



NCHRP 25-40

Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices



Project Phases and Tasks

- Phase 1 Background:
 - Task 1 Literature Review
 - Task 2 DOT Survey
 - Task 3 FHWA, EPA, and Legislative Initiatives
 - Task 4 Maintenance and Inspection
 - Task 5 Annotated outline for Guidance
- Phase 2 Assessment:
 - Task 6 BMP Performance
 - Task 7 Unit Load Reduction Modeling
 - Task 8 WLC Models
 - Task 9 Maintenance and Inspection Protocols
 - Task 10 Interim Report

- Phase 3 Tool Development
 - Task 11 Tool Development
 - Task 12 Data Collection Protocols
 - Task 13 Non-structural BMP Assessment
 - Task 14 Second Interim Report/Draft Tool
- Phase 4 Final Project Deliverables
 - Task 15 Final Deliverables



Project Goals

- Develop relationships of maintenance vs. performance
- Develop long-term understanding of changes in performance
- Develop a tool to predict performance and life-cycle costs of BMPs



Realities

- BMP Datasets are limited (~5 years was longest data set)
- Maintenance information vs. performance is lacking
- Costs are very site-specific, especially in retrofit only scenarios

Basis for Estimating BMP Performance

- Physically based hydrology and hydraulics
 - Long-term continuous simulation and data analysis
 - Percent volume captured and treated
 - Percent volume lost due to infiltration and ET
- Empirically based water quality
 - Non-parametric statistical methods
 - Determination of significant concentration reductions
 - Influent/effluent regression analysis

BMPs and Stormwater Parameters

Individual BMP Tools

- Vegetated swale
- Filter strip
- Dry detention basin
- Bioretention
- Wet pond
- Sand filter
- Permeable friction course (PFC) overlay

Stormwater Parameters

- Volume
- TSS
- Pathogens
 - Fecal coliform
 - E. coli
- Metals
 - Total copper
 - Total lead
 - Total zinc
- Nutrients
 - Total phosphorus
 - Dissolved phosphorus
 - Nitrate (NO3)
 - Total Kjeldahl nitrogen (TKN)
 - Total nitrogen (TKN + NO3)

Best Management Practices



Tool Process Steps



- 1. Average annual runoff volume from selected rain gage and site info
- 2. Annual runoff volume captured, reduced, and treated by BMP
- 3. Effluent concentrations from influent/effluent regression equations
- 4. Loads reduced/discharged (concentrations X volumes)
- 5. Whole life-costs from user provided and tool computed quantities

Data Sources – Runoff Quality

- Highway Runoff Database (HRDB) version 1.0.0a
- National Stormwater Quality Database (NSQD) version 3.1
- Excludes data prior to 1986 (year lead in gasoline was banned)

	NSQD	HRDB	Combined
# of sites	43	93	136
# of events	669	1,537	2,206
# of sample results	3,027	8,813	11,184
# ND	41	458	499

Constituent	Non-detects / Total Samples
TSS	11 / 1,713
NO3	92/1,047
TN	0 / 122
TKN	49 / 1,408
DP	32 / 217
ТР	120 / 2,022
TCu	72 / 1,808
TPb	102 / 1,683
TZn	12 / 2,099
FC	0 / 65
E. coli	0/13



SWMM Simulations

Consistent Drawdown Model Runs (Infiltration, Surface Discharge)				
Parameter	Number of Increments			
Rain Gages	343			
Modeled Imperviousness of Tributary Area	1 (100%)			
Storage Volume	10			
Drawdown Time	10			
Total – Consistent Drawdown Runs	34,300			
ET Drawdown Model I	Runs			
Parameter	Number of Increments			
Rain Gages	343			
Modeled Imperviousness of Tributary Area	1 (100%)			
Storage Volume	10			
ET Depth Increments	7			
Total – ET Runs	24,010			



