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# Hydraulic Analysis of an Established Bioretention Cell in Grove, Oklahoma

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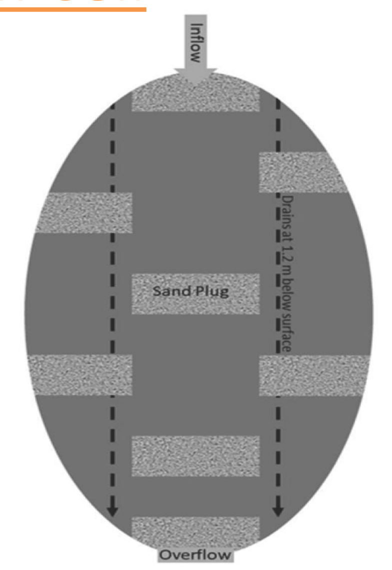
## Abstract

A bioretention cell in Grove, OK were flooded under controlled conditions with a fire hydrant to study hydraulic properties and water quality. The bioretention cell is a retrofit that was built in 2007 for runoff management and enhanced with fly ash to remove phosphorus. This cell is maintained by Grove Public Schools, which mow the surrounding grass and occasionally de-weed the cell. The Grove High School cell was flooded twice: the first to mimic dry conditions and the second time to mimic wet conditions. These experiments are a reproduction of a flood study that was completed on the cells in 2008, one year after installation. Inflow, underdrain flow, and overflow were continuously monitored. Water samples were collected and analyzed in the laboratory for electrical conductivity, chloride, dissolved phosphorus, nitrate, pH, and turbidity. During the dry condition at Grove High School, the combined flow of the underdrain and overflow was 64% of the inflow. Under wet conditions, 69% of the inflow came out of the underdrain and overflow combined. A large portion of the unaccounted flow percolates into the surrounding soil while a portion is stored in the bioretention cell. This is supported by the 5% higher outflow percentage measured during the wet condition test. The portion of flow through the underdrain was similar between the dry and wet condition, approximately 5% for both. Start of underdrain flow and overflow was delayed for the dry study compared to the wet. The underdrain steady state flowrate and the time until overflow began was delayed by 1 hour. The cell does not appear to be leaching dissolved phosphorus because concentrations were not significantly different between inlet, overflow, or underdrain for either moisture condition flood test. Nitrate concertation at the underdrain was significantly higher than the overflow but not the inlet for the dry test at Grove High School. The opposite was found for the wet test; underdrain was significantly less than the overflow. Therefore, the bioretention cell may be more efficient at reducing nitrate during the rainy season. Compared to the one year after flood test, the underdrain flow rates were half as much. A portion of the change is contributed to improved hydraulic connectivity with the surrounding soil.

## Background and Methods

### Grove High School Bioretention Cell

- Located in Grove, Oklahoma
- Bioretention cell installed in 2007
- Goal was to reduce stormwater runoff, phosphorus loading to Grand Lake, and provide educational outreach.
- Media contains 5% fly ash to enhance phosphorus sorption
- Designed with sand plugs to reduce clogging potential (figure right)
- 150 m$^2$ surface area of bioretention cell
- 2600 m$^2$ contributing area
- 5.7% surface area to contributing area
- Drainage is from an asphalt parking lot



Bioretention cell top view with sand plugs (Christianson et al. 2012)

### Field Experimental Setup

Limited data and knowledge exist on the hydraulic performance of established bioretention cells. An 8-year old bioretention cell was flooded twice. The first as a dry condition (5-day antecedent dry period) to mimic no rain prior, and the second time as a wet condition to mimic rain prior.


