research site from 10/17/18 to 6/17/2019*

Over the research period, various rain events managed to generate runoff that was collected in the drainage channel. Given that the bottom of the channel was permeable, the runoff from low-intensity rain events flowed mostly underneath the channel bed. Stronger rain events created overflows over the weir, which were reported with the level logger installed at the upstream side of the weir. Given that the pressure transducer measures a combination of atmospheric pressure and water pressure, the reading from the sensor monitoring atmospheric pressure needed to be subtracted from the results of the sensor installed at the weir. These flow events flows within the CCS channel for the period between 1/12/2019 to 3/3/2019 are shown in Figure 7.

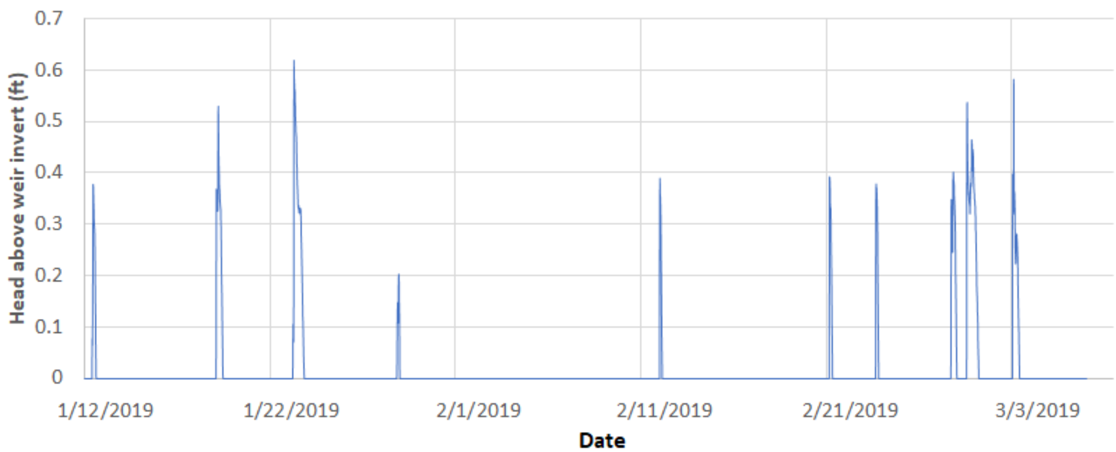


*Figure 7 – Variation of the flow depth above the weir invert between 1/12/19 and 3/3/2019*

The assessment of the performance of the CCS required most importantly an estimate of the water velocities that were observed in the CCS apparatus. It was assumed that the velocities over the CCS cells could be approximated by the average flow velocity over the weir at the downstream end of the apparatus. This introduces some simplification, given that flow velocities are likely to vary at different locations within the apparatus. Yet, given the limitations of performing these measurements in the field, this approach was selected as the most practical and feasible. Assuming that the weir behaved as a broad-crested weir, the flow rate (in CFS) can be related with the depth above the weir invert through equation 1:

$$Q = CLH^{3/2} \tag{1}$$

Where the $C$ is the weir coefficient assumed as 3.1 (Chow, 1959), $L$ is width of the weir and $H$ is the depth above the weir crest. As it was presented in Figure 5, due to the shape of the channel cross section, the width of the weir $L$ varies with the depth of the water $H$. Figure 8 presents the relationship between these geometric characteristics of this weir.

