Development of Decision Making Tool (DMT) for Determining

LID Stormwater Detention Requirements

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Draft Final Report

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Texas A&M University--Kingsville

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Chapter 1 - Project Overview

To address localized flooding in the Lower Rio Grande Valley (LRGV), Texas region and U.S.-Mexico border water quality issues associated with non-point source pollution within the Arroyo Colorado watershed, the LRGV TPDES Stormwater Task Force, in partnership with the NADB BECC U.S. EPA Border 2020 program, supported the development of an innovative Decision Making Tool (DMT) for determining stormwater detention requirements while incorporating Green Infrastructure. TAMUK has partnered with the LRGV TPDES Stormwater Task Force (STF) in the planning and delivery of the DMT with this report. In addition to this descriptive report, the Project Team is also delivering a copy of the developed Excel spreadsheet tool along with a User's Manual document for the Tool.

Local governments in the LRGV control flooding and stormwater runoff by adopting strict drainage design policies. The flat terrain characteristic of the LRGV provides stormwater engineers with complicated flow, detention and flood design problems. According to an existing drainage policy, stormwater runoff generated from new commercial developments within the LRGV is generally required to be detained at on-site for a 50- year frequency storm event and released into the receiving system at a pre-developed rate for a 10-year frequency storm event.

One conventional approach to meet the discharge goal of retaining this huge volume of runoff is to design a detention pond with large footprints. Although traditional methods of designing detention ponds are somewhat cost-effective and calculation of storage is simple using excel spreadsheet, this approach may be a cause for lost land cover and aesthetic, safety, operating, and maintenance issues in the long run. With the use of innovated practices and green infrastructure strategies, the traditional design of a large detention pond footprint can be reduced by allowing the storage volume of Low Impact Development (LID) Best Management Practices (BMPs) to be incorporated into conventional design detention calculations. The challenge is to decide how to plan those BMPs design effectively within the development boundary to meet the 10 years frequency storm discharge goal.

The developed DMT tool and project achieves the two following principal objectives-

i) To provide a unique innovative calculator that can be used to determine stormwater detention requirements at urban and rural developments in the LRGV using LID

ii) To conduct educational outreach activities in order to promote this tool to local school districts officials, colonies, institutes of higher education, city and county officials, water professionals, professional organizations and water-related organizations.

Chapter 2 - Description of the developed Decision-Making Tool (DMT)

The DMT was developed as a simple macro-enabled excel spreadsheet, which was formulated to assist in discharge calculations, and BMP planning with performance evaluations for several LID BMPs in the LRGV to meet the 10-year discharge goal from a 50-year rainfall event. The WinSLAMM model served as the foundation of the DMT database and analysis (Voorhees and Pitt, 2018). The LID BMPs and the accompanying data that were incorporated into the DMT were based on output resulting from the assessment and evaluation of actual Rio Grande Valley LID BMPs using a field-calibrated WinSLAMM model. The discharge resulting from calibrated BMP model scenarios for permeable pavements, bioretention cells, and bioswales located at LID demonstration sites throughout the LRGV was used in the project (Jones et al., 2017). The tool included calculation of storage capacity, size, and a number of BMP units needed to accomplish the objectives. In its algorithm, this tool uses the Rational Method (predevelopment conditions) and WinSLAMM transformed BMP equations (controlled conditions) to calculate the peak discharge from proposed commercial developments for the Arroyo Colorado watershed.

The DMT will be used to evaluate existing stormwater detention requirements and seek alternative LID stormwater detention requirements in lieu of a conventional detention pond. The Tool will provide information that will justify the incorporation of LID technologies in the final detention design layouts. The objective function of this tool will follow the following equation,

