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

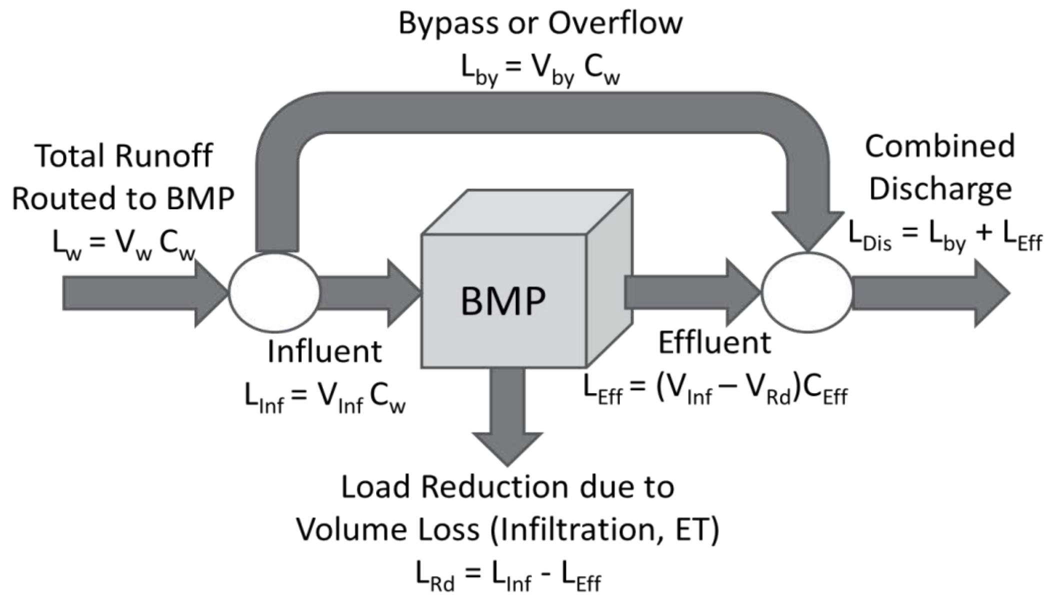
- Vegetated swale
- Filter strip
- Dry detention basin
- Bioretention
- Wet pond
- Sand filter
- Permeable friction course (PFC) overlay

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
TP	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 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 Activities - Swale

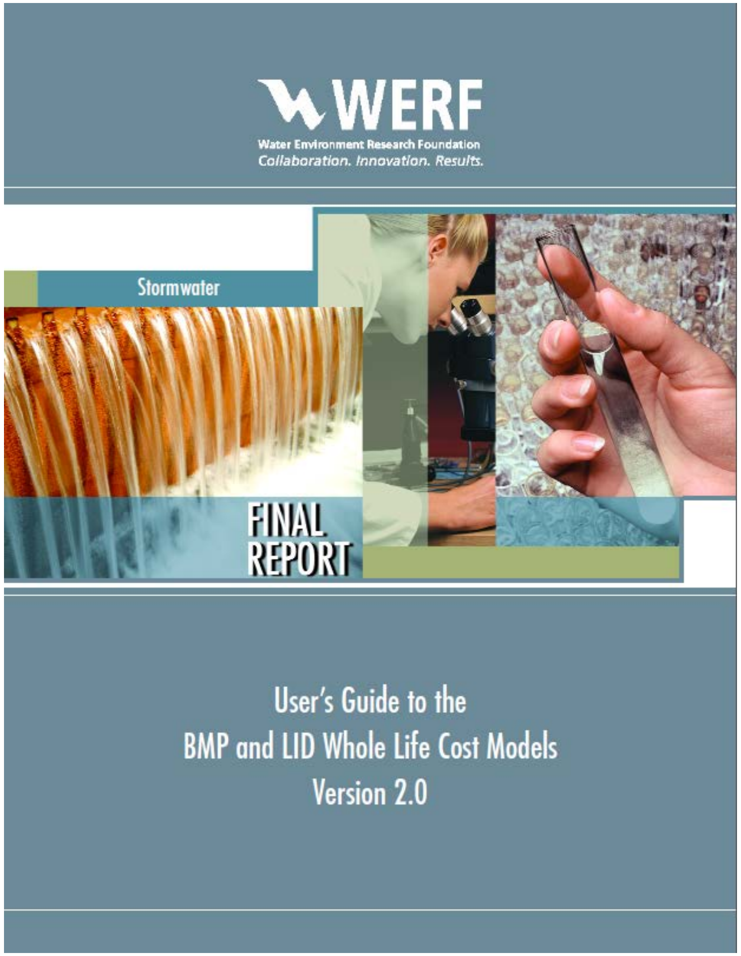
Maintenance Activity	Maintenance Frequency			Hours per Event	Crew Size	Equipment Needed	Materials & Incidentals
	Low	Medium	High				
Vegetation Management for Aesthetics (optional)	Annually	2 times per year	3 times per year	4	2	Utility Truck, Mower	-
Trash and Debris	Annually	Annually	Annually	Included 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



