Grand Lake (Oklahoma) Watershed Implementation Project Phase I
Task 5.3 Bioretention Cell Design, Evaluation, and Technology Demonstration

FY 2004 319(h) Project 5

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Introduction

Non-point source pollution from urban runoff is a major concern in many watersheds. Nutrients, heavy metals, and organic chemicals and pathogens contained in non-point source pollution, while at low concentrations, negatively impact water quality due to the large volumes and widespread nature of flow. Bioretention cells (BRC) are gaining popularity as a stormwater BMP and are in essence “functional landscaping”. They are landscaped areas that treat storm water runoff and present a broad range of potential benefits including decreased runoff; improved water quality through various physical, chemical, and biological processes; thermal attenuation; and aesthetics for a limited drainage area (Hunt and White, 2001).

Ten BRC have been constructed in Oklahoma, in a variety of land use settings, as part of an ongoing study to demonstrate the effectiveness of this technology. Eight are located in Grove, and two are located in Stillwater, as shown in Figure 1. Of the ten cells, two are residential properties, six are public or municipal properties, and two are commercial properties.

This paper provides an overview of the engineering considerations, general design procedures, site parameters, construction specifications, construction costs, lessons learned during construction, and initial water quality analysis.

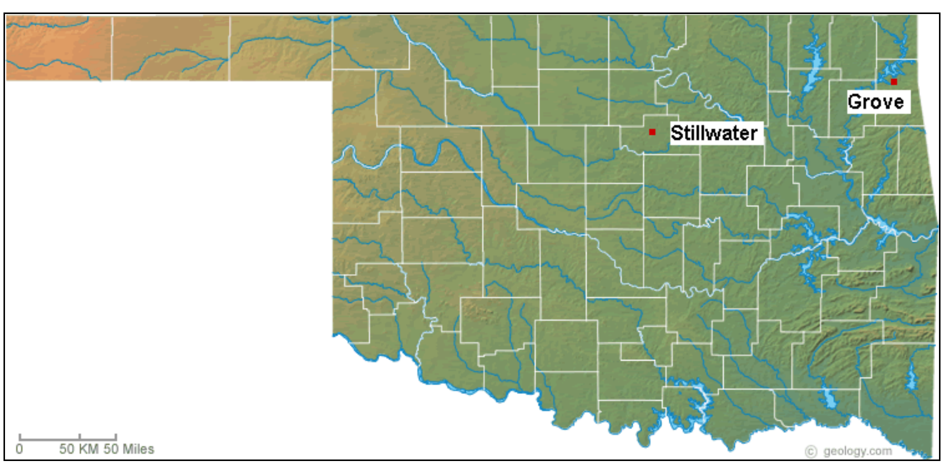

Figure 1. Map of Oklahoma depicting project locations.

Cell Design

In general, the designs for this project are consistent with the BRC guidelines set by Prince George's County (2002), Hunt, et al. (2001 and 2005), and the LID Center (2003). Figure 2 depicts a typical section of the BRC design for this project. Variations from the references cited include a 1:1 side slope for improved safety during construction, sand plugs for adequate infiltration through the top soil layer, the addition of a blend of sand and fly ash as a filter medium, and vegetation criteria suitable for eastern Oklahoma. Construction for this project was formally bid through the Oklahoma Department of Central Services, requiring a complete Plans, Specifications, and Estimate (PS&E) package.

The design can be broken down into six steps: 1) site survey, 2) cell sizing, 3) inlet and overflow bypass design, 4) filter media selection, 5) cell drainage, and 6) top soil, sand plugs, and landscaping. Design specifics and calculations are provided in the following sections.

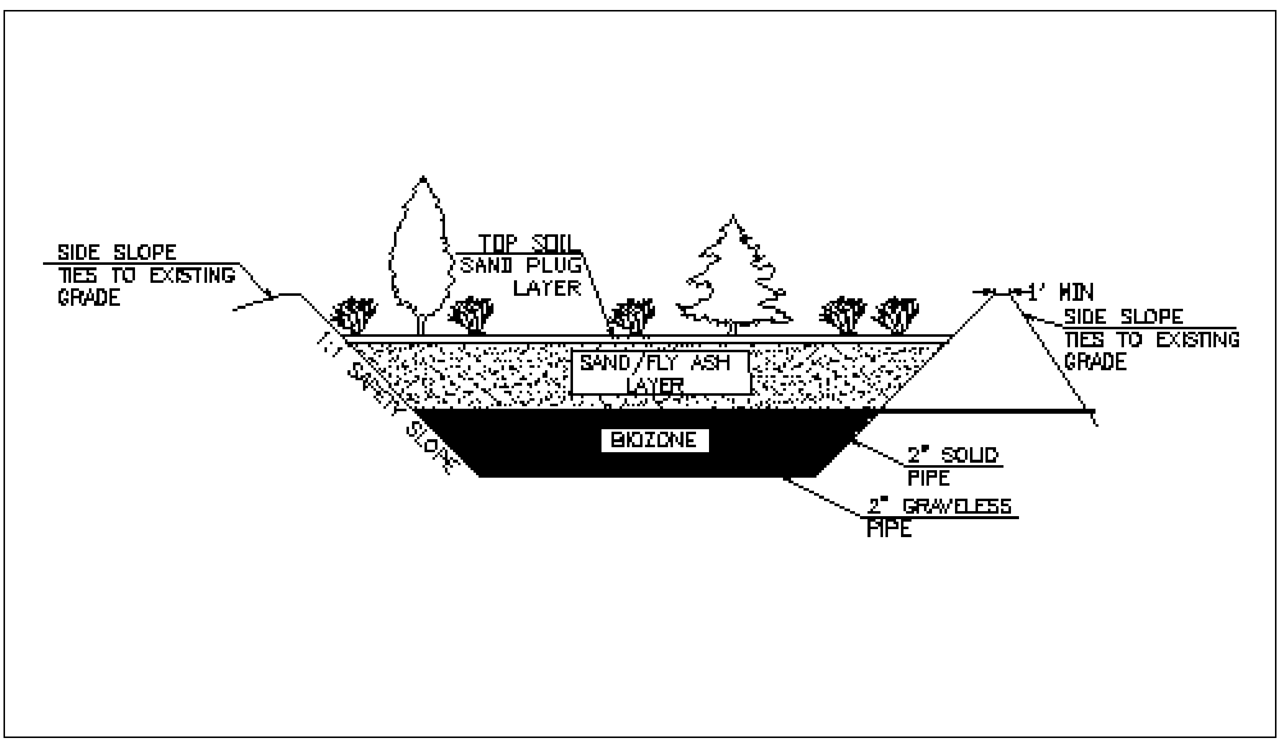

Figure 2. Bioretention cell typical section

Site Survey

The site surveys for this project were conducted in three phases. An initial visit was used to evaluate the suitability of each potential site based on visibility for demonstration purposes, access for future sampling, drainage area, and overall suitability for cell operation. The second phase included a more thorough survey to measure drainage area and existing grade. Drainage areas should be less than three acres (LID, 2003). Utility locates were also performed at this point to identify utilities in the vicinity and avoid potential conflicts and obstacles. Finally, soil surveys were conducted at each site using a Gidding's truck mounted hydraulic soil sampling and coring machine to determine soil conditions. The Grove sites had similar soils: thin silt loam top soil overlaying a clay loam with large rocks. The Stillwater site had a deep clay loam. Because of the low permeability of the subsoils, drains were required on all cells.

Cell Sizing

With the site survey complete, the dimensions of the cell were determined. The cell area, the estimated volume of water into the cell, the berm height, the cell volume, and depths of the filter layer and the biozone were calculated. Cell areas for BRC using sandy soils, range from 3 to 8% of the drainage area (Hunt and White, 2001), which was followed here. If P is the percentage and A_D (ft^2) is the drainage area, cell areas, A_C (ft^2), were simply,

$$A_C = PA_D \tag{1}$$

Initial cell area was used to determine required volumes and depths. The final cell area was refined at the end of the cell sizing calculations to accommodate a 1:1 slope on the walls of the cell for added safety during construction, as shown in Figure 5. Cell shape was also a factor in the cell area refining process as the overall shapes were varied for aesthetics.

It was arbitrarily decided that the cell would catch the first ½ inch of runoff from any storm event in the designated ponding area. An expectation is that the majority of the pollutants will be present in that first flush. However, there is little supporting data for that assumption. Given the drainage area from the site survey, the volume of the first flush, V_R (ft^3) is,

$$V_R = \frac{0.5}{12} A_D \tag{2}$$

The depth of the ponding area is dictated by the height of the berm, H_b (ft), and the expected volume of water,

$$H_b = \frac{V_R}{A_C} \tag{3}$$

The filter layer consisted of a blend of sand and 5 percent fly ash by weight. As with the ponding area, the water storage volume of the filter was arbitrarily set to equal ½ inch of runoff from the drainage area. The volume of this layer, V_F (ft^3), is based on a porosity, φ, of 0.30 and was calculated as,

$$V_F = \frac{V_R}{\varphi} \tag{4}$$

The depth of the filter layer, D_F (ft), was,

$$D_F = \frac{V_F}{A_C} \tag{5}$$

One cell at the Early Childhood Development Center was constructed with a biozone. The biozone was designated as an anaerobic layer within the BRC to encourage denitrification.

An inverted siphon was used to create the anaerobic condition by increasing the amount of head necessary for water to leave the system, thereby maintaining a constant saturated zone. This layer consisted of sand with a specification to contain no more than 5 percent fines. The volume of the biozone was again arbitrarily set to accommodate the first ½ inch of the runoff from the drainage area. Volume and depth of this layer were calculated using Equations 4 and 5 with a porosity of 0.39, which is a typical value for a clean, uniform sand (Holtz and Kovacs, 1981).

Inlet and Overflow Bypass

Inlet channel dimensions were calculated using a combination of the rational method for surface flow and Manning's equation. Since the drainage area size is limited to 3 acres or less, the rational method was an acceptable means of calculating the expected flowrate, Q_D (ft^3/s), into the inlet channel,

$$Q_D = iA_D C \tag{6}$$

Intensity, i (in/hr), was obtained for a 50-year 1-hour storm from the Rainfall Frequency Atlas of the United States (Hershfield, 1961). The dimensionless runoff coefficient, C, was assumed to be 0.95 for impermeable surfaces such as pavement and roofs (TXDOT, 2000).