Flooding experiments were completed 8 years after construction

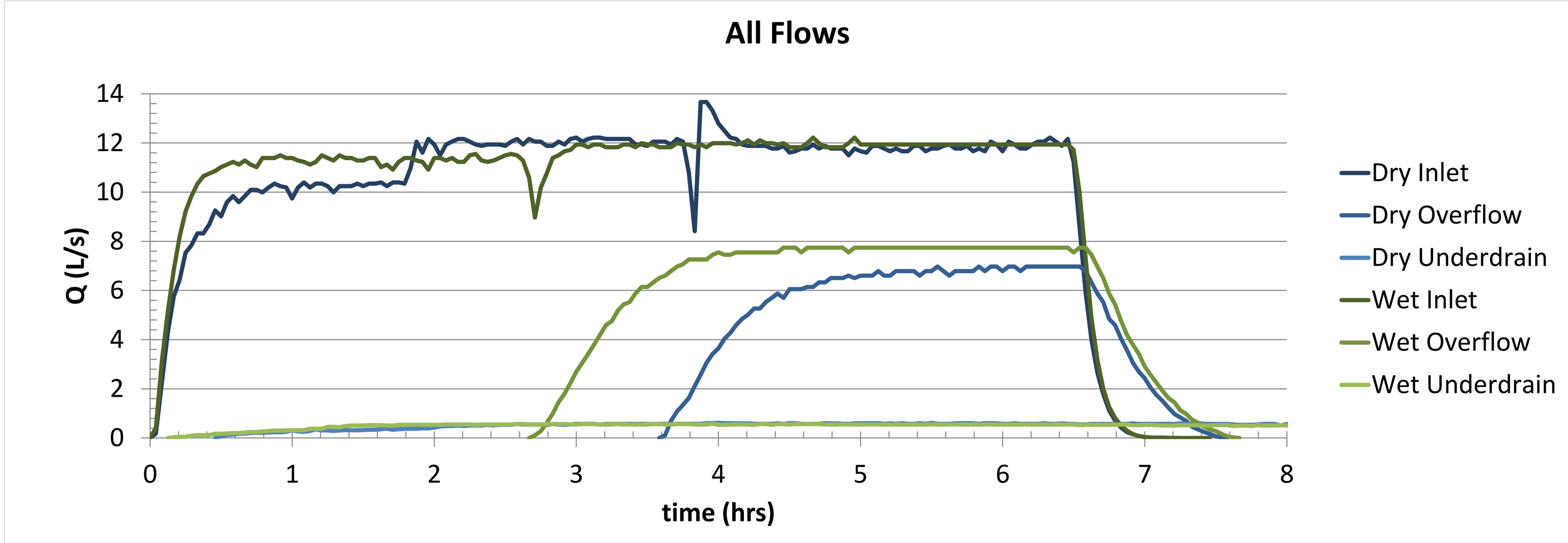
1. Regulated constant inflow from fire hydrant
2. Inflow measured with H-flume and ISCO 6712 depth sensor at 1-min interval
3. Overflow measured with a weir and ISCO 6712 depth sensor at 1-min interval
4. Underdrain flow with Palmer-Bowlus flume and ISCO 6712 depth sensor at 1-min interval

