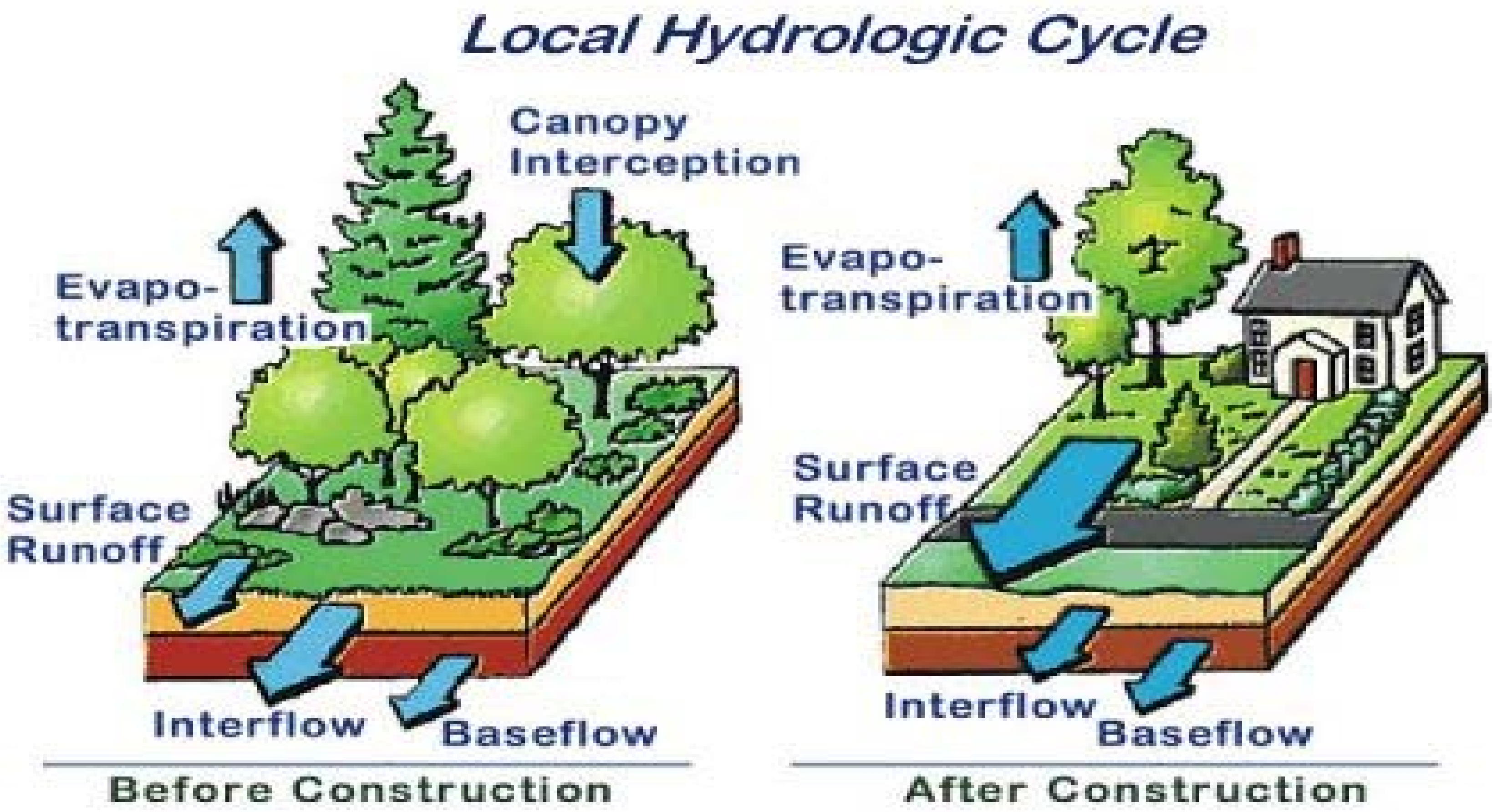
Stormwater Green Infrastructure: Evaluation, Performance and Modeling

Fouad H. Jaber, PhD, PE
Associate Professor and Extension Specialist
Biological and Agricultural Engineering
Texas A&M AgriLife Extension
Dallas Research and Extension Center

TEXAS A&M AGRILIFE RESEARCH | EXTENSION

Biological & Agricultural Engineering
Plant a seed for your future at Texas A&M

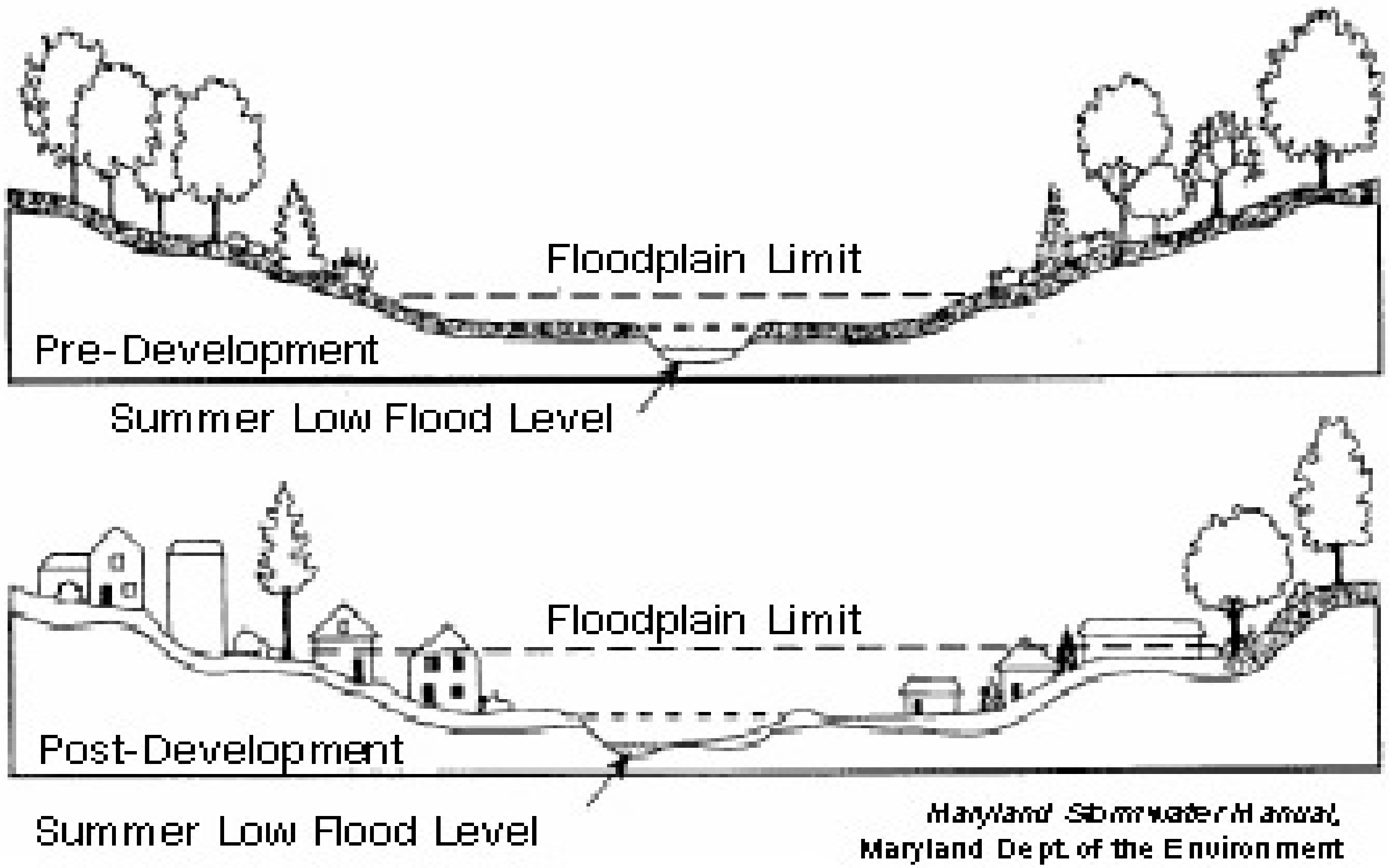
Urban vs. Natural



Why is Stormwater a Concern?

Why is Stormwater a Concern?

Why is Stormwater a Concern?



Why is Stormwater a Concern?

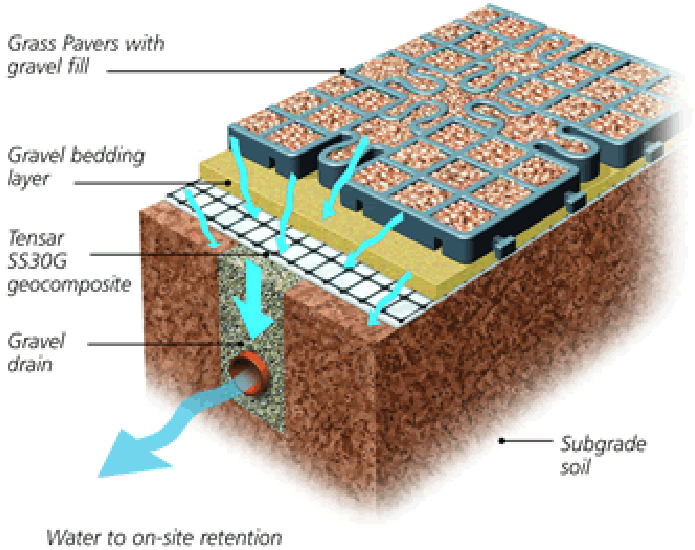
Eutrophication

- Impacts due to urbanization:
  - **Impact to aquatic habitat:** Degradation of habitat structure, loss of pool-riffle structure, reduction in base flow, increased stream temperature, and decline in abundance and biodiversity.

Fish kill at Lake Granbury.

Urban BMPs

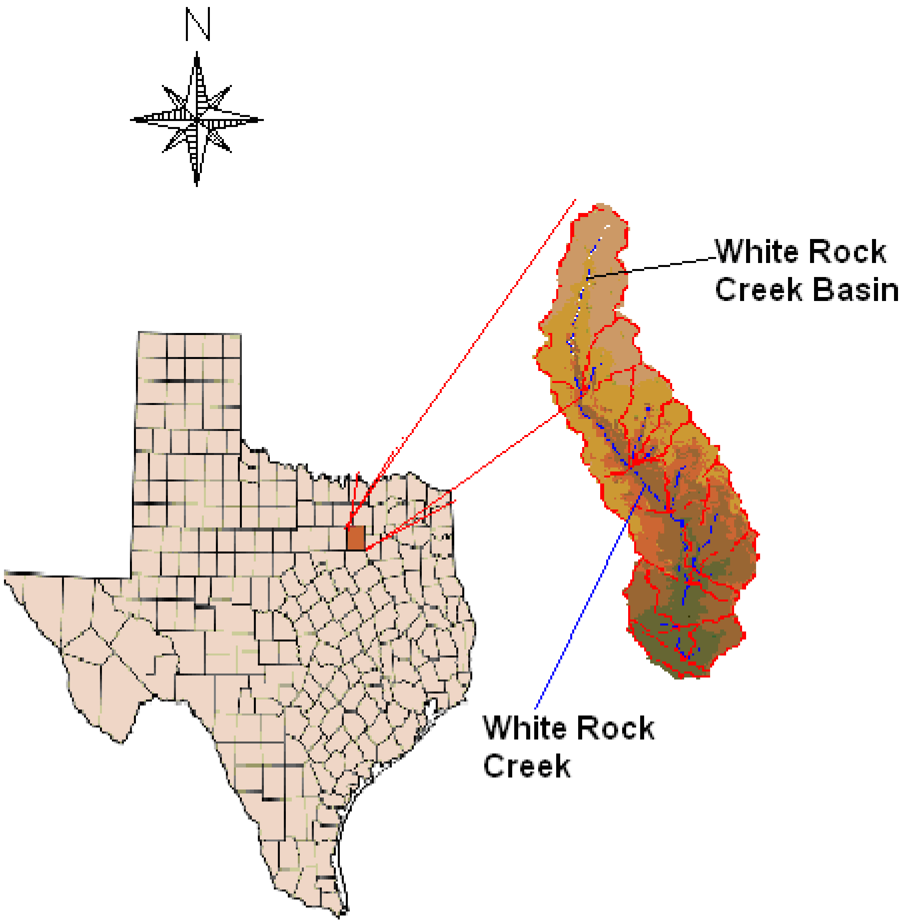
- Rain garden-bioretention areas
- Porous pavements
- Green roofs
- Rainwater harvesting



Evaluation Project in Dallas

- Five LID BMPs were built on the campus of Texas AgriLife Research and Extension, Dallas. The grant is funded by the Clean Water Act Section 319 urban nonpoint source pollution prevention program (TCEQ; EPA)
- BMPs
  - Permeable pavement
  - Bioretention area
  - Rainwater harvesting
  - Green roof
  - Detention Pond
- Monitoring for hydrology, N, P, TSS, bacteria, legacy pollutant Chlordane

Project Location

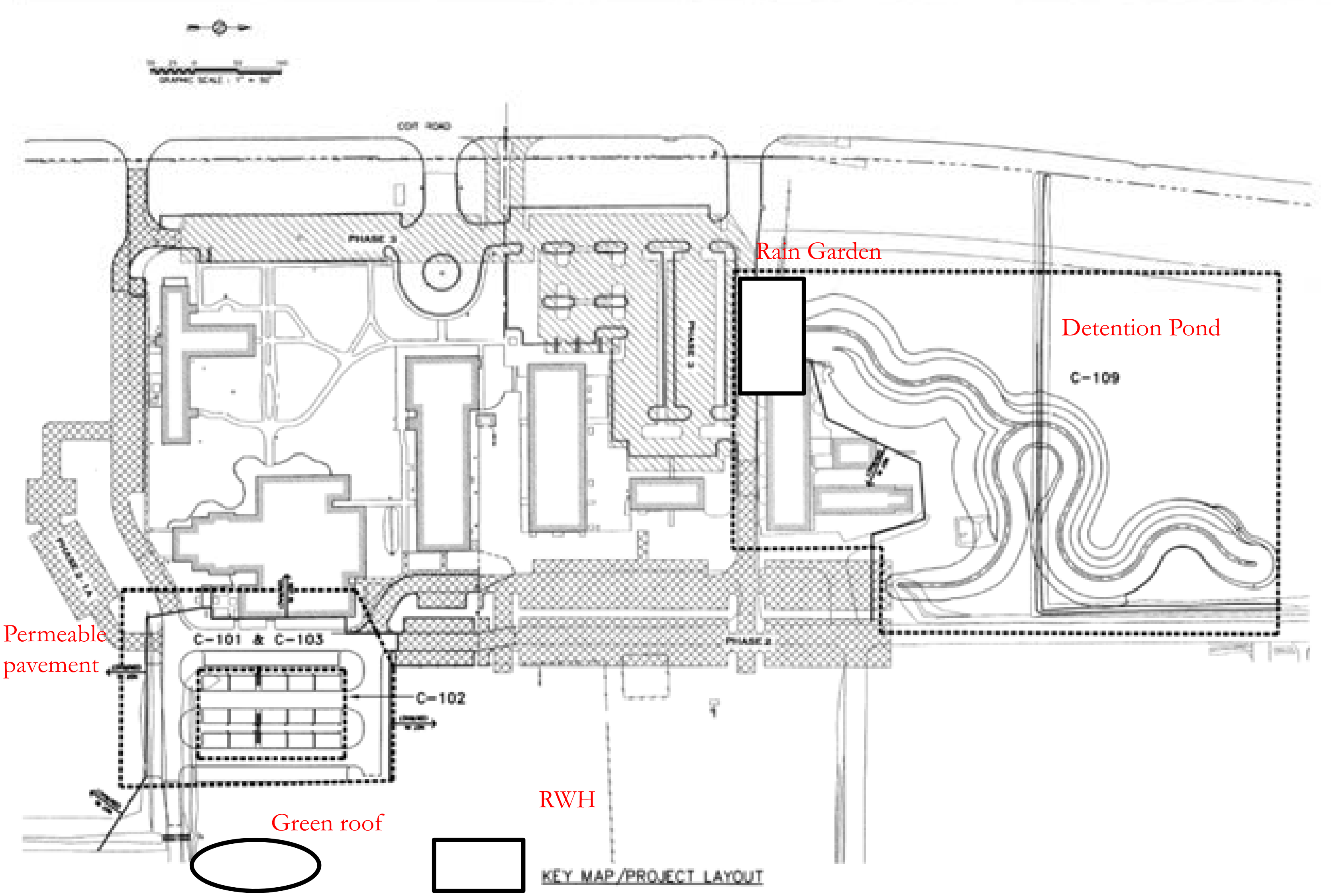


- Upper Trinity-White Rock Creek Watershed
- Clayey soil with underlying calcareous layer (Blackland Prairie Ecosystem)
- Representative of typical urban watershed

Rationale and Goals

- Need for evaluation of LID practices in the field, especially Southern US and/or Blackland soils.
- Need for data on adoption of LID practices on watershed scale
- Goals
  - Reduction of runoff volume, pollutant load in a typical urban development
  - Design, construction, evaluation of 5 LID BMPs
  - Teaching tool for integration of LID practices (de novo or retrofit)