Knowing the expected flow rate, Q (ft^3/s) into the channel, Manning's equation was employed to size inlet and outlet channels,

$$Q = \frac{1.49}{n} A_C R_h^{2/3} S_o^{1/2} \tag{7}$$

$$R_h = \frac{A}{P} \tag{8}$$

where R_{h}, (ft) is the hydraulic radius, A_c (ft^2) is the area of the channel cross-section and P (ft) is the wetted perimeter. Certain conditions were assumed for practicality. The depth of the channel, the slope, and Manning's coefficient, n, were held constant. The shape of the channel was assumed to be rectangular.

Equations 6 and 7 were equated to determine the width of the channel. The overflow channel utilized the same dimensions as the inlet channel.

An overflow bypass was designed as a weir on the back end of the cell. Values for weir height, P_W (ft), and total head above the weir, H (ft), were held constant, and the length of the weir, b (ft), was sized using the equation for a broad-crested weir,

$$Q = C_{WB} b \sqrt{g} (H)^{3/2} \tag{9}$$

where g is the acceleration of gravity. The broad-crested weir coefficient, C_{WB}, is defined by Munson, et al. (1994) as,

$$C_{WB} = \frac{0.65}{\left(1 + H/P_W\right)^{1/2}} \tag{10}$$

Inverting Equation 9 provides,

$$b = \frac{Q}{C_{WB} \sqrt{g} (H)^{3/2}} \tag{11}$$

Filter Media Selection

Phosphorus removal in BRC has been highly variable in previous research (Hsieh and Davis, 2003; Hunt, 2003). As phosphorus is a contaminant of concern in the Grand Lake watershed, it was necessary to find a means to improve phosphorus removal in BRC. Various materials have been used to remove phosphorus through mechanisms such as adsorption, ion exchange, and precipitation in wastewater treatment. Alum, lime, and iron are commonly used in chemical phosphorus precipitation. However, many researchers have expressed an interest in finding more economical sorptive materials. Fly ash is one such material. A waste product of burning coal, it is abundant and inexpensive. Zhang, et al. (2006) conducted a series of experiments to find a cost effective filter medium with both a high phosphorus sorption capacity and an adequate hydraulic conductivity to improve the removal of phosphorus in BRC.

Sorption isotherms and desorption experiments were conducted to characterize phosphorus sorption and desorption of Dougherty sand and various mixtures with fly ash. The fly ash exhibited a high phosphorus sorption predominantly due to calcium phosphate precipitation. With the addition of 5% fly ash, the distribution coefficient, K_d, of Dougherty sand was elevated from 2.08 mL/g to 398 mL/g (5.77 to 1100 in^3/lb), and phosphorus removal increased from 9.4% to 94.2%. Desorption results indicated that Dougherty sand released a large amount of phosphorus, averaging 42% of the initially sorbed phosphorus. However, Dougherty sand with 5% fly ash released negligible amounts of phosphorus, even when the initial phosphorus concentrations were increased. The end result of the study was that, in a hypothetical scenario, the sand/fly ash infiltration layer provides satisfactory phosphorus removal over a long period and enhances phosphorus retention significantly.

The infiltration capacity of filter media is an important parameter for a BRC. It is not recommended to leave water in the ponding area of BRC for longer than four days because it restricts the use of water-intolerant plants and encourages the breeding of mosquitoes and other insects (USEPA, 1999). PGDER (2002) recommends that the infiltration rate should be greater than 2.54 cm/hr (1 in/hr) in a BRC intended for runoff infiltration. The infiltration rate may be directly calculated with the hydraulic conductivity by Darcy's law and the hydraulic gradient. In the limiting case of a saturated medium with no ponding, the hydraulic gradient is equal to one, and the infiltration rate is equal to the hydraulic conductivity. Hunt (2003) suggested that the desired range of hydraulic conductivity in BRC is 1.26 cm/hr to 5.04 cm/hr (0.5 to 2.0 in/hr). However, the hydraulic conductivity requirement depends on the BRC design. If an underdrain is installed at the bottom of the cells to guarantee adequate drainage, a hydraulic conductivity of 0.42 cm/hr (0.17 in/hr) would drain 30 cm (1 ft) ponding water within 72 hours. Other infiltration systems may have different infiltration rate requirements.

A falling head permeameter (McWhorter and Sunada, 1977) was used to determine the saturated hydraulic conductivity (K_s) of Dougherty sand (Thermic Arenic Haplustalf), and the mixtures of the sand with various levels of fly ash. A 4.0 cm (1.6 in) inner diameter and 15 cm (5.9 in) long acrylic column was packed with each material. Average bulk density was 1.50 g/cm^3 (0.054 lb/in^3) for Dougherty sand and 1.58 to 1.73 g/cm^3 (0.057 to 0.062 lb/in^3) for the Dougherty sand/fly ash mixtures. The column was connected to a glass tubing reservoir containing 0.01 mol/L (0.28 mol/ft^3) calcium sulfate ($CaSO_4$) solution (Klute and Dirkson, 1986). Water flowed upward through the column, and the hydraulic gradient ranged from 2.03 m/m to 3.79 m/m.

The hydraulic conductivity (K_s) of Dougherty sand was 34 cm/hr (13 in/hr). Fly ash had an extremely low hydraulic conductivity, which could not be measured by the procedure used. The hydraulic conductivity of Dougherty sand and its mixtures with various levels of fly ash are presented in Figure 3. The hydraulic conductivity dropped exponentially with increasing fly ash content. To keep the hydraulic conductivity of amended soils higher than 2.54 cm/hr (1 in/hr), the incorporation rate of fly ash should be less than 6% calculated from the exponential relationship (Figure 3).

Due to the pozzolanic nature of fly ash and hydration reactions, the hydraulic conductivity of the sand/fly ash mixtures may decrease with an extended saturation period. To assess the effect of saturation period on the hydraulic conductivity of the sand/fly ash mixtures, Dougherty sand, D+2.5%F, and D+5%F were kept in saturation in the testing columns for 28 days and the hydraulic conductivity measured periodically. Dougherty sand was examined for comparison in this case.

The change of hydraulic conductivity over the extended saturation period for Dougherty sand, D+2.5%F, and D+5%F is shown in Figure 4. The trends were different for Dougherty sand and the sand/fly ash mixtures. Hydraulic conductivity of Dougherty sand dropped slightly first, and then recovered to the previous level. This behavior was probably due to movement of the fines through the column. However, the hydraulic conductivity of D+2.5%F and D+5%F decreased rapidly during the first 24 hours, and then stabilized after 14 days. Because of the pozzolanic reactions that occurred in the water-saturated sand/fly ash mixtures, the permeability of D+2.5%F and D+5%F was decreased. The stabilization of hydraulic conductivity after 14 days indicated the end of the pozzolanic reactions. At the end of the 28-day experiments, the

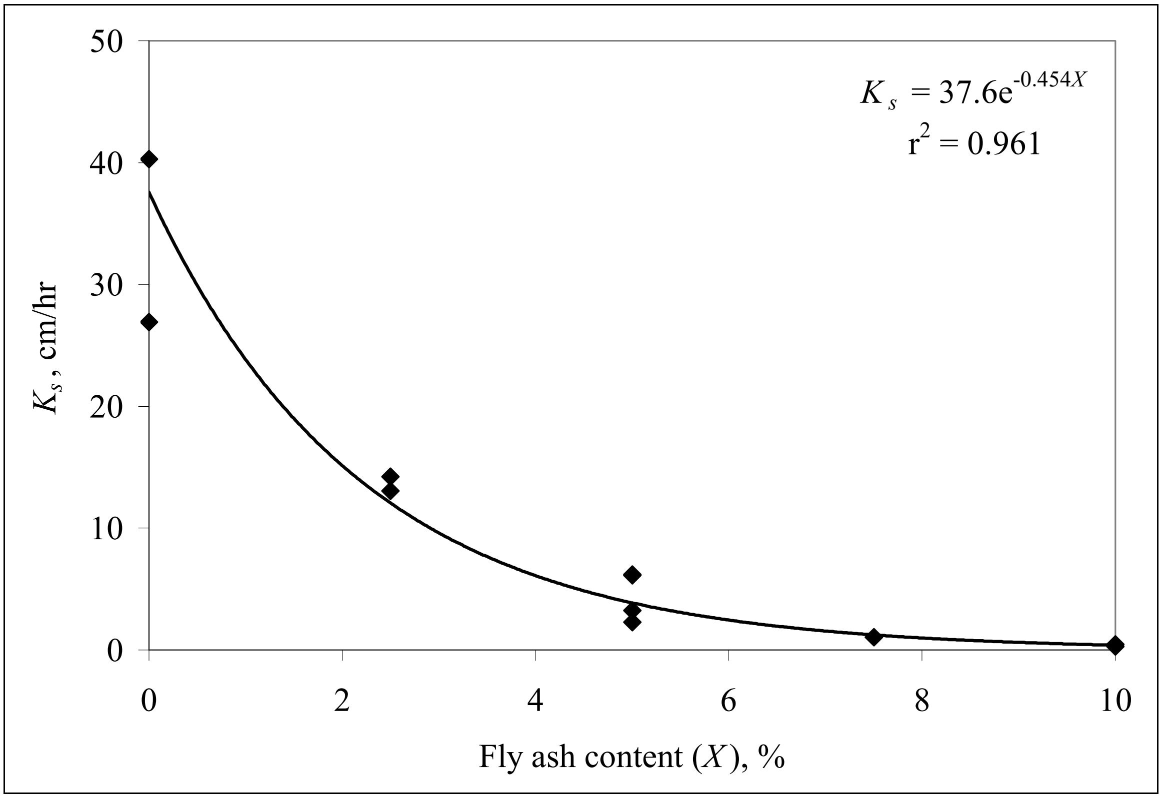

Figure 3. Effect of the fly ash addition on hydraulic conductivity of Dougherty sand.

hydraulic conductivity of D+2.5%F and D+5%F was 5.50 cm/hr and 0.91 cm/hr (2.2 and 0.36 in/hr). This characteristic of the sand/fly ash mixtures implies that their 4-day or 7-day hydraulic conductivity should be evaluated to ensure the adequate infiltration. With the final hydraulic conductivity of 0.91 cm/hr (0.36 in/hr), D+5%F still possesses an adequate hydraulic conductivity to drain 30 cm (1 ft) ponding water within 33 hours.

