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DESIGN IMPLEMENTATION

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A BLUEPRINT FOR STORMWATER INFRASTRUCTURE DESIGN: IMPLEMENTATION AND EFFICACY OF LID

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1 ABSTRACT

This study introduces a preliminary approach to integrating design framework with Low Impact Development (LID) technologies which promote education and awareness, and evaluates the impact of LID. The proposed framework, called a "BLUEprint" for Stormwater Infrastructure Design, serves as a three-tiered design performance measurement structure. To verify the proposed framework, three water conservation-based design projects in Texas were selected. The framework was applied to determine types of appropriate LID facilities in each project and to simulate their hypothetical performance with quantitative measurements utilizing same variables to compare efficacy of LID applications in each site.

First, to develop the framework, after reviewing existing LID facilities applied in previous projects, 17 LID facilities including the green roof, bio-swale, and bio-detention pond were selected and categorized into three typologies based on hydrological functionality: capture, convey, and clean. Runoff amounts and collectable rainwater were measured according to these typologies. Second, to promote public's awareness, each LID facility was suggested to be integrated with an innovative hierarchical way-finding system which illustrates the ratio of infiltrated water to total rainfall. Expanded social space and number of signage were correspondingly assessed to measure social benefits of LID. Finally, the vegetation palette effectiveness was evaluated based on drought tolerance and water treatment capacity relative to site conditions. In a comparison among the three projects, the hypothetical results showed that the LID facilities examined reduced runoff volume by up to 45% and could annually save about $10,000 by planting xeriscape vegetation with less water demand and reusing harvested rainwater for irrigation.

This result emphasizes the significance of the integrated LID design framework and efficacy-evaluating model. The proposed framework would be an effective tool in the decision making process for holistic LID design and planning with more objective design strategies using quantitative measurements.

1.1 Keywords

BLUEprint, stormwater runoff management, LID, education, efficacy

2 INTRODUCTION

Land planning strategies which emphasize stormwater runoff management, such as Low Impact Development (LID), have become increasingly utilized in design projects to minimize the impact of impervious land cover (Huber, 2010). Several design guidelines exist which expose the potentialities of utilizing LID applications and differentiate the distinctive features of LID facilities (Wynkoop, 1999; City of San Francisco, 2009; City of Houston, 2006). They have documented several suggestions including promoting the implementation of residential rain gardens and retention planters with curb cuts for bio-infiltration, vegetated roofs and permeable paving in mixed use zone (specifically in pedestrian/parking areas). However, only a few integrated approaches have attempted to investigate the actual effectiveness of LID based designs. Although the Texas Department of Transportation has shown efforts to develop engineering techniques in reducing urban runoff under the Clean Water Act (1972) (TxDOT, 2013), on-site infiltration water management systems such as bio-swales and detention ponds have not yet been examined. The first step in alleviating this quandary is begin to provide an integrated LID design framework and test the efficacy of its implementation.

Accordingly, this study proposes a framework, called "BLUEprint," as an applicable design implementation and measurement approach which guides hydrologically sensitive design and assesses its impact using quantitative methods. Simultaneously, the framework aims to increase public education and awareness about the benefits of LID applications. To substantiate its validity, the framework was applied to three water conservation-based design projects in Texas. The master plan of each project was utilized to assess the environmental, social and economic benefits of LID applications. The first site was the 26-acre Texas A&M Sediment and Erosion Control Laboratory (SEC) located in the Riverside Campus of Texas A&M University. It was formerly used as a runaway, but renovated into the secondary campus supporting various research activities. By applying LID techniques, SEC could serve as a real-world model for LID practices for students and professional to emulate. The second site was the 5-acre Lone Star Groundwater Conservation District (LSGCD) office in Conroe, Texas. Since the city had experienced water challenge due to the excessive groundwater withdrawal from the Gulf Coast aquifer, the design approaches emphasized on-site infiltration and groundwater recharge by applying LID practices. The final site was the 1.94-acre TAES Annex Building located in the main campus of Texas A&M University. The site was exposed to several drainage problems such as standing water and heavy runoff and LID practices were applied to solve those issues and to increase public awareness about LID.