BMP Operation and Maintenance Requirements

- Defines inspection requirements, maintenance triggers, and maintenance actions for selected BMPs
- Primary sources: Caltrans, Oregon DOT, Arizona DOT, Maine DOT, New York DOT, DelDOT, NCDOT, and Texas DOT
- Developed three levels of maintenance: Low, medium and high – default is correlated to rainfall (Less than 20 inches, between 20 and 35 inches, 35 inches)



Maintenance Activities

- Defined 'functional' and 'aesthetic' maintenance
- Allows user to eliminate tasks if they are not important locally
- Example (aesthetic): Vegetation trimming not correlated with BMP constituent removal performance



Maintenance	Mainte	nance Frequ	iency	Hours per	Crew	Equipment	Materials &
Activity	Low	Medium	High	Event	Size	Needed	Incidentals
Vegetation Management for Aesthetics (optional)	Annually	2 times per year	3 times per year	4	2	Utility Truck, Mower	-
Trash and Debris	Annually	Annually	Annually	Included in Vegetation Management	-	-	-
Intermittent Maintenance (including sediment management)	Every 10 years	Every 5 years	Every 2 years	8	2	Utility Truck, Loader	Disposal
Vegetation Repair	Every 10 years	Every 5 years	Every 2 years	Included in Intermittent Maintenance	-	-	-
Erosion or Rutting	Every 10 years	Every 5 years	Every 2 years	Included in Intermittent Maintenance	-	-	-
Inspection and Reporting	Annually	Annually	Annually	1	2	Utility Truck	-



BMP Life Span

BMP Type	Life-span	Limiting Factor
Vegetated Strips	8-60 years (depending on ecoregion)	Sediment Accumulation
Vegetated Swales	10-50 years (depending on ecoregion)	Sediment Accumulation
Dry Detention Basin	80 years	Pipe Material Longevity
Bioretention	80 years	Pipe Material Longevity
Retention Pond	80 years	Pipe Material Longevity
Sand Filter	75 years	Concrete Longevity
Permeable Friction Course	14 years	Sediment Accumulation



Whole Life Costs

- Built upon the WERF Whole Life Cost Models
- Line-item basis with defaults from RSMeans and research



User's Guide to the BMP and LID Whole Life Cost Models Version 2.0

Uncertainties in Cost Estimates

- Project scale and unit costs
- Retrofit vs. new construction
- Regulatory requirements
- Public vs. private projects
- Flexibility in site selection, site suitability
- Partnerships with others
- Level of experience
- State of economy
- Land costs

User-Entered Engineer's Estimate Costs	Unit	<u>Default.</u> Baseline	<u>User-Entered</u> Baseline Unit	Baseline Unit Cost used in	<u>Adjusted</u> Unit Cost	<u>Default</u> <u>Quantity</u>	<u>User-</u> Entered	<u>Quantity used</u> in Calculations	<u>Cost</u>	Guidance	
Mobilization	LS	\$1,171		\$1,171	\$1,171	1		1	\$1,171		
Clearing & Grubbing	SY	\$1		\$1	\$1	115		115	\$110		
Planting Media	CY	\$43		\$43	\$43	50		50	\$2,135	Capit	ai cos
Pea Gravel	CY	\$129		\$129	\$129	6		6	\$800		
Gravel	CY	\$27		\$27	\$27	25		25	\$670	l St	neet
Mulch	CY	\$71		\$71	\$71	6		6	\$443		
Slotted PVC Underdrain Pipe	IF	\$8		\$8	\$8	37		37	\$286		
Excavation/Grading	BCY	\$9		\$ 9	\$9	163		163	\$1,540		
Haul/Dispose of Excavated Material	CY	\$10		\$10	\$10	163		163	\$1, 679		
Finish Grading (SY):	SY	\$2		\$2	\$2	115		115	\$228		
Bioretention Vegetation (SF)	SF	\$2		\$2	\$2	74		74	\$169	Enter miniart, sher file values in the blue	
Hydroseed (SF):	SF	\$0		\$0	\$0	3		3	\$0	"User Entered Data" cells if applicable and the calculations will automatically undate to	
18" Square Trench (LF)	ĿF	\$1		\$1	\$1	37		37	\$29	override the default value. If a value is not provided, the default value will be used in	
Dewatering	DAY	\$1,200		\$1,200	\$1,200	0		0	\$0	the cost calculations	
Inflow Structure(s)	LS	\$2,200		\$2,200	\$2,200	1		1	\$2,200		
Overflow Structure (concrete or rock riprap)	CY	\$125		\$125	\$125	7		7	\$926		
Metal Beam Guard Rail	Ŀ	\$58		\$58	\$58	9		9	\$496		
Conveyance	Ŀ			\$0	\$0			0	\$ 0		
Other				\$0	\$0			0	\$0		
Other				\$0	\$0			0	\$0	1	
Other				\$0	\$0			0	\$0	1	
Other				\$0	\$0			0	\$0		
Other				\$0	\$0			0	\$0	1	
								Total Facility Base Cost	\$12,882		17