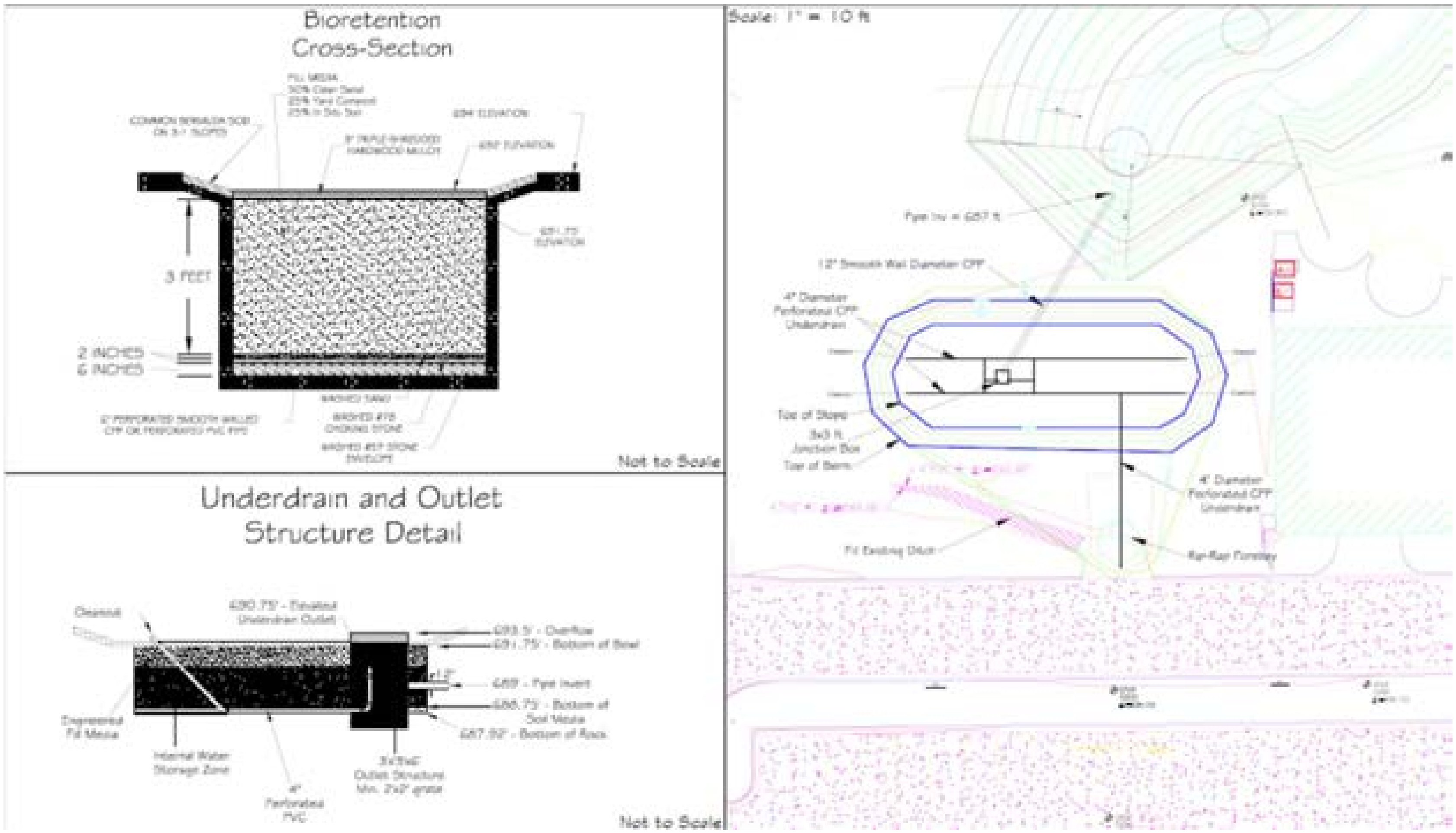
BMP Locations



Bioretention Design

- Collected from 37,000 square foot parking lot CN=94
- Include Internal Water Storage (IWS)
- Total Media Depth was 4 feet with 1.75 feet ponding depth
- Media: 25% yard waste compost, 50% sand, 25% native soil
- Planted with native plants
- 4 inch perforated pipe at bottom

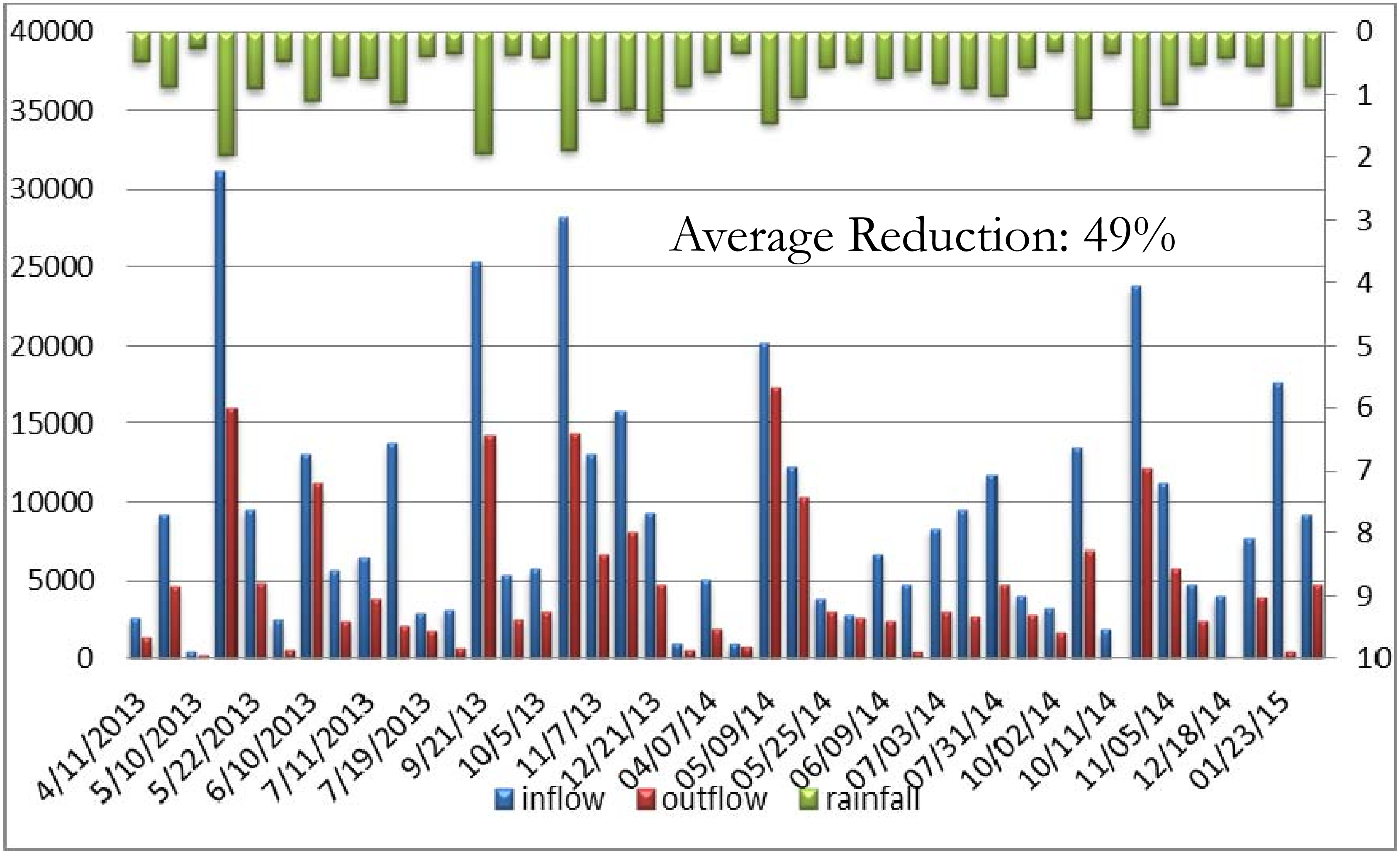
Bioretention Area



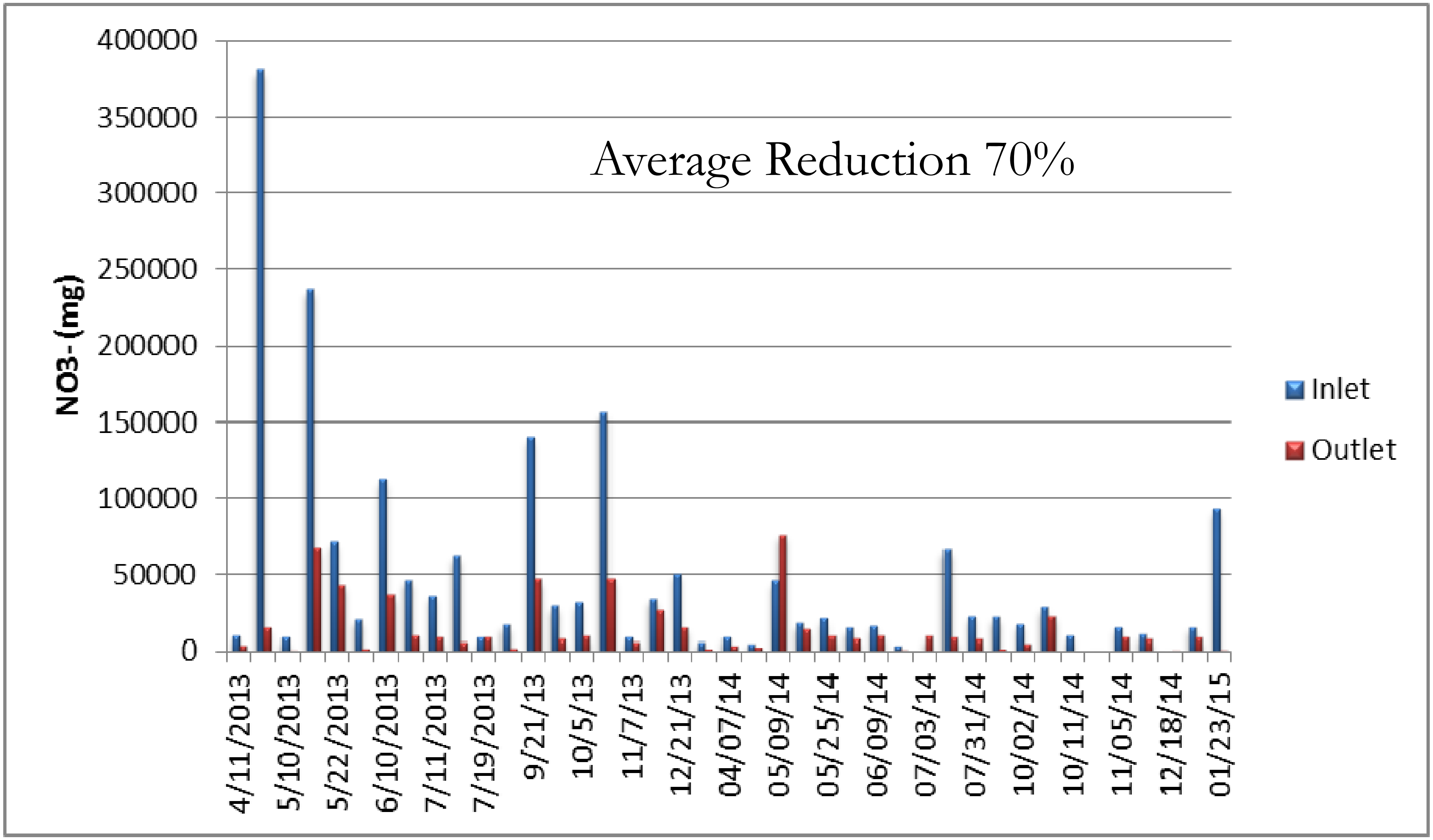
Monitoring Design

- Water Volume
  - Inflow: Flume and bubbler flowmeter
  - Outflow: pipe and bubbler flowmeter
  - Storage: Levelogger®
- Water Quality
  - Inflow: ISCO Sampler
  - Outflow: ISCO Sampler