3 DESIGN FRAMEWORK

The proposed design framework developed for this research is shown in Figure 1. The major objectives of the framework were to promote sustainable stormwater management and increase educational literacy about LID. Three phases of a design process – facility construction, planting, and way-finding system installation – were organized according to the frame of implementation units and performance measures. *LID facilities*, *the vegetation palette*, and *the informative signage* served as major design elements. Seventeen *LID facilities* were categorized into three typologies depending on their hydrological functionality: capture, convey, and clean. To increase the effectiveness of water conservation using both mechanical and biological facilities, the selected LID facilities were divided into two groups based on composing materials. While the first group (mechanical facilities) is mainly comprised of concrete requiring engineering skills, the second group (biological facilities) is reliant upon phytoremediation processes since they maximize the use of vegetation in mitigating pollutants and dissipating the energy of water flow.

Based on drought tolerance and water treatment capacity, xeriscape and phytoremediation plants were suggested as *the vegetation palette* of the proposed framework. While xeriscape plants function to reduce water demand of irrigation, phytoremediation plants serve as natural filters in cleansing contaminated runoff. Two types of phytoremediation plants are specifically suggested: phytoextraction and rhizofiltration. Phytoextraction plants mainly play a significant role in heavy metal uptake. Similarly, rhizofiltration plants are capable of taking in metals and hydrophobic organics from soil water or from water flowing through the root zone (Schnoor, 1997). Table 1 demonstrates the recommended plant lists of each vegetation palette for effective stormwater management in Texas. While xeriscape can work in conjunction with LID facilities such as green roofs and turf pavement, phytoremediation plants are able to be incorporated with filter strips, riparian buffers, rain gardens and detention/retention ponds. They are recommended to be placed upstream of treatment facilities (near pollutant sources) or downstream of all LID facilities (before or in water bodies).

The informative signage was proposed to develop an innovative hierarchical way-finding system in the framework to improve social benefits by understanding LID applications. Three different scales of signage – standing board, embedded signage within paving elements, and large informative kiosks – were proposed to convey the information of how much water could be infiltrated into the soil out of total rainfall (the water-infiltration footprint). Monthly rainfall data, monthly evapotranspiration data, and post-design runoff coefficients of surface materials would be integrated to measure infiltration ratios for each LID facility. For instance, a typical rain garden in College Station, TX revealed a 0.54 infiltration rate assuming a 70% water loss through evapotranspiration supplemented by outdoor irrigation. The calculation process is as following: in October when the highest precipitation of 4.9 inches is reported, the water loss through evapotranspiration is 4.3 inches. Under the assumption of 70% of water supplement through irrigation, the actual water loss rate through atmosphere turns out 26%. Therefore, rain gardens, where 20% of runoff is removed from total rainfall (runoff coefficient = 0.2) consequently promote 54% of rainwater to be infiltrated into the soil (100% - 26% - 20% = 54%). This number is relevantly higher than the infiltration rate of impervious pavement, which is 18%. The infiltration rates also vary depending on surface materials and regional climate conditions.