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

Capital Cost Sheet

User-Entered Engineer's Estimate Costs	Unit	Default Baseline	User-Entered Baseline Unit	Baseline Unit Cost used in	Adjusted Unit Cost	Default Quantity	User-Entered	Quantity used in Calculations	Cost
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
Pea Gravel	CY	$129		$129	$129	6		6	$800
Gravel	CY	$27		$27	$27	25		25	$670
Mulch	CY	$71		$71	$71	6		6	$443
Slotted PVC Underdrain Pipe	LF	$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
Hydroseed (SF):	SF	$0		$0	$0	3		3	$0
18" Square Trench (LF)	LF	$1		$1	$1	37		37	$29
Dewatering	DAY	$1,200		$1,200	$1,200	0		0	$0
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	LF	$58		$58	$58	9		9	$496
Conveyance	LF			$0	$0			0	$0
Other				$0	$0			0	$0
Other				$0	$0			0	$0
Other				$0	$0			0	$0
Other				$0	$0			0	$0
Other				$0	$0			0	$0
								Total Facility Base Cost	$12,882

Guidance

Enter project-specific values in the blue "User Entered Data" cells if applicable and the calculations will automatically update to override the default value. If a value is not provided, the default value will be used in the cost calculations.

Whole Life Cost Summary

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

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 Item Engineer's Estimate
Assumed Level of Maintenance	H
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)	$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

Performance Factors for Storm Drain Cleaning				
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

Whole Life Cycle Cost Factors for Storm Drain Cleaning			
Planning and Implementation	Labor	Equipment	Other
✓ Location and Frequency of Cleaning ✓ System Prioritization	✓ Type of Labor (i.e. DOT staff versus Contractor)	✓ Capital Equipment Purchase (Vactor Truck typ.) ✓ Fuel ✓ Equipment Maintenance and Depreciation	✓ Inspection ✓ Record Keeping and Reporting ✓ Traffic Control (Potentially) ✓ Disposal Costs ✓ Regulatory Permitting (Potentially)