$$S_{WP\ footprint} = S_{detention} - S_{LID1} - S_{LID2} - \ldots - S_{LIDn}$$

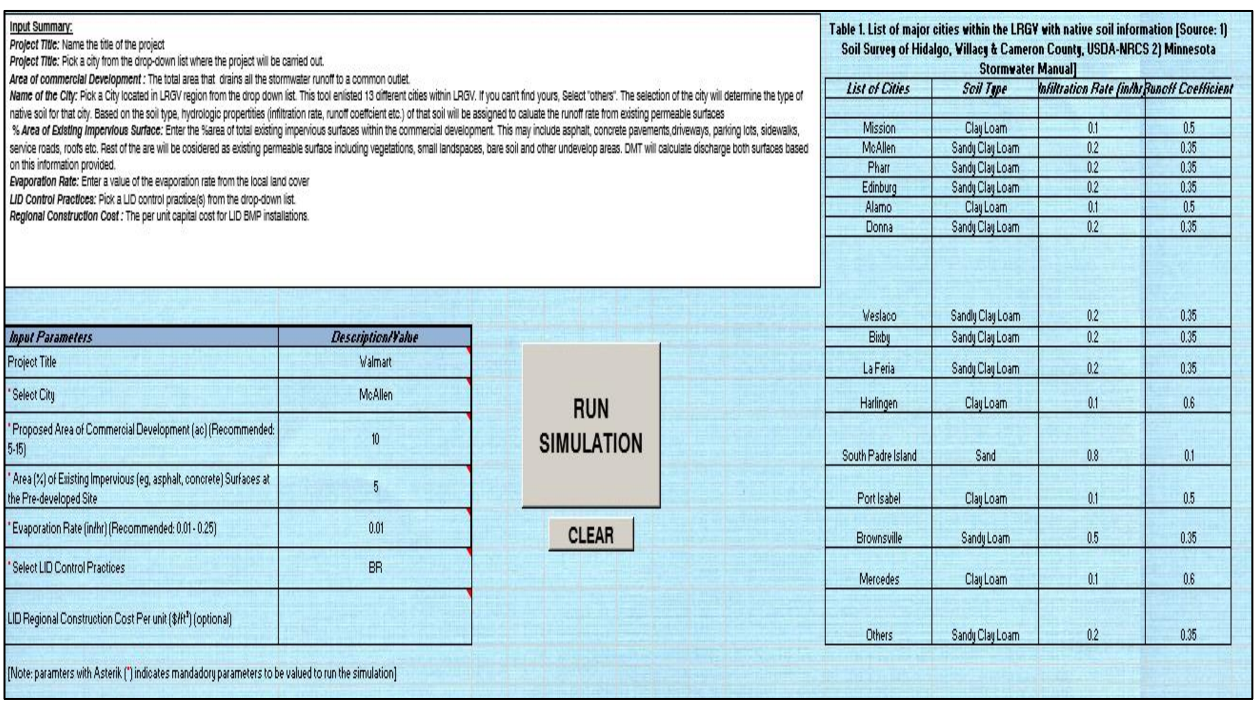

Figure 1. A screenshot of the draft proposed DMT tool with input parameters.

Chapter 3 - Project Outcomes

The DMT will benefit the public and the environment by providing innovative and critical information to the region in order to meet the challenging requirements and balancing of flooding, water quality, and public safety needs. Reducing localized flooding and identifying sustainable, economical and innovative stormwater management strategies is a key benefit projected to result from the development of the DMT.

This tool is a valuable asset for LRGV planners, stakeholders, and stormwater task force partners for the planning, design, and implementation of innovative BMPs and incorporating the outcomes into the enhancement of property development options and values. The tool and its methodology for development can be applied to other impaired watersheds and rapidly growing urban areas. The application of the DMT in urban stormwater management projects should improve the regional stormwater runoff water quality within the LRGV.

The institutionalization of GI infrastructure strategies, the introduction of low impact development programs, and the implementation of innovative planning, management and engineering approaches to water programs will not only benefit communities but also protect water quality and ecosystems. The successful institutionalization of innovative stormwater management programs will reduce NPS pollutants, mitigate localized flooding in urban, colonial, and rural settings, and improve water quality best management practices utilized by residential, commercial and industrial stakeholders. The improvement of water quality within the surface waters of the region is a significant benefit and goal for stakeholders in the new proposed Lower Laguna Madre Estuary Program. This new DMT tool will serve as a platform in demand for stakeholders, engineers, and water planners to improve the understanding of Green Infrastructure and Low Impact Development implementation in the region.

Chapter 4 - WinSLAMM and its Integration into the DMT

WinSLAMM is a unique Stormwater Quality Modeling Tool, which can evaluate stormwater controls based on the field environment and actual design values. It was designed to provide relatively complex outputs such as runoff volume, pollutant mass loadings, and effects of critical conditions on control practices. It is mostly used as a planning tool to better understand the sources of urban runoff pollutants and their control strategies. It has been widely used and extensively reviewed in different LID implementation studies in North America and has been proven reasonable in predicting stormwater flows and pollutant characteristics from a wide range of rainfall events, urban development characteristics, and control practices (Schilling et al, 2004). WinSLAMM predicts runoff based on the results of field data from the National Stormwater Database and actual design values of BMPs. It uses a simple rainfall-runoff equation (Rational Method) to predict runoff volumes with errors ranging from 10 to 30% (Voorhees and Pitt, 2018). The Model is capable of predicting results even when there is no field data, using the complete package of default calibrated files generated from previous LID data collection within the USA. By using 3-5 years of rainfall-runoff data, it is possible to calibrate the model for the future runoff and even more reliable water quality prediction. WinSLAMM is highly advanced in its LID control features. The Model can use BMPs as external control practices beyond the boundary of land use development. The model outputs can be summarized per month and incorporated into the SWAT model as a point source (Shilling et al., 2004). In this project, WinSLAMM has been used to create a DMT database for three different but proven effective BMPs including permeable pavements, bioretention cells, and bioswales based on observed data in the LRGV (Jones et al., 2017)]. WinSLAMM integration into the DMT is advantageous for several reasons. Table 1 summarizes some of the significant features of WinSLAMM which justify its application to the development of the unique DMT.

Table 1. Summary of key features of WinSLAMM for the DMT

Features	WinSLAMM
Water Quality	A unique stormwater quality modeling tool that can evaluate the runoff water from each source area
Hydrologic Process	The Model uses the concept of small storm hydrology
Land Use	Suitable for urban settings (e.g. parking lot pavement, service road, walking trail, roof, playground and others)
Complexity	The Model is moderately user-friendly

Ease of communication to Stakeholders	Communicable to a large group of stakeholders from different agencies, stormwater professionals, and university researchers
Extensive Application in LID	Widely used in LID research in the US and in many countries around the world due to its ability to consider many stormwater controls together, for a long series of rains.
Integration with Watershed Models	Very common for integration with other watershed scale and surface water quality models

Figure 2 depicts the steps in the application of WinSLAMM in the development of the DMT tool through a flowchart.