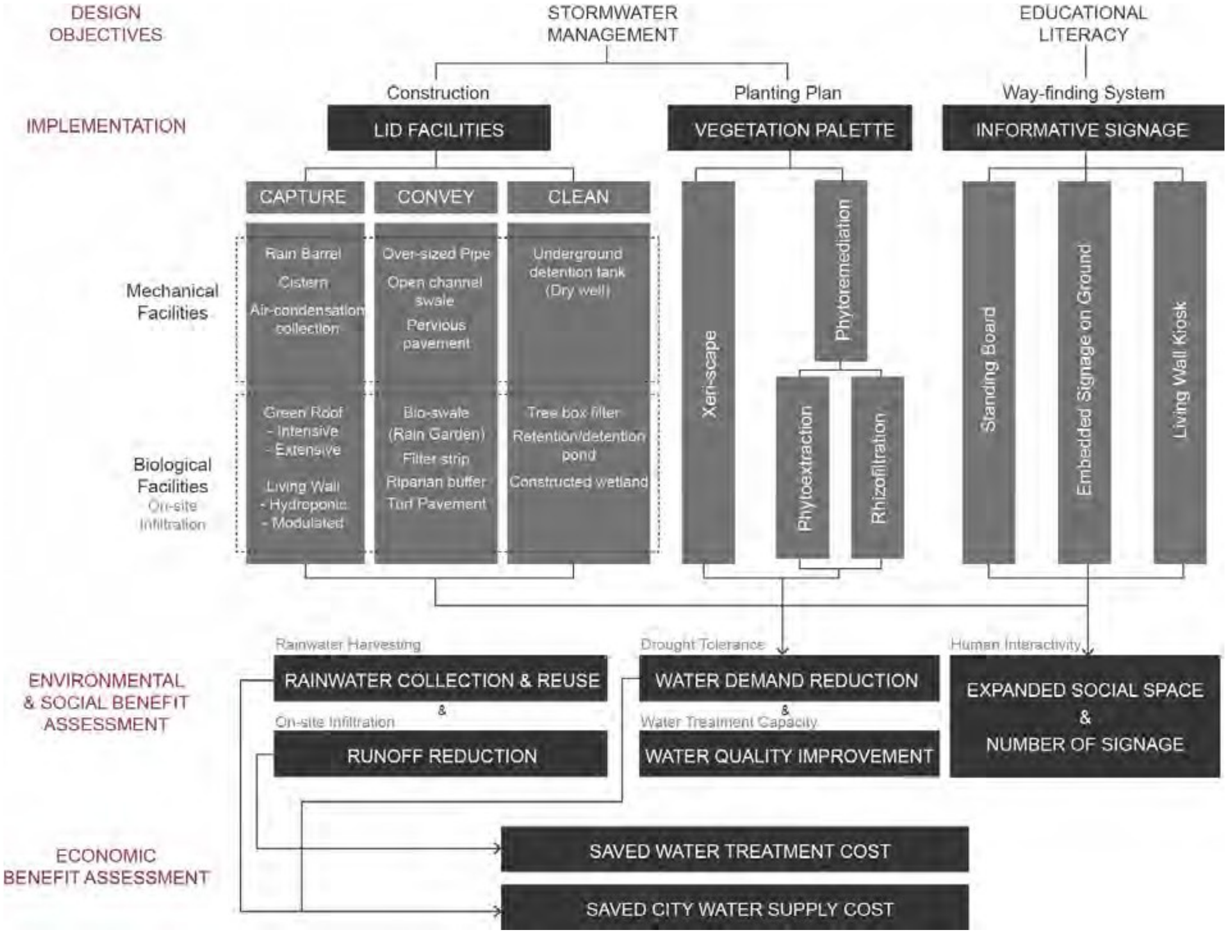

Figure 1. Proposed Framework (BLUEprint) for Stormwater Infrastructure Design

Table 1. Plant lists of vegetation palette for stormwater management

Vegetation Palette	Reference	Recommended Plants
Xeriscape	Texas Water Development Board (TWDB), 2013	Agave, Yucca, Palo Verde, Cactus, Desert Willow, Bulbine, Gayfeather, Texas Mountain Laurel, Agarita, Flame Acanthus, Blackfoot Daisy, Mesquite, Lantana, Buckeye, Rosemary, Western Redbud, most Oaks, Cypress, Sages, Acacia, Gaura, Lavender, Mexican Feathergrass, Muhly grass, Buffalo grass
Phytoremediation		
Phytoextraction	Schnoor, 1997	Sunflowers, Indian Mustard, Rape seed plants, Barley, Hops, Crucifers, Serpentine plants, Nettles, Dandelions
Rhizofiltration		Aquatic Plants - Emergents: Bullrush, Cattail, Coontail, Pondweed, Arrowroot, Duckweed - Submergents: Algae, Stonewort, Parrot Feather, Eurasian Water Milfoil, Hydrilla