Effectiveness – Storm Drain Cleaning

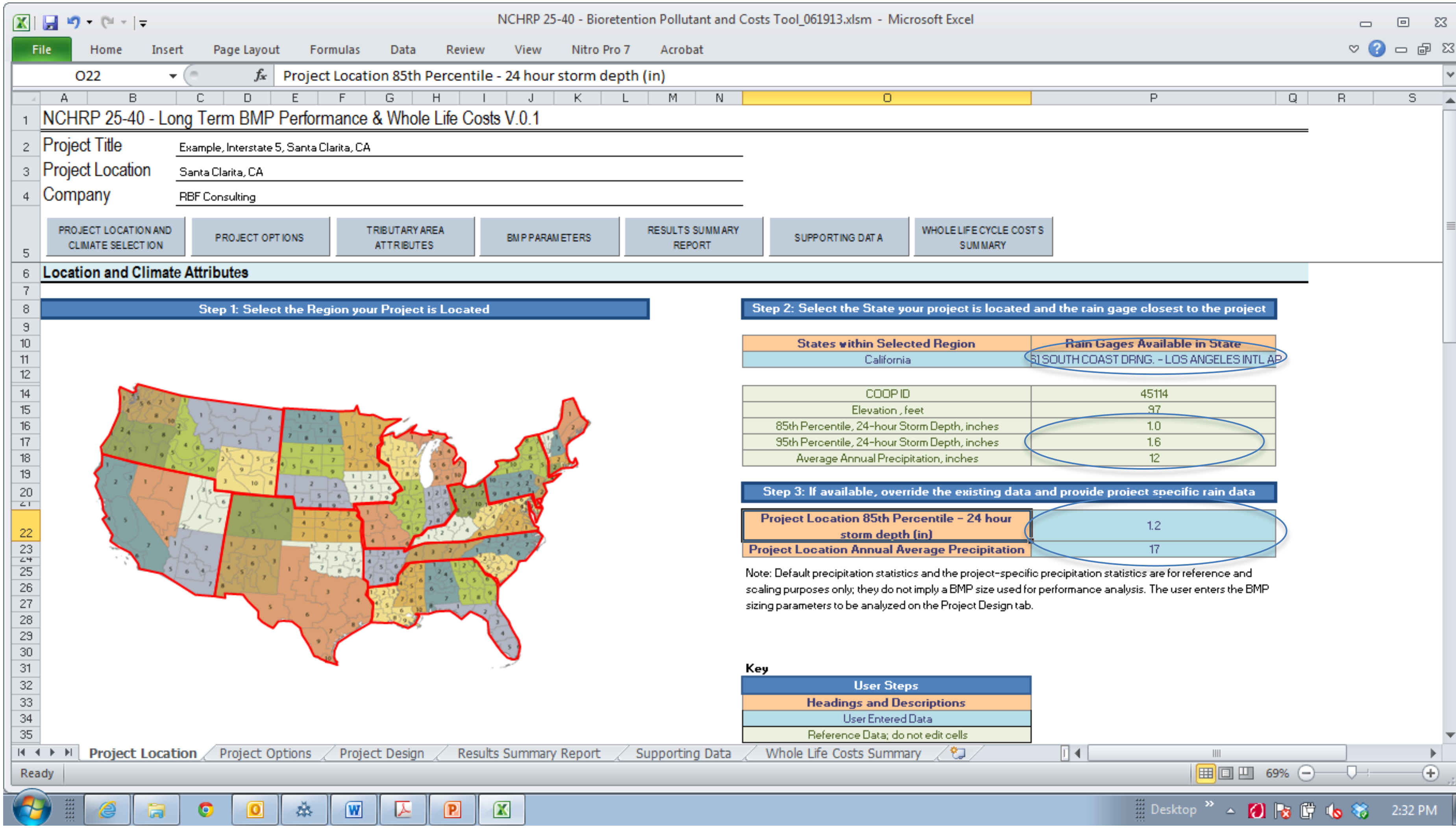
Constituent	Effectiveness		Load Reduction (Average)
	Average	Range	
Sediment [a,c]	35%	14% - 56%	500 lbs/acre
Bacteria [a]	X	1% - 2%	X
Nutrients [a,b]	X	5% - 10%	X
Trash [a,b]	X	X	X
Metals [a,b]	X	5% - 10%	X