Installation of the filter medium consisted of 6 inch lifts to keep the mixture as consistent as possible and to prevent preferential flow through this layer of the BRC. The sand specified in the design was a clean sand with less than 5% fines. Fly ash utilized was class C, obtained from the Chouteau power plant for the Grove sites and from the Sooner power plant for the Stillwater site.

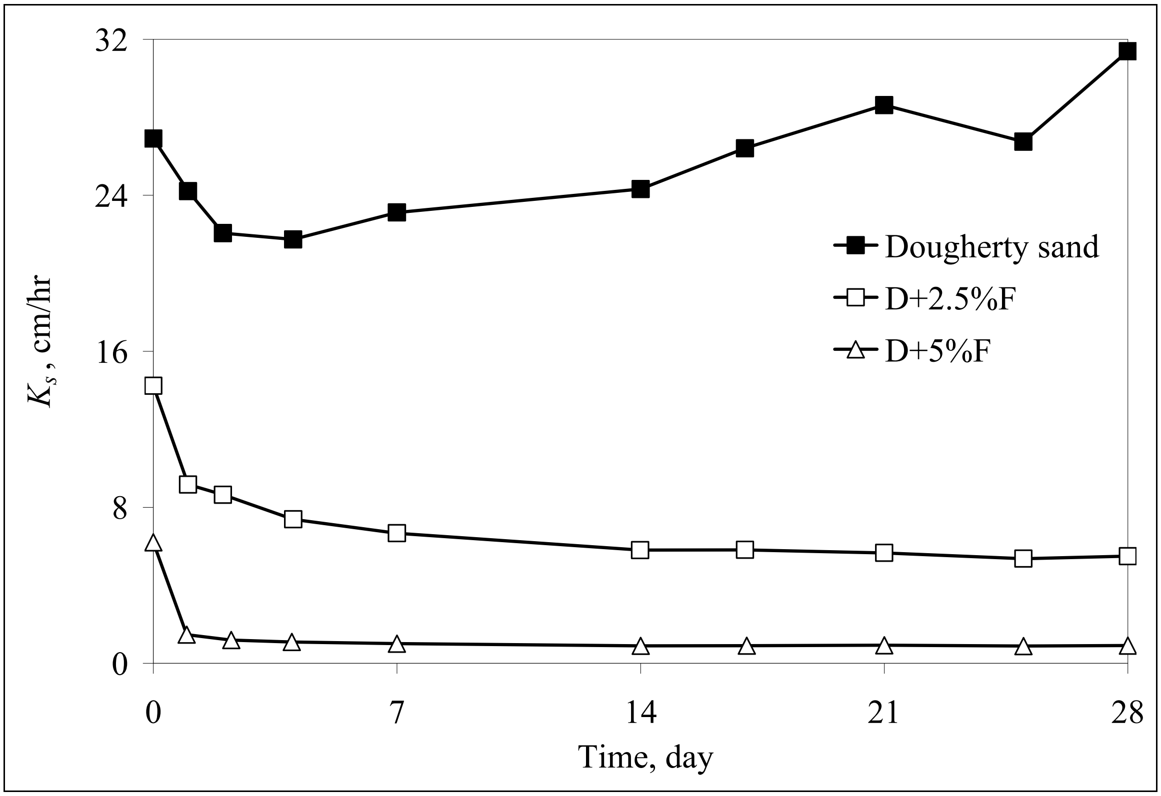

Figure 4. Effect of extended saturation period on saturated hydraulic conductivity of Dougherty sand, D+2.5%F, and D+5%F.

Combining the sand and the fly ash in the field was accomplished in two ways. The first method involved mixing with heavy equipment before placement in the cell. A load of sand was deposited near the cell site and the appropriate amount of fly ash was then mixed into the sand by repeatedly filling the bucket of a front end loader and pouring it back over the pile containing the sand and fly ash, until an even blend was achieved. The second method entailed using a roto-tiller to mix media in lifts inside the cell. A 6 inch lift of sand was placed into the cell. The appropriate amount of fly ash was then evenly distributed on top and tilled into the sand.

Cell Drainage

Drains designated for this project are corrugated gravel-free polyethylene. Sizing for the drainage pipes was based on a modified version of the Darcy-Weisbach Equation,

$$Q = \frac{\pi D^2}{4}\sqrt{\frac{S_o}{f}D(2g)} \tag{12}$$

where the slope, S_o, is assumed to be 1 percent and the Darcy coefficient, f, is 0.75, to account for the roughness of the pipe. D (ft) is the pipe diameter. A 2 inch pipe has a capacity of 0.16 ft^3/s, which is more than adequate for a cell with an area of 2,500 ft^2 and a hydraulic conductivity of 1.4 in/hr.

Top Soil, Sand Plug and Landscaping

The topsoil available in Grove, Oklahoma is a silty loam, with a hydraulic conductivity much less than 1 in/hr. Even blending equal parts sand and topsoil did not provide adequate hydraulic conductivity to ensure infiltration into the filter layer. Sand plugs were introduced as a solution for increased infiltration into the cell, and were designed for ease of construction. The topsoil layer of the BRC were specified for a depth of 1 foot, based on communication with a landscape professional (Perry, 2006). Sand plugs were randomly placed, such that no two plugs touch each other, as shown in Figure 5 below. The size and number of the sand plugs is dependent on the dimensions of the cell. However, it was determined that the sand plugs should occupy approximately 25 percent of the top soil layer. The random nature of the placement also provided flexibility for optimum placement of vegetation.

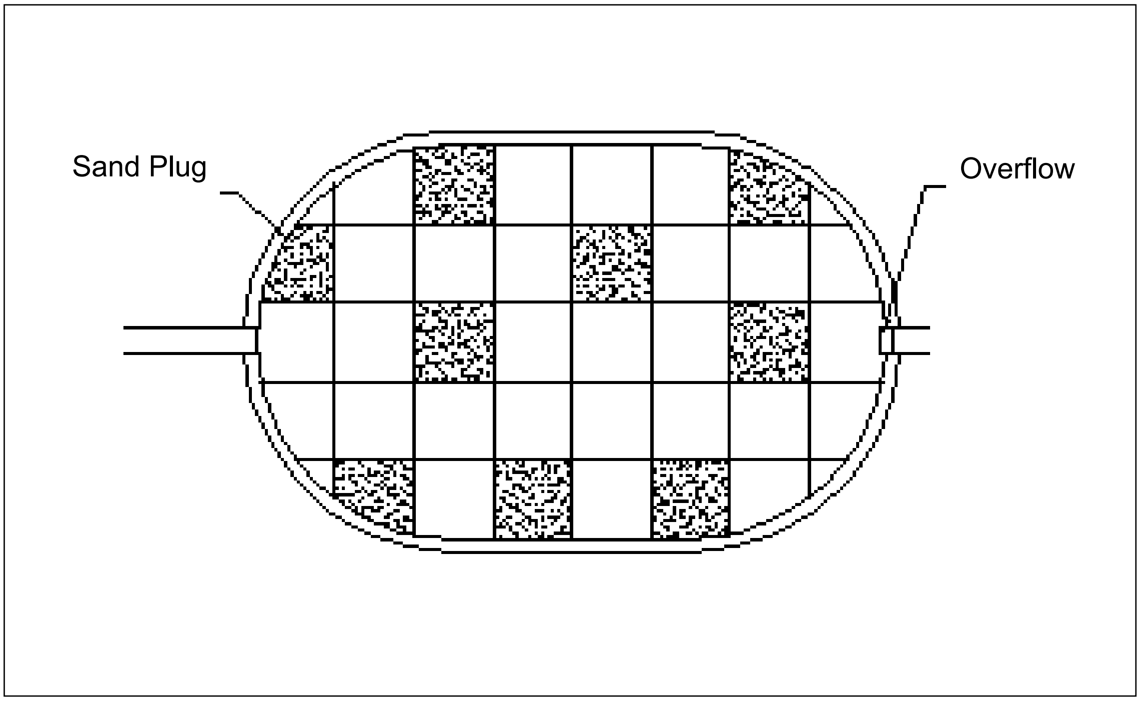

Figure 5. Example of sand plug layout**.**

Since BRC are usually in landscaped areas, plantings should be aesthetically pleasing. With that requirement in mind, the horticultural planting list was developed using the following criteria:

- Plants had to be wet and dry tolerant,
- Not N fixers,
- Noninvasive species,
- Low-maintenance requirements,
- Offer color variety,
- Plants had to be easily attainable and replaceable, and
- Include trees, shrubs, flowering perennials, ornamental grasses, and rock accents.

A conscious effort was made to include native species to the list, while some of the plants not designated as native in Table 1, such as the Red-Tipped Photinia, are native to neighboring states and this region of the country in general. Vegetation quantities were based on the guidelines presented by the planting schedule in Table 2.

Table 1. Horticultural Plant List

Plant	Native
Yaupon Holly	Yes
Bald Cypress	Yes
Heritage River Birch	Yes
Virginia Sweetspire	Yes
Amur Red Maple	Yes
Dwarf Yaupon Holly	Yes
American Holly	Yes
Wintergreen Boxwood	No
Red-Tipped Photinia	No
Great Blue Lobelia	Yes
Golden Euonymus	No
Maiden Hair Grass	No
Fountain Grass	Yes
Stella Daylily	No

Table 2. Planting schedule

Plant Type	Surface Area %
Trees	8 to 10
Shrubs	15 to 20
Flowering Perennials	1 to 5
Ornamental Grasses	10 to 15
Rock Accents	1 to 5

To maintain landscaping aesthetics and to help retain moisture for the vegetation, a 2 inch hardwood mulch layer was applied over the top soil / sand plug layer after planting the vegetation. Hardwood was used to minimize mulch floating out of the cell.