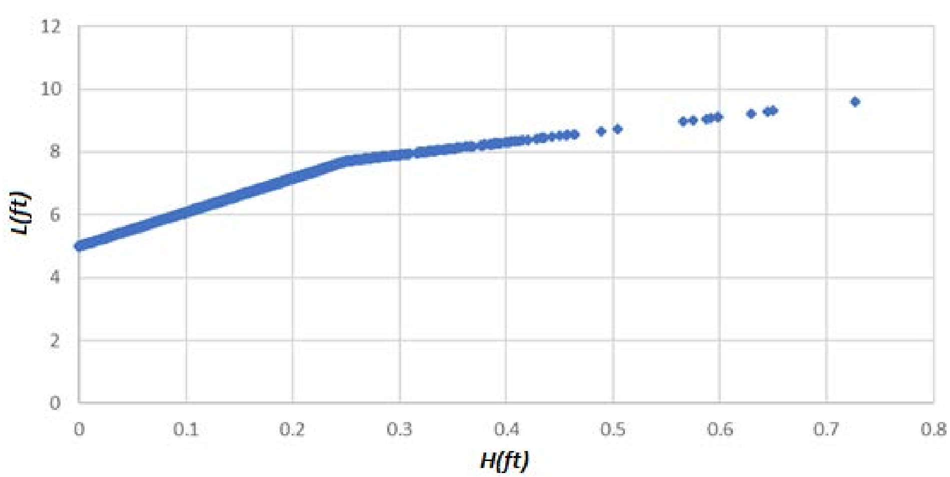


*Figure 8 – Relationship between the weir flow width L and the depth above the weir invert H.*

When these features are built in in equation 1, a depth-discharge relationship for the weir can be developed, and is shown in Figure 9. Moreover, combining the values of $L$ and $H$ in Figure 8, it is possible to estimate the flow area above the weir and with this calculate the average flow velocity over the weir, as is exemplified in Figure 10. The range flow rates and velocities presented respectively in Figures 9 and 10 are representative of measurements in the research.

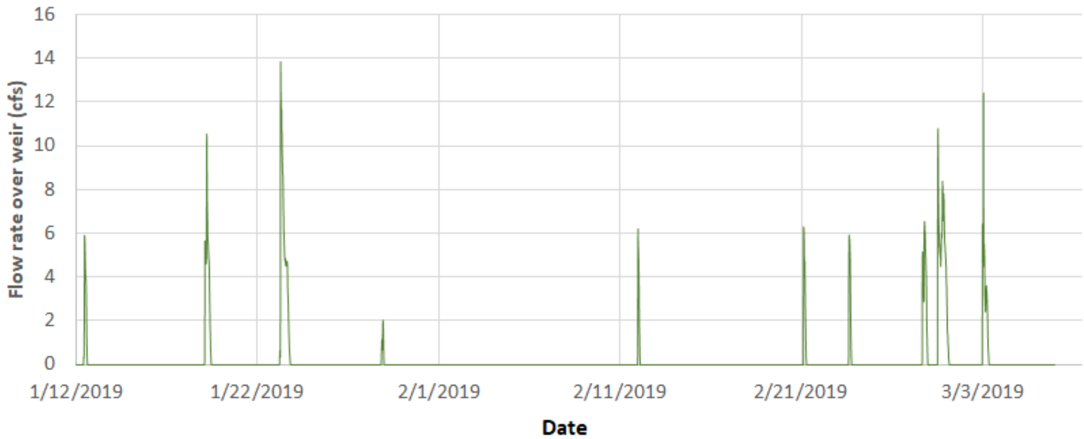


*Figure 9 – Calculated flow rate above the weir invert between 1/12/19 and 3/3/2019*