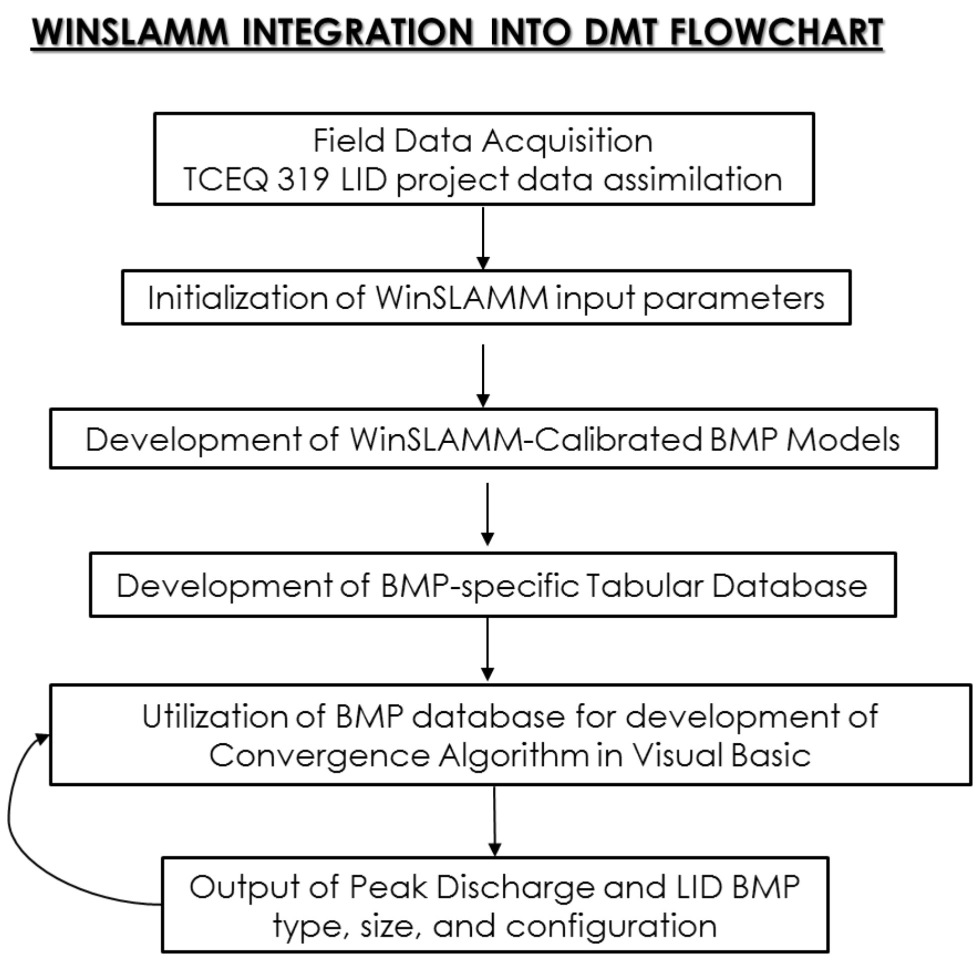

Figure 2. WinSLAMM integration into DMT development flow

Chapter 5 - Development of Calibrated WinSLAMM BMP Models

Under the TCEQ sponsored CWA 319 Arroyo Colorado LID implementation project series, flow data was monitored from several BMPs installed at several locations in the Watershed from 2010 through 2017 [TCEQ Final Report]. Design information for the BMPs was collected and used as input parameters for developing the new WinSLAMM BMP models. All the BMP models were calibrated and validated to replicate similar trends of runoff reduction patterns observed at several sites. Figure 3 shows an example calibration plot for two BMPs- 3(a). City of Brownsville (COB)-Porous Concrete Pavement (PCP), and 3(b) South Texas College (STC) -Biodetention Cell (BDC). The database for the DMT was developed in terms of peak discharge as an output resulting from the WinSLAMM calibrated BMP models by varying development sizes and BMP areas. The information gathered from the database were transformed into equations to build the algorithms for the DMT in a Visual Basic programming language platform.