4 METHODS

4.1 Framework Application

To test the applicability of the proposed framework, three water conservation-based design projects in Texas were examined through assessment of their master plans (See Figure 2). Three proposed master plans were approved by the corresponding agencies and the design construction of each site is under progress. In each plan, LID facilities were implemented in three hydrological functionality (capture, convey and clean) according to the framework and the location was determined based on existing site conditions. Table 2 elucidates a listing of LID facilities designed on each site and their specific locations.

Figure 2. Master Plans of Three LID-based Design Projects in Texas (2013). Graphics by the Authors (2a: SEC, 2b: Conroe LSGCD, 2c: TAES Annex Building.)

Table 2. LID facilities designed on each site and their specific locations

Site	Hydrological Functionality	LID facilities	Location
SEC	Capture	Cistern, green roof, living wall	Existing buildings
	Covey	Pervious pavement, open channel swale, bio-swale, filter strip, riparian buffer	Proposed parking lot, upstream of major treatment systems
	Clean	Retention pond	Upstream from off-site stormwater management system
Conroe LSGCD	Capture	Rain barrel, cistern, air-condensation collection	Existing buildings
	Convey	Over-sized pipe, pervious pavement, bio-swale, filter strip	Existing/proposed parking lot, upstream of major treatment system
	Clean	Tree box filter, detention pond	Near pollutant sources, downstream of all LID systems (at the lowest point of the site)
TAES Annex Building	Capture	Cistern, living wall	Existing buildings
	Convey	Pervious pavement, bio-swale, filter strip, turf pavement	Existing parking lot, upstream of major treatment systems
	Clean	Dry well, constructed wetland	Near capturing systems and off-site stormwater management system

Table 3. Data used for the environmental benefit measurement

Implementation	Environmental Benefits	Needed Data for Measurement	Units
LID facilities	Rainwater collection & reuse	Monthly rainfall	inch/month
		Roof size	square feet
		Roof coefficient	-
	Runoff reduction	Annual rainfall	inch/year
		Property size	acre
		Conventional design / LID design's composite runoff coefficient	-
Vegetation palette	Water demand reduction	Xeriscape plant cover	acre
		Annual reference evapotranspiration	inch/month
		Crop coefficient (K_L)	-
		Irrigation efficiency	%
	Water quality improvement	Pollutant concentration in soil	ppm
		Phytoextraction coefficient	-
		Plant density	kg DW*/acre
		Phytoremediation plant cover	acre

* DW = Dry weight

4.2 Data Collection

After applying the framework to the three selected projects to determining locations and characteristics of LID practices (facilities, vegetation palettes, and informative signage), primary data were collected to quantify environmental, social and economic benefits of each design. Then the quantitative metrics were used to measure each benefit. For each metric, comparisons were made across three cases.

Environmental & Social Benefits: To measure environmental benefits of LID, this research focused on rainwater collection and reuse, runoff and water demand reduction, and stormwater quality improvement. Table 3 summarizes data utilized in assessing environmental benefits. To calculate the volume of rainwater collection and reuse, monthly rainfall, roof size, and roof coefficient data were used, while annual rainfall, property size, and composite runoff coefficient values comparing conventional design and LID design were computed the rate of runoff reduction. To measure the environmental benefits of xeriscaping compared to the conventional landscaping, xeriscape plant cover, annual reference evapotranspiration, crop coefficient, and irrigation efficiency were employed to estimate the volume of reduced water demand. Finally, pollutant concentration in soil, phytoextraction coefficient, plant density, phytoremediation plant cover determined the extent of water quality improvement. With regard to social benefits, digital maps of three master plans were utilized to measure expanded social space after construction and number of signage.

