Evaluation of Field-Scale Stormwater Bioretention cells Hydrology and Nutrient Removal in the Arroyo Colorado Watershed, Texas

Juan Carlos Roman Perez*, Pamela Mugisha*, Tushar Sinha and Kim Jones
Graduate Research Assistant
Environmental Engineering, Texas A&M University – Kingsville

Objectives

1. Evaluate the bioretention system with different media to determine their effectiveness in improving water quality (TKN, TP, BOD5, and *E. coli*)

2. Evaluate the effectiveness of bioretention system aggregate media in reducing stormwater volume under different storm intensities

3. Determine suitable locations for bioretention cells to reduce stormwater runoff and enhance water quality

Arroyo Colorado Watershed

- Increase in industrial and population growth
- Tidal and Above Tidal segments (2201 – 2202) have concerns about elevated nutrient and bacteria levels in the river.
- A Watershed Protection Plan (WPP) was completed on 2007 and updated in 2017 to address both DO and Bacteria impairment.

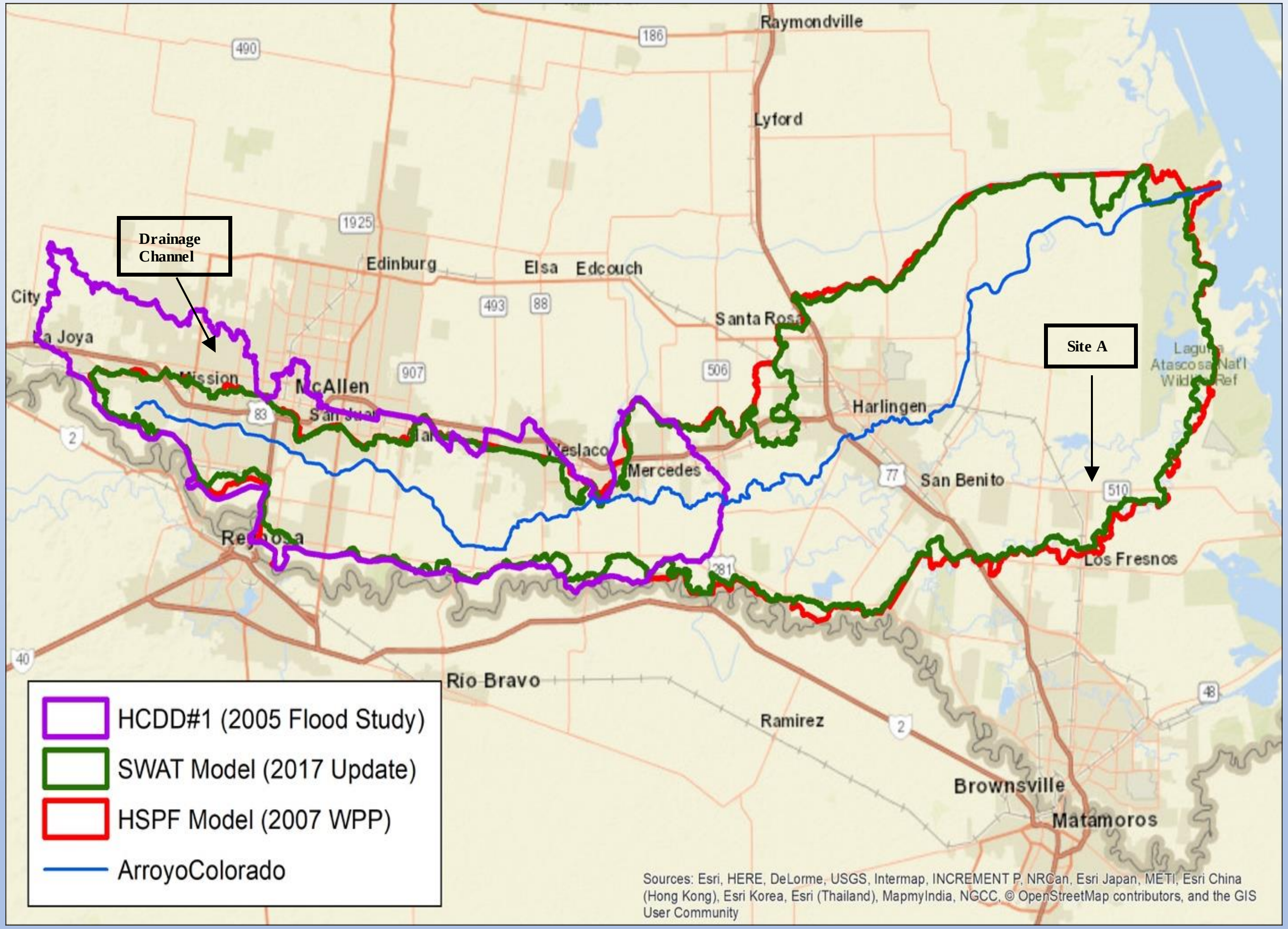


Fig 1. Arroyo Colorado Watershed Map (Source: TCEQ ACWPP QAPP, 2020)

Bioretention Cells for Stormwater Runoff Management

- Bioretention decreases peak flow discharge by retaining the captured stormwater runoff for a longer time by infiltration through filter media.
- Infiltrate 85 to 90% of the annual stormwater runoff.
- Properly designed bioretention areas will remove suspended solids, metals, and nutrients.

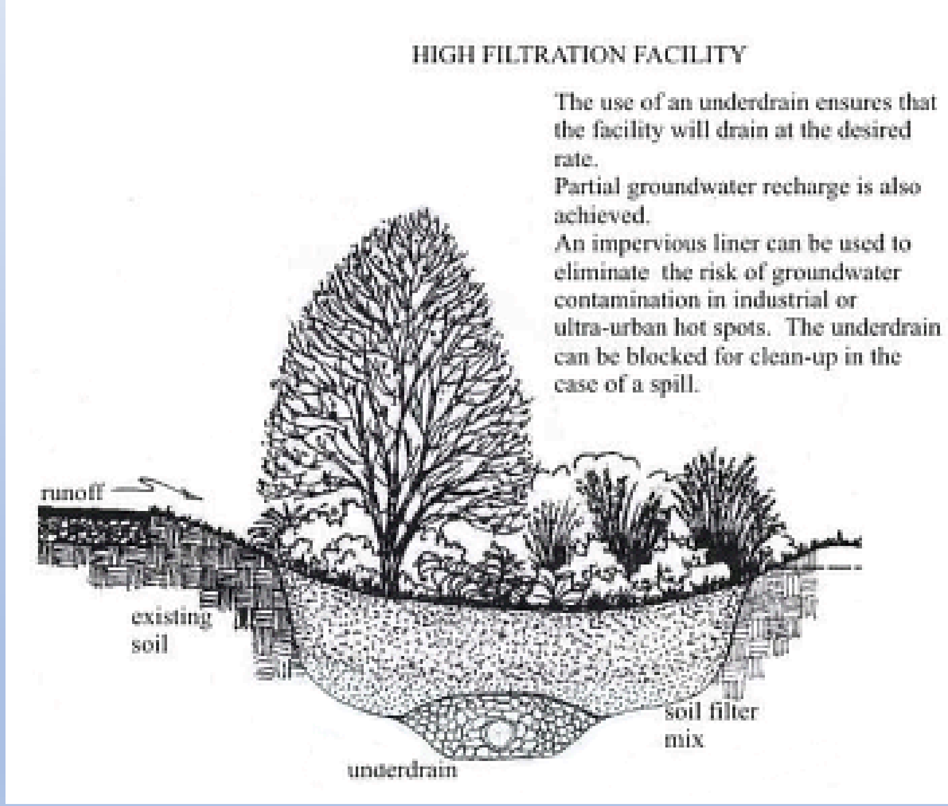


Fig 2. Typical bioretention cell.
(Source: lid-stormwater.net)

Bioretention cell layers

- Bioretention cell layers vary and are based on a baseline design.
- A common example is:
- Mulch and vegetated surface layer
- Porous soil media (usually sand as main component)
- Layer of gravel at the bottom