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Whole Life Cycle Costs Summary					
CAPITAL COSTS	Total Cost				
Total Facility Base Cost	\$12,882				
Total Associated Capital Costs (e.g., Engineering, Land, etc.)	\$7,181				
Capital Costs	\$20,063				

REGULAR MAINTENANCE ACTIVITIES	Years between Events	Total Cost per Visit	Total Cost per Year
Inspection, Reporting & Information Management	0.5	\$180	\$360
Vegetation Management with Trash & Minor Debris Removal	0.5	\$1,380	\$2,760
add additional activities if necessary	0	\$0	\$0
add additional activities if necessary	0	\$0	\$0
Totals, Regular Maintenance Activities			\$3,120

Whole Life Cost Summary

CORRECTIVE AND INFREQUENT MAINTENANCE ACTIVITIES (Unplanned and/or >3yrs. betw. events)	Years between Events	Total Cost per Visit	Total Cost per Year		
Corrective Maintenance	4	\$6,740	\$1,685		
add additional activities if necessary	0	\$0	\$0		
add additional activities if necessary	0	\$0	\$0		
Totals, Corrective & Infrequent Maintenance Activities			\$1,685		
Capital Costing Method	Line Ite	em Engineer's Estimat	e		
Assumed Level of Maintenance		Н			
Estimated Capital Cost, \$ (2013)	\$20,063				
Estimated NPV of Design Life Maintenance Costs, \$ (2013)	\$92,494				
Estimated NPV of Design Life Whole Life Cycle Cost, \$ (2013)	ign Life Whole Life Cycle Cost, \$ (2013) \$112,557				
Estimated Annualized Whole Life Cycle Cost, \$/yr (2013)	\$4,502				
Totals are based on design life with routine and major maintenance.					

NON-STRUCTURAL BMPS



Non-Structural BMPs

- Provide a basis for optimizing the selection non-structural BMPs
- Identify the program variables that DOTs can manage to improve NS BMP effectiveness, and reduce whole life costs of entire program
- Using elements of the UN's Triple Bottom Line approach



Non-Structural BMPs

- The non-structural BMPs that are qualitatively assessed within the report are:
 - Storm drain cleaning
 - Sweeping
 - Irrigation runoff reduction practices
 - Smart landscaping
 - Trash management programs (including education/outreach)
 - Elimination of groundwater infiltration (to storm drains)
 - Slope and channel stabilization
 - Winter maintenance activities (traction aides)