Site Parameters

Sites were chosen based on grade, location, drainage area, visibility, and access. Table 3 lists the sites chosen for BRC installation with approximate location, property type, land use and the size of the drainage area for each site. Of the sites listed, two are commercial properties, two are residential, and six are public. Land use includes both paved and grass. There is one site where the paved surface and the grass surface are approximately equal and one where the runoff is intercepted primarily from a roof surface. Drainage areas vary from 0.11 acre to 1.90 acres, with all but one being less than one acre.

Elm Creek Plaza and Cherokee Queen Riverboats are the two commercial sites. Elm Creek Plaza is a busy shopping center and Cherokee Queen Riverboats is a restaurant and entertainment venue. Both cells capture runoff from the parking lots at their respective sites, which would otherwise flow directly into a water body: a creek in the case of Elm Creek Plaza, and Grand Lake in the case of Cherokee Queen Riverboats.

Two other facilities are located adjacent to the lake. The Spicer residence is a single family home with property extending to the lake. The cell was constructed in back in order to intercept runoff from the property before entering directly into the lake. The Grand Lake Association has the largest drainage areas of the sites chosen for this project (1.9 acres). Runoff comes from both a parking lot and the lawn.

Table 3. List of sites designated for BRC installation in Grove and Stillwater, including approximate location, property type, land usage, and drainage area.

Site	**Approximate Location**	**Property Type**	**Land Use**	**Drainage Area (Acres)**
Elm Creek Plaza	36°34’47” N, 94°46’08”W	Commercial	Paved	0.62
Lendonwood Gardens	36°34’59” N, 94°47’13”W	Public	Turf	0.54
Grove High School	36°37’19” N, 94°44’50”W	Public	Paved	0.65
Grand Lake Association	36°36’39” N, 94°48’14”W	Public	Paved/Turf	1.90
Cherokee Queen Riverboats	36°38’05” N, 94°48’54”W	Commercial	Paved	0.45
Early Childhood Development Center	36°35’12” N, 94°46’57”W	Public	Paved (Roof only)	0.11
Spicer Residence	36°38’59” N, 94°46’08”W	Residential	Turf	0.39
Clark Residence	36°35’18” N, 94°49’36”W	Residential	Turf	0.18
OSU Botanical Gardens, Cell A, Stillwater	36°07’00” N, 97°06’01”W	Public	Paved	0.32
OSU Botanical Gardens, Cell B, Stillwater	36°07’01” N, 97°06’01”W	Public	Paved	0.90

The cell at Lendonwood Gardens is located in front of the botanical gardens and receives runoff from the gardens themselves. The Clark residence is a single family home located adjacent to a golf course. The runoff intercepted by this cell is primarily from the lawn and roof, while a small quantity may be attributed to the golf cart path separating the residential property from the golf course.

Grove High School lent itself to a BRC readily. There was an existing swale transporting runoff from the staff parking lot to the storm water drain in the city right-of-way. The cell was designed to fit inside the swale. The Early Childhood Development Center is a new preelementary facility, where the cell was placed near the main entrance and receives runoff off from the roof only.

Two sites will be part of an environmental research and education program in partnership with the Oklahoma State University Botanical Gardens in Stillwater, Oklahoma. Cell A and Cell B will receive runoff from a short stretch of roadway serving as an entrance into the botanical gardens and a nearby parking lot, respectively. Both the roadway and parking lot will be constructed in Spring 2009. Photographs of each cell during construction are exhibited in Appendix B.

Construction Costs

The sites listed in Table 4 were constructed by a contractor selected through a formal state bidding process. All eight sites are located in Grove, Oklahoma. Cost was bid on a volume basis and includes mulch but not vegetation. Cell cost ranged from \$7,368 to \$29,172. Bid costs ranged from \$7,368 at the Clark residence, which is the second smallest cell with a volume of 27 m^3 (35 yd^3), to \$29,172 at the Grand Lake Association, which had a volume of 435 m^3 (569 yd^3). The cell at Lendonwood Gardens was the smallest, but cost more to construct because of site conditions requiring tree removal and traffic control.

Final costs for all cells, with the exception of the Spicer residence were the same as the bid cost. Increased quantities of sod and soil quantities due to changes in design were responsible for the \$1500 difference between bid cost and final cost for the Spicer cell.

Table 5 lists the two BRC constructed at the Oklahoma State University Botanical Gardens in Stillwater, Oklahoma. These cells were constructed primarily “in house”. Excavation was professionally contracted, though not through a bidding process as were the cells listed in Table 4. Final costs for both Cell A and Cell B were $4,753 and $11,479, respectively. This was more than the estimated costs due to increased soil stabilization costs (hydromulching in place of sod), an increase in scope for excavation to include the trenching for the drainage outlets, and increased costs for sand, hauling and labor.

Table 4. Bioretention cell area, volume and cost as bid and constructed by a contractor in Grove, Oklahoma.

Location	Area (m^2)	Volume (m^3)	Bid Cost	Final Cost
Elm Creek Plaza	63	128	$12,496	$12,496
Lendonwood Gardens	23	19	$8,847	$8,847
Grove High School	149	161	$17,071	$17,071
Grand Lake Association	172	435	$29,173	$29,173
Cherokee Queen Riverboats	116	108	$13,796	$13,796
Early Childhood Development Center	48	70	$10,715	$10,715
Spicer Residence	101	93	$11,771	$13,271
Clark Residence	30	27	$7,368	$7,368

Table 5. Bioretention cell area, volume and cost as constructed by Oklahoma State University.

Location	Area (m^2)	Volume (m^3)	Estimated Cost	Final Cost
Cell A	28	66	$3,000	$4,753
Cell B	160	208	$7,000	$11,479

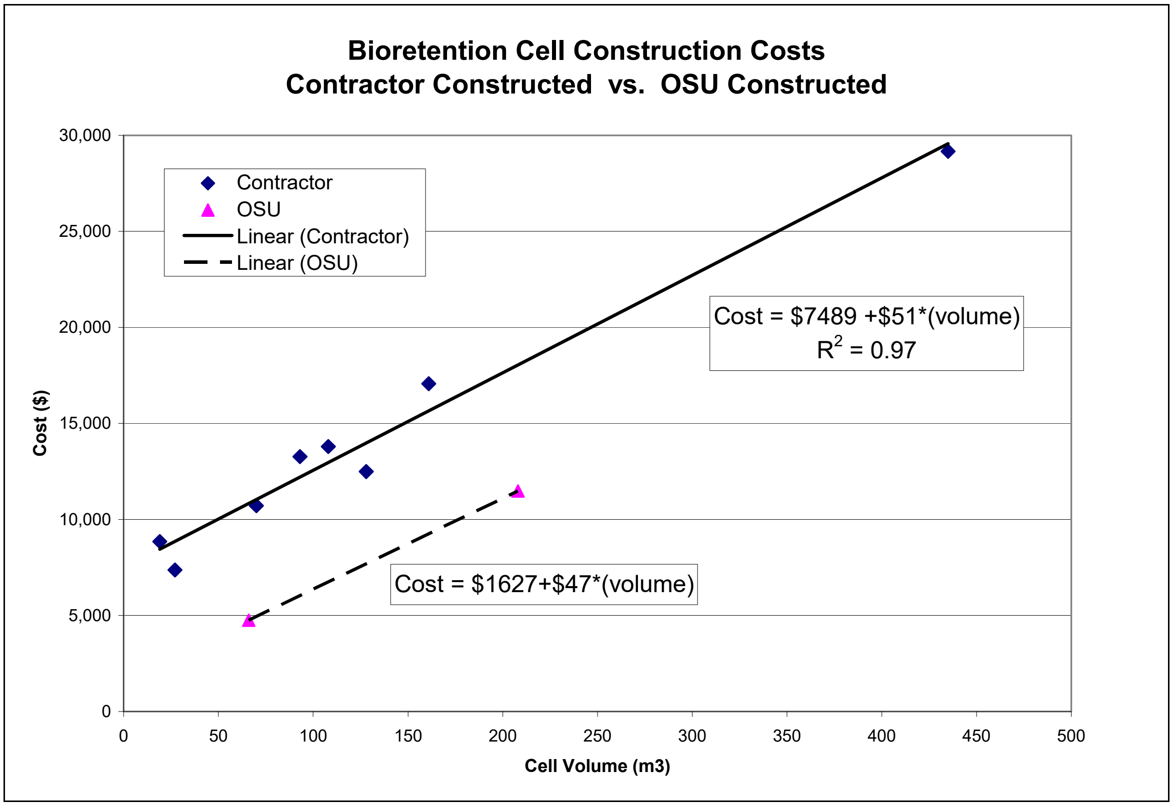

Figure 6. Comparison of Bioretention Cell costs: contractor versus OSU constructed cells

A linear regression equation was fit to cell cost as a function of volume for both contractor and in-house constructed cells in Figure 6. There is a difference of approximately $6,000 between contractor and in-house construction costs for cells of comparable sizes. However, the price difference may decrease as BRC technology becomes more common in the region and contractors learn more about what cell construction entails. Competition may also contribute to a decrease in the cost of contractor constructed projects.

Planting Costs

Planting was not part of the construction contract as bid through the state. Eight of the cells have been planted and are listed in Table 6. Material costs ranged from $526 to $3,025, depending on cell area and plant selection. Quantities were based on 65% surface coverage.

Mulch was included in the construction costs. However, three cells required additional mulch at the time of planting due to losses from cell failure, inadequate mulch size, and submersion from extreme lake water elevations. Three of the cells were planted as volunteer opportunities. The rest were contracted out to the Grove High School FFA as a fund raising activity. Labor costs, as listed in Table 6, were based upon total man-hours required per cell. Plant materials and labor for the two cells in Stillwater will be provided at no cost to this project by the OSU Botanical Gardens as part of the above mentioned environmental research and education program. Photographs of vegetated cells are exhibited in Appendix C.

Table 6. List of Bioretention Cells plant material, mulch, and labor costs in Grove, Oklahoma.