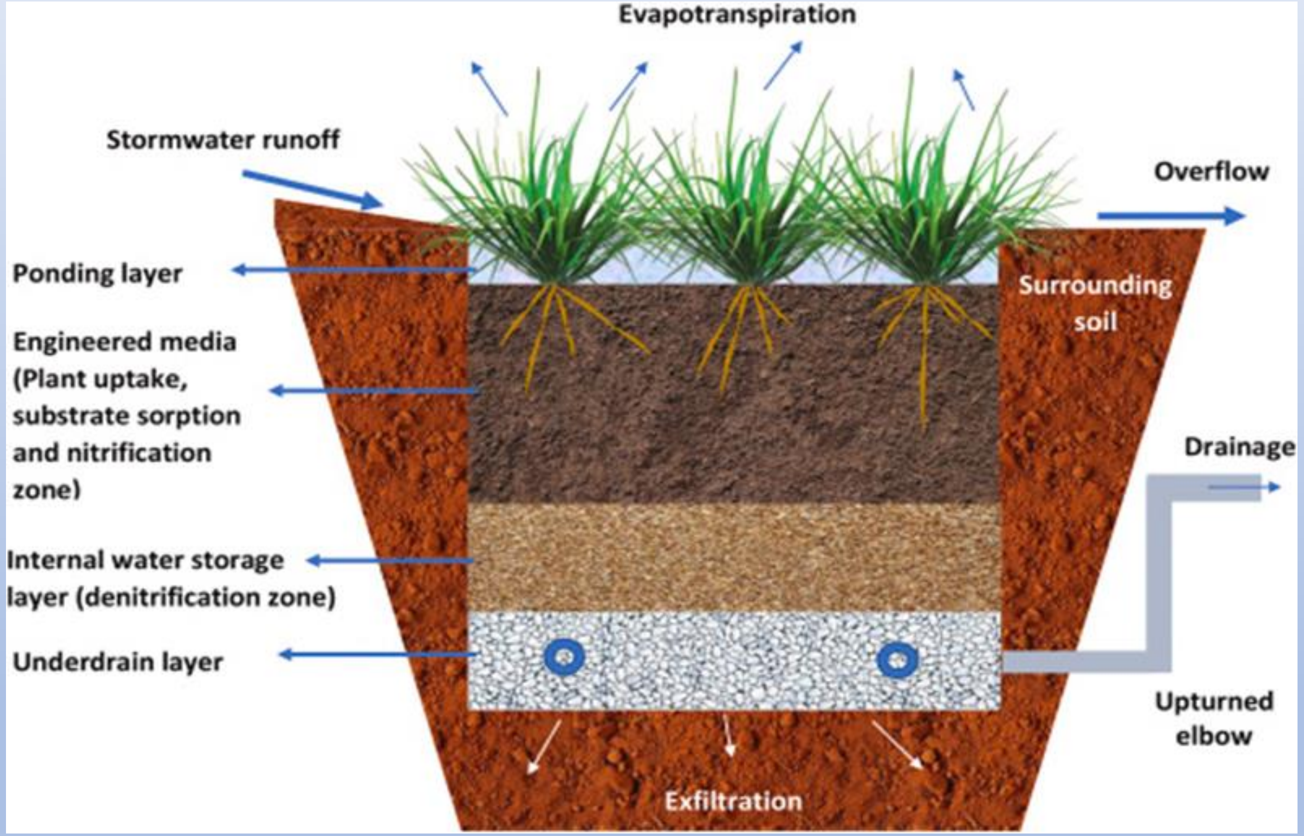


Fig 3. Bioretention cell layers.
(Source: Kuppusamy *et al*. 2021)

Advantages and Disadvantages of Bioretention Cells

Advantages

- Improve runoff quality as well as manage runoff volume
- Flexibility to be incorporated into urban landscapes
- Improvement of biodiversity and aesthetics

Disadvantages

- Not appropriate where the water table is within 6 feet of the ground surface.
- Not appropriate were surrounding soil stratum is unstable.
- In cold climates the soil may freeze, preventing runoff from infiltrating .
- Clogging

Design Variations

- Bioretention areas can be designed in several different ways.
- Next to roads, parking lots, or other paved places and are intended as swales or islands.
- Some bioretention systems are designed with an impermeable liner at the bottom of the system.
- Peak flows and volumes are reduced in this type of systems due to evapotranspiration.
- Flows from heavy storm events skip the bioretention area and will go straight to the sewer.

Bioretention Cleansing Mechanism

Pollutant	Bioretention Cleansing Mechanism
TSS	Sedimentation and filtration (e.g. Davis et al 2009)
Metals	Filtration of particulate metals, sorption of dissolved metals onto mulch layer (e.g., Davis et al, 2009), plant uptake (e.g., Toronto and Region Conservation, 2009)
Nitrogen	Sorption; uptake by microbes and plant material, uptake into soil organic matter (e.g., Henderson, 2008)
Phosphorus	Sorption, precipitation, plant uptake, uptake into soil organic matter (e.g., Henderson, 2008)
Pathogens	Filtration, UV light, competition for limited nutrients, predation by protozoa and bacterial predators (e.g., Zhang et al 2010)
Hydrocarbons	Filtration and sorption to organic matter and, then degraded by soil microbes (e.g., Hong et al 2006)

Fig 4. Bioretention Cleansing Mechanism for water pollutants. (Source: Stormwater BMP Database)

Pollutant Filtering

- Nitrate-nitrogen mass removal rates ranged from 75% and 13%. (Hunt *et al.*, 2006)
- Metals annual mass removal of zinc, copper, and lead were 98%, 99%, and 81% respectively. (Hunt *et al.*, 2006)
- TSS mass removal was up to 59% in some studies (Liu *et al.*, 2014)
- E. coli and fecal coliform efficiency removal percentages have been up to 70% in some areas. (Liu *et al.*, 2014)

Bioretention System Performance Optimization

- Inspect bioretention areas regularly for sediment build-up, structural damage and standing water.
- Inspect for erosion and re-mulch void areas on a monthly basis.
- Remove and replace dead vegetation in spring and fall.
- Remove invasive species to prevent from spreading within bioretention area.
- Do not store snow in bioretention areas.
- Periodically observe function under wet weather conditions.

Case Studies: La Esquina Bioretention and UTRGV Bioswales

Fig 4. Monitoring Equipment Installation on La Esquina Cir Bioretention Cells in Los Fresnos TX.

Fig 5. Monitoring equipment installation on UTRGV Campus Site 1 in Edinburg TX.

Fig 6. Monitoring equipment installation on UTRGV Campus Site 2 in Edinburg TX.

La Esquina Colonias Site

Fig 7. River Rock (RR) Bioretention cell system in La Esquina site. (04/26/22)

Fig 8. Recycled Concrete Aggregate (RCA) Bioretention cell system in La Esquina site. (04/26/22)

La Esquina Bioretention Cross Sectional View

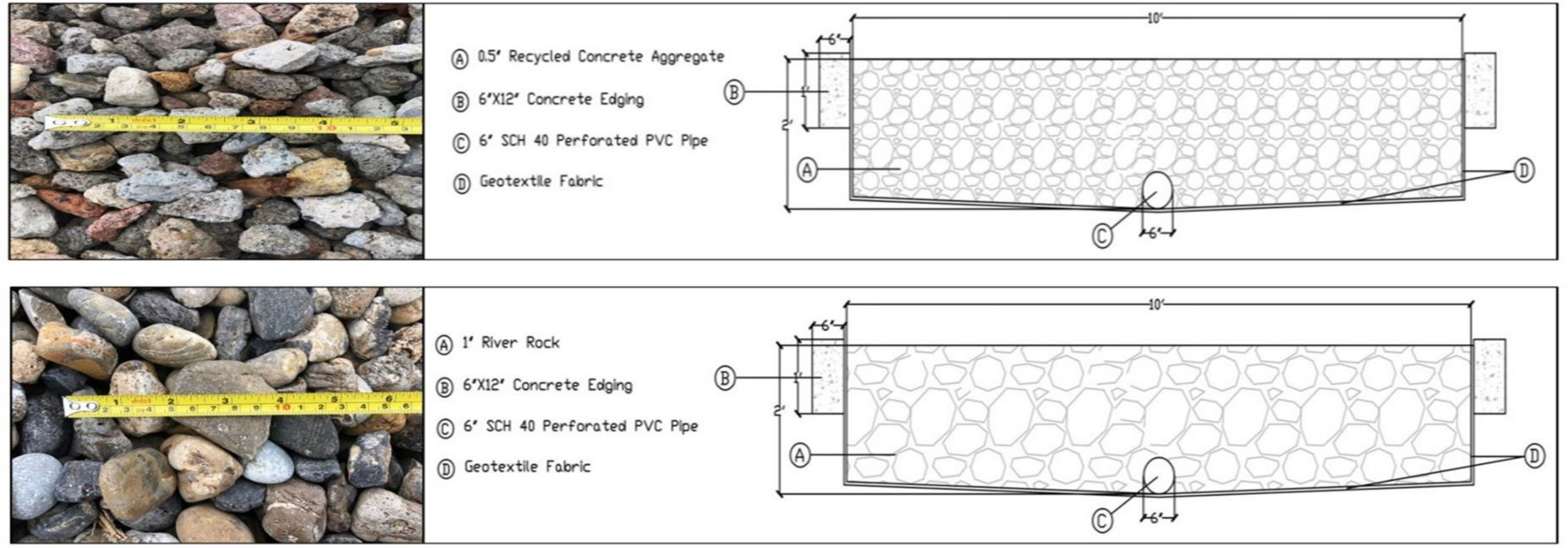
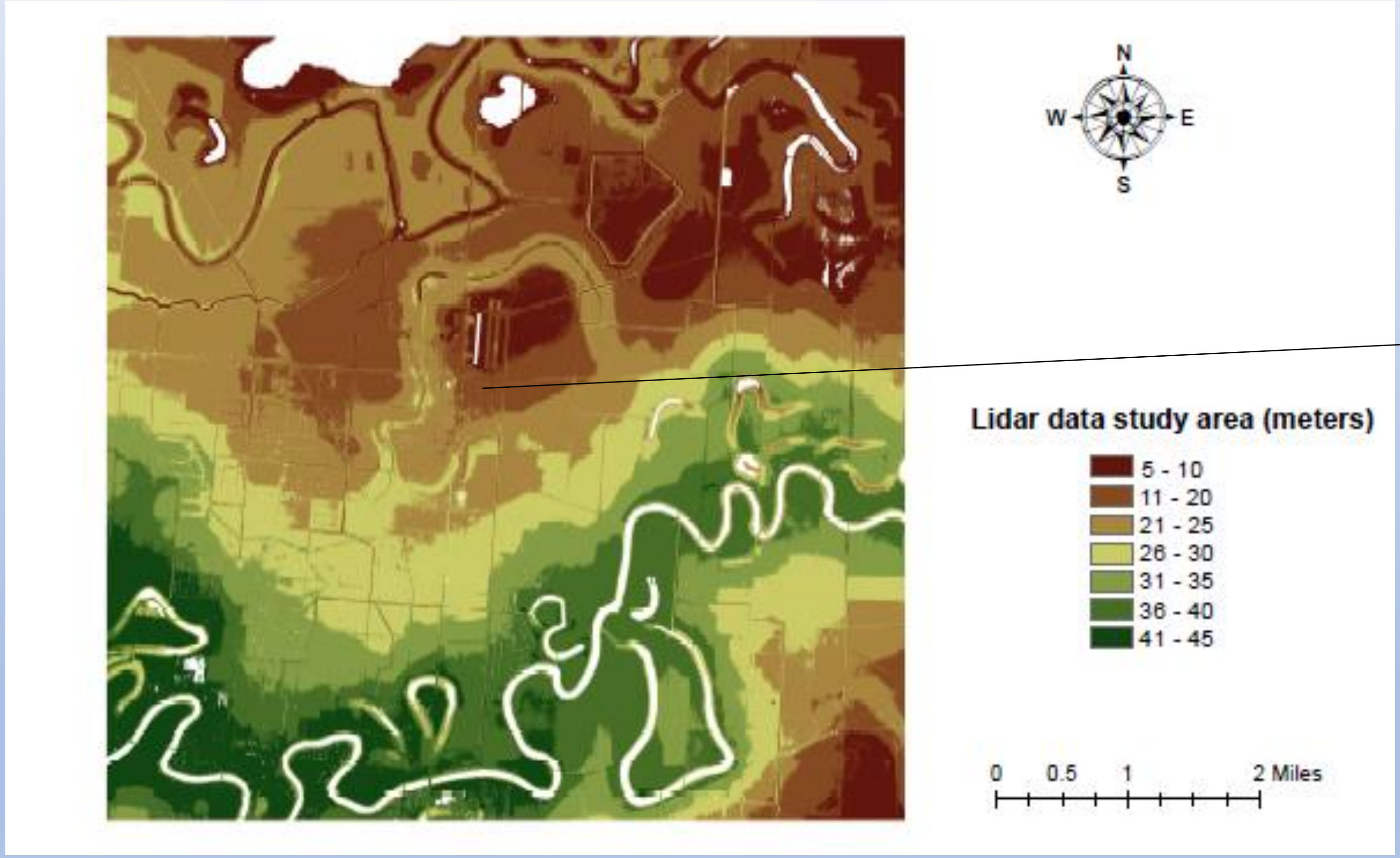