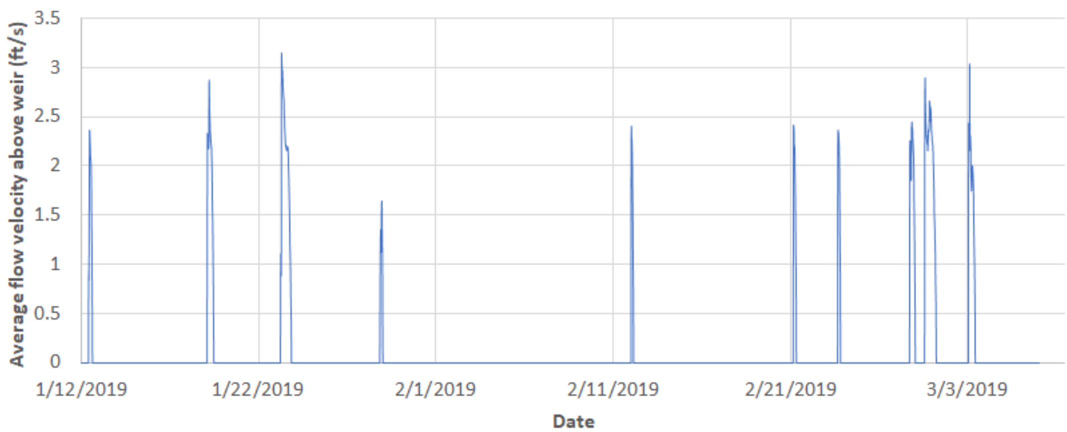


*Figure 10 - Calculated average flow velocity above the weir invert between 1/12/19 and 3/3/2019*

Even though the peak values for flow velocity exceeded 3 ft/s during various rain events in the site, flow velocity measurements performed with the current meter inside CCS cells never exceeded the detection limit of the instrument. As result, all velocity measurements within CCS were below 0.1 ft/s.

These low velocities inside CCS cells would not be anticipated to generate erosion issues, and indeed there were no signs of erosion in the channel. This was determined through two different approaches:

- Through turbidity measurements upstream and downstream of the CCS-lined channel using a HACH 2100Q handheld turbidity meter. During numerous measurements performed with grab samples, the range of turbidity values upstream from the apparatus was between 60 NTU and 95 NTU. Samples collected downstream from the apparatus presented a range of turbidity values from 55 NTU to 90 NTU. For most of these samples, there was a slight drop in turbidity values (~10%) from upstream to downstream of the CCS apparatus.

- Via observation of the channel bed, after a complete removal of the cells performed in early January, 2019. In this inspection there were no signs detected of sheet flows, rills or any other erosive process under the CCS.

## Water quality characterization

Field grab samples were taken in different rain events (October 2018, December 2018 and June 2019) at three locations within the cellular confinement system (CCS), upstream, middle and downstream. Field Samples were taken in duplicate and reported values are average values of the two samples (i.e., n=2). Duplicate samples were extremely similar in value, and no outliers were present. Water quality analysis, instruments and methods are shown in Table 1 and water quality results for each rain event are shown in Table 2.

The October rain event was a weak event with little runoff. The runoff was of terrestrial origin (specific ultraviolet absorbance, SUVA = 3.73 $mg*L^{-1}*cm^{-1}$) with little nutrients and a dissolved organic carbon content (DOC) of 11.6 mg/l. The CCS proved successful at removing organic contaminants with a DOC removal rate of 59%; however, the nutrients were below detection limit thus nutrient removal was negligible.

The December rain event was a heavy rain event with runoff of terrestrial origin (SUVA = 3.29 $mg*L^{-1}*cm^{-1}$) and detectable nutrient contaminants. The CCS removed 30% DOC, 14% COD, and between 26 – 34% of phosphorous and nitrogen species. The majority of the DOC, alkalinity, nitrate and phosphorous removal occurred in the second half of the CCS, while most of the ammonium removal occurred in the first half of the CCS. As the runoff velocity is reduced in the CCS, it is probable that sedimentation is the dominant mechanism for removal of the colloidal nutrient and organic contaminants.

The June rain event was a steady rain event off of I-85N exist 50 site with runoff of terrestrial origin (SUVA = 4.47 $mg*L^{-1}*cm^{-1}$) and selective nutrients were detectable. The water quality parameters remained constant or slightly increased throughout the CCS for all parameters, except alkalinity. Nitrate, phosphorous and TKN were all below detection limit. The samples were collected about one hour after rainfall began and there was a calm, steady flow of water into the cells with the water level beginning to overtop the weir. The June rain event was the first major flow event in four weeks; thus, we hypothesize that the contaminants captured downstream of the CCS were remnants of previous runoff organic matter that remained in the system but sloughed off due to the calm flow. The overall length of the system is ~24 ft and the flow velocity within the cells was under the detection limit of 0.1 ft/s, which would lead to an estimated residence time within the cell was 5 to 8 minutes, supporting our hypothesis.