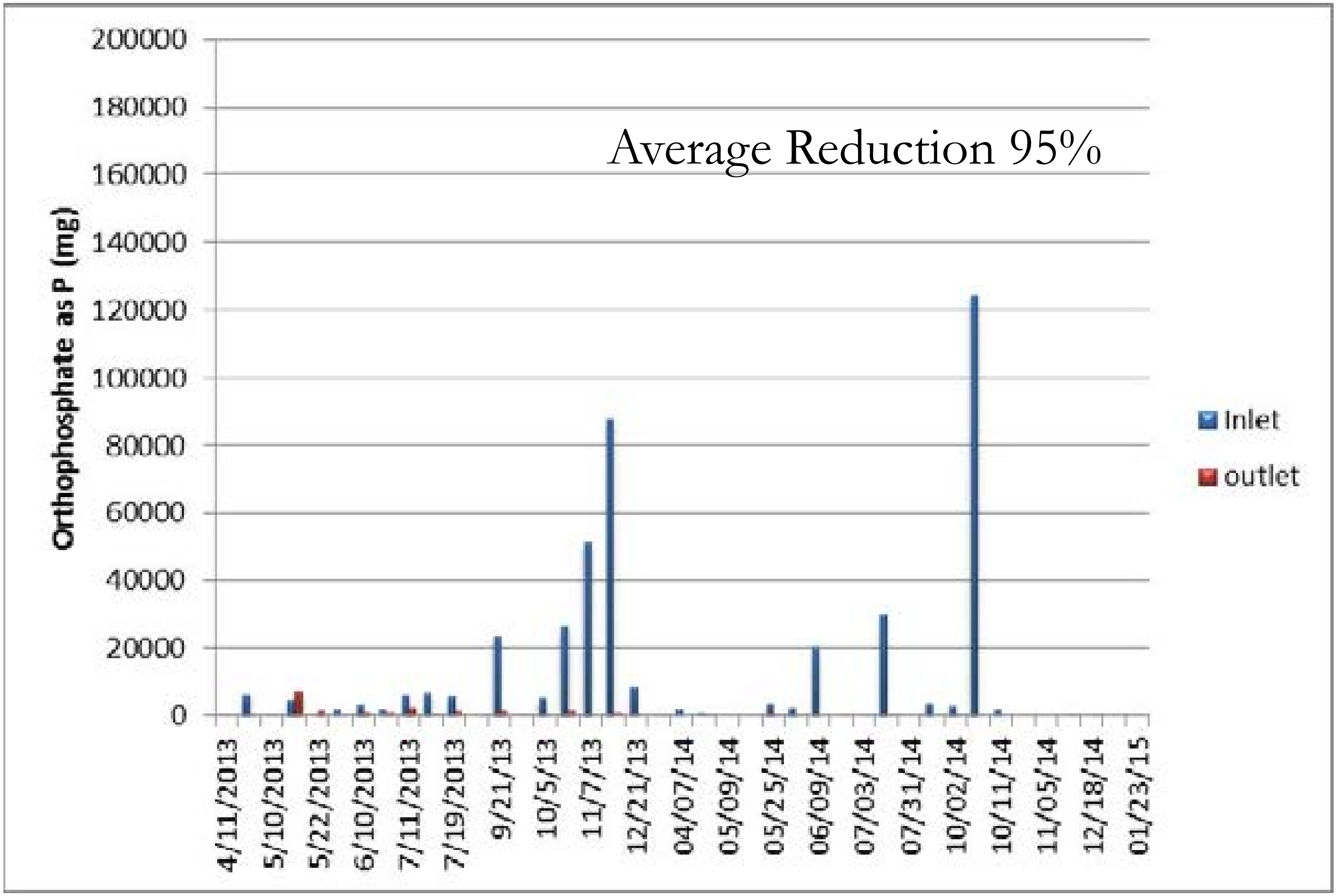
Volume Reduction



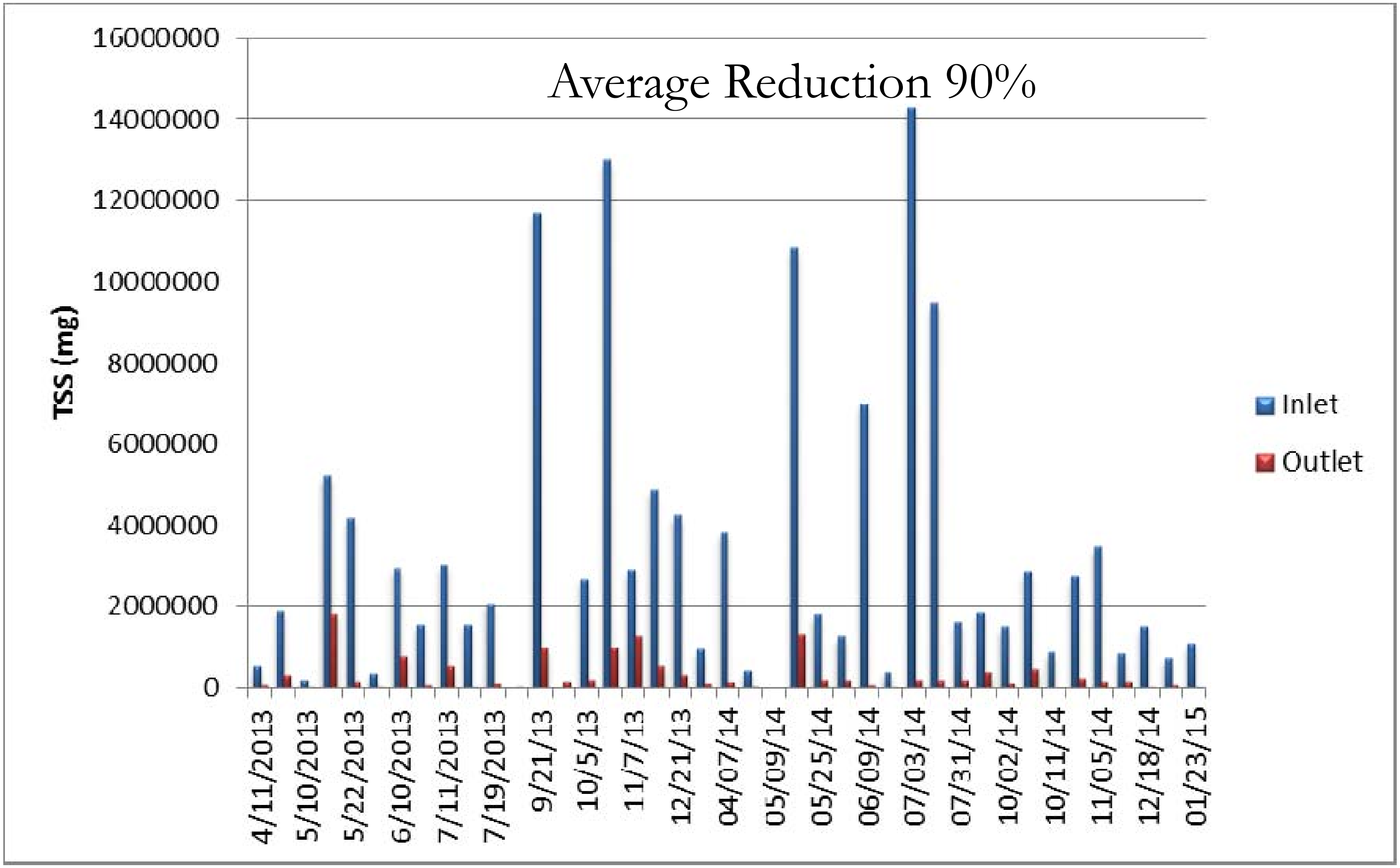
Load Reduction: Nitrate



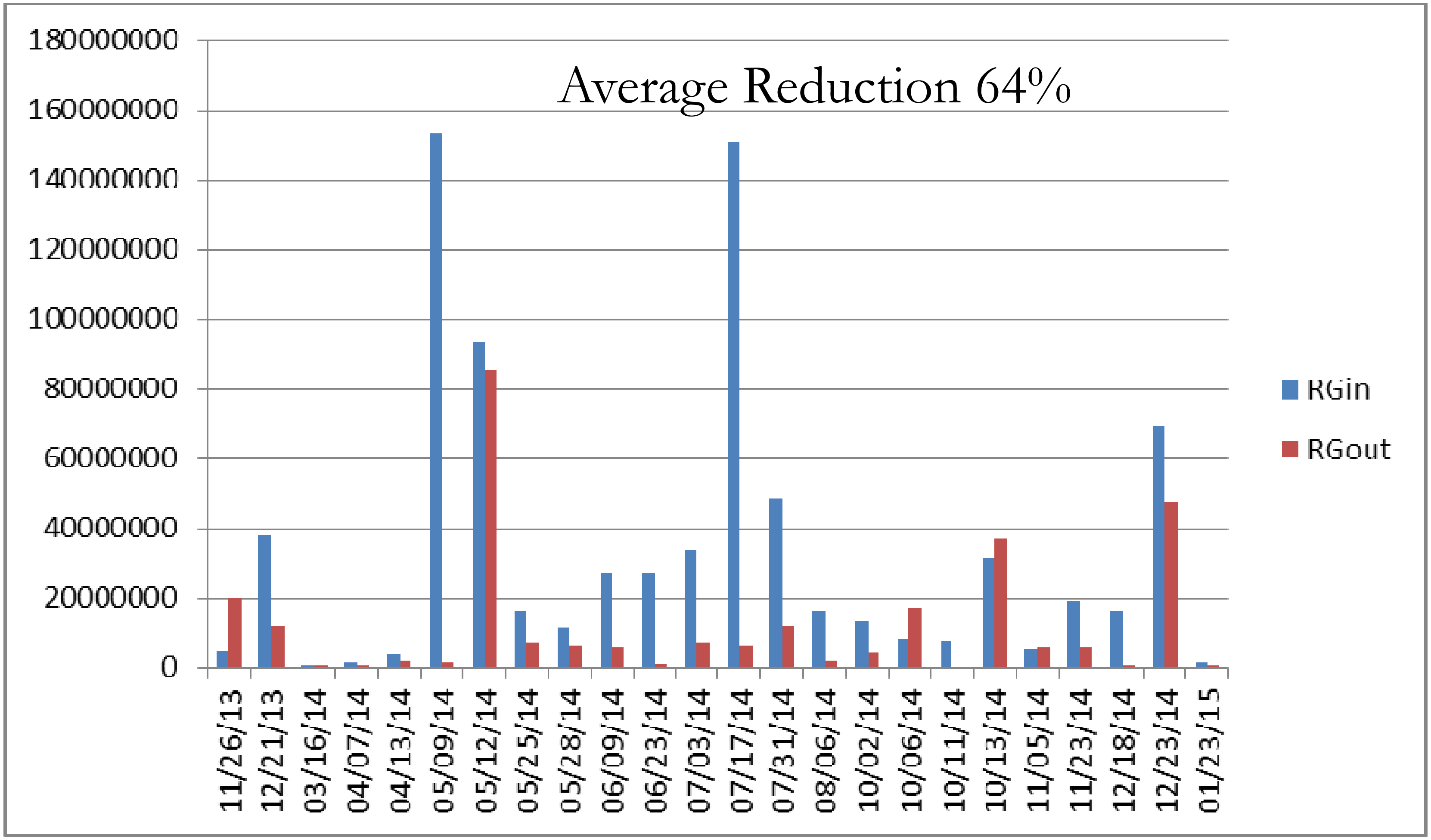
Load Reduction: Orthophosphate



Load Reduction: Sediments

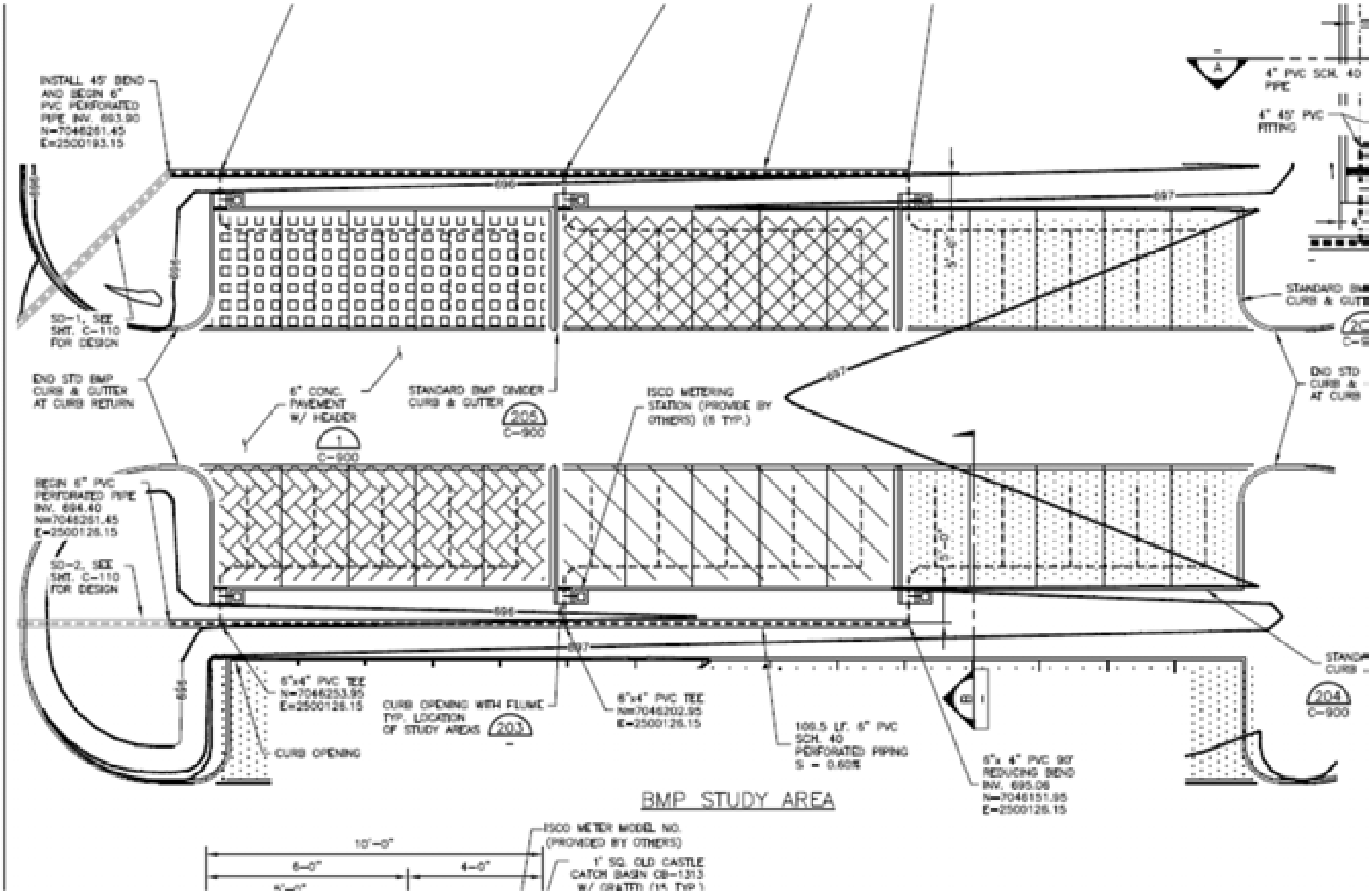


Load Reduction: E. coli



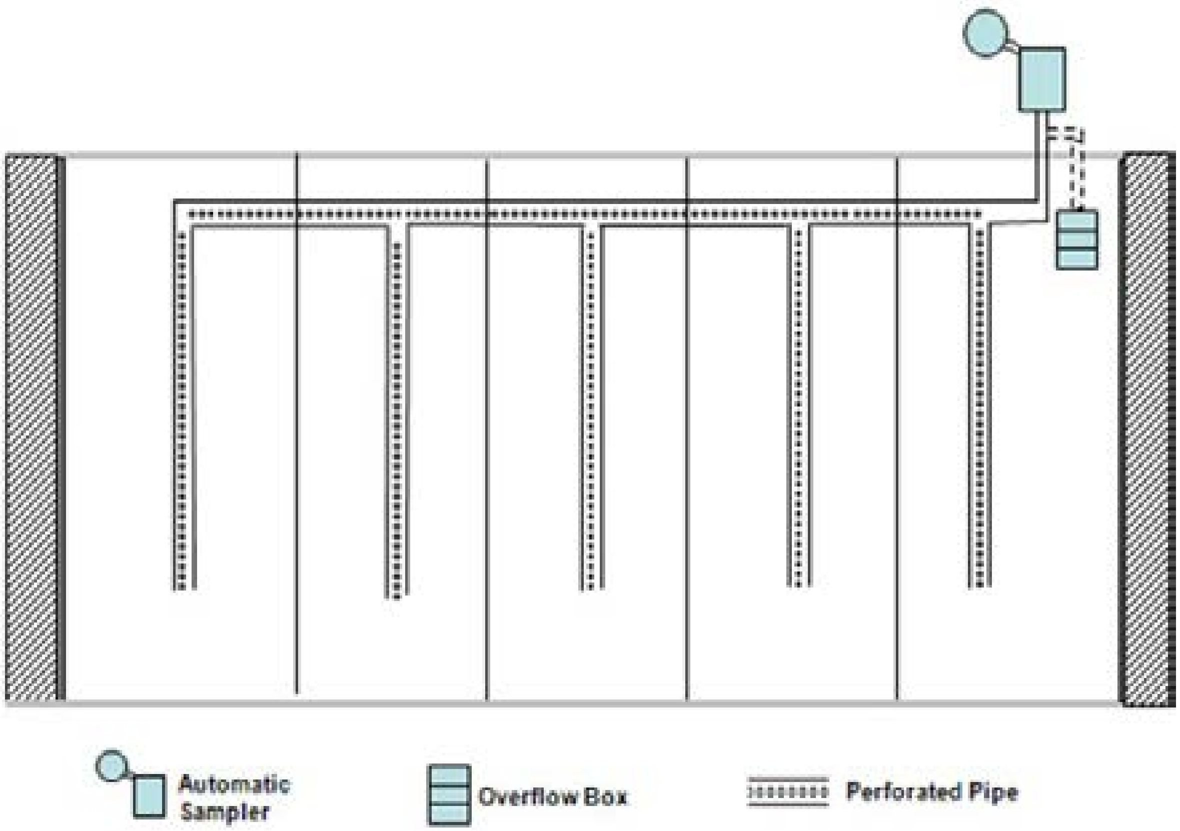
Permeable Pavement

- Newly constructed parking lot
- Comparison of 5 types pavement
- 25 experimental stalls among 52 total functional stalls
- Perforated underdrain pipes
- Total thickness = 16 inches
- Gravel layer
- Hydrologically separated with concrete curbs

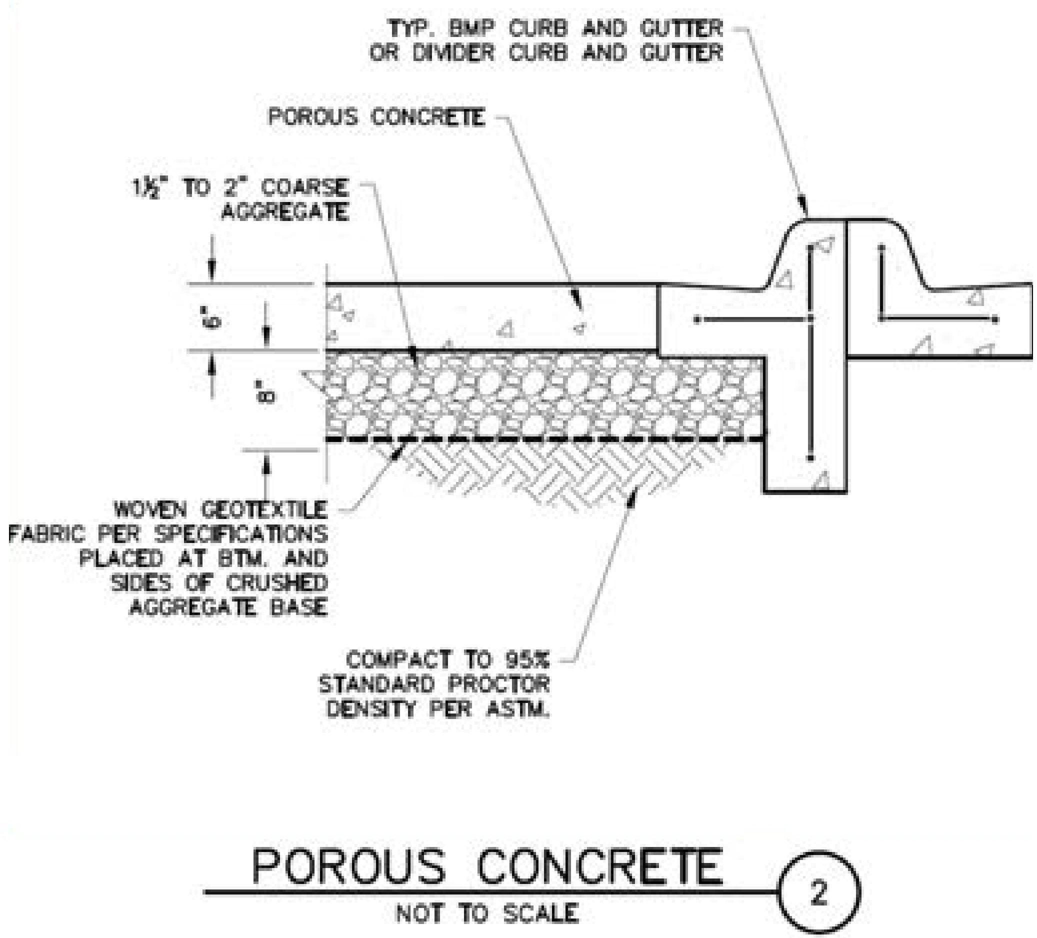

INSTALL 45° BEND AND BEGIN 6" PVC PERFORATED PIPE INV. 693.90 N=7046261.45 E=2500193.15
4" PVC SCH. 40 PIPE
4" 45° PVC FITTING
SD-1, SEE SHT. C-110 FOR DESIGN
STANDARD BMP CURB & GUTTER
END STD BMP CURB & GUTTER AT CURB RETURN
6" CONC. PAVEMENT W/ HEADER
STANDARD BMP DIVIDER CURB & GUTTER
ISCO METERING STATION (PROVIDE BY OTHERS) (6 TYP.)
END STD CURB & GUTTER AT CURB
BEGIN 6" PVC PERFORATED PIPE INV. 694.40 N=7046261.45 E=2500126.15
SD-2, SEE SHT. C-110 FOR DESIGN
6"x4" PVC TEE N=7046253.95 E=2500126.15
CURB OPENING WITH FLUME TYP. LOCATION OF STUDY AREAS
CURB OPENING
6"x4" PVC TEE N=7046202.95 E=2500126.15
106.5 LF. 6" PVC SCH. 40 PERFORATED PIPING S = 0.60%
6"x 4" PVC 90° REDUCING BEND INV. 695.08 N=7046151.95 E=2500126.15
BMP STUDY AREA
ISCO METER MODEL NO. (PROVIDED BY OTHERS)
1' SQ. OLD CASTLE CATCH BASIN CB-1313 W/ GRATED (15 TYP.)
10'-0"
6'-0"
4'-0"

Design and Monitoring

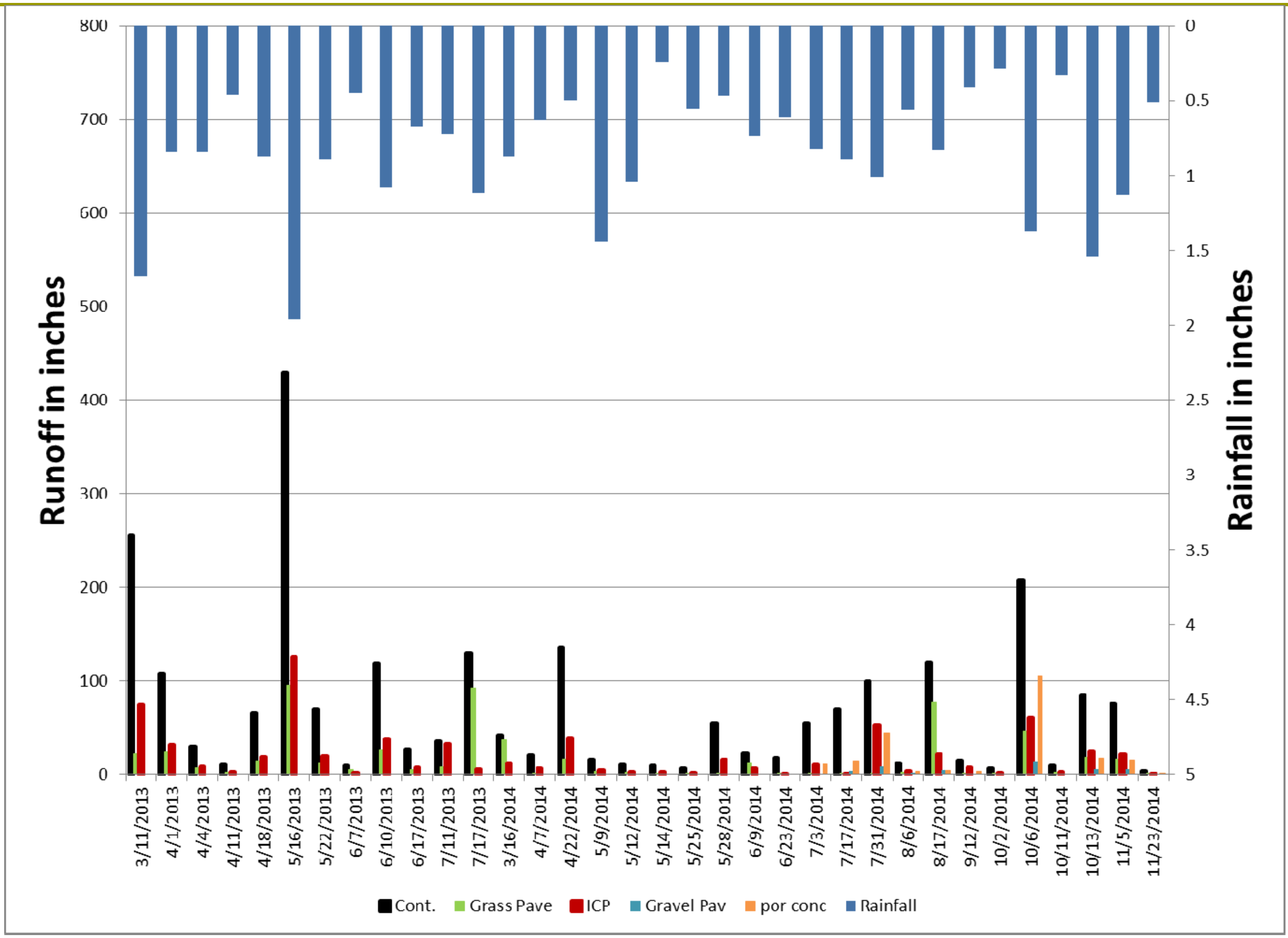
- Stalls: 18’x10’
- ISCO samplers with bubbler flow meters
- Runoff quantity and quality is measured