Location	**Area (m^2)**	**Plant Cost**	**Mulch Cost**	**Labor Cost**	**Total Cost**
Elm Creek Plaza	63	$796	$144	$750	$1,690
Lendonwood Gardens[a,b]	23	$546	-	-	$546
Grove High School[a]	149	$1,280	-	$750	$2,030
Grand Lake Association	172	3,025	456	1,000	4,481
Cherokee Queen [a] Riverboats	116	$870	-	$500	$1,370
Early Childhood [a] Development Center	48	$449	-	$400	$849
Spicer Residence[b]	101	$1,094	$150	-	$1,244
Clark Residence[a,b]	30	$526	-	-	$526

a – Mulch was included in the cost of construction and no extra was needed at the time of planting
b – Bioretention cell was planted by volunteers

Community Education

Several educational opportunities were provided throughout the duration of the project ranging from volunteer opportunities to conference presentations and proceedings publications. Community education events within the state of Oklahoma are listed as follows:

- Presentation on bioretention cell construction to the Grand Lake Watershed Foundation, Vinita, Oklahoma, October 13, 2006.
- Participated in Earth Day Celebration April 2007 to educate the public about BRC being constructed around Grove, Oklahoma.
- Kevin Gustavson, Grand Lake Watershed Implementation Project Coordinator, arranged to have volunteers plant the cell at Lendonwood Gardens in July 2007, shown in Figure 7. Rebecca Chavez gave a presentation to the volunteers before the activities commenced.

Figure 7. Volunteers plant the cell at Lendonwood Gardens.

- Poster presentation on bioretention cell design and construction at the 2007 Oklahoma Water Resources Research Institute Symposium and Governor's Water Conference, Oklahoma City, OK, October 23-25.
- Feature article written by Janet Reeder about bioretention cells constructed in Grove, published by the Agricultural Communications Department of Oklahoma State University on the university news website February, 2008, http://www2.dasnr.okstate.edu/Members/katie.reim-40okstate.edu/grove-sees-state2019s-first-bio-retention-cells/.
    - Published in the Altus Times, February 21, 2008.
    - Published in The American, Fairland, OK (Ottawa County) on February 7, 2008.
    - Published in the Perkins Journal, Perkins, OK (Payne County) on Feb. 14, 2008.
    - Published in the Morris News on February 14, 2008.
- Feature article written by Janet Reeder about FFA students participating in bioretention cell project published on the university news website by the Agricultural Communications Department of Oklahoma State University, Spring 2008, http://www2.dasnr.okstate.edu/Members/katie.reim-40okstate.edu/ffa-students-participate-in-201crain-garden201d-project/.
    - Published in The American, Fairland, OK on February 14, 2008.
- Participated in second annual Earth Day celebration at Oklahoma State University to educate the public about BRC. Stillwater, OK, April 22, 2008.

- Presented information about BRC at the Landscape IPM Workshop, Stillwater, OK May 28, 2008.
- Poster presentation on bioretention cell construction and performance at the 2008 Oklahoma Water Resources Research Institute Symposium and Governor's Water Conference, Midwest City, OK, October 28-30.

The project coordinator, Kevin Gustavson, also reported on the bioretention cell task to various groups in the Grand Lake area and beyond. Dozens of presentations were given to audiences covering a wide range of groups including volunteer groups, professional builders and landscapers, environmental groups, government workers, a tribal group, and the general public. The project coordinator also regularly updated local Conservation District Boards on project activities. For details, see "Grand Lake Watershed Implementation Project (Phase I) Final Report" (EPA FY 2004 319(h) C9-996100-12 Project 5).

In addition to formal presentations in the Oklahoma community, there were many opportunities to interact with the public on a regular basis during construction of the cells in Grove. Curious passers by would stop to see what was happening and ask questions about the project in general. Overall, the community was very receptive to the idea of what is being accomplished to help improve water quality in and around Grand Lake. This project was also presented to a broader audience as listed below.

- Presentation on bioretention cell design at the 2006 ASABE Annual International Meeting, Portland, OR, July 9-12, 2006.
- Paper published in conference proceedings. Chavez, R.A., G.O. Brown, and D.E. Storm. 2006. Bioretention Cell Design for Full Scale Project in Grove, Oklahoma. ASABE Paper No. 062305. St. Joseph, Mich: ASABE.

- Presentation on design and construction of bioretention cells in Grove, Oklahoma at the 2nd National Low Impact Development Conference, Wilmington, NC, March 12-14, 2007.
- Presentation on bioretention cell design and construction specifications at the 2007 ASABE Annual International Meeting, Minneapolis, MN, June 17-20.
- Paper published in conference proceedings. Chavez, R.A., G.O. Brown, and D.E. Storm. 2007. Bioretention Cell Design and Construction Specifications. ASABE Paper No. 072268. St. Joseph, Mich: ASABE.
- Poster presentation on bioretention cell construction at the 2008 ASABE Annual International Meeting, Providence, RI, June 29-July 2.
- Paper published in conference proceedings. Chavez, R.A., G.O. Brown, and D.E. Storm. 2008. Bioretention Cell Construction. ASABE Paper No. 084439. St. Joseph, Mich: ASABE.

Monitoring

Per the Quality Assurance Project Plan (QAPP) for this project, water quality monitoring was to occur for at least two storms per season over the two year project term, resulting in a minimum of 16 monitoring sessions for each of the two sites designated by the project team. However, monitoring was delayed for various reasons. The state bidding process was lengthier than anticipated by the researchers, and construction was delayed due to extreme weather.

Grab samples were taken from the effluent and samples were analyzed for nitrate, phosphorus, and heavy metals. Water samples were prepared and stored in accordance with the appropriate ASTM standards described in the QAPP. All samples were analyzed by the

Oklahoma State University Soil, Water, & Forage Laboratory in accordance with the laboratory's Quality Control / Quality Assurance Plan.

Stillwater Cells

Monitoring of the cells in Stillwater began in July 2008. Cell B is divided into two hydraulically separate regions. One region contains the sand / fly ash media blend for the filter layer, and the second contains only sand in the filter layer. This was done in an effort to observe the effectiveness of the fly ash in a quantifiable manner.

Table 7 gives a description of the weather conditions and time of sample collection. It also lists total solids and total suspended solids as measured from the effluent samples. For Cell A, total solids ranged from 140 mg/L to 1100 mg/L. Total solids ranged from 60 mg/L to 410 mg/L for the no fly ash side of Cell B, and from 450 mg/L to 640 mg/L for the side with fly ash. Total suspended solids ranged from 5 mg/L to 46.7 mg/L for Cell A, 0 mg/L to 101.7 mg/L for the sand only side of Cell B, and 6.7 mg/L to 26.7 mg/L for the side of Cell B with fly ash.

A list of common ions and water salinity measures found in the effluent of the cells is presented in Table 8, below. Average electrical conductivity for the cells was 687.9 μS/cm for Cell A, 492.2 μS/cm for the sand only side of Cell B, and 723.3 μS/cm for the fly ash side of Cell B. Total suspended salts (TSS) averaged 512.7 ppm for Cell A, 450 ppm for the sand only side of Cell B, and 505 ppm for the fly ash side of Cell B. Na levels in the effluent from the sand only side of Cell B, on average 11.1 ppm, are lower than those found in Cell A , averaging 119 ppm, or the fly ash side of Cell B, averaging 58.5 ppm. Ca and Mg levels were higher for the sand only side of Cell B than those of the other cells. Whereas K, B, and SO_4 contents were lower from the sand only side of Cell B than from the others.

Table 7. Water quality sample information and initial results for total solids and total suspended solids by cell

Cell	Sample #	Sample Date	Sample Time	Weather	Flowrate (gal/min)	Total Solids (mg/L)	Total Suspended Solids (mg/L)
Cell A - Southern Most Pipe	3	6/17/2008	2:49 PM	Sunny with Heavy Rain @ app. 10:00 that morning		450	38.3
	6	6/18/2008	9:00 AM	Sunny with Heavy Rain @ 7:00 that morning		390	38.3
	9	6/18/2008	2:26 AM	Sunny with Heavy Rain @ 7:00 that morning		140	20.0
	11	7/9/2008	3:35PM	Sprinkles with Heavy Rain on & off all morning		410	31.7
	13	7/9/2008	7:45PM	Sprinkles with Heavy Rain on & off all morning		750	46.7
	16	7/13/2008	10:40 AM	Clear with Heavy Rain all night (3in in last 24hrs)	0.1680	1100	5.0
	19	7/13/2008	2:01 PM	Clear with Heavy Rain all night (3in in last 24hrs)	0.0573	1070	13.3
	22	7/13/2008	5:30 PM	Clear with Heavy Rain all night (3in in last 24hrs)		980	26. 7
Cell B- South -No Fly Ash	2	6/17/2008	2:52 PM	Sunny with Heavy Rain @ app. 10:00 that morning		60	10.0
	5	6/18/2008	8:55 AM	Sunny with Heavy Rain @ 7:00 that morning		310	5.0
	7	6/18/2008	2:23 AM	Sunny with Heavy Rain @ 7:00 that morning.		340	0.0
	10	7/9/2008	3:35 PM	Sprinkles with Heavy Rain on & off all morning		410	1.7
	12	7/9/2008	7:45PM	Sprinkles with Heavy Rain on & off all morning		370	0.0
	15	7/13/2008	10:40 AM	Clear with Heavy Rain all night (3in in last 24hrs)	0.807	410	76.7
	18	7/13/2008	2:01 PM	Clear with Heavy Rain all night (3in in last 24hrs)	0.652	370	101.7
	21	7/13/2008	5:30 PM	Clear with Heavy Rain all night (3in in last 24hrs)	0.303	240	91.7
Cell B- North - Fly Ash	1	6/17/2008	2:53 PM	Sunny with Heavy Rain @ app. 10:00 that morning		600	6.7
	4	6/18/2008	8:50 AM	Sunny with Heavy Rain @ 7:00 that morning.		450	13.3
	8	6/18/2008	2:22 PM	Sunny with Heavy Rain @ 7:00 that morning.		640	10.0
	14	7/13/2008	10:40 AM	Clear with Heavy Rain all night (3in in last 24hrs)	0.968	650	26.7
	17	7/13/2008	2:01 PM	Clear with Heavy Rain all night (3in in last 24hrs)	0.594	570	30.0
	20	7/13/2008	5:30 PM	Clear with Heavy Rain all night (3in in last 24hrs)	0.361	600	25.0