**Table 1.** Water Quality Analysis, Instruments and Methods

| *Analyte* | *Measuring Units* | *Detection Limit* | *Equipment* | *Reference method* |
|---|---|---|---|---|
| pH | N/A | N/A | pH and conductivity meter | SM 4500-$H^+$ |
| $UV_{254}$ | $cm^{-1}$ | 0.001 | HACH DR-6000 UV Spectrophotometer | SM 5910 B |
| DOC | ppb | 4 | Sievers M 5310 C TOC | SM 5310 C |
| COD | mg/L | 20 | HACH DR 6000 UV Spectrophotometer | HAC Method 8000 |
| TKN | mg/L | 1-16 | HACH DR 6000 UV Spectrophotometer | Hach Method TNT826 |
| Reactive phosphorus | mg/L – $PO_4$ - P | .05 | HACH DR 6000 UV Spectrophotometer | SM 4500- P E/Hach Method 8048 |
| Total phosphorus | mg/L – $PO_4$ | .15 | HACH DR 6000 UV Spectrophotometer | SM 4500- P E/Hach Method 8048 |
| Alkalinity | mg/L as $CaCO_3$ | 2 | HACH Digital Titrator Model 16900-01 | SM 2320 B |
| $NH_3$ | mg/L $NH_3$-N | 0.015 | HACH DR 6000 UV Spectrophotometer | HACH Method 10205 |
| $NO_3$ | mg/L $NO_3$-N | 0.23 | HACH DR 6000 UV Spectrophotometer | HACH Method 10206 |

SM stands for *Standard methods for the examination of water and wastewater* (Eaton et al, 1998)

**Table 2.** Water Quality Results

| | **Sample Name** | **$UV_{254}$ ($cm^{-1}$)** | **DOC (mg/L)** | **SUVA (mg*$L^{-1}$*$cm^{-1}$)** | **Alkalinity (mg/L $CaCO_3$)** | **COD (mg/L)** | **pH** | **Nitrate (mg/L $NO_3$-N)** | **Ammonium (mg/L $NH_3$-N)** | **Reactive Phosphorous (mg/L – $PO_4$ - P)** | **Total Phosphorous (mg/L – P)** | **TKN (mg/L)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| October 2018 | **Middle** | 0.43 | 11.6 | 3.73 | 54 | 519 | 7.3 | 0.403 | BDL | BDL | BDL | BDL |
| | **Downstream** | 0.11 | 4.76 | 2.34 | 27.2 | 496 | 7.6 | 0.404 | BDL | BDL | BDL | BDL |
| | **Removal (%)** | 74 % | 59% | 37% | 50% | 4% | - | 0% | - | - | - | - |
| December 2018 | **Upstream** | 0.37 | 11.3 | 3.29 | 40.8 | 126 | 7.2 | 0.406 | 0.086 | 0.393 | 0.446 | BDL |
| | **Middle** | 0.41 | 11.1 | 3.72 | 37.4 | 87 | 7.3 | 0.414 | 0.0625 | 0.412 | 0.453 | BDL |
| | **Downstream** | 0.21 | 7.96 | 2.67 | 25.5 | 109 | 7.1 | 0.300 | 0.062 | 0.274 | 0.296 | BDL |
| | **Removal (%)** | 43 % | 30% | 19% | 38% | 14% | - | 26% | 28% | 30% | 34% | - |
| June 2019 | **Upstream** | 0.65 | 14.5 | 4.47 | 78.2 | 68 | 7.6 | BDL | 0.052 | BDL | 0.195 | BDL |
| | **Middle** | 0.67 | 14.9 | 4.48 | 64.6 | 79 | 7.5 | BDL | 0.06 | BDL | 0.22 | BDL |
| | **Downstream** | 0.69 | 15.4 | 4.51 | 57.8 | 87 | 7.5 | BDL | 0.07 | BDL | 0.23 | BDL |
| | **Removal (%)** | -7% | -6% | -1% | 26% | -29% | - | - | -29% | - | -18% | - |