Economic Benefits: The measured results of the environmental benefits were then utilized to evaluate economic benefits. Table 4 illustrates data employed to assess saved water treatment cost and saved city water supply cost. Annually reduced runoff volume and water treatment cost unit determined total saved water treatment cost. Similarly, annually collectable rainwater, reduced water demand by xeriscaping and city water rate were used to estimate saved city water supply cost. Inflation rates in US were ultimately applied to the final output to be agreed in dollar value of 2013.

4.3 Benefit Measurement

Rainwater Collection & Reuse: For the comparison among the three water conservation-based design projects in Texas, collectable rainwater of each project was measured by using a simple calculation method introduced by Texas Water Development Board (TWDB, 2005). For example, Table 5 shows the consequential process of calculation for the SEC Lab project. Derived from the rainfall data in College Station and the roof size of buildings on the site, the estimated annual collectable rainwater volumes were indicated on the last column in table 5. The same methodology was applied in evaluating rainwater supply for the other two projects. In the case of the SEC Lab, 0.5 million gallons of rainwater could be annually captured and reused for outdoor irrigation.

Table 4. Data used for the economic benefit measurement

Economic Benefits	Needed Data for Measurement	Units
Saved water treatment cost	Annually reduced runoff volume	gallon
	Water treatment cost unit	$/gallon
Saved city water supply cost	Annually collectable rainwater	gallon
	Reduced water demand by xeriscaping	gallon
	City water rate	$/1000 gallons

Table 5. Collectable rainwater in the SEC Lab project

(A) Average annual rainfall [in.]*	(B) *= (A) × 0.62* Average annual rainfall [gal. per sq.ft.]	(C) *= (B) × 21182.10sf*** Potential volume of water from collection area [gal.]	(D) *= (C) × 0.9**** Estimated annual supply to collection tank [gal.]
38.47	23.85	505,223	454,701

* Average annual precipitation recorded from 2000 to 2013 at College Station, Easterwood Field Station

** Roof size *** Coefficient of asphalt shingle roof (TWDB, 2005)

Table 6. Comparison between conventional design and LID design runoff coefficients of the SEC Lab project

	Type	Facilities	Size [ac]	Runoff Coeff.*
Conventional Design	Light Industrial Area	Concrete pavement / conveyance pipes / open channel swale	26.04	**0.65**
LID Design	Grassland <7% (clay)	Turf pavement, filter strip	10.19	0.2
	Grassland >7% (clay)	Reparian buffer, filter strip	0.34	0.3
	Retention pond	Constructed wetland, retention/detention pond	4.9	1
	Bush/Tree area	Bio-swale (rain garden), green roof	4.98	0.2
	Roof	Asphalt shingle/ membrane roof	0.49	0.85
	Paved Area	Vehicle road, sidewalk	4.43	0.82
	Porous pavement	Sidewalk, parking lot	0.71	0.45
				0.48**

* *Design and construction of sanitary and storm sewers* (1969), p.332. Copyright 1969 by the Joint Committee of the ASCE and the Water Pollution Control Federation

** Composite runoff coefficient of LID design

Runoff Reduction: After the application of LID techniques, the reduction in total runoff volume compared to the conventional design approach was measured for each project by using one of the benefit toolkits introduced by Center for Neighborhood Technology (CNT, 2010). Changes of runoff coefficients (*C*) from conventional design to LID design were used to represent retention rates of each LID facilities as *C* values imply a variety of surface conditions. Table 6 demonstrates calculation of composite runoff coefficients for the SEC Lab project. With an assumption that the typical runoff coefficient of conventional design is 0.65, the number was lowered to 0.48 after LID application in this case. Based on changes in surface material and runoff coefficients, the annually reduced runoff volume was then calculated using average annual rainfall data.