Pervious Concrete Cross Section



Results: Volume



Volume Reduction Rates

	PICP	Pervious Concrete	Grass Pavers	Gravel Pavers
Reduction Rate	**71%**	**74%**	**78%**	**93%**

Results: Water Quality

	Control (mg)	Grass Pave (mg)	Grass Pave % reduction	ICP (mg)	% reduction
NO3	221.98	857.55	**-286%**	654.27	**-195%**
NH4	272.07	173.43	**36%**	60.64	**78%**
TKN	2327.54	1760.51	**24%**	1023.3	**56%**
Orthophosphate	2.46	12.08	**-391%**	20.84	**-747%**
Total Phosphorus	53.66	85.37	**-59%**	107.87	**-101%**
TSS	59833.46	9648.71	**84%**	32306	**48%**

TSS Reduction in Per Conc: 57%

in Gravel pavers: 48%

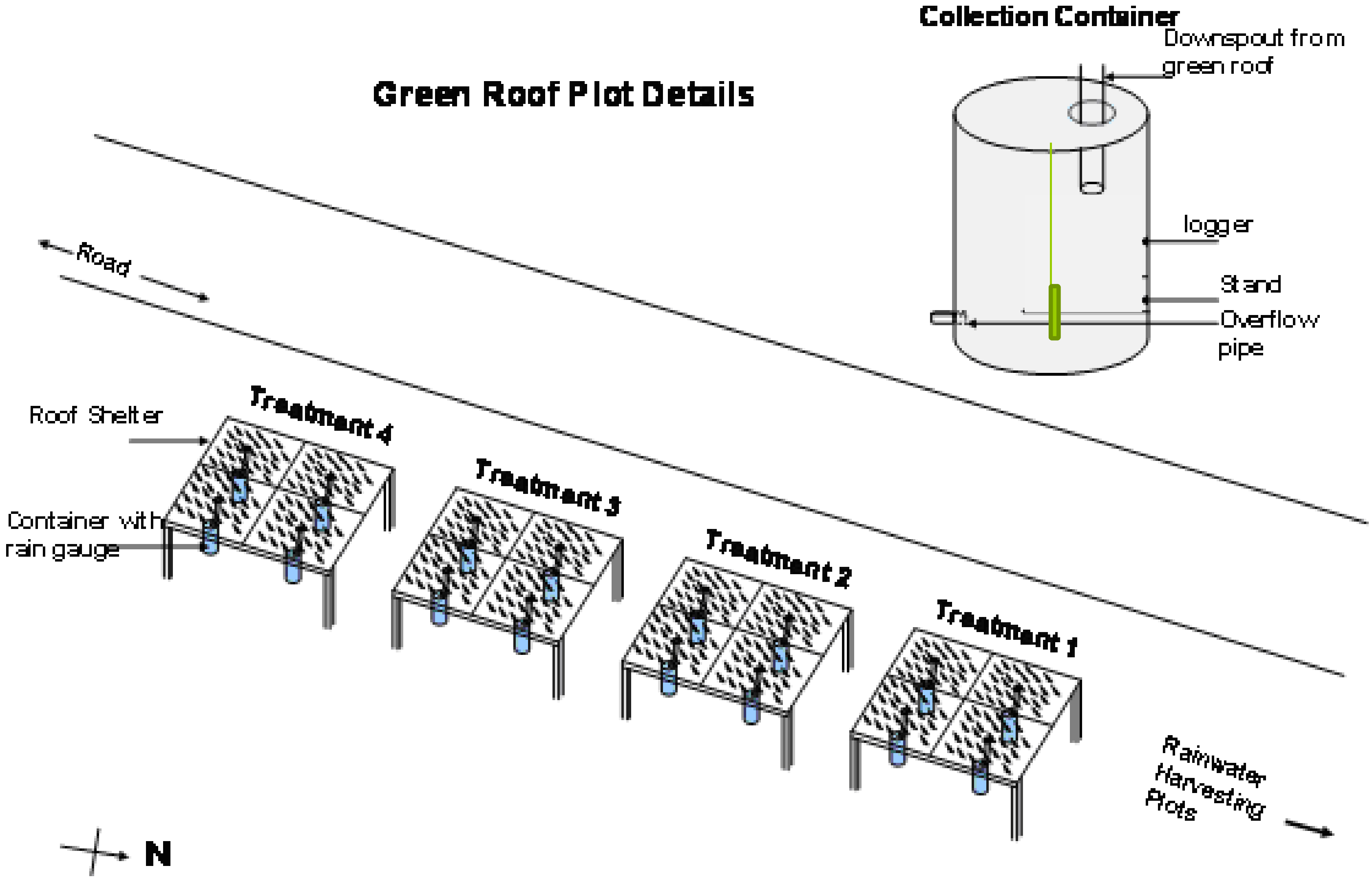
Results

- Percent contribution other than TSS appeared high because of the minute amounts found in the control runoff
- Nitrate and orthophosphate concentrations were still low in general from all treatments.
- Permeable pavement is constructed to collect runoff from paved areas with a minimum amount of soluble chemicals in the water and TSS is the major target pollutant.

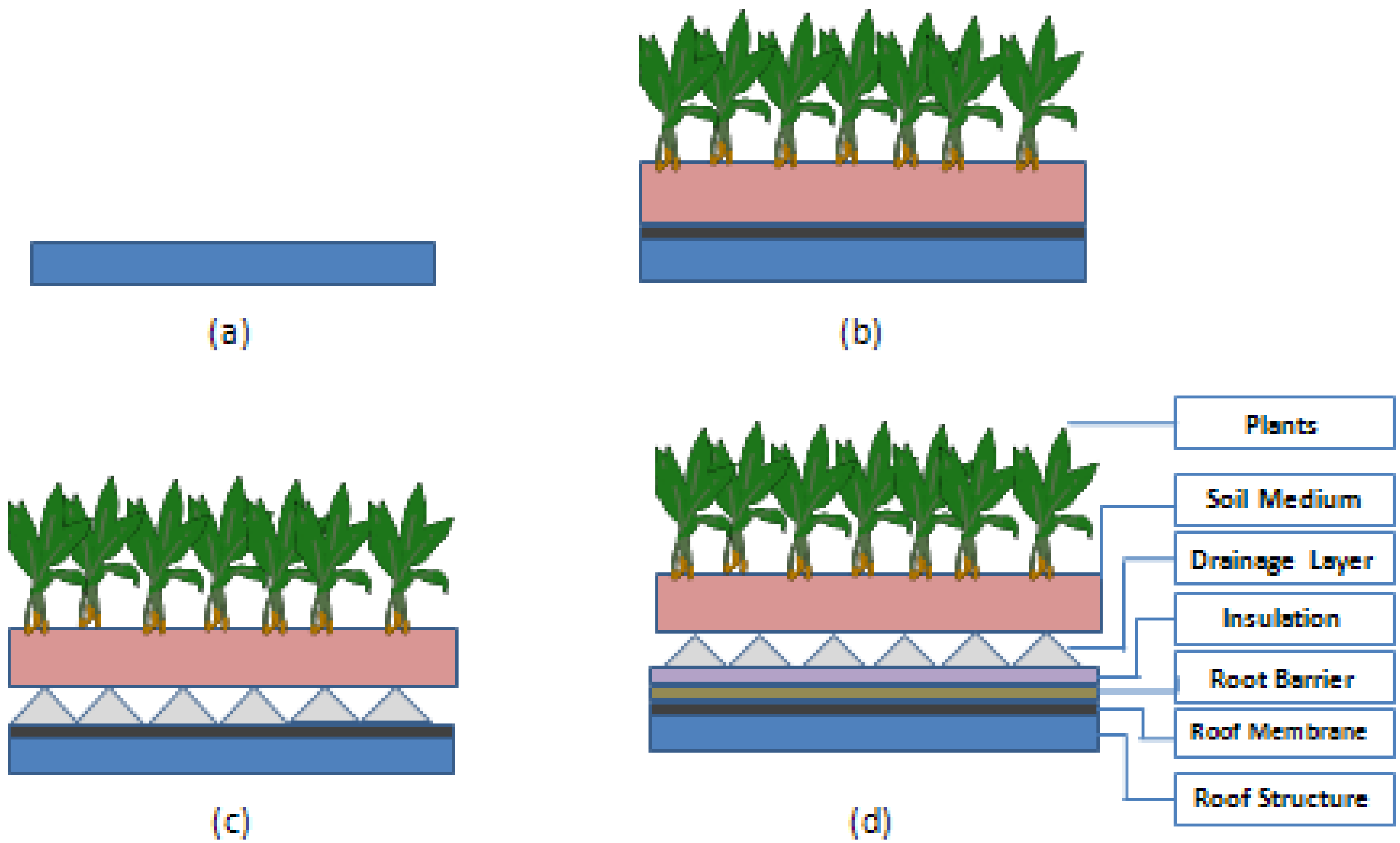
Green Roofs in North Texas

- Experimental Component
  - 4 roof shelters, represent residential roofs
  - Each divided into 4 parts, with 4 types of growing media
  - Different layers of soil, drainage, insulation, roofing membrane
  - Runoff volume, water quality

Green Roof Plot Details



Growth Medium



Vegetation

- Selected based on location, wind, rainfall, air pollution, height of the building, shade and soil depth.
- Roof microclimate can be extreme, requiring hardy plants, adapted to the local climate.
- drought tolerant, have a growth pattern that covers the soil, have very low need for maintenance such as fertilizers, insecticide, herbicides, mowing or trimming, be perennial or self-sowing and be fire resistant

Volume Reduction

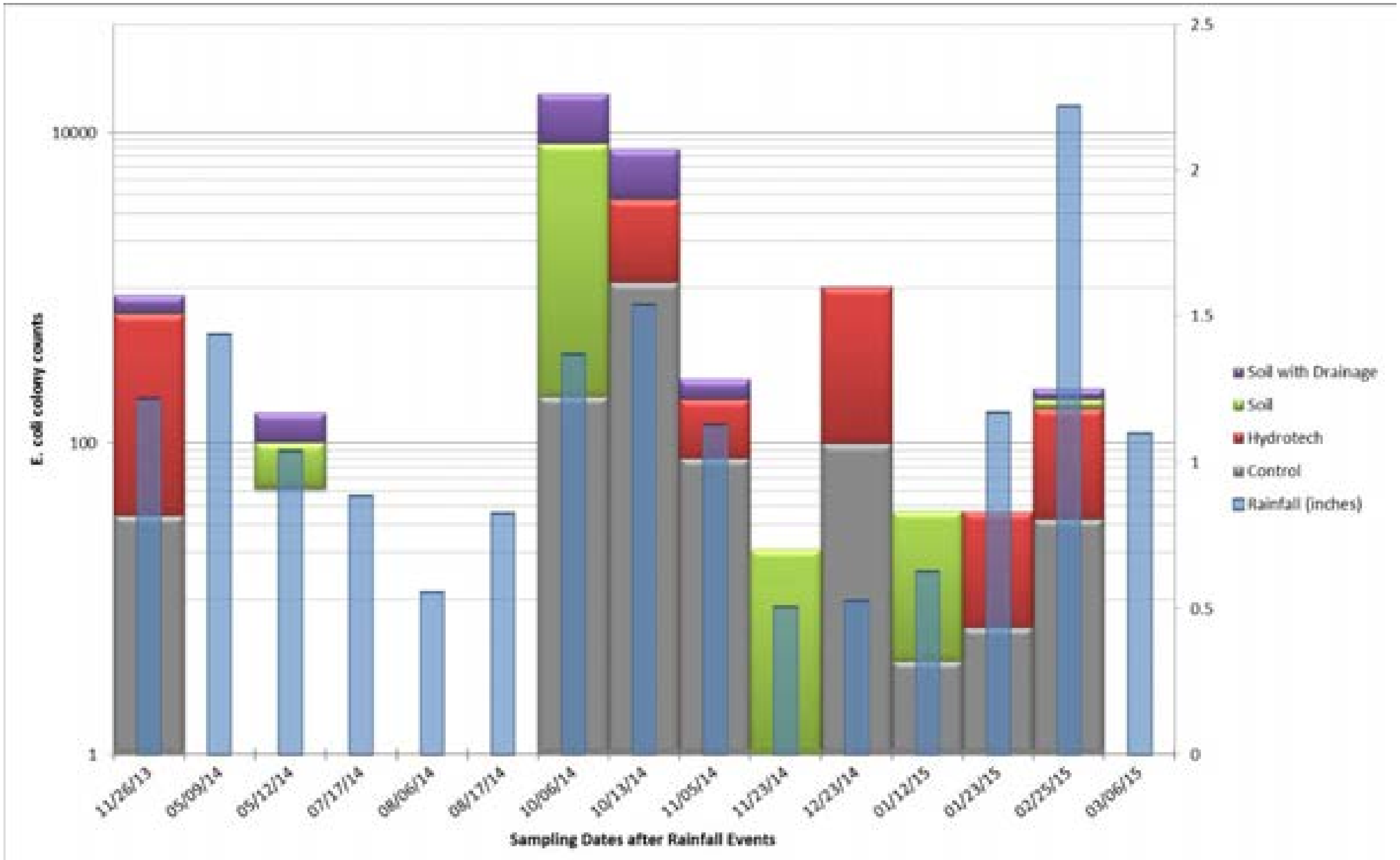
Event	Rainfall	C	H	H reduction	S	S reduction	SD	SD Reduction
Date	inches	gals	gals	%	gals	%	gals	%
12/28/12	1.52	13.04	8.67	33.51%	8.40	35.58%	8.62	33.90%
01/10/13	2.61	39.13	25.67	34.40%	23.13	40.89%	28.15	28.06%
02/11/13	0.9	8.40	5.13	38.93%	5.19	38.24%	2.18	74.05%
03/11/13	1.67	19.71	7.02	64.38%	12.51	36.53%	6.31	67.99%
04/01/13	0.84	2.71	0.00	100.00%	0.00	100.00%	0.00	100.00%
04/04/13	0.84	3.51	1.30	62.96%	1.29	63.25%	1.29	63.11%
04/18/13	0.87	6.96	0.70	89.94%	0.00	100.00%	1.18	83.05%
05/16/13	1.96	24.61	5.62	77.16%	2.63	89.31%	7.32	70.26%
05/22/13	0.89	4.25	0.10	97.67%	0.00	0.00%	0.36	91.53%
06/10/13	1.08	7.73	2.42	68.69%	1.18	84.73%	0.67	91.33%
06/17/13	0.67	0.80	0.00	100.00%	0.00	100.00%	0.00	100.00%
07/11/13	0.72	1.72	0.00	100.00%	0.00	100.00%	0.30	82.53%
07/17/13	1.12	9.27	4.07	56.09%	1.60	82.74%	2.86	69.19%
09/21/13	1.93	7.44	5.37	27.82%	1.12	84.95%	2.66	64.25%
10/16/13	1.88	7.26	3.25	55.23%	5.78	20.39%	3.6	50.41%
10/27/13	1.24	5.25	4.43	15.62%	4.25	19.05%	2.83	46.10%
11/05/13	1.08	5.55	2.54	54.23%	0.04	99.28%	2.24	59.64%
11/26/13	1.22	3.89	0.53	86.38%	1	74.29%	0	100.00%
12/21/13	1.42	7.02	4.19	40.31%	4.4	37.32%	6.96	0.85%