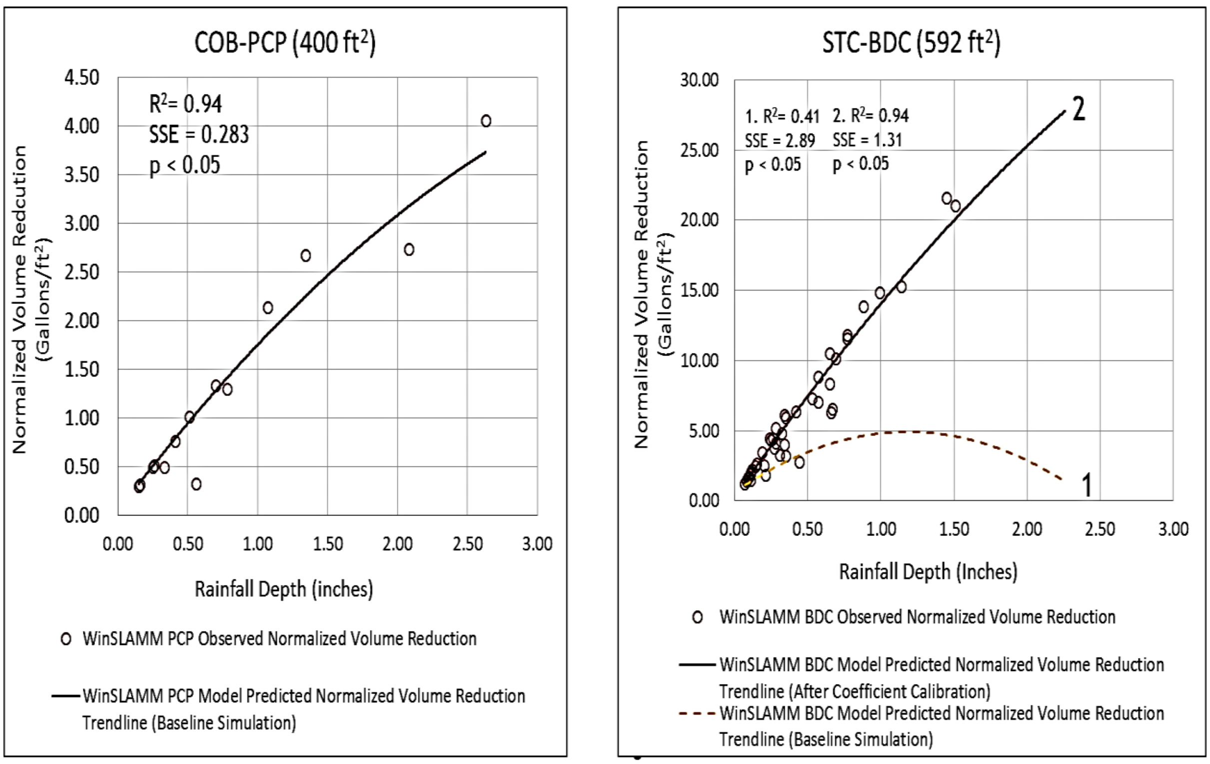

Figure 3. Example Calibration Plot for WinSLAMM BMP Models for (a). City of Brownsville (COB)-Porous Concrete Pavement (PCP), and (b) South Texas College (STC) -Biodetention Cell (BDC).

Chapter 6 – DMT Framework

As a planning tool, the DMT accepts input parameters such as the area for development, the percentage of impervious areas in the project zone, LID preferences and local cost data. In its algorithm, this planning tool accounts for runoff coefficients for different surfaces types and other local hydrologic inputs such as evaporation rate and seasonal variations. This tool can also estimate the LID lifecycle cost based on the local per unit construction costs, and maintenance and operating costs of BMPs. Figure 4 shows the overall framework of the DMT.

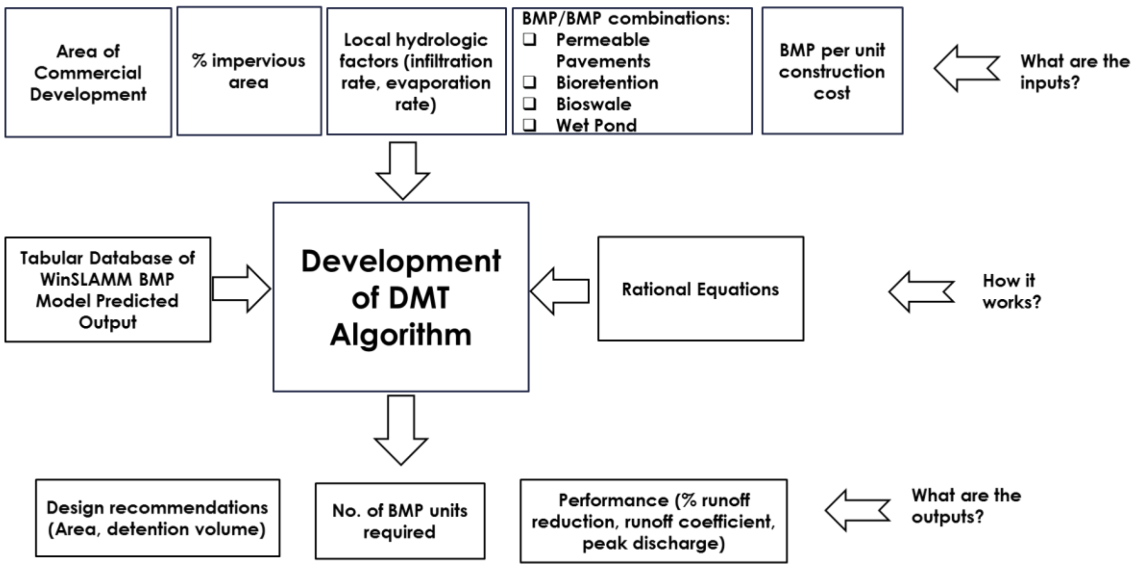

Figure 4. The framework of the DMT demonstrating input parameters, methodology, and outcomes of the tool.

DMT Input Parameters and Steps for Execution

Below is an overview of the DMT implementation steps with added detail outlined in the included User's Manual for the tool.

- *Project Title:* Name the title of the project
- *Select City:* Pick a city from the drop-down list where the project will be carried out. The cities included thus far are located in the LRGV region and can be selected from the drop-down list. This tool has been initialized with soil data and type for 13 different cities within LRGV to date. If the regional city to be evaluated for BMP implementation is not included in the list, select "others". The selection of the city will determine the type of native soil included in the BMP infiltration estimates for that project. Based on the soil type, hydrologic properties of that soil will be assigned to estimate the runoff rate from existing permeable surfaces.