Fig 9. La Esquina bioretention cell cross section (Source: TCEQ ACWPP QAPP 2020)

La Esquina Colonias Site Description



La Esquina Cir, two BMPs are installed and currently being monitored for the TCEQ ACWPP.
LIDAR Data is classified by elevation points (meters). Brown (lowest elevation points) to Green (highest elevation points).

Fig 10. La Esquina Colonias, Los Fresnos, Texas, LIDAR Data.(Source: USGS Lidar data, 2018)

La Esquina Colonias Site Description

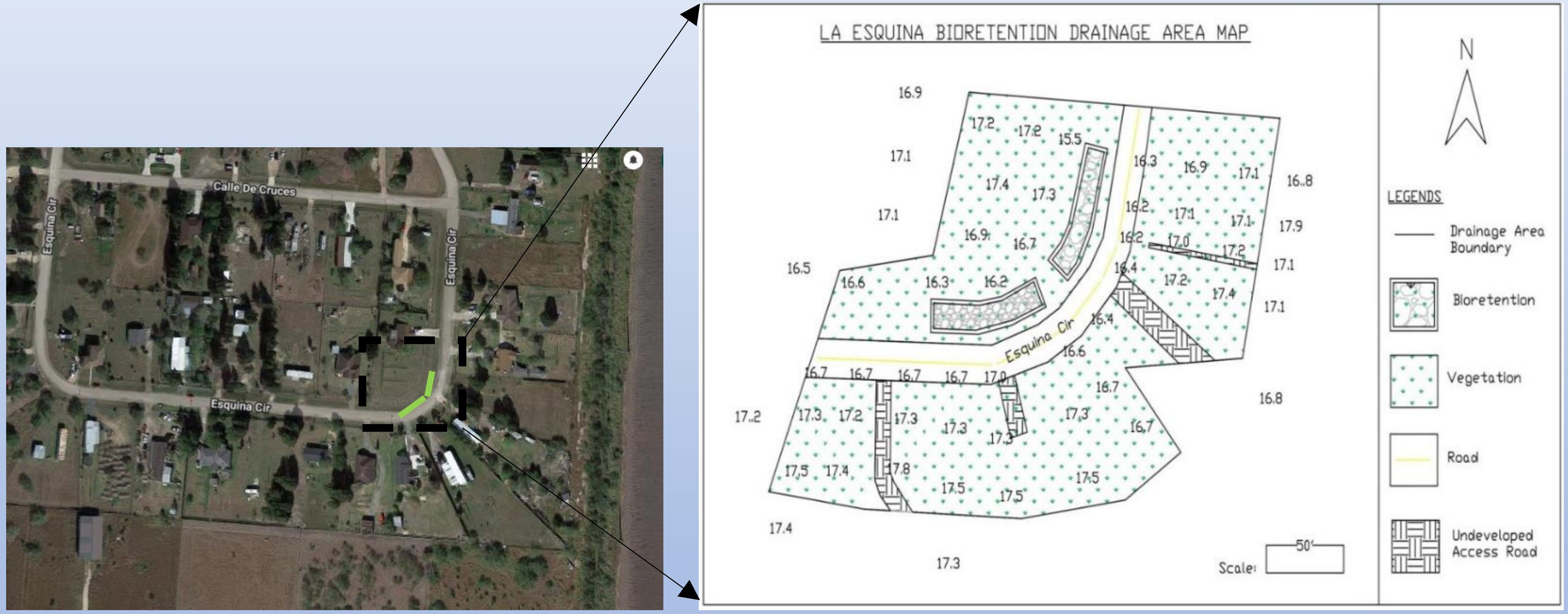


Fig 11. Closeup to La Esquina Colonias, Los Fresnos, Texas, drainage area zones for the bioretention cells.
(Source:*Google Earth*, 2021; TCEQ ACWPP QAPP 2020)

Schematic diagram for the proposed LID BMP in La Esquina Colonias, Los Fresnos, Texas