Volume Reduction

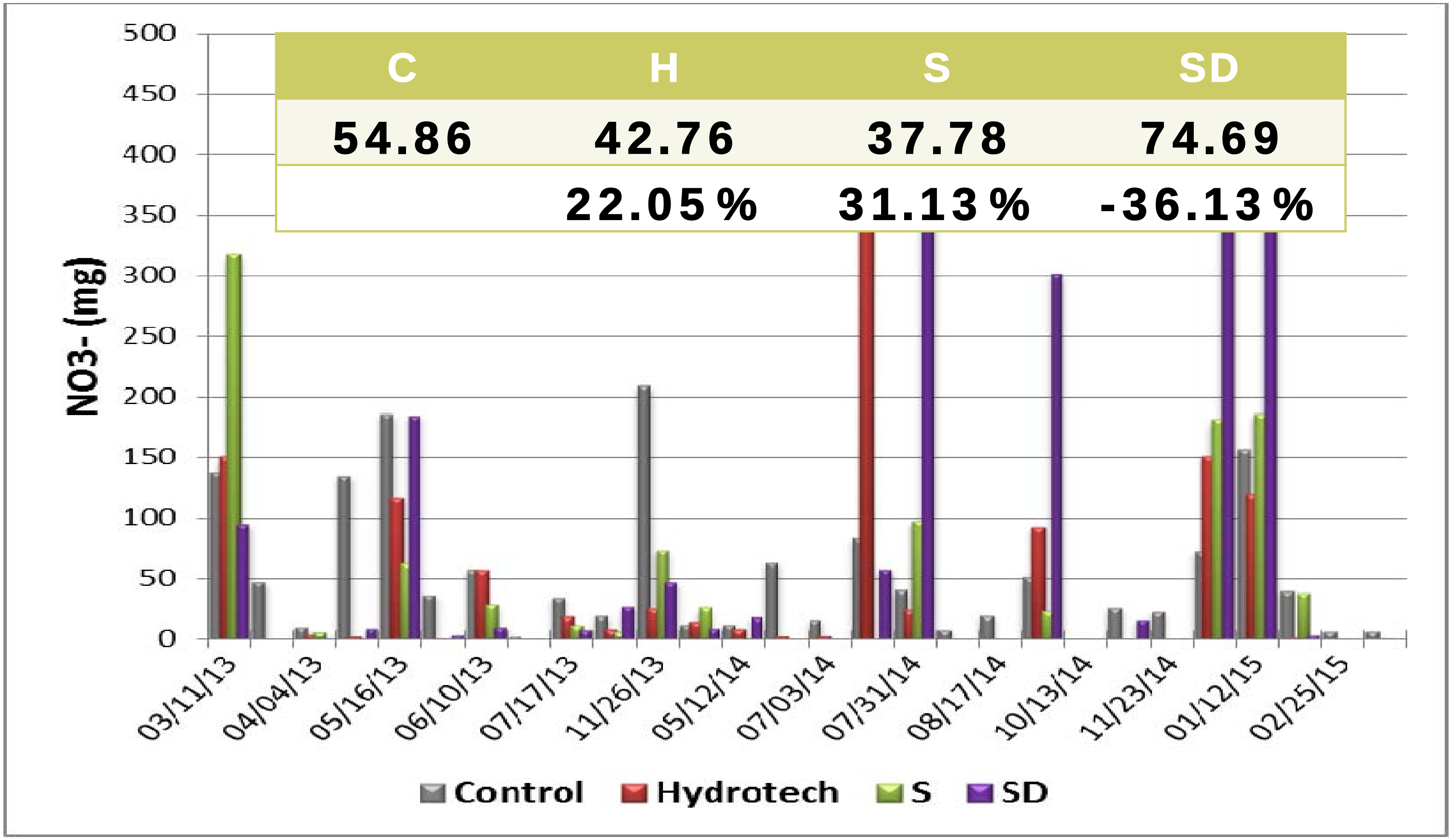
Total Volume Reduction from C	65.39%	76.05%	75.33 %

Event	Rainfall	C	H	H reduction	S	S reduction	SD	SD Reduction
Date	inches	gals	gals	%	gals	%	gals	%
05/09/14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
05/12/14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
06/09/14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
07/03/14	0.82	5	3.4	0.32	0.17	0.97	0.17	0.97
07/17/14	0.89	6.7	1.47	0.78	0.1	0.99	2	0.70
07/31/14	1.01	7.7	6.1	0.21	0.24	0.97	1.18	0.85
08/06/14	0.56	2.7	0	1.00	0	1.00	0.29	0.89
08/17/14	0.83	4.7	1.18	0.75	0	1.00	0.29	0.94
10/06/14	1.37	15.8	5.54	0.65	2.47	0.84	4.1	0.74
10/13/14	1.54	22	11.9	0.46	8.7	0.60	9.3	0.58
10/13/14	1.54	22	11.9	0.46	8.7	0.60	9.3	0.58
11/05/14	1.13	9.02	0.17	0.98	0.35	0.96	0.29	0.97
11/23/14	0.51	2.5	0	1.00	0	1.00	0	1.00
12/23/14	0.53	3.89	0.59	0.85	0.35	0.91	0	1.00
01/12/15	0.63	4.5	0.66	0.85	2.4	0.47	0.94	0.79
01/23/15	1.17	7.58	3.56	0.53	3.63	0.52	3.28	0.57
02/02/15	0.72	35.7	25	0.30	1.12	0.97	0	1.00
02/25/15	2.22	15.58	8.63	0.45	1.36	0.91	5.66	0.64
03/06/15	1.1	2.36	0	1.00	1.35	0.43	0.17	0.93

E. Coli counts

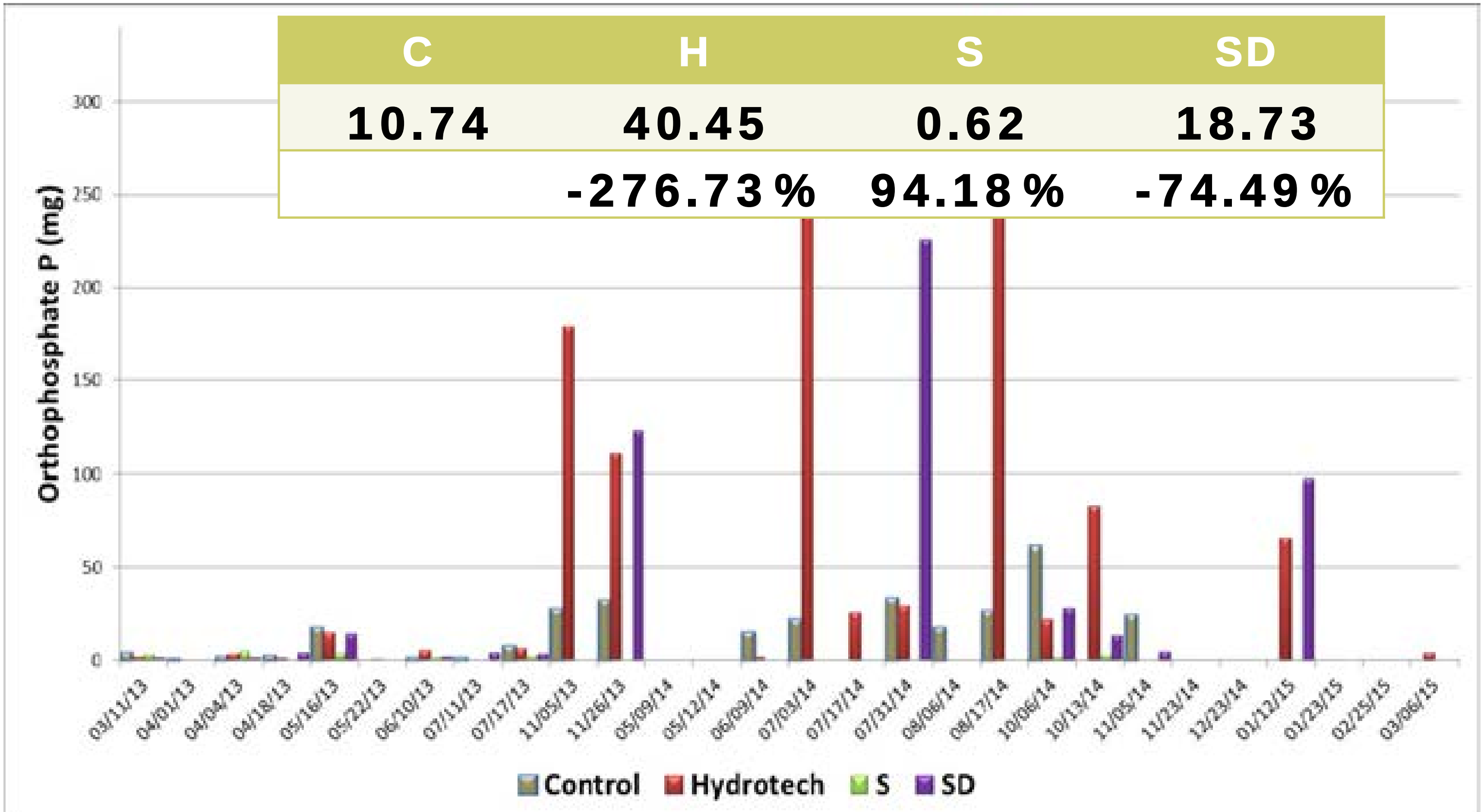


Nitrate Loads



C	H	S	SD
54.86	42.76	37.78	74.69
	22.05%	31.13%	-36.13%

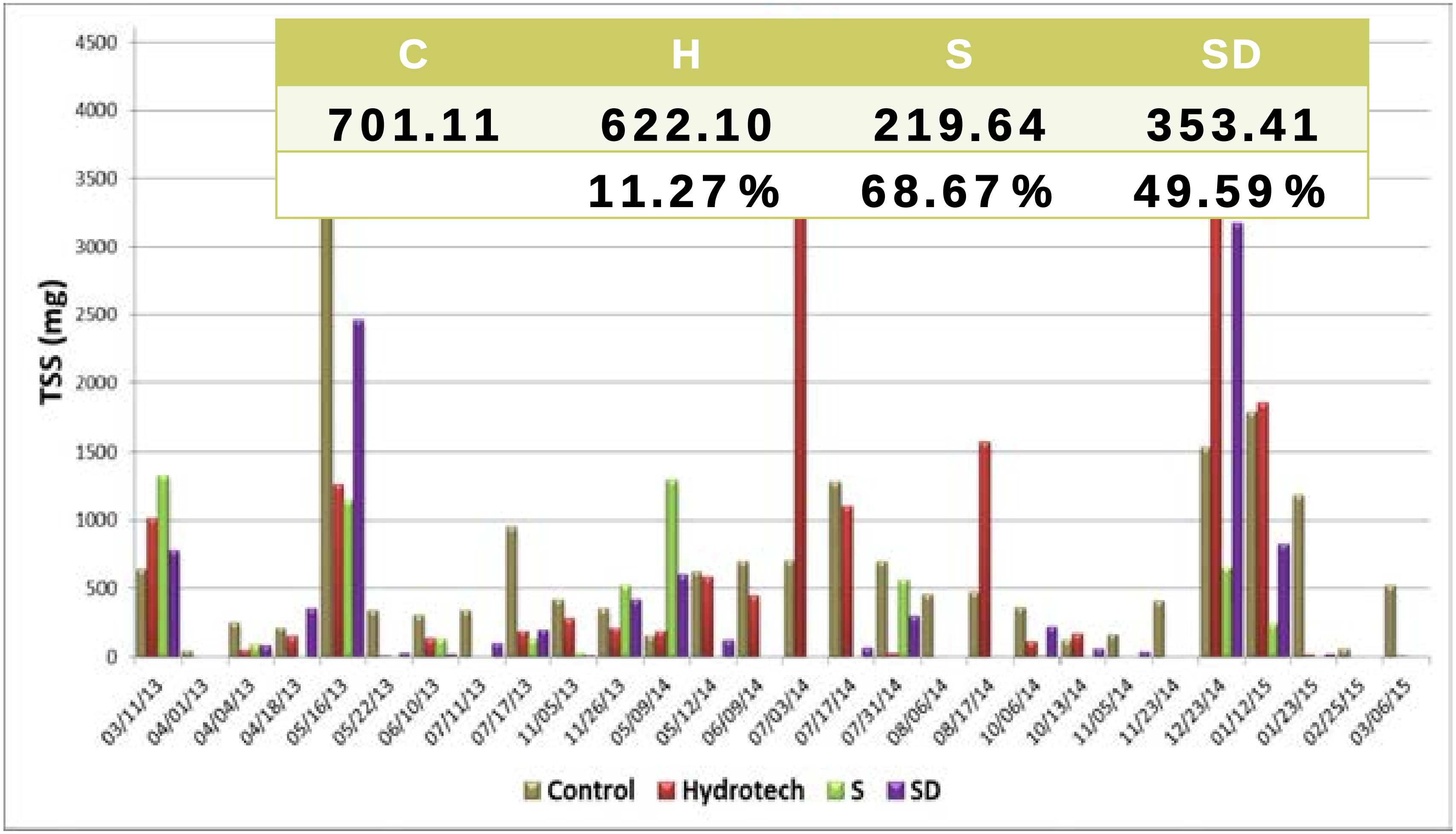
Orthophosphate Loads



C	H	S	SD
10.74	40.45	0.62	18.73
	-276.73%	94.18%	-74.49%

TSS Loads

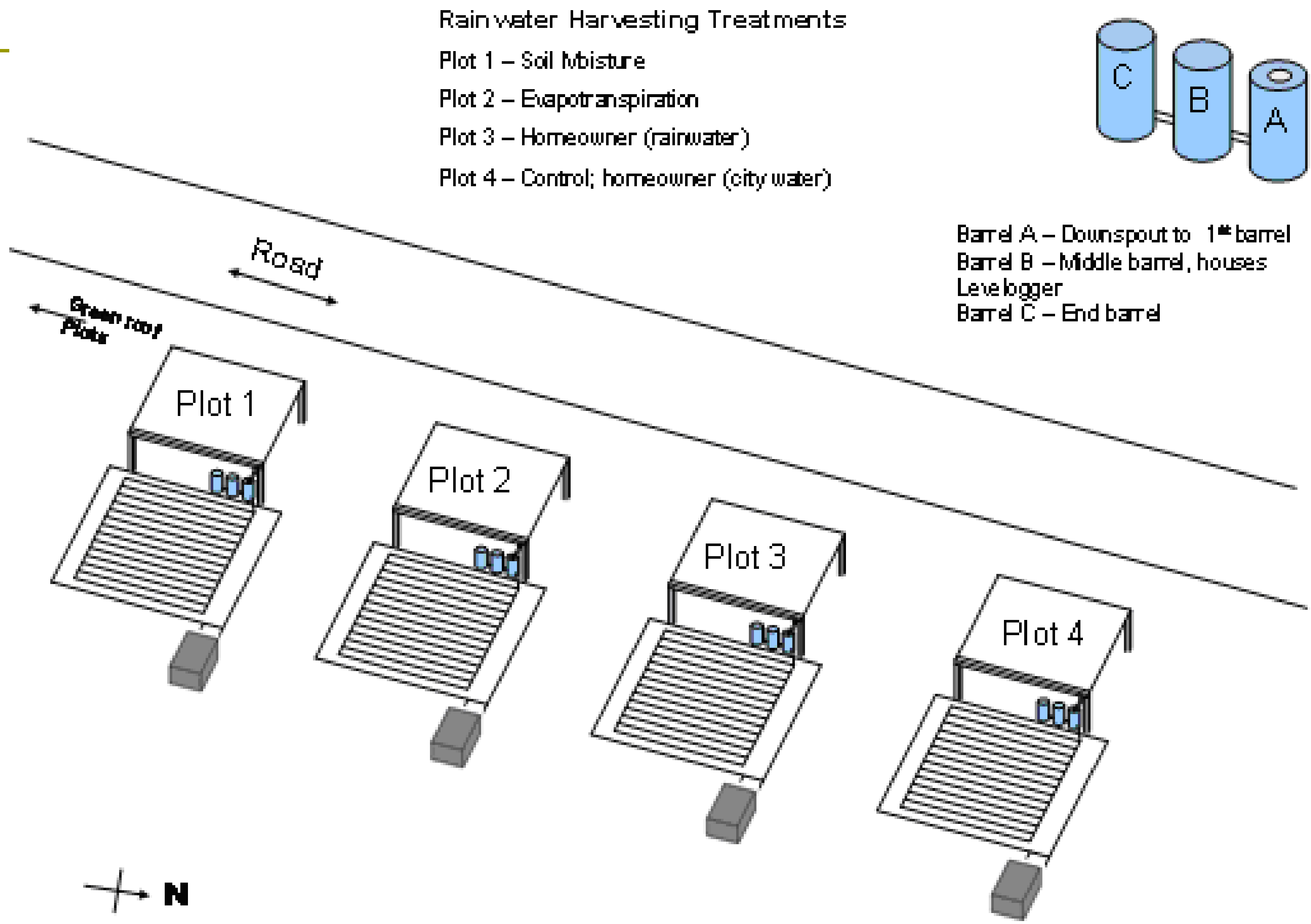
C	H	S	SD
701.11	622.10	219.64	353.41
	11.27%	68.67%	49.59%