Table 8. Common ions and water salinity measures by cell

Cell	Sample #	EC (µS/cm)	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cl (ppm)	SO4 (ppm)	B (ppm)	TSS (ppm)	PAR (%)	SAR (%)	EPP (%)	ESP (%)
Cell A - Southern Most Pipe	3	487	100	7	4	0	18.94	36.7	1.57	321	0.56	13.6	8.7	15.7
	6	423	77	6	23	2	5.49	40.3	1.63	366	0.19	4.1	5.3	4.5
	9	502	94	7	20	0	6.53	55.2	2.04	377	0.25	5.7	5.8	6.6
	11	485	32	7	32	9	7.4	38	1.9	320	0.17	1.3	5.1	0.6
	13	744	165	12	18	1	9.95	103.3	3.23	554	0.43	10.1	7.5	11.9
	16	1259	167	20	13	0	12.57	135.6	4.53	831	0.9	12.7	11.5	14.8
	19	281	161	21	13	1	13.84	142.1	4.24	460	0.9	11.7	11.6	13.8
	22	1322	156	21	22	0	12.06	143.1	4.63	873	0.72	9.1	10	10.8
Cell B- South -No Fly Ash	2	500	11	6	76	18	5.09	21.1	0.22	418	0.09	0.3	4.4	0
	5	472	10	6	72	17	1.01	17.2	0.2	400	0.1	0.3	4.4	0
	7	520	11	6	80	19	3.65	18.9	0.18	462	0.09	0.3	4.4	0
	10	687	14	8	105	26	6.66	32.8	0.23	616	0.11	0.3	4.5	0
	12	678	15	8	102	25	6.42	29.6	0.24	637	0.11	0.3	4.5	0
	15	333	9	7	54	12	7.54	13.3	0.08	355	0.13	0.3	4.7	0
	18	369	10	7	55	13	7.31	13.9	0.09	373	0.13	0.3	4.7	0
	21	379	9	7	56	13	6.27	14.1	0.12	337	0.13	0.3	4.7	0
Cell B- North - Fly Ash	1	843	59	14	39	0	6.31	77.5	3.13	556	0.36	2.6	6.9	2.5
	4	506	51	10	15	0	2.98	73.6	2.83	334	0.42	3.6	7.4	3.9
	8	617	62	13	17	0	5.59	81.9	3.23	574	0.5	4	8.1	4.4
	14	759	60	17	36	0	7.04	84.8	3.23	501	0.45	2.7	7.7	2.7
	17	793	60	18	41	0	6.06	86.5	3.32	523	0.45	2.6	7.7	2.5
	20	822	59	18	60	0	5.99	89.2	3.36	543	0.38	2.1	7	1.8

Nitrate and phosphorus contents were also measured in the effluent of the cell, as exhibited in Table 9. Effluent pH values were lower for the sand only side of Cell B than for either the fly ash side of Cell B or Cell A. Alkalinity was lower in the effluent samples taken from Cell A and the fly ash side of Cell B, than for the sand only side of Cell B. NO_3-N was lower in the effluent collected from the sand only side of Cell B. However, Ortho-P content measured in the effluent from the fly ash side of Cell B were lower than that measured in the effluent from the sand only side of the same cell.

Table 9. Effluent pH, nutrients, and alkalinity by cell

Cell	Sample #	pH	NO3_N (ppm)	CO3 (ppm)	HCO3 (ppm)	Hardness (ppm)	Alkalinity (ppm)	Ortho - P
Cell A - Southern Most Pipe	3	9.5	2.84	63.2	80	10	169	0.22
	6	8.4	2.58	3.1	206.8	66	175	0.32
	9	9	3.71	32.9	156.9	52	183	0.18
	11	7.4	4.03	-	182.5	117	150	1.12
	13	9	8.18	35.4	200.8	51	223	1.64
	16	10.1	13.87	107.2	0	33	165	0.06
	19	10.1	14.11	91.3	3.9	35	153	nes
	22	7.3	14.1	-	95.6	56	78	0.07
Cell B- South -No Fly Ash	2	7.9	4.53	-	276.3	263	226	0.16
	5	8.1	3.61	-	272.6	249	223	0.1
	7	8.1	3.88	-	320.3	277	263	0.18
	10	7.6	6.78	-	417.5	368	342	0.13
	12	7.3	6.6	-	445.5	356	365	0.14
	15	7.3	0.71	-	251	186	206	0.06
	18	7.5	0.51	-	267.6	189	219	0.07
	21	6.8	0.93	-	231.2	194	190	0.08
Cell B- North - Fly Ash	1	10.4	3.59	126.2	32.8	97	158	0.07
	4	9.7	2.85	51.3	9.3	37	92	0.07
	8	10	3.13	70.5	320.3	45	111	0.07
	14	9.3	8.73	70.7	0	92	106	0.05
	17	9.3	8.73	24.2	80.7	103	106	0.06
	20	10	8.68	62.6	54.8	151	148	0.06

Metal contents were also measured in the effluents from the two cells as listed in Table 10. Marked differences are visible in the Fe contents when comparing both sides of Cell B. The effluent from the fly ash side of Cell B had lower Fe contents, ranging from 0.06 ppm to 0.19 ppm, than the sand only side which had contents ranging from 0.10 ppm to 5.81 ppm.

Table 10. Metal content measured in cell effluent.

Cell	Sample #	Fe (ppm)	Cu (ppm)	Pb (ppm)
Cell A - Southern Most Pipe	3	0.60	0.03	<.02
	6	2.48	0.02	<.02
	9	18.39	0.02	0.06
	11	0.97	0.02	<.02
	13	2.69	0.02	<.02
	16	0.64	0.07	0.03
	19	0.52	0.07	<.02
	22	0.34	0.07	0.03
Cell B- South -No Fly Ash	2	0.10	<.02	<.02
	5	0.13	<.02	<.02
	7	0.35	0.03	<.02
	10	0.44	<.02	<.02
	12	0.11	<.02	<.02
	15	5.77	<.02	<.02
	18	5.60	<.02	<.02
	21	5.81	<.02	<.02
Cell B- North - Fly Ash	1	0.06	0.03	<.02
	4	0.13	0.02	0.05
	8	0.19	0.02	<.02
	14	0.14	0.02	<.02
	17	0.08	0.02	<.02
	20	0.13	0.02	<.02

Grove Cells

Storm events were simulated for the cells at Grove High School and the Grand Lake Association in Grove in August 2008. The primary objective of the experiments was to quantify the cell hydraulic performance. Treated city water was supplied from fire mains. While not representative of treatment efficiency, water samples were taken during the tests to provide insight into any possible leaching from cell materials. Two 12-hour storms were simulated at Grove High School, the first was a 25-year event and the second was a 10-year event to observe a wet initial condition. The storm at the Grand Lake Association was a 5-year 12-hour event. Samples were collected at the inlet, outlet, and overflow at both cells. Total dissolved solids, total solids, and metal contents for samples taken from Grove High School for the initial dry condition, 25-year storm, are reported in Table 11. The same parameters are reported for the samples taken from the Grand Lake Association for the initial dry condition and Grove High School for the wet initial condition in Table 12 and Table 13, respectively. Results show that no significant leaching occurred from the cells' material.

Lessons Learned

Overall, the design process translated well to the construction of the BRC for this project. However, lessons were learned in the field and are presented in this section.

Mixing fly ash in the field presented a challenge and was approached using the two previously described methods. The challenge arose in ensuring an adequately mixed medium on such a large scale, and neither method was considered adequate. Samples were taken during placement and the variability is being quantified now and will be reported at a later date.

Table 11. Grove High School - Dry Initial Condition

	Bottle ID	Sample Date	Sample Time	Sample #	Total Solids (mg/L)	Sample #	Total Suspended Solids (mg/L)	Sample #	Fe (ppm)	Cu (ppm)	Pb (ppm)
Inlet	1A	8/2/2008	7:08	1	300	1	100	1	0.08	<.02	0.05
	2A	8/2/2008	8:05	2	500	2	100	2	0.10	<.02	<.02
	3A	8/2/2008	9:32	3	500	3	100	3	0.12	<.02	<.02
	4A	8/2/2008	11:03	4	200	4	100	4	0.05	<.02	0.02
	5A	8/2/2008	12:38 p	5	300	5	100	5	0.03	<.02	0.02
Outlet	1B	8/2/2008	7:38	6	400	6	100	6	0.02	<.02	<.02
	2B	8/2/2008	8:01	7	300	7	0	7	0.14	<.02	<.02
	3B	8/2/2008	8:31	8	300	8	0	8	0.05	<.02	<.02
	4B	8/2/2008	9:06	9	200	9	200	9	0.03	<.02	<.02
	5B	8/2/2008	9:34	10	200	10	100	10	0.06	<.02	<.02
	6B	8/2/2008	10:06	11	400	11	0	11	0.03	<.02	<.02
	7B	8/2/2008	10:33	12	200	12	0	12	0.04	<.02	<.02
	8B	8/2/2008	11:04	13	200	13*	90	13	0.04	<.02	<.02
	9B	8/2/2008	11:35	14	200	14*	40	14	0.04	<.02	<.02
	10B	8/2/2008	12:21 p	15	200	15*	16	15	0.09	<.02	<.02
	11B	8/2/2008	1:03	16	100	16*	90	16	0.04	<.02	<.02
	12B	8/2/2008	1:40	17	200	17	0	17	0.11	<.02	<.02
	13B	8/2/2008	3:27	18	100	18	100	18	0.05	<.02	<.02
	14B	8/2/2008	7:55					19	0.03	<.02	<.02
Overflow	1C	8/2/2008	9:02	19	0	19	100	20	0.34	<.02	<.02
	2C	8/2/2008	9:48	20	0	20	100	21	0.16	<.02	<.02
	3C	8/2/2008	10:32	21	0	21	0	22	0.10	<.02	0.02
	4C	8/2/2008	11:18	22	100	22	100	23	0.21	<.02	<.02
	5C	8/2/2008	12:03 p	23	0	23	100	24	0.17	<.02	<.02
	6C	8/2/2008	12:38	24	100	24	0				