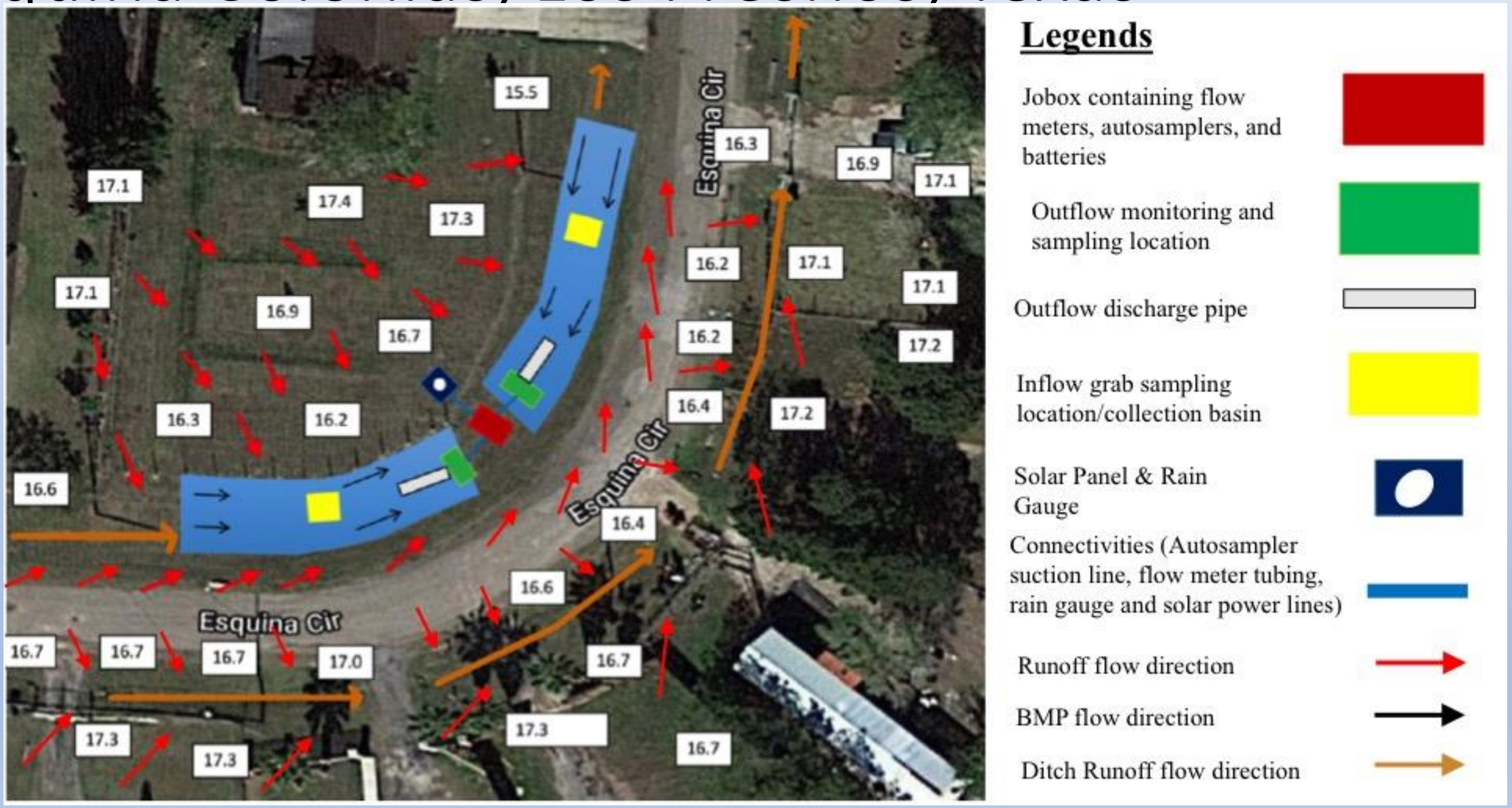


Fig 12. Schematic Diagram for the proposed LID BMP monitoring site.
(Source: *Google Earth*, 2021; TCEQ ACWPP QAPP 2020)

Table 1. Bioretention Cell Characterization

Total drainage area for La Esquina Colonias	**45,595 ft^2 (1.05 acre)**
Drainage area zones	Vegetation 37,428 ft^2 Asphalt road 5,992 ft^2 Undeveloped road 2,178 ft^2
Total drainage area for La Esquina Bioretention Cells	16,675.4 ft^2
Drainage area zones	Vegetation 11,228 ft^2 Asphalt road 4,794 ft^2 Undeveloped road 653 ft^2
Runoff Coefficient	Vegetation 0.3 Asphalt road 0.8 Undeveloped road 0.3

Number of bioretention cells	**Two**
Dimensions of each bioretention cell	Length = 9 m (30 ft.) Width = 3 m (10 ft) Depth = 0.45 m (1.5 ft)
Bioretention media	River Rock (1-inch avg dia.) Recycled Concrete Aggregate (0.5-inch avg dia.)
Hydraulic conductivity	River Rock (0.043 cm/s) Recycled Concrete Aggregate (0.035 cm/s)
Porosity	River Rock (0.45) Recycled Concrete Aggregate (0.49)

(Source: TCEQ ACWPP QAPP 2020)

BMP Measured Performance Approach

- **Volume load reduction is estimated as:**

$$\boldsymbol{VLR = \frac{(In - flow\ volume) - (Out - flow\ volume)}{In - flow\ volume} * 100}$$

- Where,
- VLR = Volume load reduction (%)
- In-flow volume = runoff volume entering the BMP (gallons)
- Out-flow volume = runoff volume exiting the BMP (gallons)

- **Water quality Pollutant Elimination Capacity is estimated as:**

$$\boldsymbol{EC = \frac{Ci - Co}{Ci} * 100}$$

- Where,
- EC = Elimination Capacity%
- Ci = Inflow concentration (mg/L or MPN/100 ml)
- Co = Outflow Concentration (mg/L or MPN/100 ml)

Source: (Luo et al., 2020)

Volume Reduction

Rainfall (inches)	1.10	Days since last precipitation (12)
BRC Media	In-flow volume (gal)	Out-flow volume (gal)
RR	160	89
RCA	160	49

Table 2. Volume reduction results for a storm event of 1.10 inches of precipitation

Rainfall (inches)	0.58	Days since last precipitation (11)
BRC Media	In-flow volume (gal)	Out-flow volume (gal)
RR	108	59
RCA	108	37

Table 3. Volume reduction results for a storm event of 1.51 inches of precipitation

Rainfall (inches)	1.51	Days since last precipitation (8)
BRC Media	In-flow volume (gal)	Out-flow volume (gal)
RR	282	195
RCA	282	127

Table 4. Volume reduction results for a storm event of 0.58 inches of precipitation

Volume Reduction

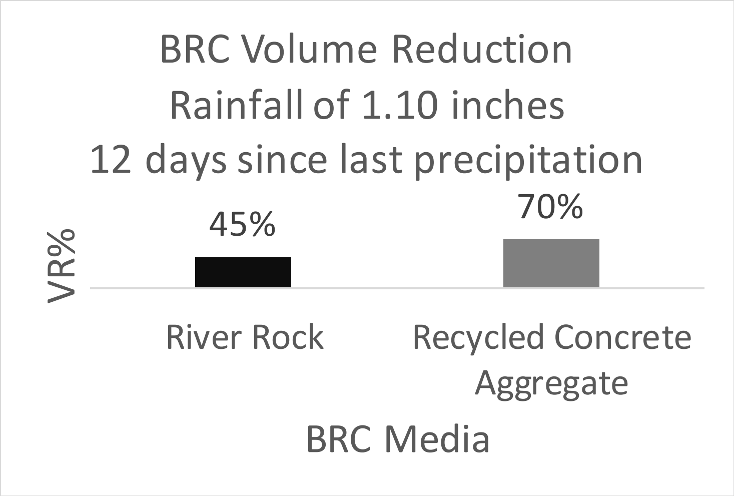


Fig 13. BRCs volume reduction comparison chart for a 1.10 inches rainfall event on 12/20/2021.

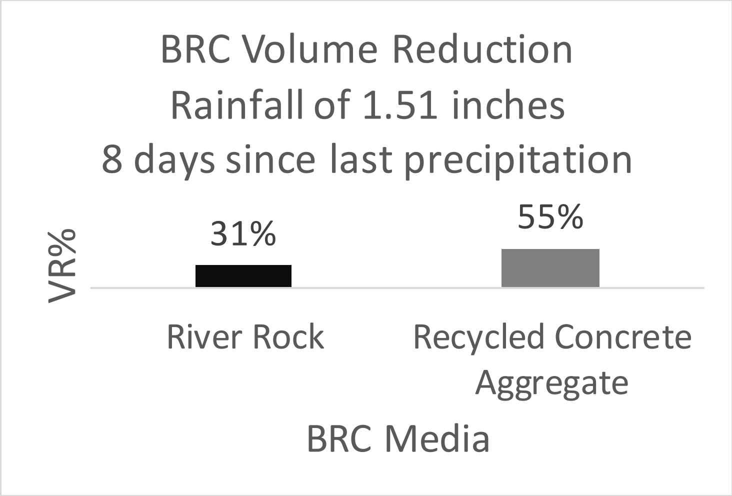


Fig 15. BRCs volume reduction comparison chart for a 1.51 inches rainfall event on 02/07/2021.

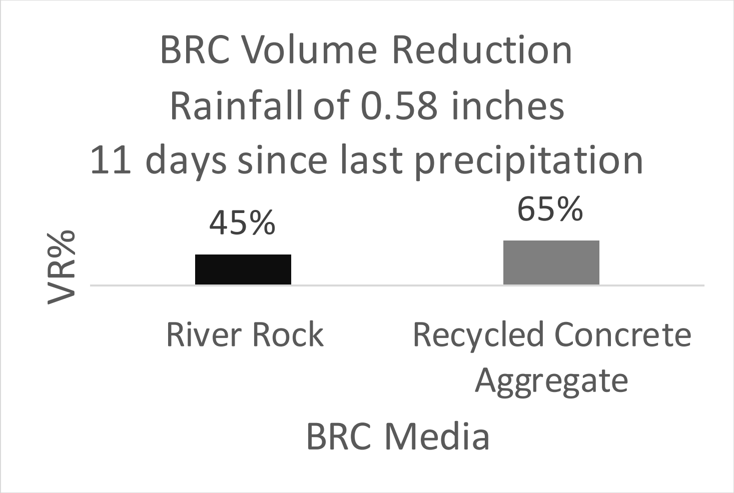


Fig 14. BRCs volume reduction comparison chart for a 0.58 inches rainfall event on 01/21/2021.

TKN, TP, TSS Load

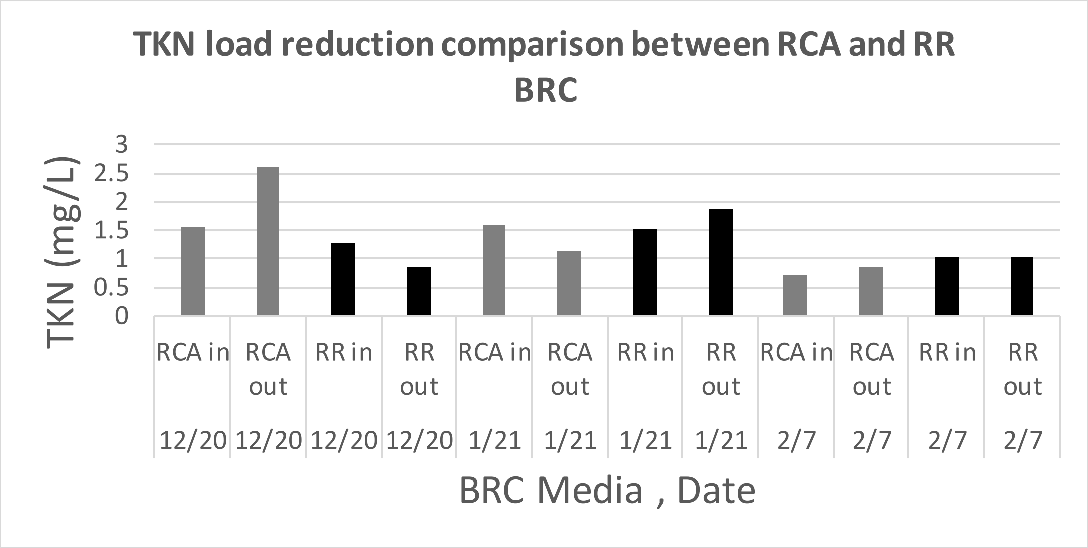


Fig 16. Total Kjeldahl Nitrogen (TKN) load reduction comparison between both bioretention cells.