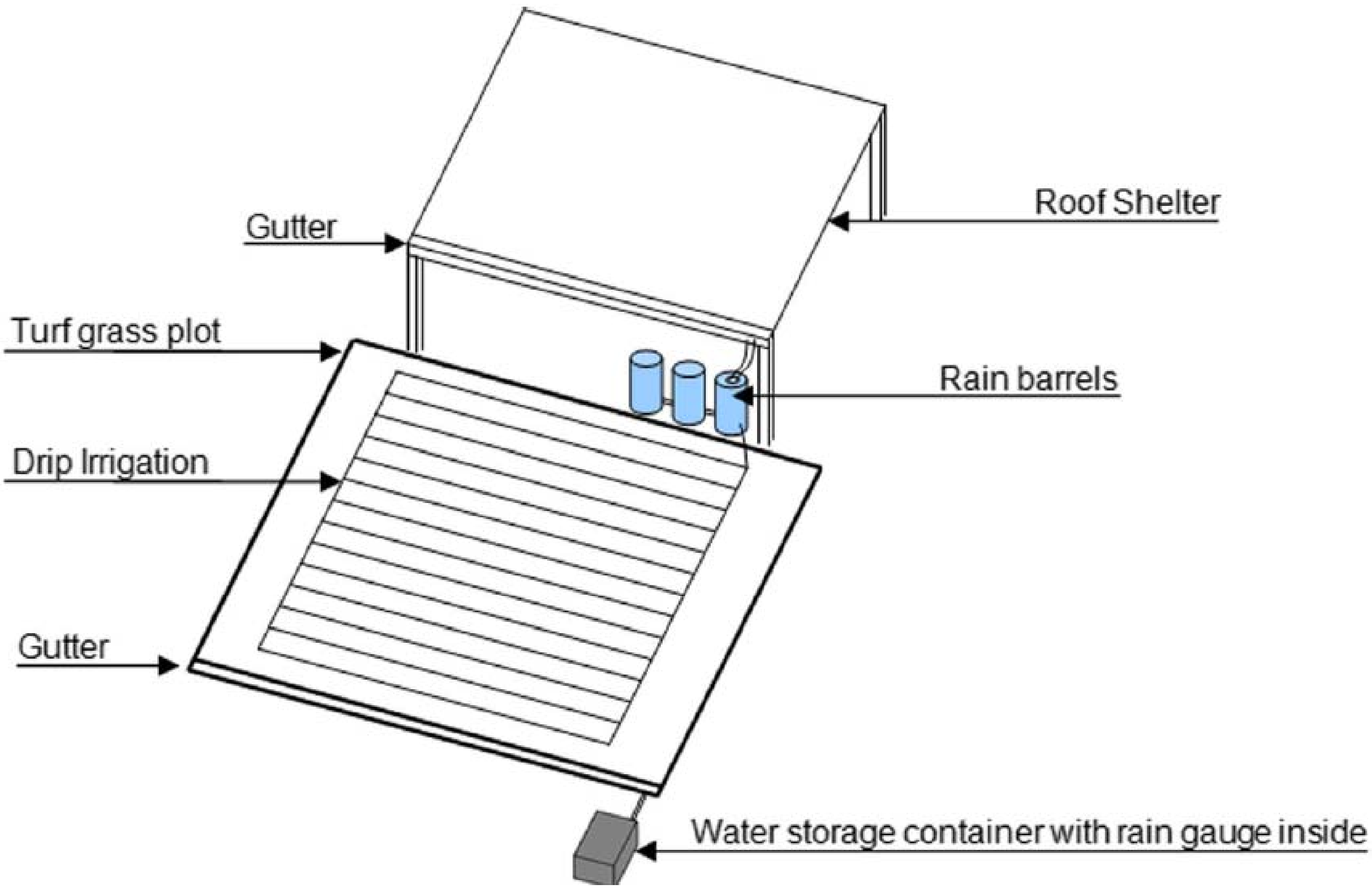


Rainwater Harvesting

- Demonstration Component
  - Four cisterns (300, 500, 1500, and 2500 gallon) that serve AgriLife Buildings
  - Storage and outflow measured
  - Serves a drip irrigation system
- Experimental Component
  - 4 roof shelters, represent residential roofs, 55 gallon tanks(3/plot)
  - Turf lawn associated with each, drip irrigation
  - 4 Treatments- Soil moisture, Evapotranspiration, Home owner (rain water), Control: Home owner (city water)
  - Inflow, outflow, water quality

Experimental plot layout

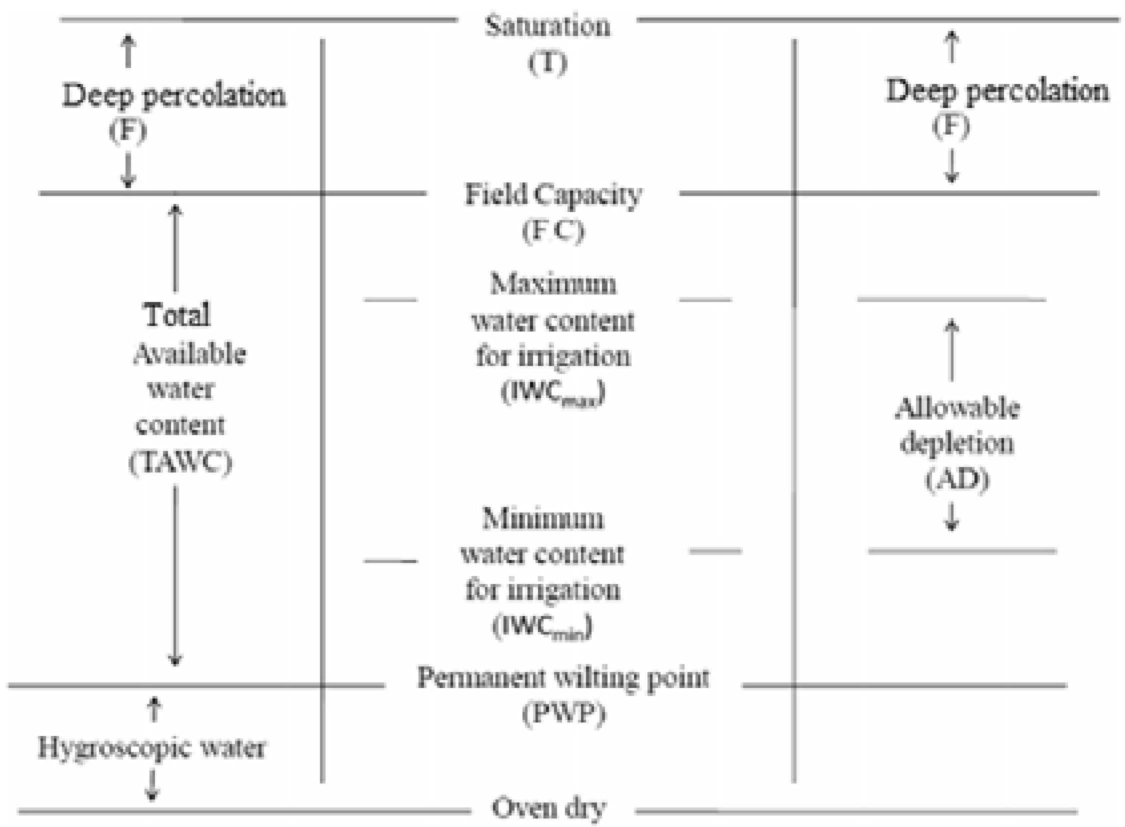



Roof Shelter
Gutter
Turf grass plot
Rain barrels
Drip Irrigation
Gutter
Water storage container with rain gauge inside

Time Based Irrigation

Month	Frequency of irrigation
Jan–Feb	Biweekly
March	Weekly
April–May	Once every 3 days
Jun–Aug	Daily
Sep	Once every 2 days
Oct	Weekly
Nov–Dec	Biweekly

Soil moisture based irrigation



ET-based Irrigation

For ET-based irrigation treatment, four steps were done to estimate volume of water applied. First, published ET data and crop coefficients were utilized to calculate daily irrigation requirements (ETc):

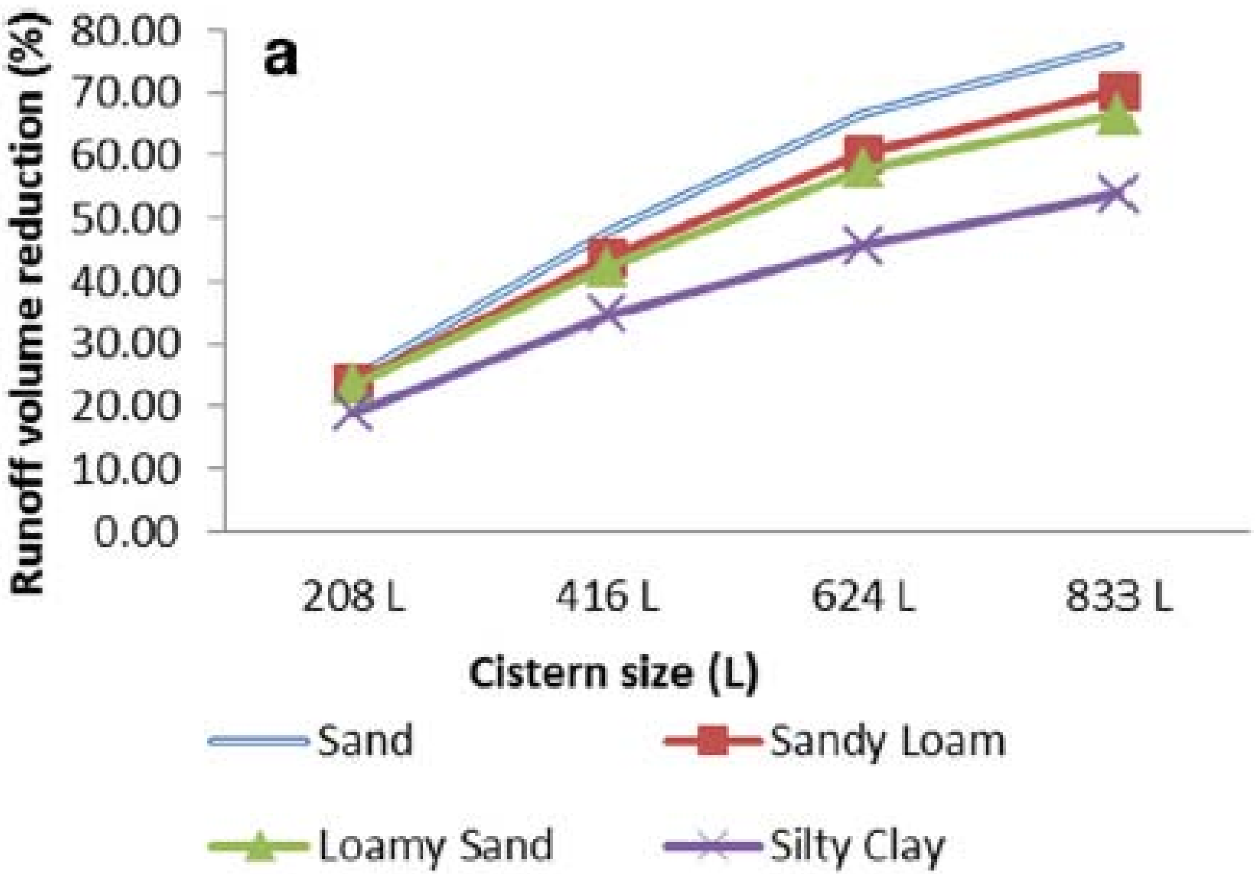
$$ETc = ET_0 \times Kc \quad (18)$$

where:

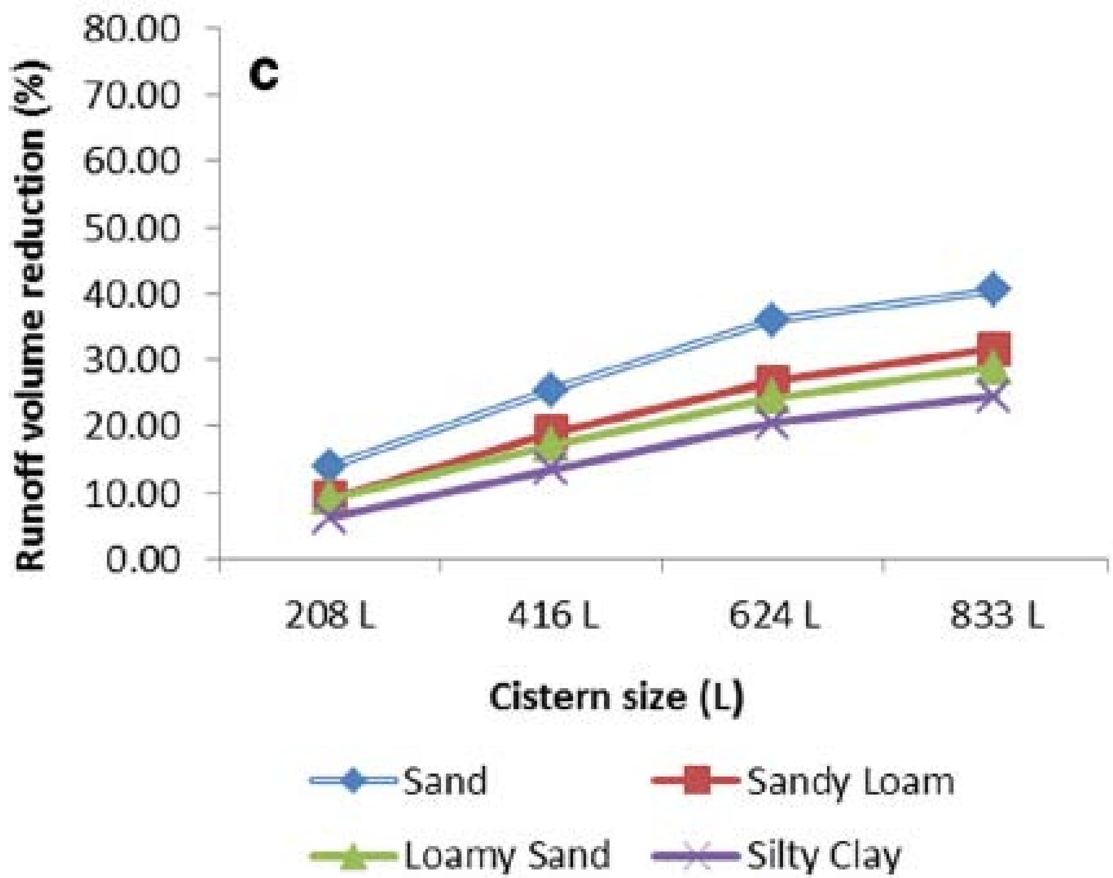
ET_c crop evapotranspiration

ET_o rate of evapotranspiration from a reference surface that is not short of water