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

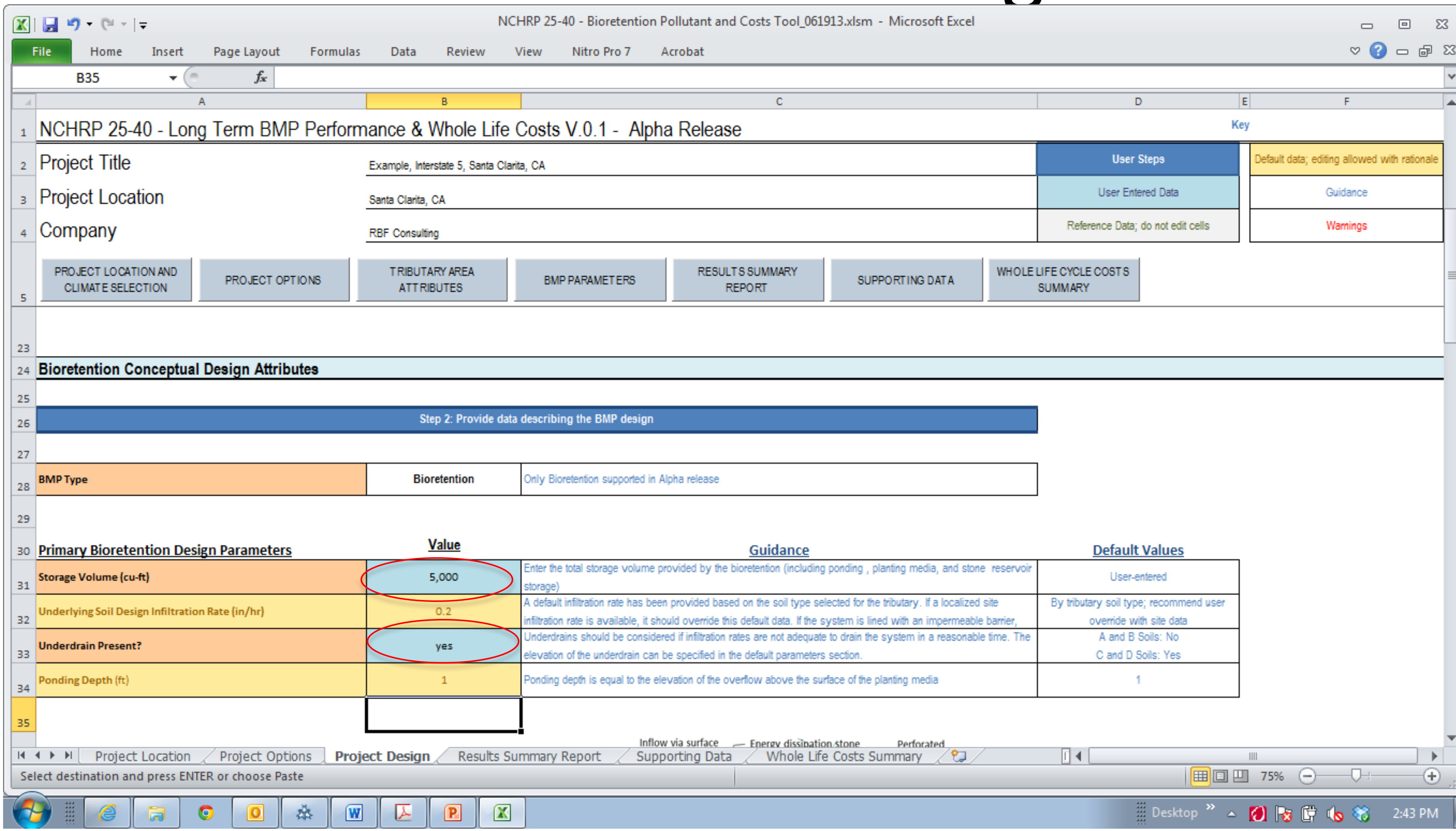
Sustainability Rating Table – Storm Drain Cleaning

Effectiveness					Cost per Location [a]	Social / Institutional Impacts	Sustainability Rating
Bacteria	Nutrients	Sediment	Trash	Metals			
Low	Low	Low-Medium	Medium	Low	$550 to $2100	Low	Low