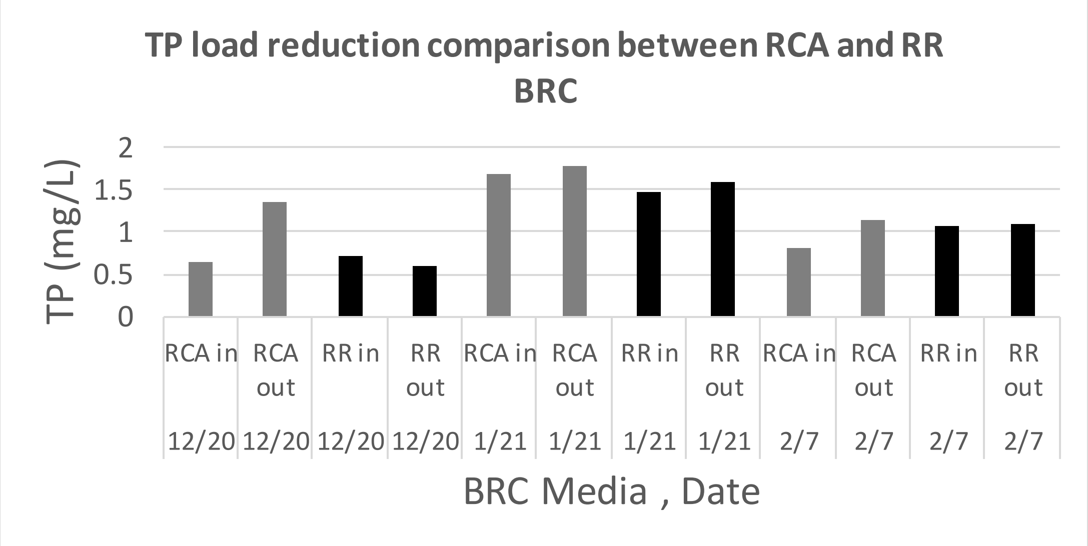


Fig 17. Total Phosphorus(TP) load reduction comparison between both bioretention cells.

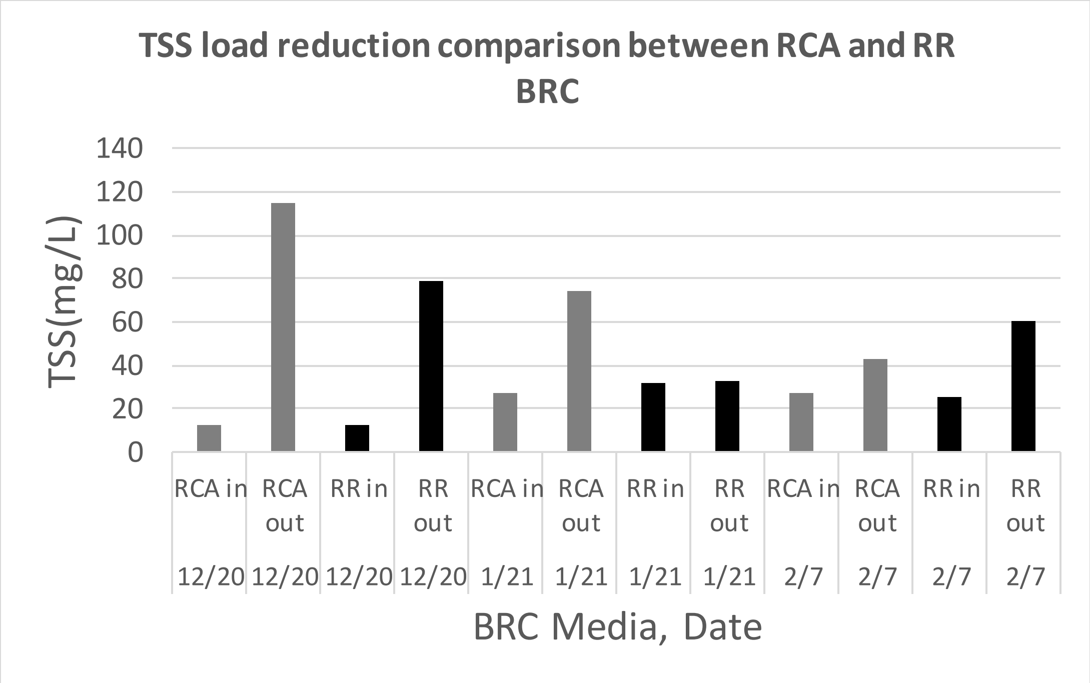


Fig 18. Total suspended solids (TSS) load reduction comparison between both bioretention cells.

BOD5, E. Coli Load

Date: 12/20/21		
Precipitation: 1.10 inches	BOD_5 @ 20 C (mg/L)	*E. coli* (MPN)
RCA – IN	5.92	>24196
RCA - OUT	7.6	>24196
RR – IN	6.44	>24196
RR - OUT	8.08	>24196
BRC Media	BOD5 EC%	E. coli EC%
RCA	-30	-
RR	-30	-

Table 5. BOD5, *E. Coli* and EC results results for a storm event of 1.10 inches of precipitation.

Date: 1/21/22		
Precipitation 0.58 inches	BOD_5 @ 20 C (mg/L)	*E. coli* (MPN)
RCA - IN	<5.00	>2420
RCA - OUT	<5.00	>2420
RR - IN	3.07	>2420
RR - OUT	<5.00	>2420
BRC Media	BOD5 EC	E. coli EC
RCA	-	-
RR	-	-

Table 6. BOD5, *E. Coli* and EC results for a storm event of 0.58 inches of precipitation.

Date: 2/7/22		
Precipitation 1.51 inches	BOD_5 @ 20 C (mg/L)	*E. coli* (MPN)
RCA - IN	1.36	98040
RCA - OUT	1.76	68670
RR - IN	1.84	120330
RR - OUT	3.08	77010
BRC Media	BOD5 EC %	E. coli EC%
RCA	-30	30
RR	-70	40

Table 7. BOD5, *E. Coli* and EC results for a storm event of 1.51 inches of precipitation.

Table 8. Storage, Preservation and Handling Requirements

Parameter	Container*	Minimum Sample Volume (ml)	Preservation	Holding Time**
TKN	**Plastic**	**250**	**Cool to 4°C, H_2SO_4 to pH <2**	**28 days**
TP	**Plastic**	**250**	**Cool to 4°C H2S04 to pH <2**	**28 days**
TSS	**Plastic**	**1000(based on turbidity)**	**Cool to 4°C**	**7 days**
BOD_5 20°C	**Plastic**	**300**	**Cool to 4°C**	**48 hours**
E. Coli	**Sterile Container**	**250**	**Ice (cool to < 6 but not frozen)**	**30 hours**

(Source: ACWPP QAPP 2020)

Results and Discussion

- TKN and TP effluent concentrations are strongly correlated with antecedent rainfall depth and temperature.
- TSS concentration were higher on all effluent samples. This could be due to sediment buildup in the underdrain pipe as a result of washout/leaching in the bioretention media area.
- Selecting the appropriate aggregate media for the bioretention system will depend on the availability of local resources in the study area and the parameters of concern in the stormwater runoff.

WinSLAMM Model Implementation

- Evaluate the effects of different storm intensities on stormwater runoff.
- Based on historical data, different rainfall intensities will be selected to run the model.
- NOAA's Precipitation Frequency Data Server (PFDS) will be used for the point precipitation frequency (PF) estimates to select three different 60-minute storm events with different recurrence intervals (1 in 5 years, 1 in 10 years and 1 in 20 years) in the Brownsville Weather Station to run the model.

Source: (Pitt & Voorhees, 2004)

WinSLAMM Model Advantages

- Field Data and actual design parameters can be used as input parameters for the model.
- Can reliably predict runoff amounts with a prediction error of roughly 10 to 30%.
- Many researchers employed and validated it, and it proved to be accurate in predicting Stormwater flows and pollutant characteristics.
- Employs a straightforward rainfall-runoff equation (Rational Method - Thomason, 2019).
- Even if there is no field data, you can forecast results by utilizing the default calibrated files.