Table 12. Grand Lake Association - Dry Initial Condition

	Bottle ID	Sample Date	Sample Time	Sample #	Total Solids (mg/L)	Sample #	Total Suspended Solids (mg/L)	Sample #	Fe (ppm)	Cu (ppm)	Pb (ppm)
Inlet	1A	8/3/2008	8:16	25	100	25	0	25	0.11	<.02	0.02
	2A	8/3/2008	10:16	26	100	26	140	26	0.04	<.02	<.02
	3A	8/3/2008	12:43 p	27	100	27	50	27	0.14	<.02	<.02
	4A	8/3/2008	2:15	28	300	28	60	28	0.11	<.02	<.02
Outlet	1B	8/3/2008	8:31	29	1000	29*	220	29	0.66	<.02	0.02
	2B	8/3/2008	9:37	30	400	30	80	30	0.21	<.02	0.03
	3B	8/3/2008	10:42	31	300	31	50	31	0.71	<.02	<.02
	4B	8/3/2008	11:32	32	1100	32	30	32	0.08	<.02	0.03
	5B	8/3/2008	12:30 p	33	400	33	20	33	0.13	<.02	0.03
	6B	8/3/2008	1:31	34	400	34	30	34	0.20	0.06	<.02
	7B	8/3/2008	2:29	35	600	35	0	35	0.23	<.02	0.03
	8B	8/3/2008	3:30	36	400	36	30	36	0.36	<.02	<.02
	9B	8/3/2008	5:46	37	400	37	0	37	0.16	<.02	<.02
	10B	8/3/2008	12:12 a	38	400	38	40	38	0.16	<.02	<.02
	11B	8/3/2008	5:20	39	220	39	0				
Overflow	1C	8/3/2008	10:29	40	30	40	30	39	0.64	<.02	<.02
	2C	8/3/2008	11:15	41*	70	41	0	40	0.39	<.02	<.02
	3C	8/3/2008	12:02 p	42	60	42	60	41	0.15	<.02	<.02
	4C	8/3/2008	12:43	43*	20	43	0	42	0.06	<.02	0.02
	5C	8/3/2008	1:29	44	200	44	0	43	0.23	<.02	<.02
	6C	8/3/2008	1:46	45	120	45	100	44	0.15	<.02	<.02
	7C	8/3/2008	2:04	46	90	46	30	45	0.12	<.02	<.02
	8C	8/3/2008	2:24	47	90	47	0	46	0.12	0.11	<.02
	9C	8/3/2008	2:52	48	-10	48	57	47	0.07	<.02	<.02
	10C	8/3/2008	3:05	49	80	49	50	48	0.07	<.02	<.02

Table 13. Grove High School - Wet Initial Condition

	Bottle ID	Sample Date	Sample Time	Sample #	Total Solids (mg/L)	Sample #	Total Suspended Solids (mg/L)	Sample #	Fe (ppm)	Cu (ppm)	Pb (ppm)
Inlet	1A	8/3/2008	8:11 p	50	140	50	60	49	0.05	<.02	<.02
	2A	8/3/2008	8:41	51	90	51	100	50	0.04	<.02	<.02
	3A	8/3/2008	9:11	52	160	52	10	51	0.03	<.02	<.02
	4A	8/3/2008	9:41	53	100	53	50	52	0.03	<.02	<.02
	5A	8/3/2008	10:31	54	10	54	30	53	0.17	<.02	0.02
Outlet	1B	8/3/2008	8:03 p	55	170	55	30	54	0.07	<.02	<.02
	2B	8/3/2008	8:30	56	80	56	0	55	0.09	<.02	<.02
	3B	8/3/2008	9:00	57	30	57	130	56	0.03	<.02	<.02
	4B	8/3/2008	9:29	58	260	58	0	57	0.18	<.02	<.02
	5B	8/3/2008	10:01	59	200	59	80	58	0.05	<.02	<.02
	6B	8/3/2008	10:33	60	70	60	10	59	0.08	<.02	<.02
	7B	8/3/2008	11:01	61	200	61	70	60	0.09	<.02	<.02
	8B	8/3/2008	11:30	62	180	62	0	61	0.07	<.02	<.02
	9B	8/3/2008	12:39 a	63	260	63	120	62	0.01	<.02	<.02
	10B	8/3/2008	5:40	64	300	64	0	63	0.15	<.02	<.02
	11B	8/3/2008	7:58	65	270	65	0				
Overflow	1C	8/3/2008	9:51 p	66	150	66	0	64	0.26	<.02	<.02
	2C	8/3/2008	10:07	67	210	67	0	65	0.13	<.02	<.02
	3C	8/3/2008	10:21	68	150	68	0	66	0.24	<.02	<.02
	4C	8/3/2008	10:37	69	20	69	110	67	0.13	<.02	<.02
	5C	8/3/2008	10:56	70	170	70	0	68	0.08	<.02	<.02
	6C	8/3/2008	11:06	71	100	71	0	69	0.12	<.02	<.02
	7C	8/3/2008	-	72	150	72	0	70	0.18	<.02	<.02
	8C	8/3/2008	11:11	73	130	73	10	71	0.17	<.02	<.02

Fly ash storage is an issue that needs to be addressed. During the construction phase of this project, Oklahoma experienced significant rain. Fly ash exhibits pozzolanic characteristics when exposed to even small amounts of moisture. Clots of fly ash are formed and it is difficult to sift through the large quantities of fly ash to effectively remove them. This poses many issues of concern such as effective sorption capacity, preferential flow within a non-uniform medium, and achieving an even blend of sand and fly ash. The contractor stored the fly ash underground in a pit and covered it with a tarp. A similar method was used for short term storage at the Stillwater site. Under typical climate conditions this would be appropriate. However, a better solution would be to store the fly ash in weather proof/resistant vessel such as a trailer.

Utilities presented another challenge. During the design phase of the project, every effort was made to avoid placing cells near utilities. We called the state call dig number (utility locator), worked with city employees, and studied as-builts. However, in an urban setting, good planning does not always mean that utilities will not be an issue. As a result, we were forced to work around the utilities at a few sites during construction. We were fortunate that the Grove contractor was experienced working with utilities and was very careful about digging, even when we had received clearance at a site.

Another point of interest is to observe the differences in capabilities and costs when comparing construction by a contractor versus construction in-house. On average, the contractor was able to complete a cell within four days, with three people, a backhoe and a bobcat. The cells constructed by OSU averaged six days, using five people, two tractors, a dingo, and a roto-tiller. Most of the additional time required for the in-house construction was during the backfilling process. The contractor was able to use heavy equipment with a greater capacity for moving soil than the process employed by the in-house team, which relied more on man-power and smaller, more readily available equipment. It costs approximately $6,000 more to have a contractor build a cell. However, it takes half the time and considerably less man power and equipment. Differences in cost and labor are attributed to the issues surrounding man versus machine and in-house versus contractor labor.

There were two cell failures. The first was at Elm Creek Plaza, where the cell receives runoff from a parking lot and sits on a stream bank. Berm failure occurred due to fugitive water from a neighboring property during a 50 year storm, providing roughly twice the design flow. The flow destroyed the overflow weir that was poorly placed on the streambank. The cell was repaired and reinforced, and the overflow was moved to a different location to alleviate the possibility of a repeated failure. The property owner also had the channel between the two properties cleaned out and deepened. One positive outcome is that immediate benefits with regard to erosion have been observed at this site. During construction it was necessary to rebuild the bank as it had eroded substantially in the time between the design and construction phases, and the cell would not have fit as designed.

The second failure was at the Spicer residence. The cell is located near the lakefront, above the GRDA takeline and the U.S. Army Corps of Engineer's regulation line. Excessive rains after a long period of drought have caused the lake to rise to unusually high elevations. The shore effects at the high lake elevations caused erosion of the cell berm. Repairs commenced once the water receded. The berm was repaired and reinforced. High water levels around the lake area also delayed construction and submerged the Cherokee Queen cell, but caused no significant damage.

Conclusion

Via this project ten demonstration bioretention cells have been built in Oklahoma; eight in Grove and 2 in Stillwater. Cells range in size from 19 m^3 to 435 m^3 (25 to 569 yd^3), and embrace residential, commercial, and public sites. The cell filter media incorporates fly ash to provide additional sorption and removal of phosphorous. Extensive public education efforts have been completed including special events, youth lectures and news releases. Public education efforts will continue as part of the Oklahoma Agricultural Extension Service and Oklahoma Agricultural Experiment Station. Technical results at this time are limited to the design, building processes, costs and construction issues. Those results have been presented at state and national professional meetings. At this time, the monitoring results are inadequate to provide strong conclusions. Testing and monitoring of the cells will continue under separate funding, and will be reported in referred literature as appropriate.

Having a construction crew (Ball Construction) who took an interest in the project and was willing to re-work the cells made a huge difference in the success of this project. Along with EPA funding, Oklahoma State University's contractual and in-kind support and the property owners' participation, Oklahoma Conservation Commission once again demonstrates its commitment to finding ways to meet the intention of §319 of the Clean Water Act as evidenced in this project.

References

Chavez, R.A., G.O. Brown, and D.E. Storm. 2006. Bioretention Cell Design for Full Scale Project in Grove, Oklahoma. ASABE Paper No. 062305. St. Joseph, Mich: ASABE.

Chavez, R.A., G.O. Brown, and D.E. Storm. 2007. Bioretention Cell Design and Construction Specifications. ASABE Paper No. 072268. St. Joseph, Mich: ASABE.

Hershfield, D. M. 1961. Technical paper No. 40: Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. Engineering Division, Soil Conservation Commission Service, USDA. Washington, D.C.

Holtz, R. D. and W. D. Kovacs. 1981. *An Introduction to Geotechnical Engineering*, 104-105. Englewood Cliffs, NJ: Prentice Hall.

Hunt, Bill. Bioretention / Rain Garden Hydraulic & Hydrologic Design Worksheet. NCSU, Raleigh, NC. Available at: http://legacy.ncsu.edu/classes-a/bae/cont_ed/bioretention/lecture/rain_garden.pdf. Accessed on 12 October 2005.

Hunt, W. F and N. White. 2001. Designing Rain Gardens (Bio-Retention Areas). Urban Waterways. AG-588-3. Raleigh, NC: North Carolina Cooperative Extension Service.