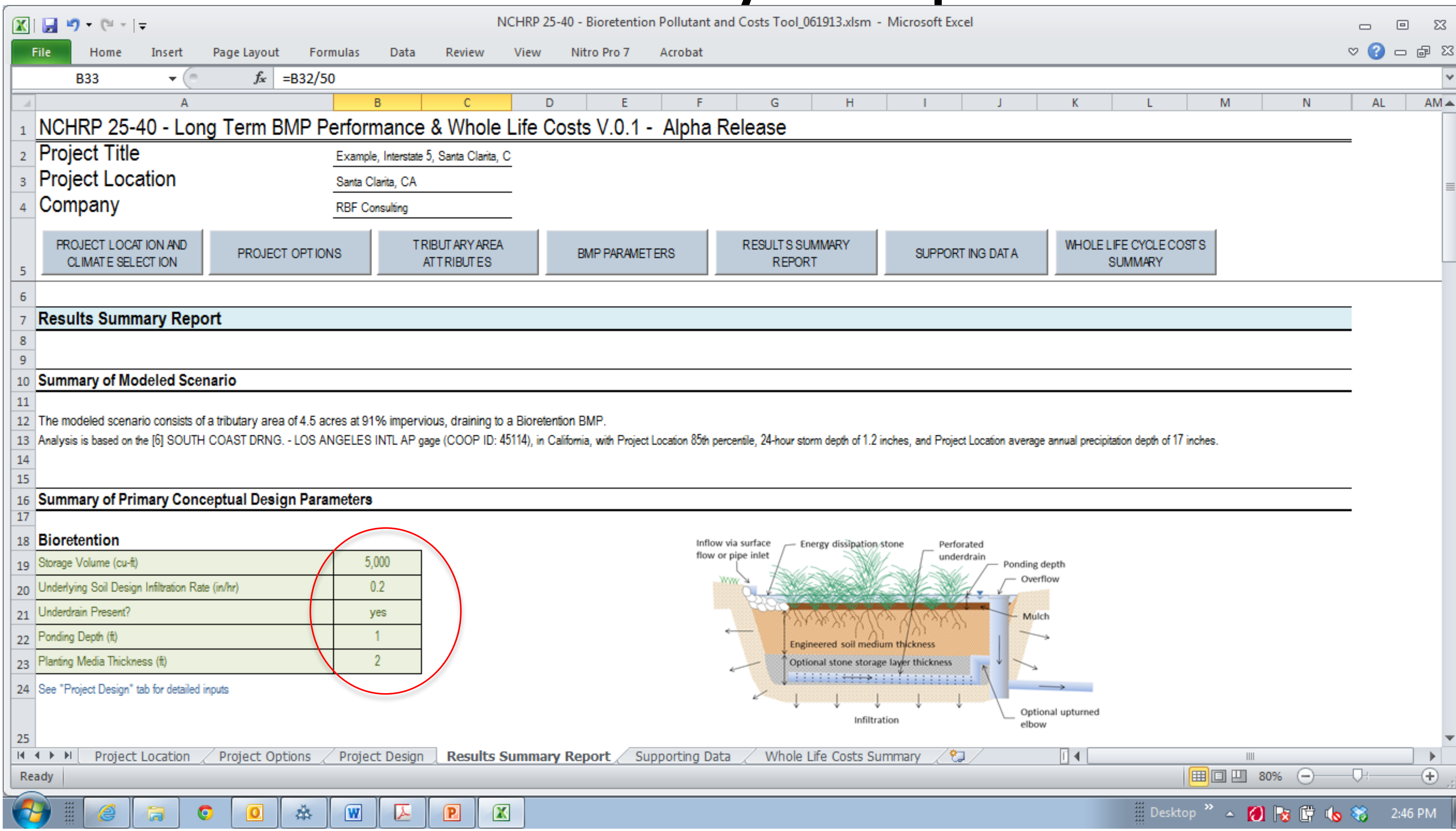
Tool Example: Bioretention



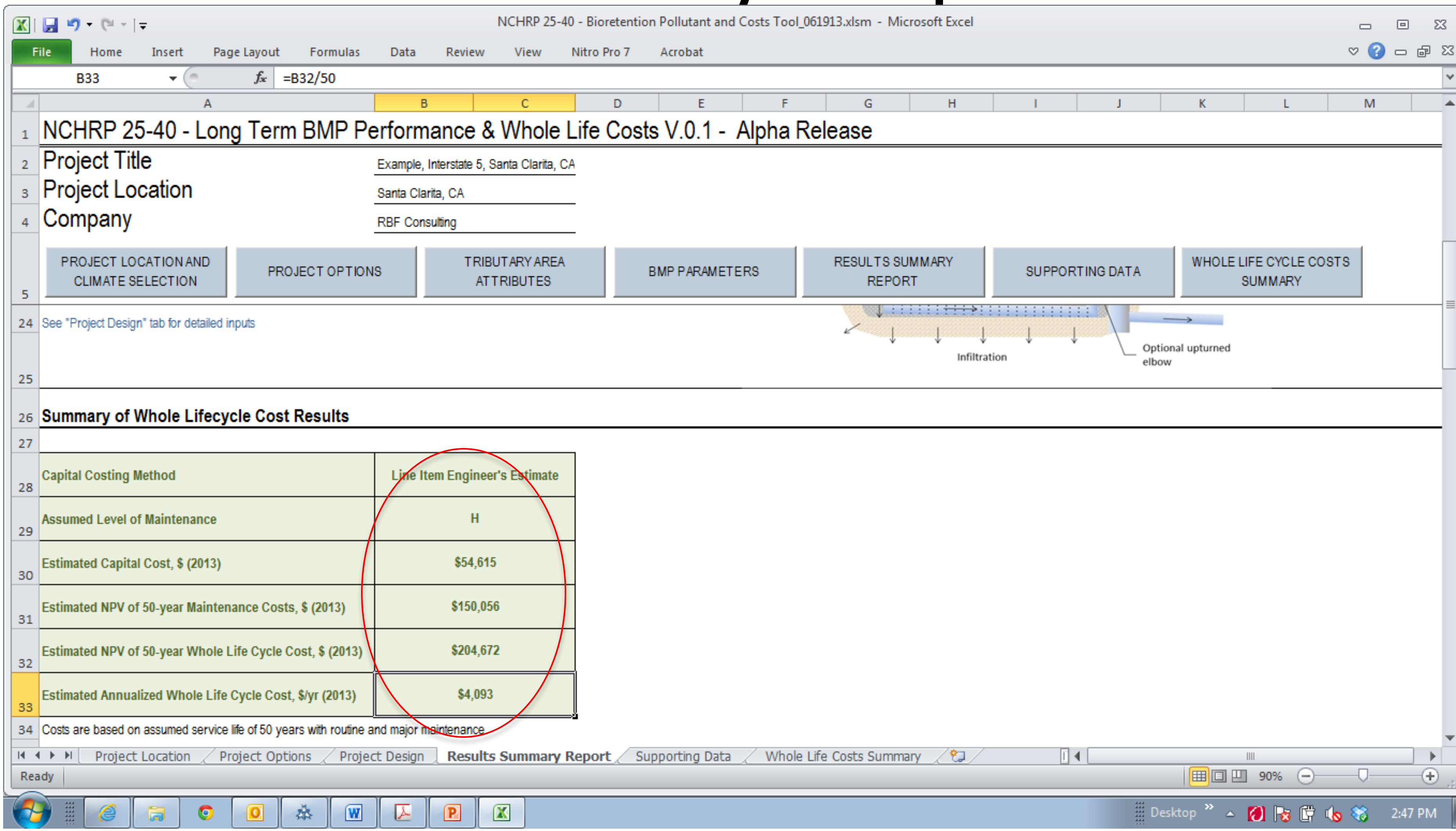
Bioretention Design



Summary Output



Summary Output



NCHRP 25-40 - Bioretention Pollutant and Costs Tool_061913.xlsm - Microsoft Excel

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Project Title	Example, Interstate 5, Santa Clarita, CA
Project Location	Santa Clarita, CA
Company	RBF Consulting

PROJECT LOCATION AND CLIMATE SELECTION | PROJECT OPTIONS | TRIBUTARY AREA ATTRIBUTES | BMP PARAMETERS | RESULTS SUMMARY REPORT | SUPPORTING DATA | WHOLE LIFE CYCLE COSTS SUMMARY