Source: (Pitt & Voorhees, 2004)

WinSLAMM Model Calculations

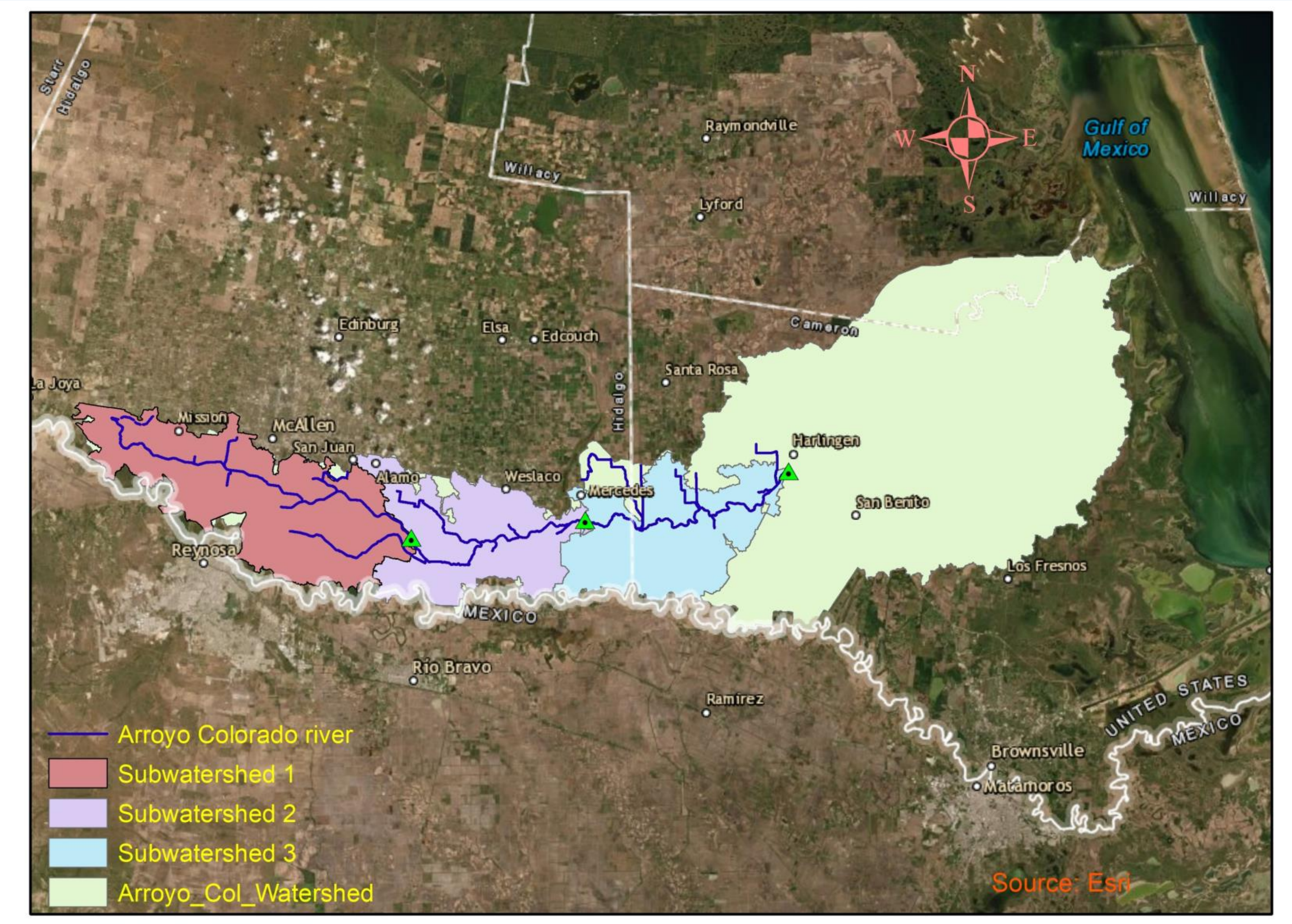
- **WinSLAMM Runoff Volume Calculation**
- WinSLAMM uses the rational method. The equation is as follows.
- Runoff Volume (ft^3) = Rainfall Depth (in) * Source Area (a) * Runoff Coefficient * unit conversion

Source: (Pitt & Voorhees, 2004)

Cost of implementing bioretention cells in the valley

- Three subwatersheds in the Arroyo Colorado watershed with high amounts of urban land use were selected for analysis of costs associated with bioretention cells.

Map showing selected subwatersheds



Cost of implementing bioretention cells in the valley

- The Sustain model was used to model bioretention cells as well as other LIDs and determine the approximate costs and removal efficiencies of these cells when installed at different locations in the three subwatersheds.

Map showing Bioretention suggested locations

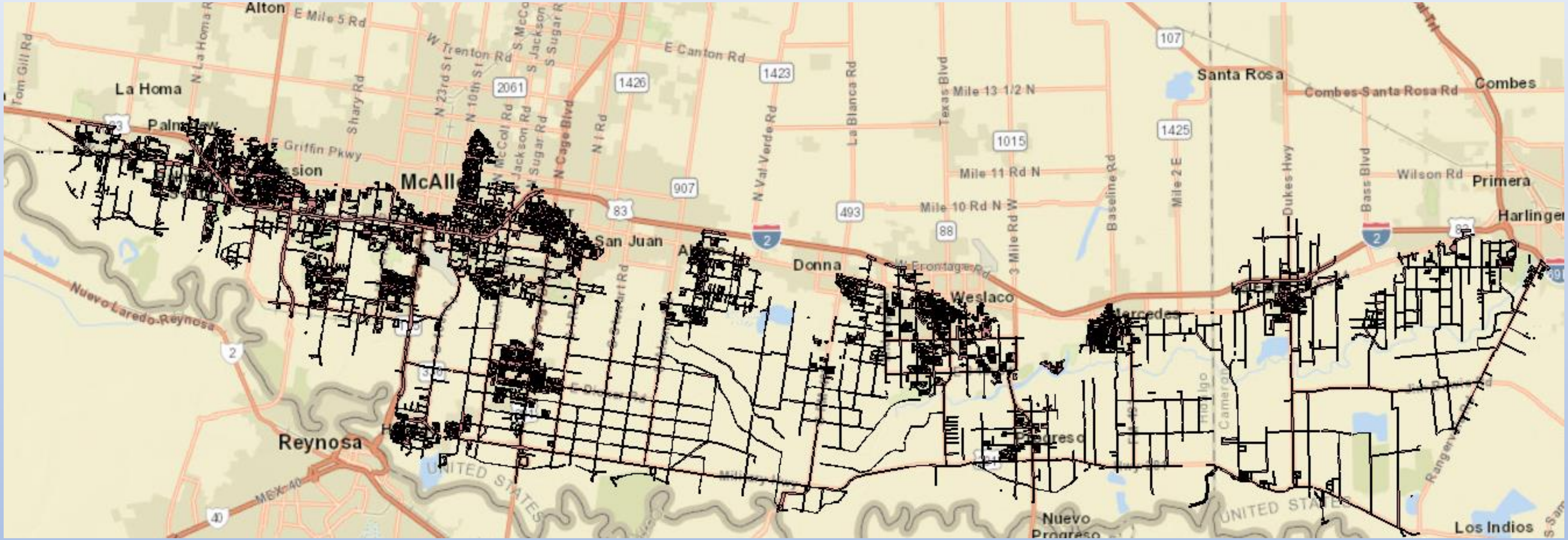


Figure showing proposed locations of bioretention cells in the watershed (Source: ESRI ArcMap)

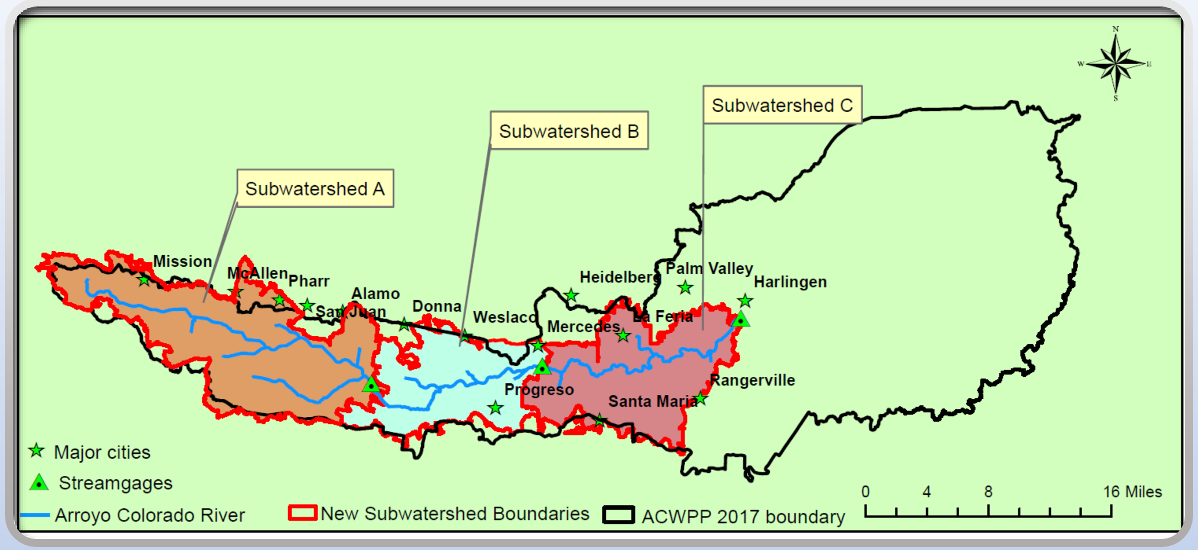
A total of 865 bioretention cells were determined as required for the three subwatersheds.