***BDL – below detection limit**

## Final remarks and future research

This research has demonstrated the feasibility of empty CCS to control erosive processes in stormwater drainage channels in the context of post-construction stormwater management. This innovative channel lining strategy has never been tested in this context, and various practical questions were answered through this AWRRI-sponsored project. These questions included what are the best methods to deploy and anchor CCS cells, CCS effectivity in preserving the channel invert from erosive forces, evaluation of water velocity within cells, and changes in water quality parameters as flows passed through the CCS apparatus.

While the research was fundamentally important to show the applicability of CCS, there are various points that warrants further investigations. The following points could be considered in the development of future research to further evaluate this channel lining alternative:

- The conditions testing were limited by the site used in the research. Flow velocities were not exceedingly high, as one would obtain in a flume in a laboratory condition. Thus the upper limit of applicability of CCS has not been determined in this work.
- The amount of sediments arriving at the testing site was small, which prevented a quantification of capability of CCS to retain sediments over the duration of the experiments.
- Further evaluation of water quality characteristics would enable the assessment and long-term quantification of the CCS performance in improving stormwater runoff.
- While not the initial focus of this research, it is also anticipated that CCS could be an alternative to control sediments in the context of stormwater management in construction sites, both in terms of erosion and sediment control.

The support provided by AWWRI was fundamental to arrive at these conclusions. Our research team is currently engaged in developing research proposals to enable a follow-up of this research and attempt to address some of the questions that are presented above.

## Products

The research has supported the development of two oral presentations:

- Stormwater management: Innovations and challenges for the City of Campo Grande in the Future – Presented in the City Council of the Campo Grande, MS, Brazil, June 2019.
- An Innovative Lining Strategy to Prevent Channel Erosion. Jose Vasconcelos, Auburn University - To be presented in the Alabama Water Resources Conference and Symposium, Orange Beach, September 2019.

An abstract has also been submitted (albeit outside the report period) for the 2020 ASCE EWRI World Environmental and Water Resources Congress in Las Vegas, NV. The submission period was after the report period given that the call for abstracts was not open in June 2019. The submission title is:

- A field assessment of empty CCS to prevent post-construction stormwater channel erosion.

Finally, it is also planned to submit research results to the 53rd International Conference on Water Management Modeling in Toronto, Canada, in February 2020. The call for abstracts is open.

## Information Transfer

There were no courses, or training activities that could be considered as information transfer activities that resulted from the research project.

## Student Support

This research supported a total of four students: two graduate students support and two undergraduate students:

- Jalil Jamily, graduate student, Auburn University
- Ross Ellis, graduate student, Auburn University
- Katharine Conaway, undergraduate student, University of Alabama
- Alysa Evans, undergraduate student, University of Alabama

## Notable Achievements and/or Awards

This result have supported the development of the following research projects in the areas of civil engineering construction that is related to stormwater management. The following research proposal was funded by Auburn University Highway Research Center:

- Life-cycle cost analysis of alternative channel stabilization technologies, by Jorge A. Rueda, Jose G. Vasconcelos, Wesley Zech, and Wesley Donald

There was an additional proposal submitted after the project reporting period but supported with the findings of this research.

- Development of Cost-Effective Erosion Control Systems for Drainage Ditches and Water Channels using Reclaimed Asphalt Pavement, submitted to C.W. Matthews Contracting Company, Atlanta, GA

Finally, additional proposal submittals are being prepared, also following the positive results obtained in this research.

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# Appendix: Additional photographs of CCS installation


*Figure 11 – Clearing of vegetated channel*

*Figure 12 – Resulting bottom of the channel after clearing of channel vegetation. Soil was slightly covered with residual vegetation, and with high erosive potential*

*Figure 13 – Transition between the cleared channel and the beginning of the rip-rap lined channel.*


*Figure 14 – Installation of the CCS in the region cleared from vegetation*