See "Project Design" tab for detailed inputs

Infiltration

Optional upturned elbow

Summary of Whole Lifecycle Cost Results

Capital Costing Method	Line Item Engineer's Estimate
Assumed Level of Maintenance	H
Estimated Capital Cost, $ (2013)	$54,615
Estimated NPV of 50-year Maintenance Costs, $ (2013)	$150,056
Estimated NPV of 50-year Whole Life Cycle Cost, $ (2013)	$204,672
Estimated Annualized Whole Life Cycle Cost, $/yr (2013)	$4,093

Costs are based on assumed service life of 50 years with routine and major maintenance

Project Location | Project Options | Project Design | Results Summary Report | Supporting Data | Whole Life Costs Summary

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Summary Output

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Summary of Volume and Pollutant Load Performance

Volume and Pollutant Load Performance	Average Annual Volume, cf/yr	Percent of Baseline Runoff Volume, %	Average Annual Pollutant Loads: Pathogens (CFU/yr)		Metals (lb/yr)			Nutrients (lb/yr)					Sediment (lb/yr)
			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]
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
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
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
Total Volume Reduction	20,200	8.8%	5E+14	3.41E+14	0.0592	0.258	0.309	1.33	2.86	4.17	0.315	0.557	190
ET Reduction	3,880	1.7%	-	-	-	-	-	-	-	-	-	-	-
Infiltration Reduction	16,300	7.1%	-	-	-	-	-	-	-	-	-	-	-
Treatment Reduction	-	-	2.64E+15	1.74E+15	0.259	1.34	1.46	0	10.1	10	0.771	0	963
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
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
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
% Annual BMP Load Reduction	-	-	56%	54%	48%	55%	50%	9%	40%	30%	30%	9%	54%

Annualized Cost Per Unit of Performance	Hydrologic Performance		Pathogens ($/10^12 CFU)		Metals ($/lb)			Nutrients ($/lb)					Sediment ($/lb)

Project Location | Project Options | Project Design | Results Summary Report | Supporting Data | Whole Life Costs Summary

Summary Output

NCHRP 25-40 - Bioretention Pollutant and Costs Tool_061913.xlsm - Microsoft Excel

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Project Title: Example, Interstate 5, Santa Clarita, C

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Summary of Average Water Quality Concentrations

Average Annual Water Quality Summary Table	Average Annual Concentration									
	Pathogens (CFU/100ml)		Metals (µg/L)			Nutrients (mg/L)					Sediment (mg/L)
	E. Coli	Fecal Coliform	Total Copper	Total Lead	Total Zinc	Nitrate [NO3]	Total Kjehldahl Nitrogen	Total Nitrogen	Dissolved Phosphorus	Total Phosphorus	Total Suspended Solids [TSS]
Influent Concentration	8740	5970	46.97	204.96	244.75	1.05	2.27	3.31	0.25	0.44	150.91
Treated Effluent Concentration	87	271	8.46	6.19	28.57	1.05	0.77	1.82	0.14	0.44	7.88
Whole Effluent Concentration*	4258	3025	27.06	101.94	132.59	1.05	1.49	2.54	0.19	0.44	76.64

* Accounting for treated effluent quality, bypass effluent quality, capture efficiency and volume reduction