- *Area of Commercial Development:* The total project area that drains all the stormwater runoff to a common outlet.
- *Percentage Area of Existing Impervious Surface*: The fractional area of total existing impervious surfaces at the predeveloped site proposed for the mixed-use development should be entered as a percentage. Impervious areas may include asphalt, concrete pavements, driveways, parking lots, sidewalks, service roads, roofs and others. The remainder of the area will be considered as existing permeable surface including vegetation, small land spaces, bare soil and other undeveloped areas. The DMT will calculate discharge for all the types of surfaces included for a given event based on the information provided.
- *Evaporation Rate*: A value of an estimated evaporation rate from the local land surface is entered.
- *LID Control Practices:* Select a LID control practice(s) from the drop-down list.
- Regional Construction Cost: The per unit construction costs for LID BMP installations in the region can be entered.

Chapter 7 – DMT Algorithm Basics

Calculation of Peak Discharge and Runoff Volume using the Rational and Modified Rational Method without control practice (Method from Adhout et al., 2016)

Peak discharge for an event was calculated using the Rational Method along with a subtraction of volumetric evaporation. In the discharge calculation, the rainfall intensity was assumed to be the seasonal average for each of the LRGV three counties. The intensity is multiplied by a seasonal variation factor of 3.8 to simulate a wet weather condition season (Voorhees and Pitt, 2018).

The runoff volume = Peak discharge * Storm duration.

<u>Pre-development condition, 10 years 24 hr. storm event:</u>

$$\mathbf{Q_{p,10} = [i_{10} * \{(C_i * A_i) + (C_p * A_p)\} * SVF] - (E*A)}$$

$$\mathbf{V_{p,10} = Q_{p,10} * t}$$

<u>Post-development condition, 50 years 24 hr. storm event:</u>

$$\mathbf{Q_{p,50} = (i_{50} * C_i * A * SVF) - (E*A)}$$

$$\mathbf{V_{p,50} = Q_{p,50} * t}$$

Where,

$Q_{p,10}$ = Peak discharge from 10 years 24 hr. storm event (cfs)

$Q_{p,50}$ = Peak discharge from 50 years 24 hr. storm event (cfs)

$V_{p,10}$ = Peak Volume of Runoff from 10 years 24 hr. storm event (cf)

$V_{p,50}$ = Peak Volume of Runoff from 50 years 24 hr. storm event (cf)

i_{10} = average rainfall intensity of 10 years 24 hr. storm event for Hidalgo, Willacy and Cameron county = 0.3 inches/hr.

i_{50} = average rainfall intensity of 50 years 24 hr. storm event for Hidalgo, Willacy and Cameron county = 0.5 inches/hr.

A = Total area of proposed commercial development (acres)

A_i = Total area of existing impervious cover at the pre-developed site (acres)

C_i = Runoff coefficient for existing impervious cover = 0.98 (assumed)

A_p = Total area of impervious cover at the pre-developed site (acres)

C_p = Runoff coefficient for impervious cover = 0.98 (assumed)

SVF= Seasonal variation factor, for wet seasons = 3.8 (assumed)

E = Evaporation Rate (inches/hr.)

t = time = 24hr = 86400 sec

Calculation of Peak Discharge and Runoff Volume with Single Control Practice

Figure 5 is a schematic showing the mechanisms taken into consideration for the calculations in WinSLAMM for a single control practice.

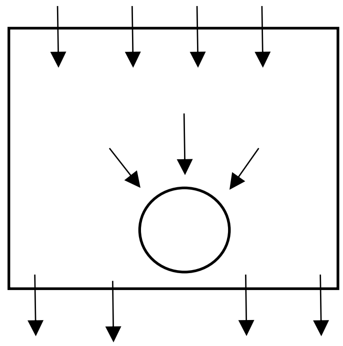

Figure 5. WinSLAMM Runoff reduction mechanism within LID control practices

$Q_{p,LID}$ = (WinSLAMM translated LID controlled discharge equation at Post-developed condition) – (Volumetric Evaporation Rate)

$$Q_{p,LID} = (b*A - c) - (E*A)$$

Where,

$Q_{p,LID}$ = Peak discharge with single control practice (cfs)

b,c = Coefficients, which depend on the size of installation of control practice.

A = Total area of proposed commercial development (acres)

E = Evaporation Rate (inches/hr.)

Calculation of Peak Discharge and Runoff Volume with Combined Control Practices in Series

$Q_{p,comb}$ = (Peak discharge from 50 years 24 hr. storm event) – (Reduction of Peak discharge by LID1 + Reduction of Peak discharge by LID2 + Reduction of Peak discharge by LID3 + …….)

$$= Q_{p,50} - \{(Q_{p,50} - Q_{p,LID1}) + (Q_{p,50} - Q_{p,LID2}) + (Q_{p,50} - Q_{p,LID3})\}$$

$$= (Q_{p,LID1} + Q_{p,LID2} + Q_{p,LID3}) - 2\,Q_{p,50}$$

$$Q_{p,comb} = (Q_{p,LID1} + Q_{p,LID2} + Q_{p,LID3}) - 2Q_{p,50}$$

$Q_{p,comb}$ = Peak discharge when commercial development is incorporated with combination of BMPs in series

$Q_{p,LID1}$ = Peak discharge when commercial development is incorporated with LID control practice 1

$Q_{p,LID1}$ = Peak discharge when commercial development is incorporated with LID control practice 1

$Q_{p,LID2}$ = Peak discharge when commercial development is incorporated with LID control practice 2

$Q_{p,50}$ = Peak discharge from 50-years 24-hr storm event (cfs)