Water Demand Reduction: Xeriscape is one of the strong strategies to conserve water by reducing its consumption by plants. The following equation illustrates how to calculate the irrigation requirement (IR) of xeriscape (Smeal, 2007).

$$IR = 0.623\ \times ET_0 \times K_L \times\ A\ \div IE \quad (1)$$

Where; IR is irrigation requirement [gallons]; 0.623 is a constant to convert inches to gallons; ET$_0$ *is reference evapotranspiration [inches]; K*$_L$ *is plant coefficient; CA is canopy area [square feet]; and IE is irrigation efficiency*

The reference evapotranspiration (ET$_0$) refers to the “regionally specific estimate of the amount of water lost from a medium-height, cool season grass growing in an open field” (U.S. Green Building Council, 2010). Additionally, plant coefficients (K$_L$) which vary by plant species are utilized with ET$_0$ to estimate the actual evapotranspiration rate of specific plants. While plant coefficients of xeriscape plants normally range from 0.1 to 0.3, most wildflowers and grasses have the medium value (0.6) (TWDB, 2013). Therefore, to compare LID projects to conventional landscape designs and calculate water demand reduction by xeriscaping, we presume that conventional landscaping would have the medium value of plant coefficients. Also, another assumption is made: the irrigation efficiency of xeriscape garden is 95%. Based on these suppositions, Eq. (1) was applied in assessing reduced amounts of outdoor irrigation water.

Water Quality Improvement: Phytoremediation plants play a pivotal role in purifying contaminated soil or runoff (EPA, 2000). To estimate how much metals are removed from soil, *Brassica juncea* (Indian Mustard), one of the most effective phytoextraction plants found in previous studies (Kumar, 1995; Schnoor, 1997; EPA, 2000), were widely planted in three projects. For estimating water quality improvement, laboratory-measured phytoextraction coefficients found by Kumar (1995) were significantly used. The last column in Table 7 demonstrates the amount of metal uptake within the shoot of *Brassica juncea* in an acre when they were planted by 3 tons dry weight per acre. We assumed that the pollutant concentration in soil is below the EPA standard (EPA, 1995). Based on the calculation in Table 7, the total amounts of metal uptake by *Brassica juncea* at three different sites were assessed.

Human Interactivity Increase: Two indirect measures were utilized to evaluate the increase of human interactivity in the three selected projects: expanded social space and number of the water-infiltration footprint signage. These indicators are frequently addressed by the Landscape Architecture Foundation (LAF) in measuring social values of constructed designs (*Landscape Architecture Foundation*: https://lafoundation.org/research/landscape-performance-series/case-studies/). To promote public awareness of LID application, this research proposed an innovative hierarchical way-finding system integrated with each LID facility, called water-infiltration footprint. While the increased social space was calculated on the digital map, the number of three different types of outdoor signs was counted on the final master plans.

Cost Saving: Rainwater harvesting, drought tolerance of plant specimen, and on-site infiltration resulted in direct water use and treatment cost savings. One of the benefit toolkits introduced by Center for Neighborhood Technology (CNT, 2010) was used to estimate saved water treatment cost. First, the sum of collected rainwater and reduced water demand multiplied by city water rates represented the avoided cost in city water supply. Second, reduced runoff volume multiplied by water treatment rates indicated the saved cost in water filtration process.

Table 7. Measurement of metal uptake amounts by *Brassica juncea*

Pollutant	**Pollutant Concentration (Clean Water Act Section 503.) [mg/kg DW][ppm]**	**Phytoextraction coefficient* (*Brassica juncea*)**	**Metal Uptake [Metal mg/kg DW (shoot)]**	**Metal Uptake within the surface biomass of the plant in an acre [kg]****
Cr	3000	58	174000	415.78
Cd	39	52	2028	4.85
Ni	420	31	13020	31.11
Cu	1500	7	10500	25.09
Pb	300	1.7	510	1.22
Zn	2800	17	47600	113.74
Total				**591.78**

* The ratio of metal concentration in the surface biomass of plant (g metal/g dry weight tissue) to the initial soil concentration of the metal (g metal/g dry weight soil) (Kumar *et al.*, 1995).