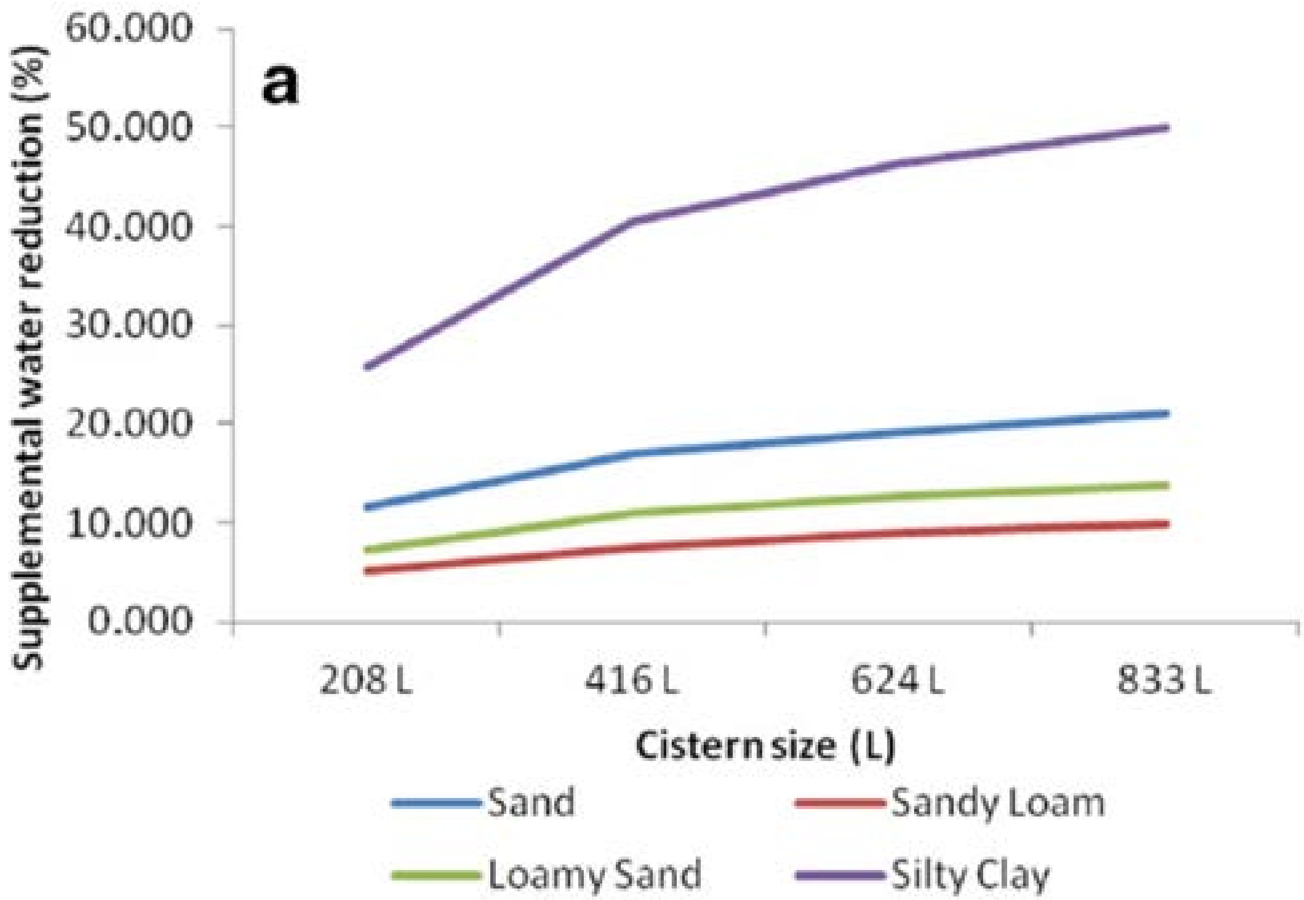
Runoff from time based



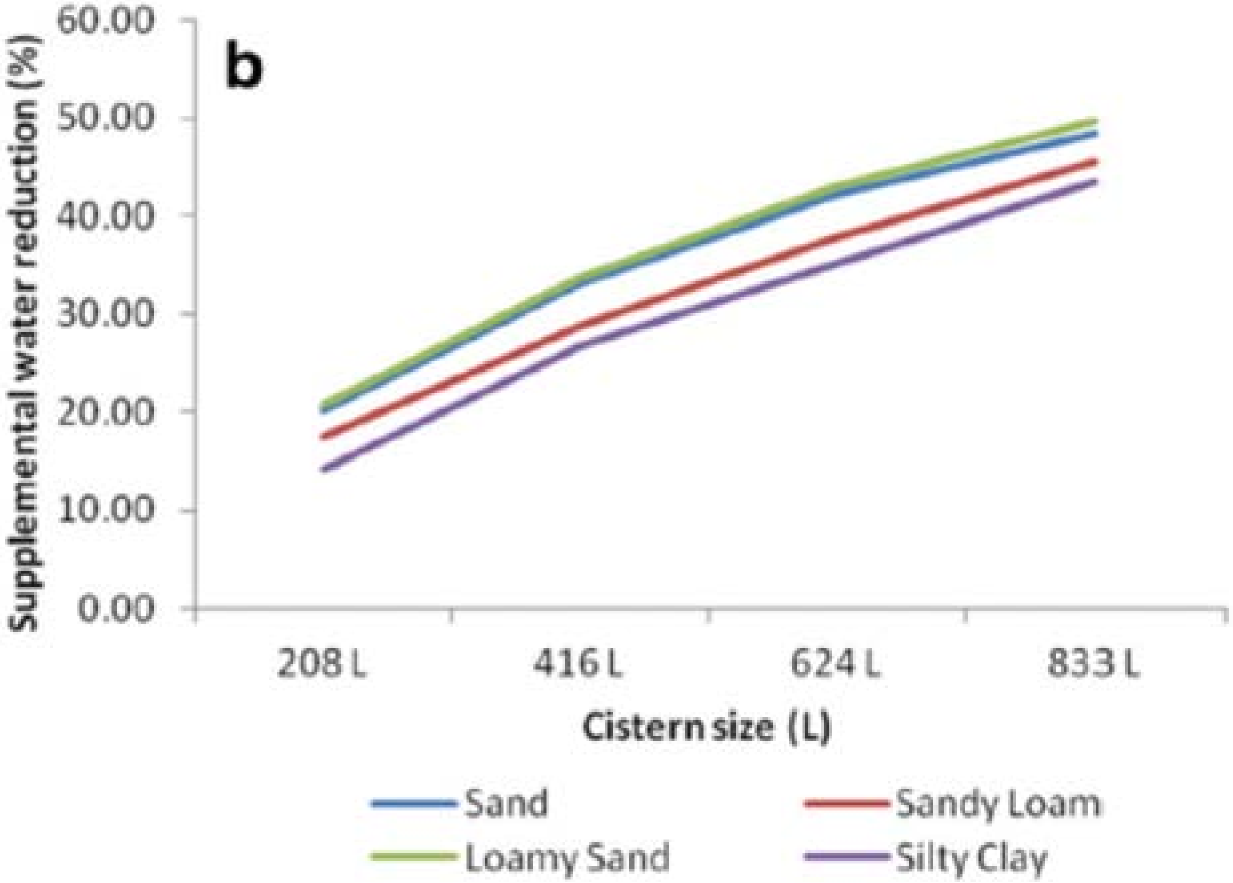
Runoff from ET-based

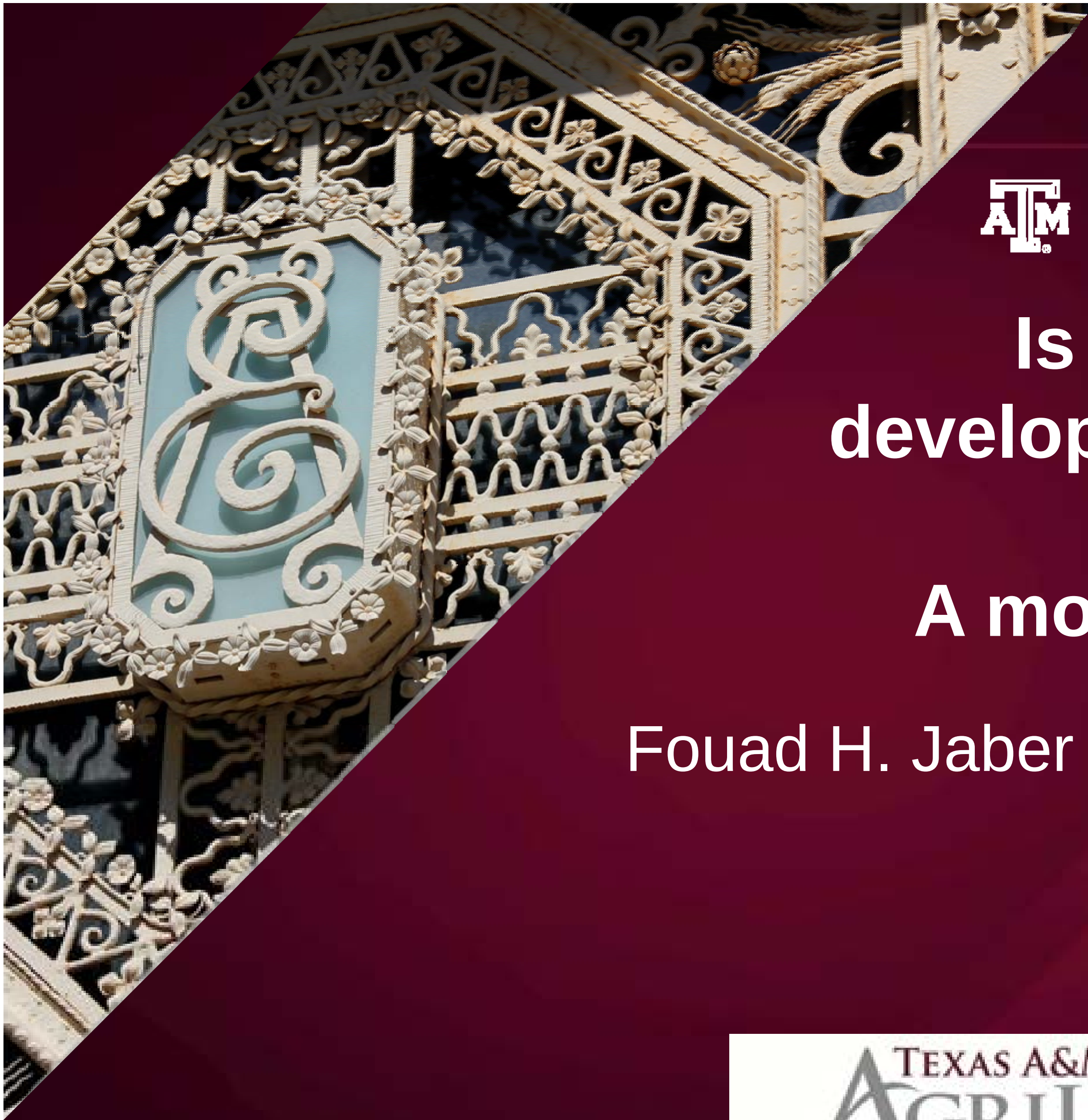


Water Savings from RWH



Water Savings Soil Moisture





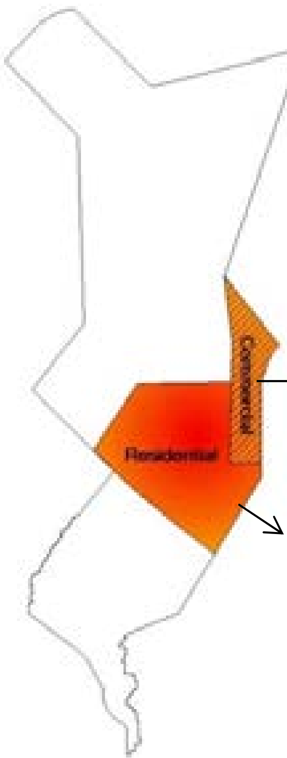
BIOLOGICAL & AGRICULTURAL ENGINEERING
TEXAS A&M UNIVERSITY

Is high density development an LID practice? A modeling study

Fouad H. Jaber and Mijin Seo

TEXAS A&M AGRILIFE RESEARCH | EXTENSION

Urban Land Uses (1. UHD)



5% of total area (0.28 FAR)

16% of total area (10 units/ac)

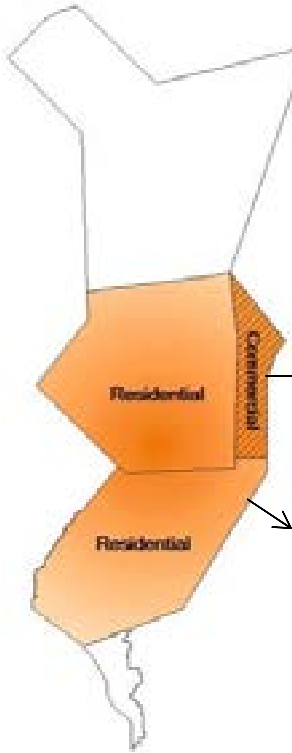
Compact high-density urban design

A heavily developed area and maximized site perviousness

Land use	Urban design	Urban ratio	Impervious/pervious fraction (in %)	
			Residential	Commercial
UHD	**Compact urban form with high density**	**21%**	**61/39**	**68/32**
UMD	Conventional urban form with medium density	56%	44/56	75/25
UMC	Conservational urban form with medium density	56%	41/59	68/32

Source of designs: League City, designed by Edminster, Hinshaw, Russ and Associates, Inc. (EHRA)

Urban Land Uses (2. UMD)



5% of total area (0.23 FAR)

51% of total area (3 units/ac)

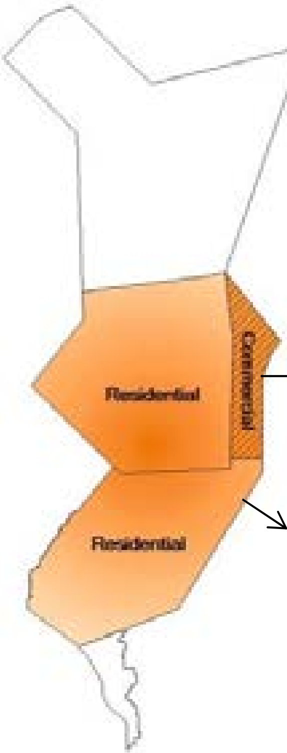
Conventional medium-density urban design

A typical pattern in the United States

Land use	Urban design	Urban ratio	Impervious/pervious fraction (in %)	
			Residential	Commercial
UHD	Compact urban form with high density	21%	61/39	68/32
UMD	**Conventional urban form with medium density**	**56%**	**44/56**	**75/25**
UMC	Conservational urban form with medium density	56%	41/59	68/32

Source of designs: League City, designed by Edminster, Hinshaw, Russ and Associates, Inc. (EHRA)

Urban Land Uses (3. UMC)



5% of total area (0.23 FAR)

51% of total area (3 units/ac)

Conservational medium-density urban design

Include conservational areas under the same base format with conventional urban form

Land use	Urban design	Urban ratio	Impervious/pervious fraction (in %)	
			Residential	Commercial
UHD	Compact urban form with high density	21%	61/39	68/32
UMD	Conventional urban form with medium density	56%	44/56	75/25
UMC	**Conservational urban form with medium density**	**56%**	**41/59**	**68/32**

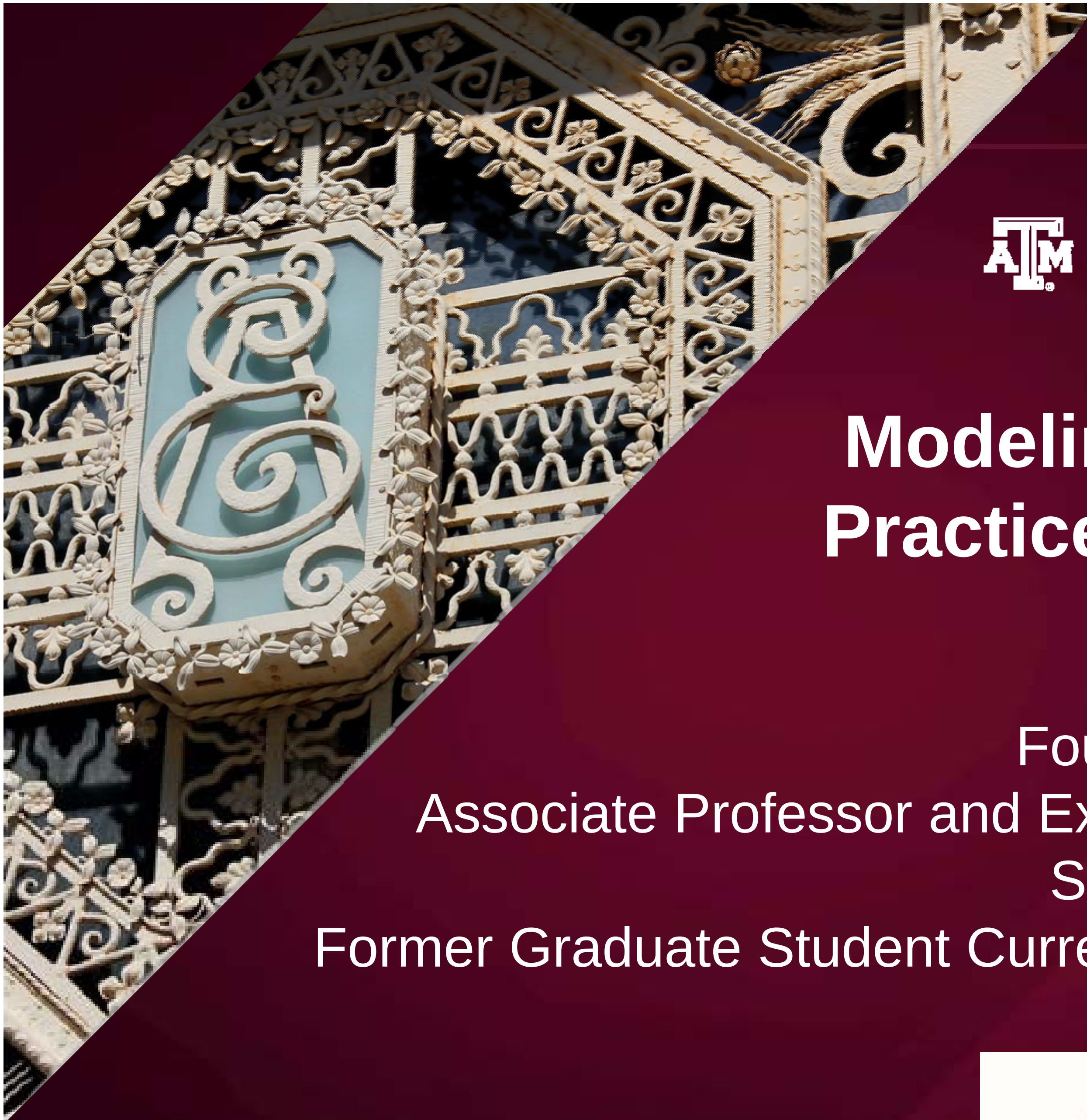
Source of designs: League City, designed by Edminster, Hinshaw, Russ and Associates, Inc. (EHRA)

Post-LIDs results

- Final result values

Scenario	SURQ (mm)	NO_3 (kg)	TP (kg)	Difference (% reduction)		
				SURQ (mm)	NO_3 (kg)	TP (kg)
UHD	374.66	430.92	431.64	52.97 (14%)	101.37 (24%)	46.45 (11%)
UHDLIDs	**321.69**	**329.55**	**385.19**			
UMD	473.32	591.87	449.55	135.51 (29%)	186.03 (31%)	110.69 (25%)
UMDLIDs	**337.81**	**405.85**	**338.86**			
UMC	462.73	577.19	443.46	117.80 (25%)	170.51 (30%)	97.43 (22%)
UMCLIDs	**344.93**	**406.68**	**346.03**			