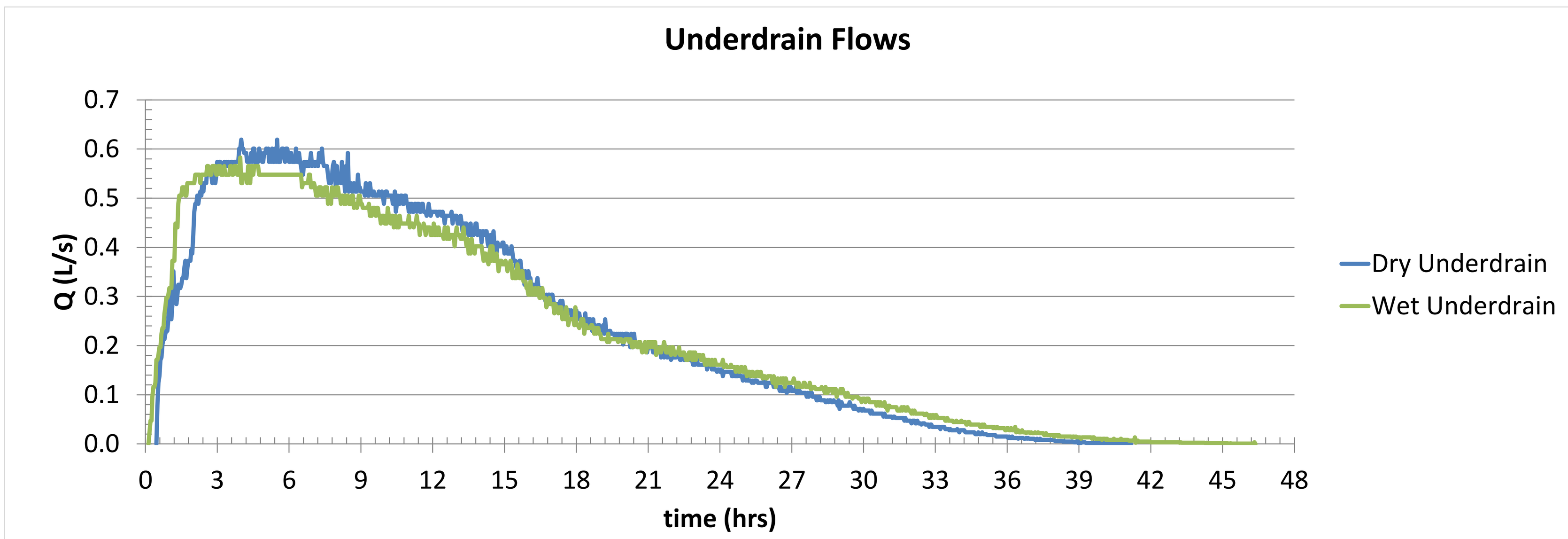

### Laboratory Analysis

1 L grab samples were collected at set time intervals. Samples were analyzed in the laboratory for:

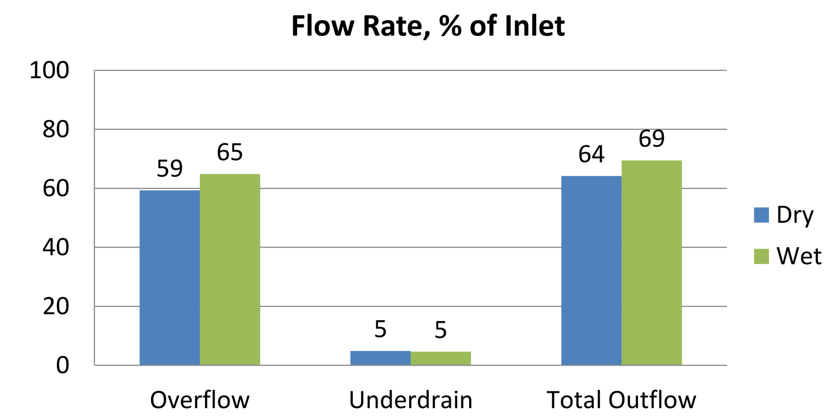
- Electrical conductivity, chloride, nitrate, dissolved phosphorus, pH, and turbidity

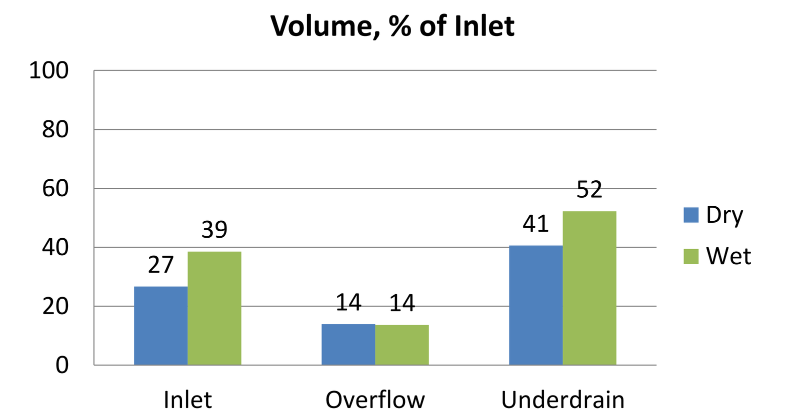
## Hydraulic Analysis




The dry condition study discharged less water at a lower flow rate and delayed time than the wet condition study. 10% less water was discharged during the dry condition study. This may be contributed to the low residual moisture content in the filter media and surrounding soil. Overflow for wet study occurred approximately 1 hour sooner than the dry study. Additionally, the wet condition underdrain flow occurred 18 minutes sooner and took an hour less to reach steady state flow compared to the dry condition study. Regardless of prior soil moisture, the bioretention cell reduced peak flow and total volumes. Outlet volumes were reduced by 59% for the dry condition and 48% for the wet condition. Peak flows were reduced by over 30%.




## Comparison to 1-year after flood test

| | | Steady State Inflow (L/s) | Steady State Overflow (L/s) | Steady State Underdrain (L/s) |
|---|---|---|---|---|
| GHS-dry | 1-year after installation | 9.87 | 6.5 | 1.2 |
| | 8-years after installation | 11.77 | 7.0 | 0.57 |
| GHS-wet | 1-year after installation | 9.22 | 5.3 | 1.2 |
| | 8-years after installation | 11.94 | 7.7 | 0.55 |

Comparison between inflow volumes and total outflow volumes is not direct because the peak rates and length of test differ. The inflow rate for 8-year after construction study were higher than the 1-year after study, though the underdrain flow rates were less.

Image left: Water coming out of vole hole just outside the berm of the bioretention cell. Water appearing outside the cell suggested a high connectivity with the surrounding soil.

Image below: 8-year after construction flooded cell showing the established vegetation.