**Individual dry mass of *Brassica juncea* is 0.426g for shoot and 0.485g for whole plant (Shoot accounts for 87.8% of the whole plant) (Boucher, 2013).

5 RESULTS

5.1 Rainwater Collection & Reuse

In the cross-case comparisons among the three projects (Table 8), the SEC lab gathered the largest volume of rainwater through harvesting systems but the reuse rate was the lowest since large volume of rainwater in SEC was directly flowing into retention ponds for the purpose of storing water and reusing it for laboratory experiments. On the other hand, the TEAS Annex Building project efficiently saved outdoor irrigation water by reusing captured rainwater.

5.2 Runoff Reduction

The SEC lab relatively reduced the largest runoff volume compared to the other two projects, yet the actual reduction rate was the lowest (see Table 9). On the other hand, the Conroe LSGCD project and the TAES Annex Building project reported higher runoff reduction rates although the project sites were smaller. The two projects not only successfully minimized total impervious area but also modified drainage flow paths to increase travel time of runoff.

5.3 Water Demand Reduction

Table 10 exhibits how much water was annually conserved by xeriscaping in the three projects. Xeriscaping saved a range of 50-85% of irrigated water in all projects, resulting in a lessening on the city water supply. In the comparison between the LSGCD project and the TAES Annex Building project, the higher water loss through evapotranspiration for the same acreages, more irrigation water saved.

Table 8. Cross-case comparisons of annually collectable rainwater

	SEC	Conroe LSGCD	TAES Annex Bldg
Annual rainfall [in]*	38.47	50.44	38.47
Roof size [sf]	21,182.10	11,620.87	11,266.87
Annually collectable rainwater [gal]	454,701	327,075	241,858
Reuse rate [%]**	1.7	5.1	12.0

* Average annual precipitation recorded from 2000 to 2013 at the nearest weather station to the sites
** (Collectable rainwater volume on roof / total rainfall volume on site) x 100

Table 9. Cross-case comparisons of runoff reduction

	SEC	Conroe LSGCD	TAES Annex Bldg
Annual precipitation [in]	38.47	50.44	38.47
Size [ac]	26.04	4.75	1.94
Runoff coefficient (conventional design)	0.65	0.65	0.65
Runoff coefficient (LID design)	0.48	0.36	0.44
Total annual runoff reduction [gal]	4,625,411.19	1,887,143.58	425,678.26
Reduction rate [%]*	26.2	44.6	32.3

* [p1-(Runoff volume in LID design / runoff volume in conventional design)] x 100

Table 10. Cross-case comparisons of plant's water demand reduction by xeriscaping

	SEC	**Conroe LSGCD**	**TAES Annex Bldg**
Xeriscape plant cover [ac]	2.24	0.2	0.2
Annual ET_0 [in]*	56.32	54.9	56.32
K_L**	0.1-0.3	0.1-0.3	0.1-0.3
Irrigation requirement of xeriscape garden [gal/year]	360,381.91 - 1,081,145.72	31,365.68 - 94,097.03	32,176.96 - 96,530.87
Irrigation requirement of conventional garden [gal/year]	2,162,291.43	188,194.06	193,061.73
Reduced water demand [gal/year]	1,081,145.72 - 1,801,909.53	94,097.03 - 156,828.38	96,530.87 - 160,884.78
Reduction rate [%]	50-83	50-83	50-83

* Averages computed using climate data from the National Weather Service (Texas A&M AgriLife Extension, 2013).
** Data from Texas Water Development Board (TWDB, 2013).

5.4 Water Quality Improvement

The total amounts of metal uptake by *Brassica juncea* at three different sites were represented in Table 11. As long as the pollutant in soil was within a safe level, a maximum of 2,000 kg of metals could be taken up in the SEC lab project. Since the SEC lab was previously a brownfield abandoned as an old airport, the function of phytoremediation plants would be more effective than other two sites. In addition, as shown in table 10 lead (Pb) was much more difficult to be removed than Cadmium (Cd).