- SURQ: UMCLIDs > UMDLIDs > UHDLIDs
- NO_3 : UMCLIDs > UMDLIDs > UHDLIDs
- TP : UHDLIDs > UMCLIDs > UMDLIDs



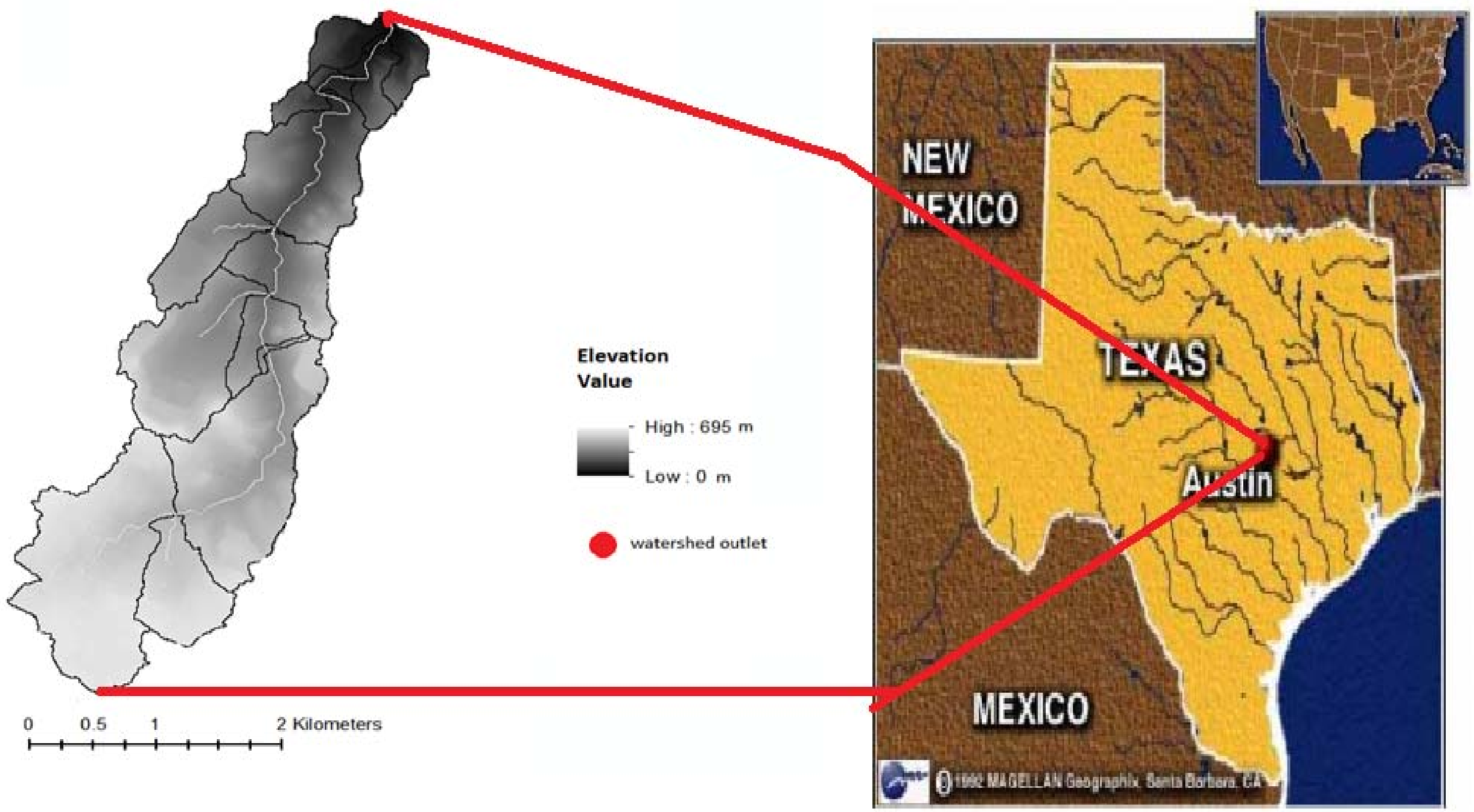
BIOLOGICAL & AGRICULTURAL ENGINEERING
TEXAS A&M UNIVERSITY

Modeling LID Effect Practices on Stream Health

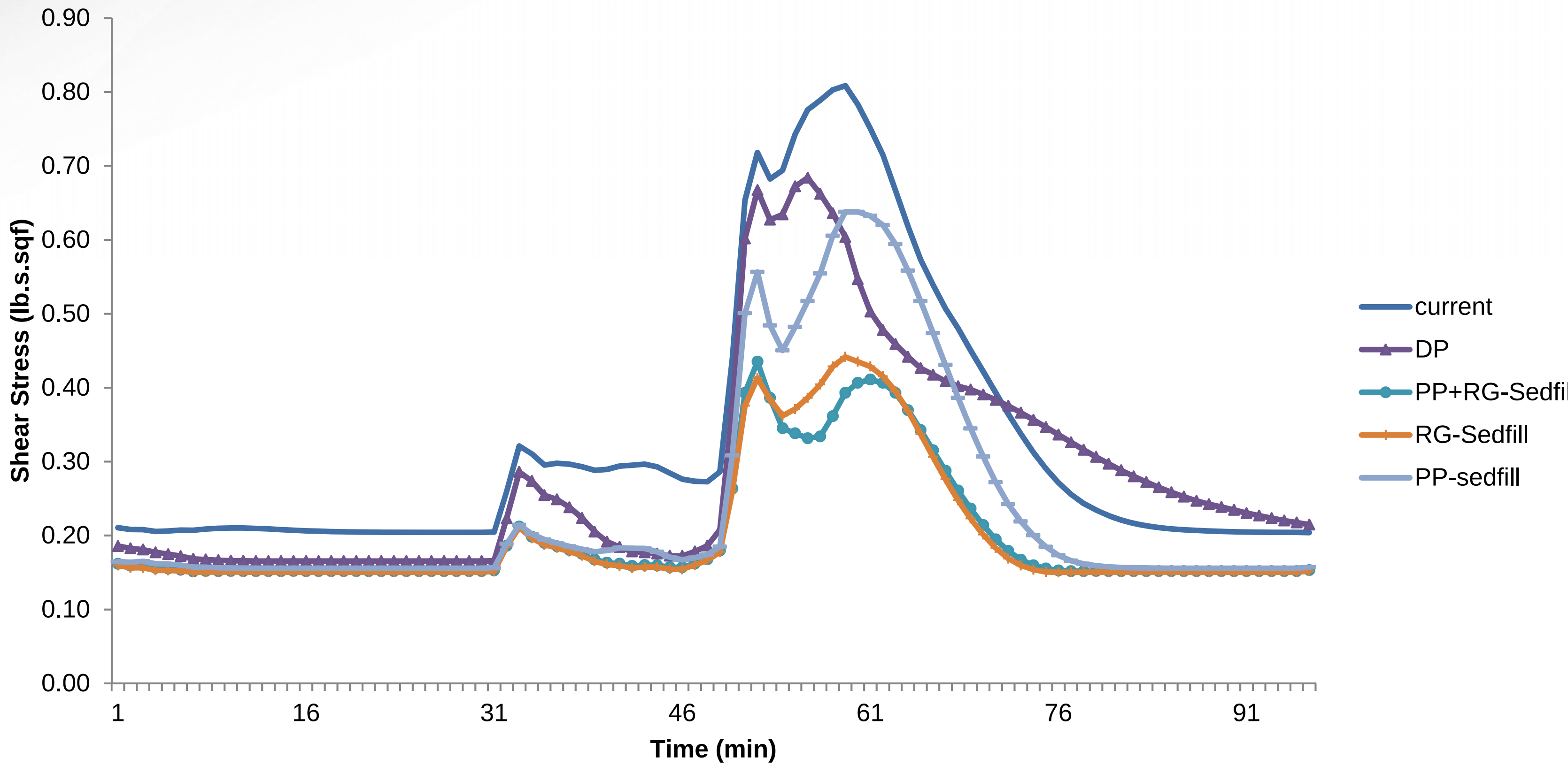
Fouad H. Jaber, PhD
Associate Professor and Extension Specialist
Sa'd Shannak, PhD
Former Graduate Student Currently at KAPSARC

TEXAS A&M AGRILIFE RESEARCH | EXTENSION

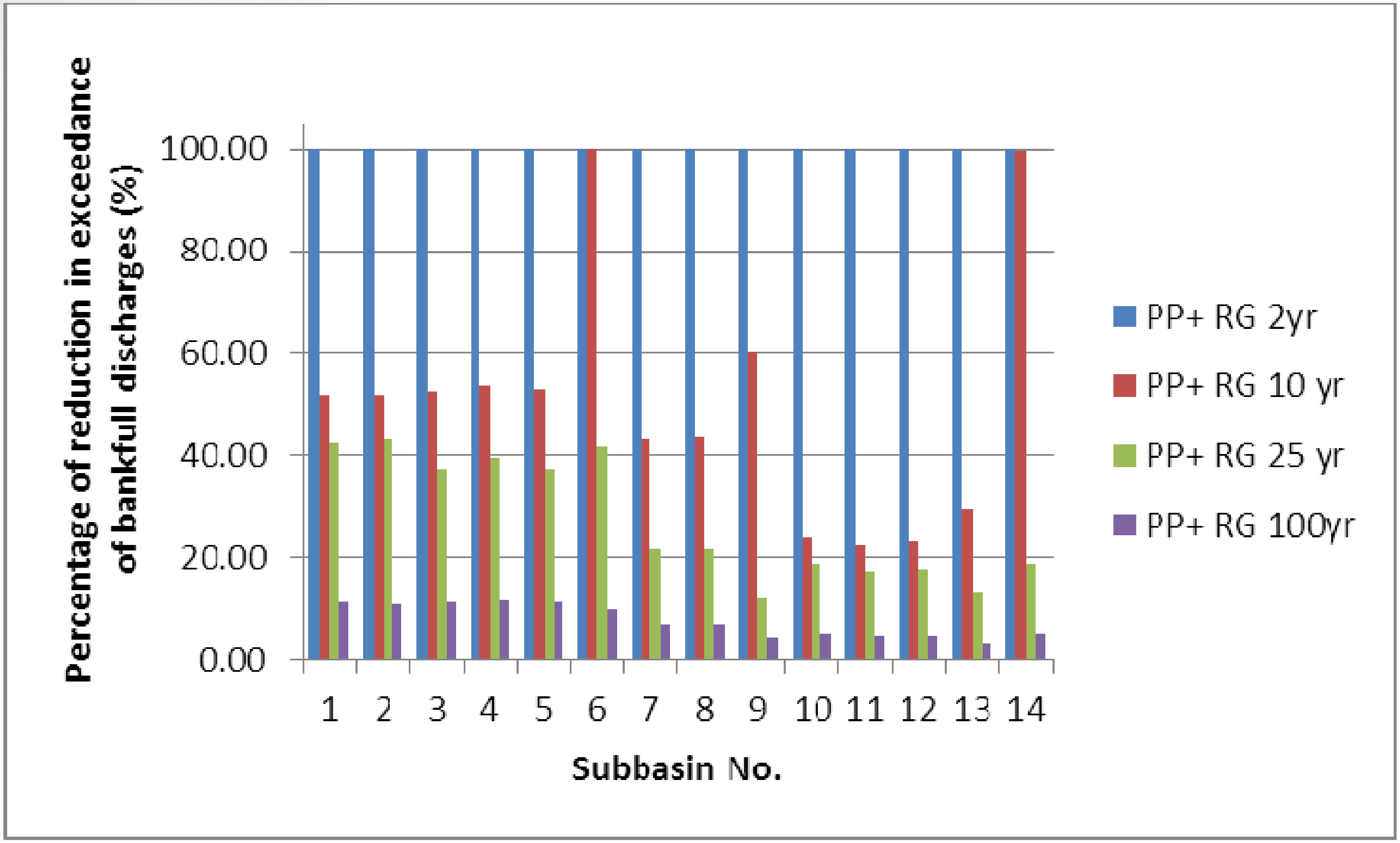
BLUNN CREEK WATERSHED- AN OVERVIEW



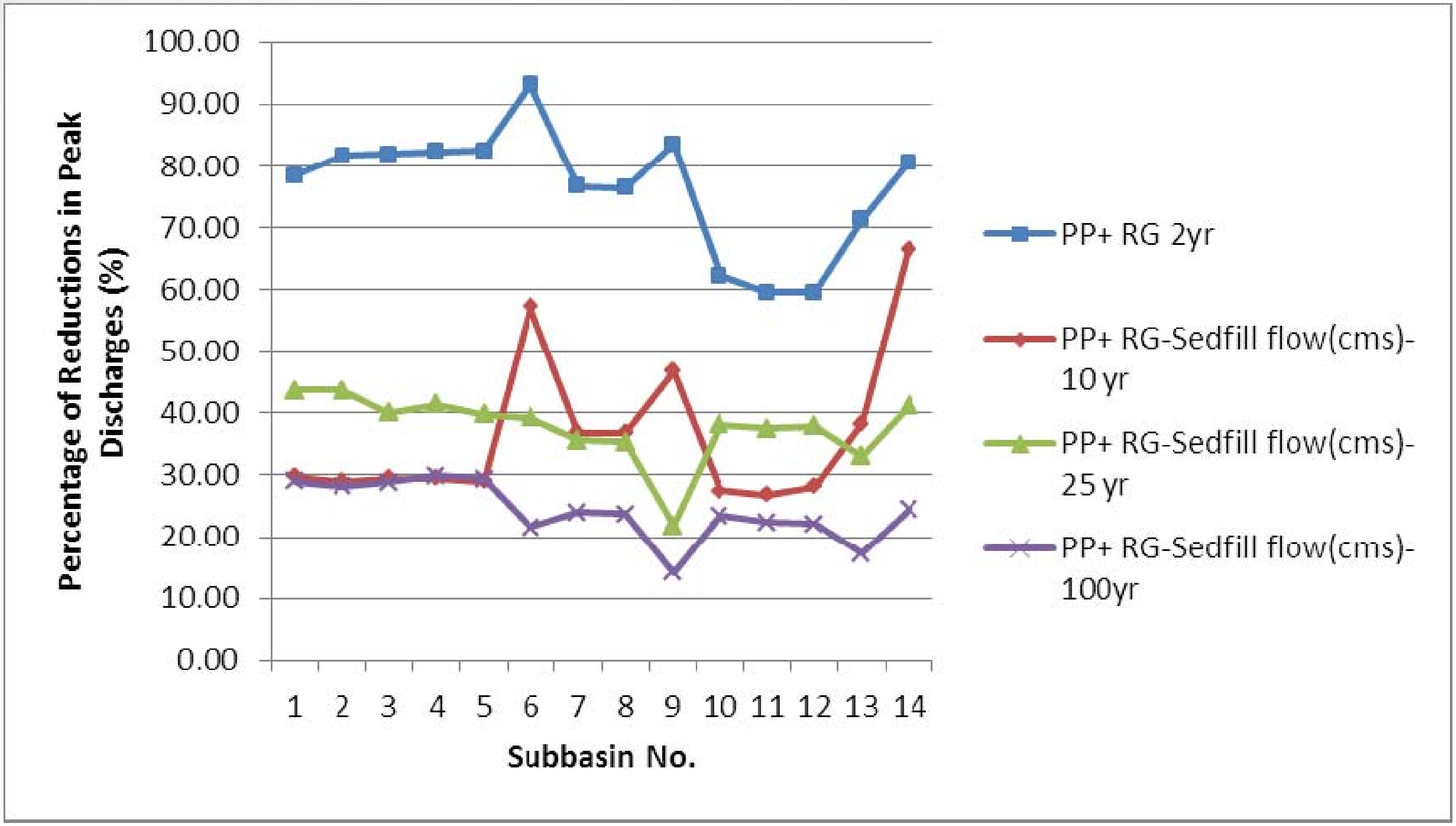
Results of LID on Shear Stress



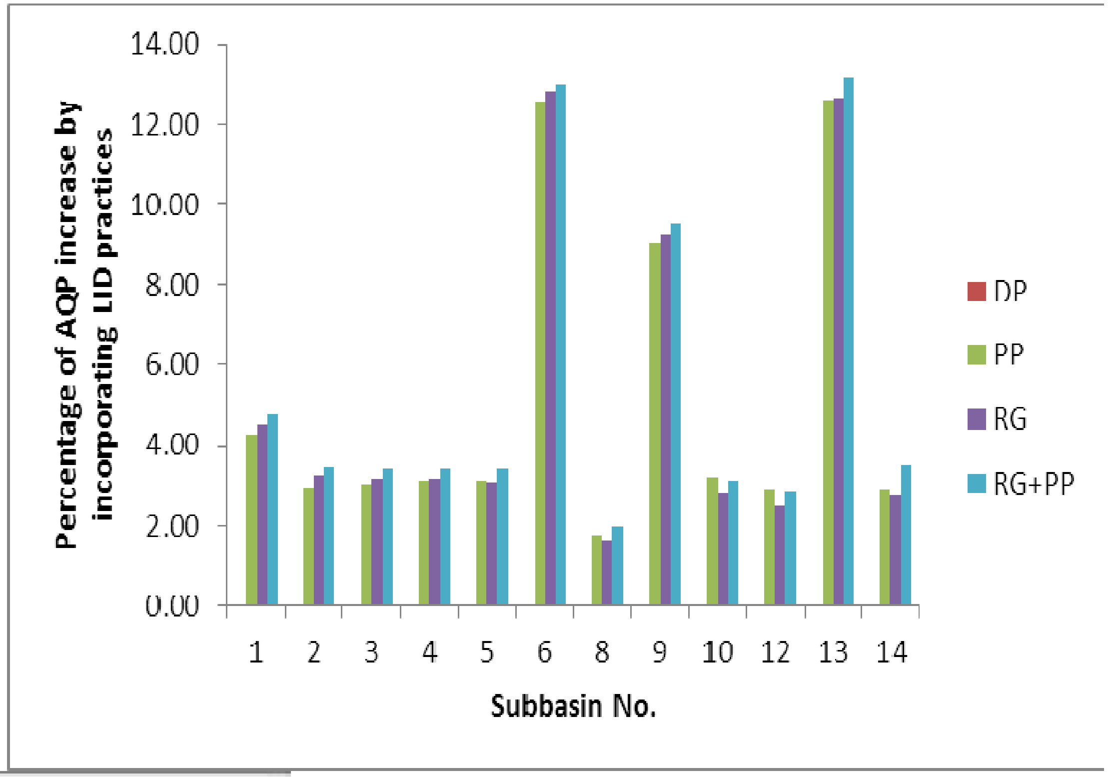
Reduction in flooding due to LID

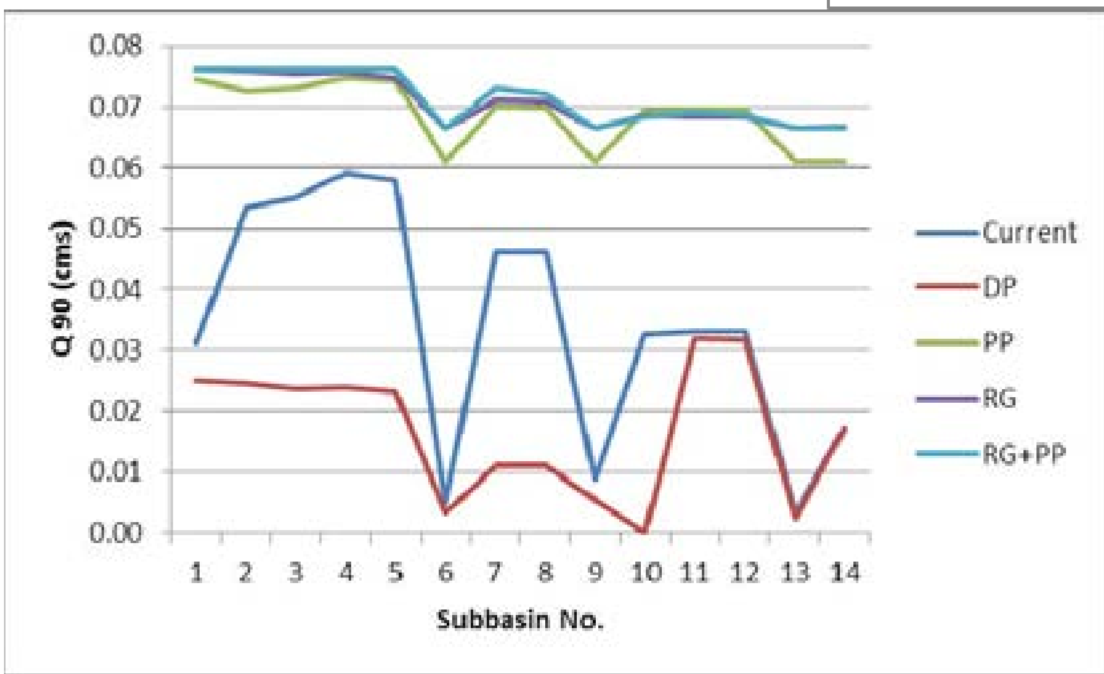


Reduction of Peak Flow



Combining bioretention area with permeable pavement resulted with the greatest percentage of AQP value increase, followed by RG only, PP and DP





Greatest increase in baseflow resulted when combining bioretention area with permeable, followed by RG only, PP and lastly DP

Acknowledgements

- This research was made possible by a CWA 319 (h) NPS grant provided by USEPA and TCEQ
- Texas AgriLife Research for providing funds and the location for the constructed BMPs.
- Modeling studies funded by Texas Sea Grant, USEPA, TCEQ and the City of League City, TX

TEXAS A&M AGRILIFE RESEARCH | EXTENSION

Fouad H. Jaber, PhD, PE

Associate Professor and Extension Specialist

Biological and Agricultural Engineering

Texas A&M AgriLife Extension

Dallas Research and Extension Center

f-jaber@tamu.edu

972-952-9672