Summary of Performance and Whole Life Cost Factors – Storm Drain Cleaning

	F	Performance Fac	tors for Storm Drain Cle	eaning
Pollutants Addressed	Internal DOT Variables Influencing Performance	Performance Range	Advantages	Disadvantages
 ✓ Sediments ✓ Trash ✓ Organic Debris ✓ Bacteria ✓ Heavy Metals ✓ Nutrients ✓ Oils ✓ Grease 	 ✓ Frequency of Cleaning ✓ Timing of Cleaning Relative to Storm Activity ✓ Type of Equipment Used 	(Refer to Table 8-2)	 ✓ Low institutional barriers 	 Low to modest reduction of targeted constituents High costs associated with labor, equipment, disposal, and traffic control Potential permitting and regulatory constraints Potential Physical & Access Constraints
	Who	e Life Cycle Cost	t Factors for Storm Drai	n Cleaning
Planning and Implementation	Labor	E	quipment	Other
 ✓ Location and Frequency of Cleaning ✓ System Prioritization 	 ✓ Type of Labor (i.e. DOT staff versus Contractor) 	 ✓ Capital Eq (Vactor T ✓ Fuel ✓ Equipme Deprecia 	quipment Purchase ruck typ.) nt Maintenance and tion	 ✓ Inspection ✓ Record Keeping and Reporting ✓ Traffic Control (Potentially) ✓ Disposal Costs ✓ Regulatory Permitting (Potentially)

Effectiveness – Storm Drain Cleaning

	Effectiveness	Load Reduction	
Constituent	Average	Range	(Average)
Sediment ^{a,c}	35%	14% - 56%	500 lbs/acre
Bacteria ^a	Х	1% - 2%	Х
Nutrients ^{a,b}	Х	5% - 10%	Х
Trash ^{a,b}	Х	Х	Х
Metals ^{a,b}	Х	5% - 10%	Х

Notes: a CWP 2006 (nutrients reported as nitrogen) b Pitt 1985 (metals reported as zinc) c Pitt and Voorhees 1995



Sustainability Rating Table – Storm Drain Cleaning

Effectivene	ess				Social /	Sustainability			
Bacteria	Nutrients	Sediment	Trash	Metals	Cost per Location *	Impacts	Rating		
Low	Low	Low-Medium	Medium	Low	\$550 to \$2100	Low	Low		