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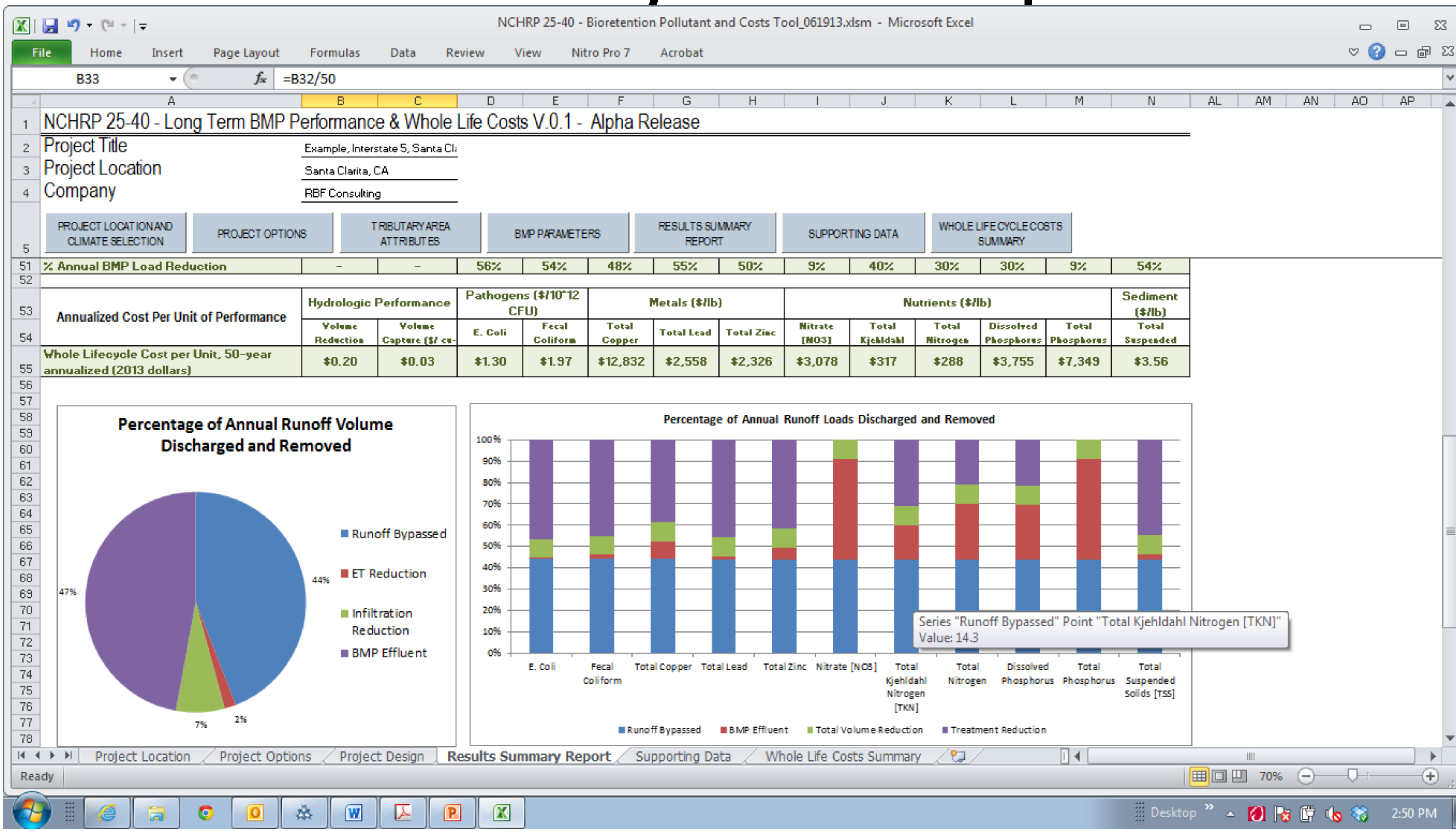
Summary Cost Output



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Annualized Cost Per Unit of Performance	Hydrologic Performance		Pathogens ($/10^12 CFU)		Metals ($/lb)			Nutrients ($/lb)					Sediment ($/lb)
	Volume Reduction	Volume Capture ($/ cu-	E. Coli	Fecal Coliform	Total Copper	Total Lead	Total Zinc	Nitrate [NO3]	Total Kjeldahl	Total Nitrogen	Dissolved Phosphorus	Total Phosphorus	Total Suspended
% Annual BMP Load Reduction	-	-	56%	54%	48%	55%	50%	9%	40%	30%	30%	9%	54%
Whole Lifecycle Cost per Unit, 50-year annualized (2013 dollars)	$0.20	$0.03	$1.30	$1.97	$12,832	$2,558	$2,326	$3,078	$317	$288	$3,755	$7,349	$3.56

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