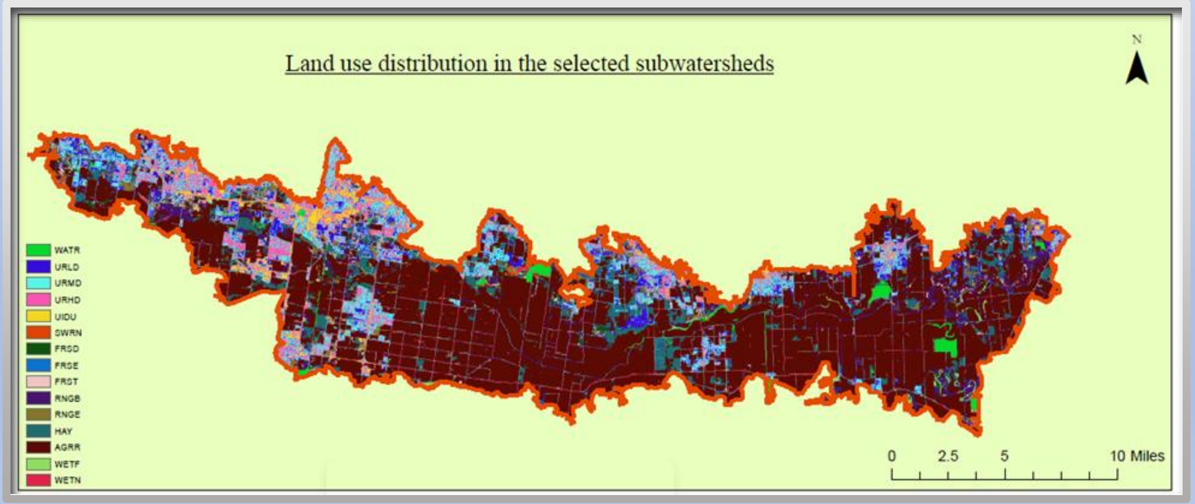
Modelling

- After determining the proposed locations of the bioretention cells, a SWAT (Soil and Water Assessment Tool) model was set up, calibrated and validated so as to obtain HRU time series for use in a SUSTAIN (System for Urban Stormwater Treatment and Analysis Integration) model.

SWAT model details

- Subwatersheds and land use distribution in the selected subwatersheds



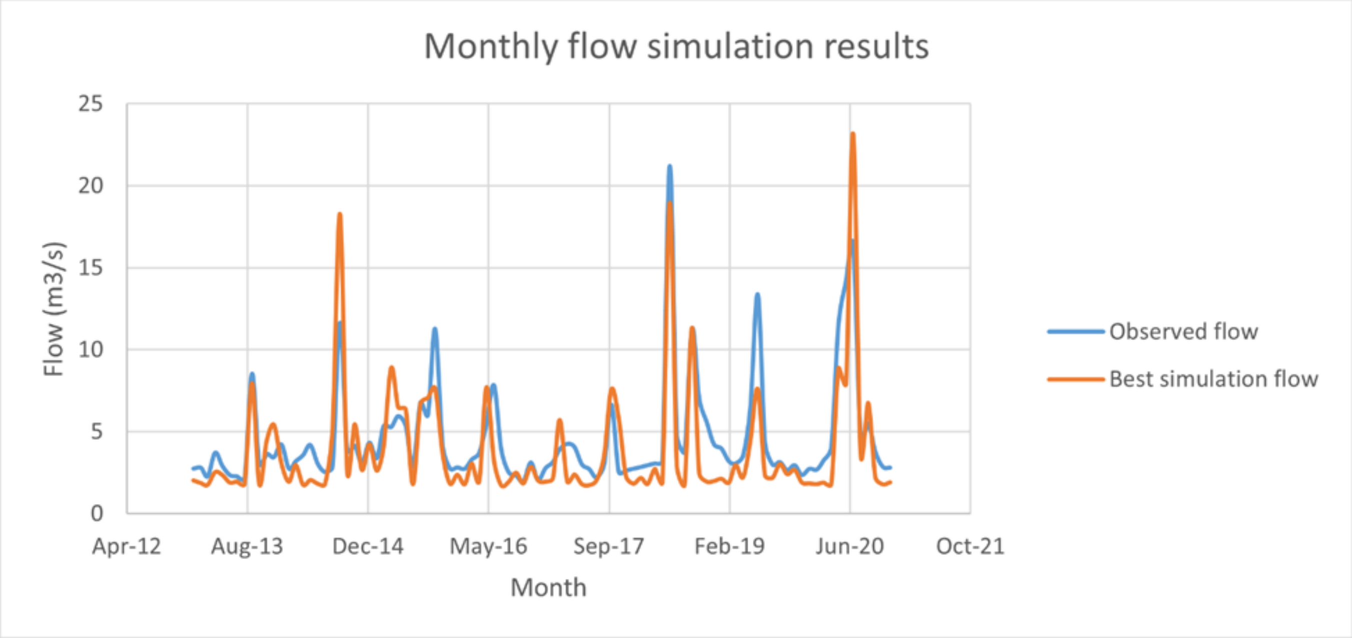


Source: Esri ArcMap

SWAT calibration results for flow and water quality

Parameter name	Value
R^2	0.75
NSE	0.51

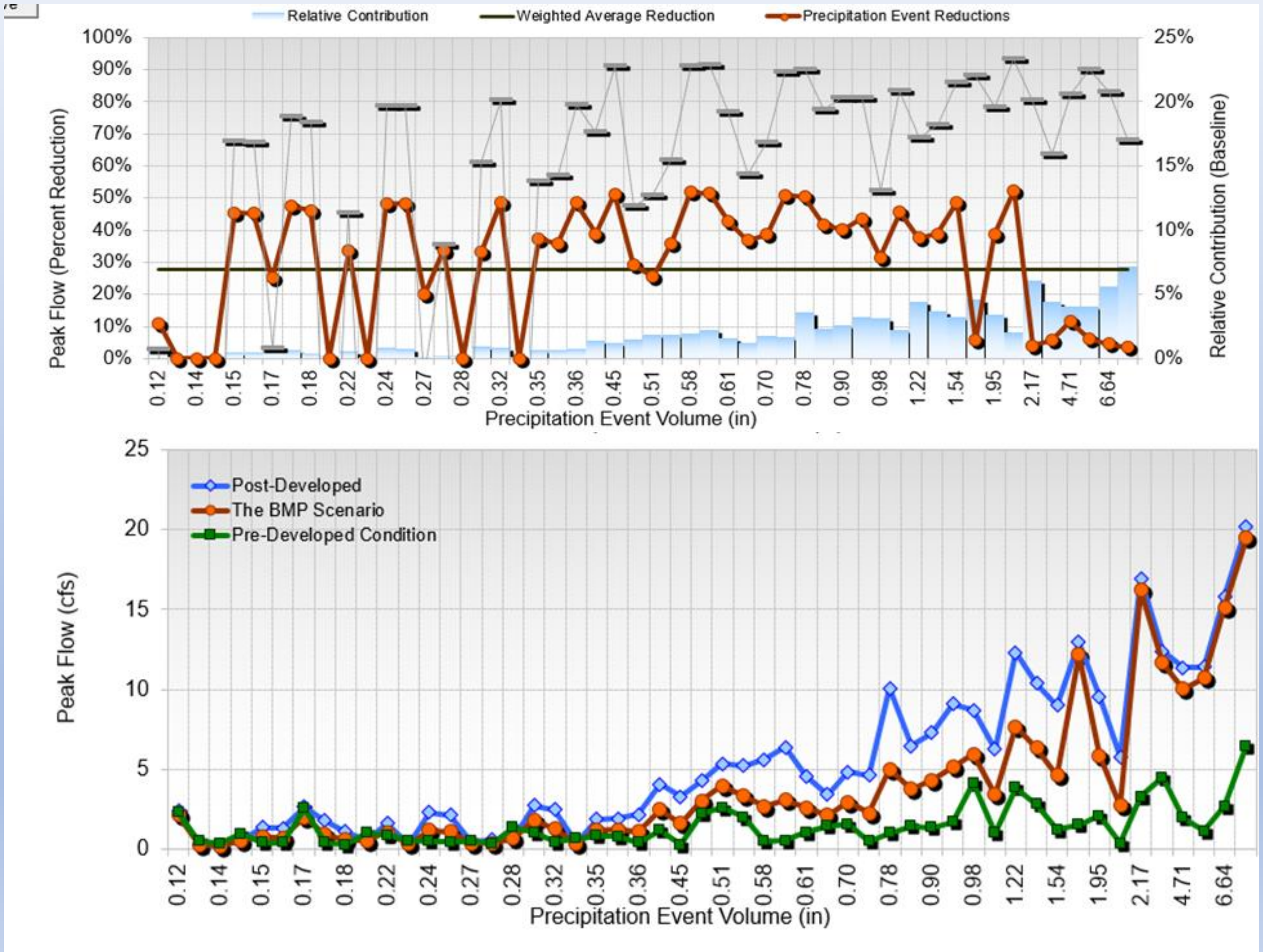
Variable name	R2	NSE
Sediment	0.51	0.54
Ammonia Nitrogen	0.8	0.5
Total phosphorous	0.6	0.8