Chapter 8 – Project Deliverables and Suggested Enhancements

Status	Suggestions for Enhancements
-Development of Calibrated WinSLAMM Models for three different BMPs have been accomplished -Permeable Pavement -Bioretention -Biowsale	-Local cost information of BMPs construction can be expanded
-DMT Database has been created and the convergence algorithm was development for BMPs size determination	-Feedback from local engineers/planners/stakeholders will continue to be gathered through pilot testing with two cities
-Version 1 DMT as a form of the macro-enabled spreadsheet has been developed along with a User's Manual for the DMT	-Additional boundary conditions (If needed)
	-Availability of local materials
	-Inventory on drainage policies can be expanded

Chapter 9 – Outreach and Education

Educational outreach activities were performed by the project team in order to promote the DMT to local officials, city and county managers, water professionals, professional organizations and water-related organizations. The LRGV NPDES SWTF is comprised of 17 local governments and entities with a total population of over 500,000. The workshop announcements were solicited through websites, utility mailouts, e-mail databases, regulatory list servers, professional organizations, ISDs, and other delivery tools. The DMT was presented to benefit residential, commercial, industrial educational, professional and government stakeholders through the delivery of innovative information, by providing a venue with opportunities to disseminate and share knowledge between stakeholders, and by engaging young professionals, students, and educators with new science and engineering paradigms.

The project team has completed the three following workshops thus far with the LRGV SW Task Force partners during the period of April 2018-May 2018.

- October 10, 2017 – BECC Green Infrastructure Forum
- April 24, 2018 – Lower Rio Grande Valley TPDES Stormwater Task Force DMT review workshop in San Benito, TX
- May 17, 2018 – Workshop at the 20th Annual Lower Rio Grande Valley Water Quality Conference at South Padre Island, TX, May 12-17.

Chapter 10 – Future work to expand tool use in the LRGV

Implementation of a Decision-Making Tool (DMT) for Determining LID Stormwater Detention Requirements for the Cities of Weslaco and San Benito, TX

The DMT can be pilot tested with specific information for two significant Arroyo Watershed cities-Weslaco, and San Benito. In its future algorithm, the DMT will incorporate some of the existing drainage policies of two Watershed cities and some BMP-specific economic analysis as major justification for LID implementation in the Watershed. According to existing drainage policy, stormwater runoff generated from new commercial developments within these cities is generally required to be detained at on-site for a post-development 25- year frequency storm event and released into a receiving system at 25-year predevelopment discharge rate (San Benito) or 10 years predevelopment discharge rate (Weslaco). According to the City of Weslaco drainage ordinances, the area of impervious cover should not exceed 5,000 square feet for 10,000 square feet of construction. The city of Weslaco requires the length of a drainage ditch to be at least 75-feet [CWSMP, 2004], whereas the City of San Benito restricts the size to be at least 5-acres in the area [CCSMP, 2008]. These are examples of new inputs and enhancement to be made in the decision-making tool to expand its implementation.

In its future version, DMT tool can provide a cost-benefit analysis of BMPs based on the analyzed costs in terms of construction and O&M costs of the BMPs, and benefits in terms of runoff reduction, property value increases, leasehold revenue, flood damage mitigation and groundwater recharge. The successful implementation and adoption of the DMT at these two important urban centers in the Watershed will provide for expanded green infrastructure and improvement in water quality in the Arroyo Colorado.

Proposed DMT enhancements for expanded implementation:

- Calibrated WinSLAMM models for several key BMPs integrated into table lookup or Solver subroutines for DMT tool implementation.
- Enhancement of the DMT tool with drainage policy constraints and economic data and analyses
- Implementation of DMT tool for two specific Watershed cities and their drainage policies

References

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City of Weslaco Stormwater Management Program (2004). Developed in accordance with the requirements of TCEQ-TPDES General Permit TXR040000.

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Shilling, F., Sommarstrom, S., Kattelmann, R., Washburn, B., Florsheim, J., & Henly, R. (2004). *California Watershed Assessment Manual*. Prepared for the California Resources Agency.

Voorhees, J., and Pitt, B. (2018). *WinSLAMM User's Guide*, P&V Associates.

Appendices A, B and C attached

Appendix A

Appendix A.1. Initialization of WinSLAMM model input parameters for the permeable pavement monitored at the City of Brownsville-Monte Bella Park.

Parameters	Unit	COB-PCP	Comment/Source
Porous Pavement Area	acres	0.009	Field Measured (Alam, 2016)
Peak to Average Ratio		3.8	NURP Source Area PSD File (WinSLAMM)
Pavement Surface Thickness	inch	3.0	LRGV LID BMPs Final Report, 2015
Pavement Surface Porosity	Dimensionless	0.20	Perviouspavement.org
Aggregate Bedding Thickness	inch	6.0	LRGV LID BMPs Final Report, 2015
Aggregate Bedding Porosity	Dimensionless	0.35	Stormtech Techsheet (2012)
Aggregate Base Reservoir (base + Sub-base) Thickness	inch	9.0	LRGV LID BMPs Final Report, 2015
Aggregate Base Reservoir porosity	Dimensionless	0.35	Stormtech Techsheet (2012)
Pavement Area to Aggregate Base Area Ratio	Dimensionless	1.00	Default
Perforated Pipe Underdrain diameter	inch	4.0	LRGV LID BMPs Final Report, 2015
Pipe Underdrain Invert Elevation	inch	0.5	LRGV LID BMPs Final Report, 2015
No. of underdrain pipe	Dimensionless	1	LRGV LID BMPs Final Report, 2015
Subgrade Seepage Rate	in/hr	0.05	Literature value for Sandy Clay Soli
Initial/max Surface Infiltration Rate	in/hr	2000	Bean (2007)
Percent Solid Removal Upon Cleaning	%	50	Permeable Pavement Tech Note, Wisconsin Department of Natural Resources (2014)
Surface Clogging Load	lb/ft^2	0.06	Permeable Pavement Tech Note, Wisconsin Department of Natural Resources (2014)
Restorative Cleaning Frequency	Dimensionless	Never Cleaned	Default