Tool Example: Bioretention



Bioretention Design

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з	Project Location	Santa Clarita, CA				User Entered Data	Guidance			
4	Company	RBF Consulting				Reference Data; do not edit cells	Warnings			
5	PROJECT LOCATION AND CLIMATE SELECTION PROJECT OPTIONS	T RIBUTARY AREA ATT RIBUTES	BMP PARAMETERS	RESULT'S SUMMARY REPORT	SUPPORTING DATA	WHOLE LIFE SUM	CYCLE COST S MMARY			=
23										
24	Bioretention Conceptual Design Attributes									
25										
26		Step 2: Provide data	describing the BMP design	1						
27										
28	ВМР Туре	Bioretention	Only Bioretention supported in	n Alpha release						
29		-	•							
30	Primary Bioretention Design Parameters	Value		<u>Guidance</u>		Default Values	-			
31	Storage Volume (cu-ft)	5,000	Enter the total storage volume storage)	e provided by the bioretention (including	ponding , planting media, and stone	e reservoir	User-entered			
32	Underlying Soil Design Infiltration Rate (in/hr)	0.2	A default infiltration rate has b infiltration rate is available, it s	een provided based on the soil type sel should override this default data. If the s	ected for the tributary. If a localized s ystem is lined with an impermeable	site B barrier,	By tributary soil type; recommend user override with site data			
33	Underdrain Present?	yes	Underdrains should be consid elevation of the underdrain ca	dered if infiltration rates are not adequate in be specified in the default parameters	to drain the system in a reasonable section.	e time. The	A and B Soils: No C and D Soils: Yes			
34	Ponding Depth (ft)	1	Ponding depth is equal to the	elevation of the overflow above the sur	face of the planting media		1			
35										
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10	Summary of Modele	Scenario																						
11																								
12	2 The modeled scenario consists of a tributary area of 4.5 acres at 91% impervious, draining to a Bioretention BMP.																							
13	Analysis is based on the [6]	SOUTH COAST I	DRNG LOS	ANGELES	INTL AP ga	ge (COOP ID:	15114), in C	alifornia, with Pro	ject Location δ	35th percer	ntile, 24-hour	storm depth of	1.2 inches,	and Proje	ect Location a	verage ar	nual precipi	tation dept	h of 1 / inche	S.				
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28	Capital Costing Method	Line Item Engineer's Estimate					
29	Assumed Level of Maintenance	н					
30	Estimated Capital Cost, \$ (2013)	\$54,615					
31	Estimated NPV of 50-year Maintenance Costs, \$ (2013)	\$150,056					
32	Estimated NPV of 50-year Whole Life Cycle Cost, \$ (2013)	\$204,672					
33	Estimated Annualized Whole Life Cycle Cost, \$/yr (2013)	\$4,093					
34	Costs are based on assumed service life of 50 years with routine	and major maintenance					-
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36	Summary of Volume and Pollutant Load Perform	mance													
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39	Volume and Pollutant Load Performance		Percent of	Pathogen	s (CFU/yr)		Metals (lb/yr)				Nutrients (Ib/yr)			Sediment (lb/yr)	
40		Average Annual Volume, cf/yr	Baseline Runoff Volume, %	E. Coli	Fecal Coliform	Total Copper	Total Lead	Total Zinc	Nitrate [NO3]	Total Kjehldahl Nitrogen [TKN]	Total Nitrogen	Dissolved Phosphorus	Total Phosphorus	Total Suspended Solids (TSS)	=
47	Baseline Average Annual Runoff Volume	229,000	-	5.67E+15	3.87E+15	0.671	2.93	3.5	15.1	32.4	47.3	3.57	6.32	2160	
A2	2 Runoff Bypassed	101,000	44.1%	2.5E+15	1.71E+15	0.296	1.29	1.54	6.63	14.3	20.8	1.57	2.78	950	
43	BMP Captured	128,000	55.9%	3.17E+15	2.17E+15	0.376	1.64	1.96	8.42	18.1	26.5	2	3.54	1210	
44	F Deduction	20,200	8.8%	3E+14	3.41E+14	0.0592	0.258	0.309	1.33	2.80	4.1/	0.315	0.00/	190	
46	5 Infiltration Reduction	16.300	7.1%				-	-				-			
47	7 Treatment Reduction	-	-	2.64E+15	1.74E+15	0.259	1.34	1.46	0	10.1	10	0.771	0	963	
48	BMP Effluent	108,000	47.1%	2.66E+13	8.28E+13	0.057	0.0417	0.192	7.09	5.19	12.3	0.911	2.98	53.1	
49	Total Discharge	209,000	91.2%	2.52E+15	1.79E+15	0.353	1.33	1.73	13.7	19.5	33.1	2.48	5.76	1000	
50	D BMP Load Reduction	-	· ·	3.14E+15	2.08E+15	0.319	1.6	1.76	1.33	12.9	14.2	1.09	0.557	1150	
51	Annual BMP Load Reduction		-	56%	54%	48%	55%	50%	9%	40%	30%	30%	9%	54%	ł
53	Annualized Cost Per Unit of Performance	Hydrologic	Pathogens (\$	/10^12 CFU)	Tel	Metals (\$/lb)			TULAI	Nutrients (\$/lb)		T . 1	Sediment (\$/lb)		
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85	Influent Concentrat	tion						874	40	5970	46.97	204.96	244.75	1.05	2.27	3.31	0.25	0.44	150.91		
86	Treated Effluent Co	oncentration						87	r	271	8.46	6.19	28.57	1.05	0.77	1.82	0.14	0.44	7.88		
87	Whole Effluent Cor	centration*						425	i8	3025	27.06	101.94	132.59	1.05	1.49	2.54	0.19	0.44	76.64		
88 89 90 92 93 94 95 96 97 98 97 98 99 14 R€	Accounting for treat Accounting for treat Project ady	t Location	y, bypass efflueri	t quality, cap ptions	Project	Design	Results	Summar	y Rep	ort / Sup	porting Data	Whole I	ife Costs Sui	nmary 📿 🕈]/	14		■□	% — · · ·		■ ● ● ● ●
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Summary Cost Output





Summary

- Tool provides 'default' values for all data, but is completely flexible in the use of user data
- Provides estimate of load reduction via: Infiltration, evaporation, and transpiration losses and pollutant concentration
- Provides whole life cost estimate
- Excellent tool to quickly assess the 'best' BMP for a design installation