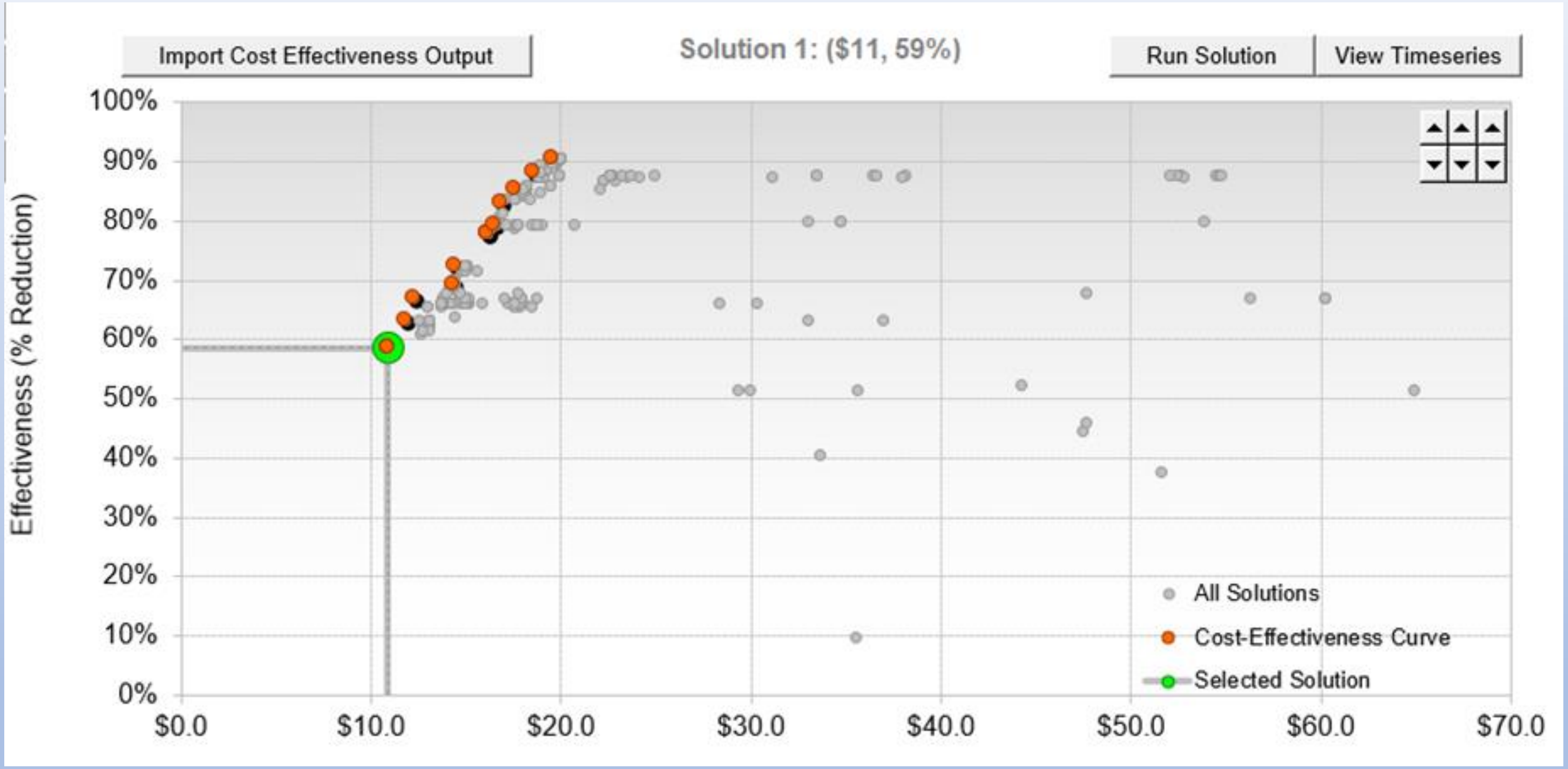
SWAT-SUSTAIN Linkage

- After the SWAT model was calibrated and validated, the obtained HRU time series were extracted into the SUSTAIN model which was set up and validated.
- When the flow and water quality results from SUSTAIN matched those of SWAT, BMP optimization was carried out to determine the reduction in runoff, and water quality parameters using bioretention cells and the corresponding costs.

Effect of bioretention cells on runoff reduction

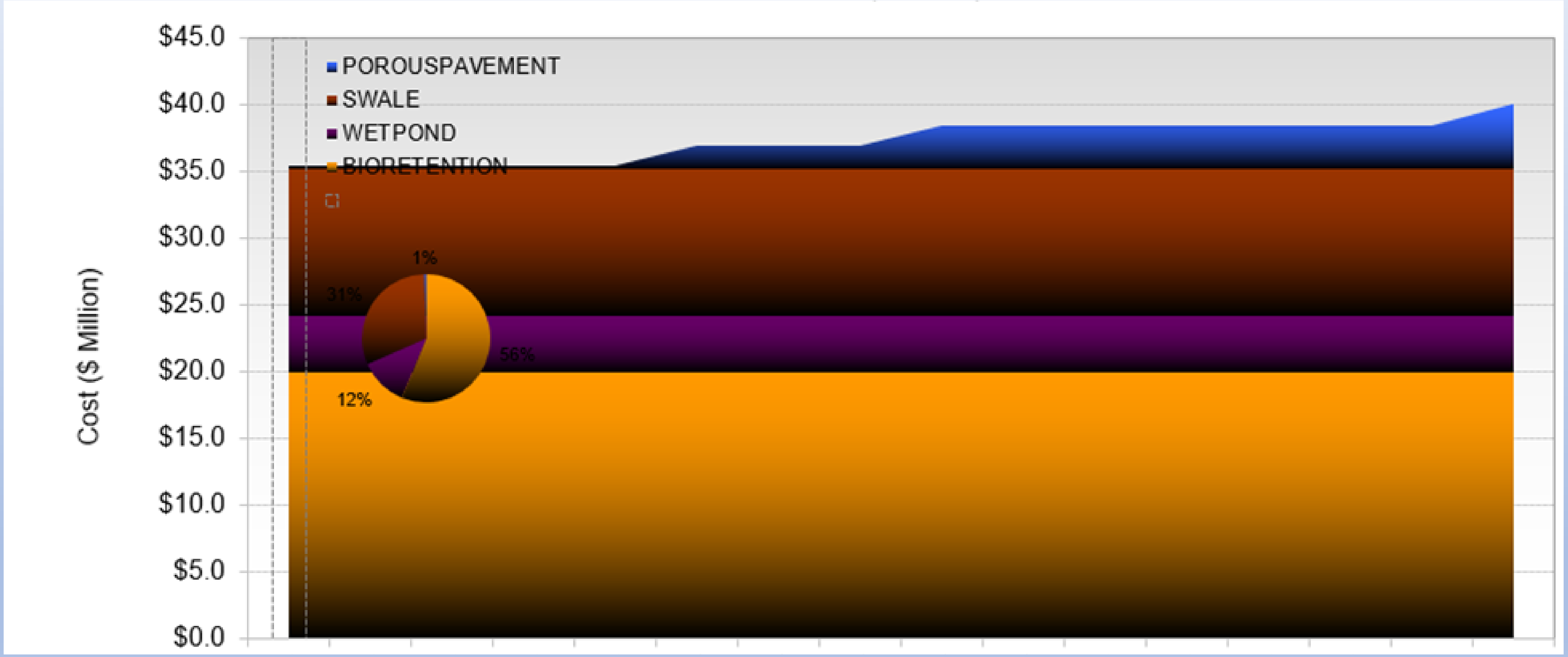


Best solution for reduction of TSS, TP, and TN



The lowest cost incurred for reduction of TSS,TP and TN is $11 for each bioretention cell and this achieves 59% reduction of these water quality parameters. (Cost estimate is based on the SUSTAIN cost database installed with the SUSTAIN program files)

Cost comparison between Bioretention cells and other LIDs



Source: EPA SUSTAIN

Potential Outcomes

- This research will yield meaningful results in the treatment of urban stormwater runoff in the Lower Rio Grande Valley.
- WinSLAMM calibrated bioretention cell models will aid in the prediction of runoff and pollutant loadings for a broader range of rainfall intensities.
- These models can be used to replicate a similar pattern of runoff and load reduction in other lower Rio Grande Valley sites with different drainage areas.
- In terms of volume reduction and nutrient removal, this study will add new knowledge on two cost-effective materials, recycled concrete aggregate and river rock.

Acknowledgments

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- We would like to thank our mentors in TAMUK for their excellent guidance, patience and support to do research in this field. I'd like to thank them for allowing me to take part in Low Impact Development (LID) research projects for stormwater management.
- We also would like to thank UTRGV, TCEQ, LID Task Force Members, and Cameron County Public Works staff members for their help throughout this research study.

- Activities related to this research study:

  - Played an important role in the TCEQ ACWPP QAPP, 2020

  - Presented in EPA Region 6 Stormwater Conference 2021 (NOLA)

  - Presented in Virtual Workshops for LID Task Force Members 2021 (LRGV, TX)

  - Presented in 24^{th} Annual Water Quality and Management Stormwater Conference (SPI, TX)

Questions?

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