Appendix A.2. Initial (or calibrated) runoff coefficient values used in the WinSLAMM Porous Concrete Pavement model.

Rainfall Depth (inches)	Runoff Coefficients		
	pervious-sandy	pervious-silty	pervious-clay
0.040	0.000	0.000	0.000
0.080	0.000	0.000	0.000
0.120	0.000	0.000	0.000
0.200	0.000	0.000	0.000
0.390	0.005	0.021	0.023
0.590	0.007	0.030	0.038
0.790	0.010	0.042	0.058
0.980	0.012	0.044	0.069
1.200	0.014	0.052	0.076
1.600	0.016	0.054	0.120
2.000	0.018	0.200	0.200
2.400	0.019	0.200	0.200
2.800	0.020	0.200	0.200
3.200	0.021	0.200	0.200
3.500	0.022	0.200	0.200
3.900	0.023	0.200	0.250
4.500	0.024	0.200	0.300

Appendix A.3. WinSLAMM Model generated tabular outputs in terms of post-development peak discharge from Permeable Pavement-Incorporated Commercial Development for 50-years frequency storm event for different sizes of commercial development and permeable pavement installation areas.

		Area of Commercial Development (acres)		
		5	***10***	***15***
PP Installation Areas (acres)	***0.10***	7.50	15.06	22.62
	0.20	7.44	14.98	22.53
	0.40	7.35	14.86	22.37
	0.80	7.17	14.68	22.19
	1.00	7.08	14.58	22.09
	2.00	6.46	14.08	21.56
	3.00	3.44	13.58	21.02
	4.00	0.43	12.77	20.51
	5.00	0.35	10.23	19.98
	10.00		0.36	6.10
	15.00			0.36

Appendix B

Appendix B.1. Initialization of WinSLAMM model input parameters for the Engineered Bioswale monitored at the Cameron County Drainage Dristrict#1 Parking Lot.

Parameters	Unit	CCDD#1-BS	Comment/Source
Total Drainage Area	acres	0.257	Field Measured (Alam, 2016)
The fraction of Drainage Area Served by the Swale	Dimensionless	0.15	Field Measured (Alam, 2016)
Total Swale Length	ft	108	Field Measured (Alam, 2016)
Average Swale Length to Outlet	ft	108	Field Measured (Alam, 2016)
Typical Bottom Width	ft	10	LRGV LID BMPs Final Report, 2015
Typical Swale Side Slope	Dimensionless	4.0	LRGV LID BMPs Final Report, 2015
Typical Longitudinal Slope	Dimensionless	0.020	Default
Swale Retardance Factor	Dimensionless	D	Database for Different Plant Types used in Grass Swale, WinSLAMM v. 10.2.1
Typical Plant/Grass Height	inch	5	Database for Different Plant Types used in Grass Swale, WinSLAMM v. 10.2.1
Swale Dynamic Infiltration Rate for Sandy Clay	inch/hr	0.025	Database for Swale Dynamic Infiltration rate for different Soil Type, WinSLAMM v. 10.2.1

Appendix B.2. Initial (or calibrated) runoff coefficient values used in the WinSLAMM Engineered Bioswale model.

Rainfall Depths (inches)	Runoff Coefficients		
	pervious-sandy	pervious-silty	pervious-clay
0.040	0.000	0.000	0.000
0.080	0.000	0.000	0.000
0.120	0.000	0.000	0.000
0.200	0.000	0.000	0.000
0.390	0.005	0.021	0.023
0.590	0.007	0.030	0.038
0.790	0.010	0.042	0.058
0.980	0.012	0.044	0.069
1.200	0.014	0.052	0.076
1.600	0.016	0.054	0.120
2.000	0.018	0.200	0.200
2.400	0.019	0.200	0.200
2.800	0.020	0.200	0.200
3.200	0.021	0.200	0.200
3.500	0.022	0.200	0.200
3.900	0.023	0.200	0.250
4.500	0.024	0.200	0.300

Appendix B.3. WinSLAMM Model generated tabular outputs in terms of post-development peak discharge from Engineered Bioswale-Incorporated Commercial Development for 50-years frequency storm event for different sizes of commercial development and bioswale lengths.

		Area of Commercial Development (acres)		
		5	***10***	***15***
BS Length (ft)	***20***	*7.57*	*15.16*	*22.74*
	50	*7.56*	*15.14*	*22.72*
	100	*7.53*	*15.11*	*22.70*
	200	*7.48*	*15.06*	*22.64*
	500	*7.33*	*14.90*	*22.48*
	1000	*7.08*	*14.64*	*22.21*
	2000	*6.59*	*14.12*	*21.67*
	5000	*5.18*	*12.59*	*20.07*
	10000	*3.10*	*10.17*	*17.49*
	20000	*1.77*	*5.93*	*12.69*

Appendix C

Appendix C.1. Initialization of WinSLAMM model input parameters for the Bioretention Cell monitored at the South Texas College McAllen Campus Parking Lot.