## Water Quality Analysis

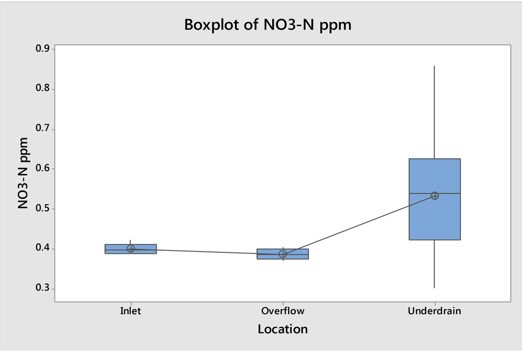
Overall there are fewer significant differences among parameters for the dry condition study compared to the wet condition study. The prolonged exposure of water to the fly ash amended media prior to the wet study most likely contributed to the reduction of EC, Cl, $NO_3$-N, and pH. The higher inlet turbidity is a result of sediment wash off from the parking lot during the first flush. Turbidity at the inlet decreaseed to near zero after the first sample and as a result there are no significant differences among locations.

### Table of average values of measured parameters

| | Dry Condition | | | Wet Condition | | |
|---|---|---|---|---|---|---|
| Location | Inlet | Overflow | Underdrain | Inlet | Overflow | Underdrain |
| n | 6 | 6 | 15 | 7 | 8 | 14 |
| EC (µS/cm) | 317 | 316 | 272 | **299 A** | **315 A** | **257 B** |
| Cl (ppm) | 19.93 | 13.23 | 11.25 | **13.48 A B** | **21.06 A** | **9.63 B** |
| **$NO_3$-N (ppm)** | **0.40 A B** | **0.39 A** | **0.53 B** | **0.39 A** | **0.37 A** | **0.31 B** |
| Ortho P (ppm) | 0.04 | 0.05 | 0.04 | 0.03 | 0.03 | 0.05 |
| pH | 7.6 | 7.6 | 7.6 | **7.7 A** | **7.5 A B** | **7.5 B** |
| Turbidity (NTU) | 27.9 | 1.04 | 0.97 | 23.5 | 7.11 | 0.51 |

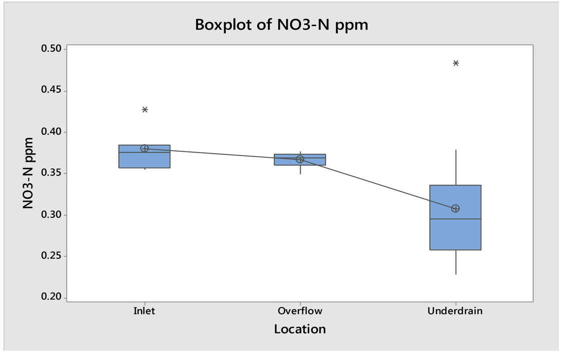
Means that do not share a letter are statistically different at a 95% confidence level
Mean with no letters are not statistically different at a 95% confidence level

Dry Condition




- Nitrate increased during the dry condition study but decreased during the wet condition.
- Overall, concentrations are low for both studies.
- Saturation in the cell prior to the wet condition study most likely contributed to the reduction.

Wet Condition




## Local and Regional Impacts

- Grove Schools is responsible for the cells maintenance. Majority of maintenance is mowing the surrounding grass and de-weeding the cell periodically.
- Grove High and four other cells have educational signage (image right)
- Over a dozen researchers have worked on these bioretention cells and have produced publications, reports, and presentations.
- Success of the Grove bioretention cells are an excellent example of LID for Oklahoma and the region.


Bioretention cell and educational signage

## Conclusion

- The bioretention cell continues to provide flow rate and quantity reduction.
  - Greater than 30% reduction of peak flow rates both dry and wet conditions.
  - 59% and 48% volume reduction between inlet and total outflow for dry and wet respectively.
- Underdrain flow was only 5% of the inflow rate for both studies.
- Phosphorus did not change between the inlet and outlets, therefore the cells does not appear to be leaching phosphorus.
- The underdrain flow rate is approximately have rate from the 1-year after study, though the total outflow did not increase suggesting that the established cell is more hydraulically connected to the surrounding soil.
- Nitrate efficiency may be better during the rainy season compared to dry periods.
- Limited maintenance was required to have a functioning bioretention cell.
- The cell continuous to be a local success story and educational exhibit for Grove, OK.

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Citations: Christianson, R. D., Brown, G. O., Chavez, R. A., & Storm, D. E. (2012). Modeling field-scale bioretention cells with heterogeneous infiltration media. *Transactions of the ASABE*, *55*(4), 1193-1201.