Hunt, W.F. (2003) Pollutant removal evaluation and hydraulic characterization for bioretention stormwater treatment devices. PhD dissertation. Department of Agricultural and Biological Engineering, the Pennsylvania State University, PA.

Klute, A. and C. Dirkson. 1986. Chapter 28; “Hydraulic Conductivity and Diffusivity: Laboratory Methods” in Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. American Society of Agronomy and Soil Science Society America, Madison, WI.

Low Impact Development (LID) Center. 2003. Urban Design Tools. Beltsville, MD: Low impact Development Center, Inc. Available at: www.lid-stormwater.net. Accessed 5 October 2005.

McWhorter, D.B. and D.K. Sunada, 1977. Ground water hydrology and hydraulics. Water Resources Pub., Fort Collins, CO.

Munson, B.R.; D.F. Young; T.H. Okiishi, 1994. *Fundamentals of Fluid Mechanics: Second Edition*. 680-681. New York, NY: Wiley and Sons, Inc.

Perry, Megan. 2006. Personal Communications. Stillwater, OK.

Prince George’s County Department of Environmental Resources (PGDER). 2002. Bioretention manual. Program & Planning Division, Department of Environmental Resources, Prince George’s County, MD.

Texas Department of Transportation. 2000. TXDOT Project Development Training: Hydraulic Design. Austin, TX: Human Resources Division Training, Quality and Development Technical Training Section.

U.S. Environmental Protection Agency (USEPA). 1999. Storm water technology fact sheet: Bioretention. *EPA 832-F-99-012*, USEPA, Washington, DC.

Zhang, W. 2006. Improvement of Phosphorus and Heavy Metal Retention in Stormwater Treatment. MS thesis. Stillwater, Oklahoma: Oklahoma State University. Department of Biosystems and Agricultural Engineering.

Appendix A

Deliverables

Subtask #	Description	Due Date	Date Submitted
5.3.1	QAPP	August 2006	August 17, 2006
5.3.2	Letter report describing demonstration of media suitable for use in the prototype bioretention cells and an evaluation of the media places in the cells	April 2007	October 16, 2006
5.3.3	Publish designs for bioretention cells in commercial and residential areas	March 2007, 2008	October 16, 2006
5.3.3	Identify cooperators and write contracts for ten bioretention cells (at least 9 in the Grand Lake Watershed)	March 2007, 2008	February 15, 2007
5.3.4	Report documenting the public learning session(s)-documentation will include a measure of the volunteer-time devoted to these learning sessions and other volunteer time related to the project.	To be included in final report	December 2008
5.3.5	Water quality analysis of cell influent and effluent and seepage to groundwater	October 2008	December 2008
5.3.6	Final Report	October 2008	December 2008

Appendix B

Photographs of Bioretention Cell Construction Sites

Cherokee Queen

Top Left: Site prior to cell construction. **Middle Left:** Adding fly ash to sand. **Bottom left:** Mixing fly ash and sand for filter layer. **Top Right:** Completed drainage. **Middle Right:** Alternate view of drainage. **Bottom Right:** Front end loader backfilling filter media.

Cherokee Queen

Top Left: Partially backfilled cell. **Middle Left:** Flags marking sand plug locations. **Bottom left:** Completed top soil / sand plug layer. **Top Right:** Application of hardwood mulch. **Middle Right:** Completed, unplanted cell. **Bottom Right:** Overflow weir.

Grand Lake Association

Top Left: Site prior to cell construction. **Middle Left:** Installation of silt fence. **Bottom left:** Removal of grass from designated excavation area. **Top Right:** Marking cell location. **Middle Right:** Cell excavation. **Bottom Right:** View of 1:1 side slope during excavation.

Grand Lake Association

Top Left: Reading elevations to establish excavation depth. **Middle Left:** Excavation of trench for drainage outlet. **Bottom left:** Installation of drainage outlet. **Top Right:** Front loader leveling cell floor. **Middle Right:** Completed excavation. **Bottom Right:** Installing drainage system.

Grand Lake Association

Top Left: Securing filter fabric to drainage pipes to prevent clogging. **Middle Left:** Bobcat loading sand to cover drainage pipes. **Bottom left:** Front end loader covering drainage pipes with sand. **Top Right:** Bobcat applying sand to cell. **Middle Right:** Blending sand/fly ash filter medium. **Bottom Right:** Heavy equipment blending sand and fly ash.

Grand Lake Association

Top Left: Leveling one filter layer lift. **Middle Left:** Sand plug placement. **Bottom left:** Completed top soil/sand plug layer. **Top Right:** Application of mulch. **Middle Right:** View of overflow weir. **Bottom Right:** Completed overflow weir.

Grove High School

Top Left: Site prior to cell construction. **Middle Left:** View of rocky soil conditions encountered during excavation of this site. **Bottom left:** Cell excavation. **Top Right:** Application of sand lift prior to drainage pipe placement due to rocky site conditions. **Middle Right:** Drainage pipe placement. **Bottom Right:** Securing filter fabric to drainage pipe.

Grove High School

Top Left: Installation of outlet drainage. **Middle Left:** Placement of filter layer lift. **Bottom left:** Sand plug placement. **Top Right:** Front end loader placing top soil around sand plugs. **Middle Right:** View of completed, unplanted cell from inlet. **Bottom Right:** View of completed, unplanted cell from overflow weir.

Lendonwood Gardens

Top Left: Site prior to cell construction. **Middle Left:** View of cell outline **Bottom left:** Cell excavation. **Top Right:** View of completed cell and outlet excavation. **Middle Right:** Marking sand plug locations. **Bottom Right:** View of flags marking sand plug outlines.

Lendonwood Gardens

Top Left: Front end loader placing sand plugs in designated locations. **Middle Left:** Measuring sand plug height. **Bottom left:** Filling top soil around sand plugs. **Top Right:** Leveling top soil / sand plug layer. **Middle Right:** Vegetation layout for cell. **Bottom Right:** Volunteer group of Master Gardeners planting cell.

Elm Creek Plaza

Top Left: Site prior to cell construction. **Middle Left:** Drainage pipe layout. **Bottom left:** Load of mixed filter medium ready to be placed in cell. **Top Right:** Completed drainage. **Middle Right:** View of liner used to stabilize cell wall. **Bottom Right:** Installation of one lift of filter layer.

Elm Creek Plaza

Top Left: Placement of top soil around sand plugs. **Middle Left:** Completed cell after a rain event. **Bottom left:** View of damaged cell. **Top Right:** View of reinforced stream bank behind cell. **Middle Right:** Front end loader placing rock to reinforce stream bank. **Bottom Right:** View of repaired cell.

Early Childhood Development Center

Top Left: Site prior to cell construction. **Middle Left:** Removing sod from designated excavation area. **Bottom left:** Outlining cell shape and location. **Top Right:** Measuring elevations along cell edges. **Middle Right:** View of cell layout. **Bottom Right:** Front end loader beginning cell excavation.

Early Childhood Development Center

Top Left: View of cell with monitoring wells in center. **Middle Left:** Installation of overflow weir. **Bottom left:** Measuring location for drainage outlet. **Top Right:** View of drainage outlet. **Middle Right:** Grove High School FFA students digging holes to plant vegetation. **Bottom Right:** FFA students planting cell.

Clark Residence

Top Left: Site prior to cell construction. **Middle Left:** Drilling to obtain soil samples for site survey. **Bottom left:** Reading elevation and coordinates from GPS unit during site survey. **Top Right:** Excavated cell filled with water after a storm during construction. **Middle Right:** Assembly of air hammer. **Bottom Right:** Start of tunnel under golf path for drainage outlet.

Clark Residence

Top Left: Air hammer tunneling under golf path. **Middle Left:** Installation of drainage outlet. **Bottom left:** Completed, unplanted cell. **Top Right:** OSU engineer planting cell. **Middle Right:** OCC project coordinator planting cell. **Bottom Right:** View of plant layout for cell.

Spicer Residence

Top Left: Site prior to cell construction. **Middle Left:** View of cell boundaries. **Bottom left:** Drainage outlet installation. **Top Right:** Cell excavation. **Middle Right:** Installation of drainage system. **Bottom Right:** Placement of filter layer lift.

Spicer Residence

Top Left: View of filter layer lift. **Middle Left:** Receiving a truck load of sand. **Bottom left:** Placing top soil around sand plugs. **Top Right:** Leveling top soil/sand plug layer. **Middle Right:** View of rock inlet. **Bottom Right:** View of completed, unplanted cell.

Botanical Gardens (Cells A & B)

Top Left: Excavation of Cell B. **Middle Left:** Construction of berms for Cell B. **Bottom left:** Excavation of Cell A. **Top Right:** Excavation of drainage outlet for Cell B. **Middle Right:** Hydromulching cell berms. **Bottom Right:** View of hydromulched berm for Cell B.

Botanical Gardens (Cells A & B)

Top Left: Drainage layout for Cell B. **Middle Left:** Completed drainage system for Cell B. **Bottom left:** Measuring plastic barrier to hydraulically separate Cell B. **Top Right:** Placement of plastic barrier in Cell B. **Middle Right:** Securing the bottom of the plastic barrier under a layer of sand. **Bottom Right:** Spreading sand for filter layer in Cell B.

Botanical Gardens (Cells A & B)

Top Left: Dingo leveling sand lift. **Middle Left:** Adding fly ash to sand. **Bottom left:** Dingo spreading fly ash evenly over sand lift. **Top Right:** Spreading fly ash over sand lift. **Middle Right:** Tilling fly ash into sand lift. **Bottom Right:** Completed filter layer.

Botanical Gardens (Cell A & B)

Top Left: Collecting samples from tilled filter layer lift in Cell A. **Middle Left:** Manually spreading fly ash over sand lift. **Bottom left:** Adding fly ash to sand lift. **Top Right:** Tilling fly ash into sand lift. **Middle Right:** Sand plug locations. **Bottom Right:** View of sand plug placement.

Appendix C

Photographs of Completed Bioretention Cells

Cherokee Queen

Early Childhood Development Center

Grand Lake Association

Elm Creek Plaza

Grove High School

Lendonwood Gardens

Clark Residence

Spicer Residence

Appendix D

Plans, Specifications, and Estimate Package for
the Construction of the Bioretention Cells
(see attached)