Parameters	**Unit**	**Value**	**Comment/Source**
Total Drainage Area	ft2	17,424	Field Measured (Ahmed & Yeasir, 2015)
Top Area	ft2	592	LRGV LID BMPs Final Report, 2015
Bottom Area	ft2	592	LRGV LID BMPs Final Report, 2015
Total Depth	ft	4.13	LRGV LID BMPs Final Report, 2015
Typical Width	ft	4.0	LRGV LID BMPs Final Report, 2015
Native Soil Infiltration Rate (Sandy Clay)	inch/hr	0.05	LRGV LID BMPs Final Report, 2015
Infiltration Rate Fraction-Bottom	Dimensionless	1.0	Default
Infiltration Rate Fraction-Side	Dimensionless	1.0	Default
Rock Filled Depth	ft	0.63	LRGV LID BMPs Final Report, 2015
Rock Filled Porosity	Dimensionless	0.32	Engineering Media Database for Biofiltration, WinSLAMM v. 10.2.1
Engineered Media Infiltration Rate	inch/hr	5.24	Laboratory Estimated (Ahmed & Yeasir, 2016)

Engineered Media Depth	ft	2.5	LRGV LID BMPs Final Report, 2013
Engineered Media Porosity	Dimensionless	0.37	Engineering Media Database for Biofiltration, WinSLAMM v. 10.2.1
Inflow Hydrograph Peak to Average Flow Ratio	Dimensionless	3.8	Default
Number of Upstream Drainage System	Dimensionless	1	LRGV LID BMPs Final Report, 2015
Underdrain Pipe Diameter	ft	0.5	LRGV LID BMPs Final Report, 2015
Underdrain Pipe Invert Elevation from Datum	ft	0.05	LRGV LID BMPs Final Report, 2015
Number of Pipe at Invert Elevation	Dimensionless	1	LRGV LID BMPs Final Report, 2015
Top soil Porosity/Saturation Moisture Content	Dimensionless	0.35	Engineering Media Database for Biofiltration, WinSLAMM v. 10.2.1
Soil Field Moisture Capacity (Clay loam)	Dimensionless	0.080	Engineering Media Database for Biofiltration, WinSLAMM v. 10.2.1
Top Soil Permanent Wilting Point (Clay loam)	Dimensionless	0.025	Engineering Media Database for Biofiltration, WinSLAMM v. 10
Plant Type	Dimensionless	Shrubs	Field Observation
The fraction of Biofilter that is vegetated with plant	Dimensionless	1.0	Default
Root depth of Plant	ft	1.0	Database for Different Plant Types used in Biofiltration, WinSLAMM v. 10.2.1
ET Crop Adjustment Factor	Dimensionless	0.55	Database for Different Plant Types used in Biofiltration, WinSLAMM v. 10.2.1

Appendix C.2. Initial and adjusted runoff coefficient values used in the WinSLAMM Bioretention cell baseline and calibrated model, respectively.

Rainfall Depth (inches)	**Initial Runoff Coefficients**			**Adjusted Runoff Coefficients (Decreased by 66%)**		
	pervious-sandy	**pervious-silty**	**pervious-clay**	**pervious-sandy**	**pervious-silty**	**pervious-clay**
0.040	0.000	0.000	0.000	0.000	0.000	0.000
0.080	0.000	0.000	0.000	0.000	0.000	0.000
0.120	0.000	0.000	0.000	0.000	0.000	0.000
0.200	0.000	0.000	0.000	0.000	0.000	0.000
0.390	0.005	0.021	0.023	0.002	0.007	0.008
0.590	0.007	0.030	0.038	0.002	0.010	0.013
0.790	0.010	0.042	0.058	0.003	0.014	0.020

0.980	0.012	0.044	0.069	0.004	0.015	0.023
1.200	0.014	0.052	0.076	0.005	0.018	0.026
1.600	0.016	0.054	0.120	0.005	0.018	0.041
2.000	0.018	0.200	0.200	0.006	0.068	0.068
2.400	0.019	0.200	0.200	0.006	0.068	0.068
2.800	0.020	0.200	0.200	0.007	0.068	0.068
3.200	0.021	0.200	0.200	0.007	0.068	0.068
3.500	0.022	0.200	0.200	0.007	0.068	0.068
3.900	0.023	0.200	0.250	0.008	0.068	0.085
4.500	0.024	0.200	0.300	0.008	0.068	0.102

Appendix C.3. WinSLAMM Model generated tabular outputs in terms of post-development peak discharge from Bioretention Cell-Incorporated Commercial Development for 50-years frequency storm event for different sizes of commercial development and bioretetnion installation areas.

		Area of Commercial Development (acres)		
		5	***10***	***15***
BDC Installation Area (ft2)	***500.00***	7.55	15.12	22.69
	1000.00	7.52	15.07	22.62
	2000.00	7.49	15.02	22.55
	3000.00	7.44	14.96	22.47
	5000.00	7.36	14.83	22.31
	10000.00	7.19	14.63	22.07
	20000.00	6.24	13.86	21.15
	50000.00	1.70	10.00	17.56
	100000.00	0.98	1.73	10.80
	200000.00	0.32	1.05	1.55