5.5 Human Interactivity Increase

Table 12 shows that the TAES Annex Building project had the largest increase in social space (27%). The proposed LID plaza and living wall library areas in the TAES project helped create this increase. Also, 23 to 49 outdoor water-infiltration footprint signs for education were stationed in projects. Overall, the TAES Annex Building project represented the largest achievement in fostering public education about LID as the density of signs per one acre of social space was the highest in this project (43/acre).

5.6 Cost Saving

Economic benefits of LID were assessed in Table 13. As a result, three LID projects generated an annual profit of $1,100 to $7,300 in saving city water supply and water treatment cost. Since the city of Conroe exposed higher water rate for non-residential land than other cities due to the emerging issue of groundwater depletion, the LSGCD project could have avoided the largest cost by stormwater management strategies. Furthermore, the saved water supply cost by rainwater harvesting and xeriscaping far overweighed the saved water treatment cost by on-site infiltration in all three projects.

Table 11. Cross-case comparisons of metal uptake amounts by *Brassica juncea*

		SEC	**Conroe LSGCD**	**TAES Annex Bldg**
Phytoremediation plant cover [ac]		3.32	0.26	0.19
Metal uptake within the surface biomass of the plan [kg]	Cr	1,380.38	109.35	78.17
	Cd	16.09	1.27	0.91
	Ni	103.29	8.18	5.85
	Cu	83.30	6.60	4.72
	Pb	4.05	0.32	0.23
	Zn	377.62	29.91	21.38
	Total	**1964.72**	**155.64**	**111.26**

Table 12. Cross-case comparisons of social benefits

		SEC	**Conroe LSGCD**	**TAES Annex Bldg**
Size [ac]		26.04	4.75	1.94
Expanded social space [ac] (Rate of increase [%])		5.28 (20)	1.12 (24)	0.53 (27)
Number of signage	Standing board	14	10	9
	Embedded signage	31	15	13
	Living wall kiosk	4	2	1
	Total	**49 (9/ac)**	**27 (24/ac)**	**23 (43/ac)**

Table 13. Cross-case comparisons of cost saving by LID application

	SEC	**Conroe LSGCD**	**TAES Annex Bldg**
Annually saved water supply cost	$6,048	$7,113	$1,079
Annually saved water treatment cost*	$461	$188	$43
Total saving (2013 price)	**$6,509**	**$7,302**	**$1,122**

* Apply US inflation rate to covert dollar value of 2009 to 2013. Cumulative rate of inflation from 2009 to 2013 is 8.6%. (US Inflation Calculator, 2013)

6 CONCLUSION & DISCUSSION

This study emphasized the significance of LID based-design and evaluated its efficacy of post-implementation. The proposed three-tiered framework and performance measurement structure (the “BLUEprint”) served as a framework in guiding overall design plans of the three LID projects. The projected results of environmental, social and economic benefits implied significant contributions of LID techniques to water conservation and groundwater recharge; in total, all projects annually saved 3 million gallons of water supply and reduced 6 million gallons of runoff, generating an annual profit of $15,000. However, the small pool of design projects lowers the external validity of this study. Larger design samples of LID application would aid in establishing more applicable framework. In addition, indirect factors such as reduced flooding risk need to be quantified in dollar value to assess the avoided environmental damage cost to prevent underestimation of economic impact. The elaborate process of benefit measurements accompanied by cost analysis would also build up the proposed framework and help determine design impacts. Above all, field assessment after the current construction of the sites will be needed to rectify errors between observed data and projected data.

Overall, the proposed framework would be an effective tool in the decision making process for holistic LID design and planning with more objective design strategies using quantitative measurements. Since the framework could be variously applied not only to micro scaled projects such as parking lot design but also to macro scaled plan and environmental policy, it would bring a wide range of benefits to property owners, developers, and municipal governments. By further developing the measuring structure into detail indicators with varied weights, the system of LID would be strengthened and the framework would serve to be applied to multiple case studies and design practices in the future.

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