Preliminary Stormwater Control Plan
For a Regulated Project
88 Vivian Street Project, San Rafael

Prepared Date: March 2021

Revised: January 2022

This template is to be used in conjunction with the instructions, criteria, and minimum requirements in the Bay Area Stormwater Management Agencies Association's (BASMAA's) *Post-Construction Manual*.

This Stormwater Control Plan was prepared using the template dated October 2018.

Prepared for:

Ashton 3, LLC
5 Hoya Street
Rancho Mission Viejo, California 32694
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Prepared by:

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I. Project Data

Table 1. Project Data Form

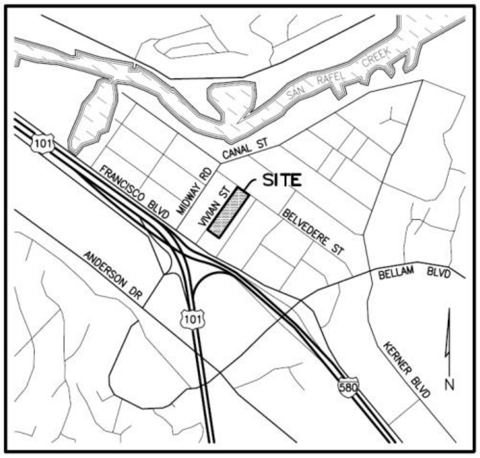
Project Name/Number	88 Vivian Street Project
Application Submittal Date	[to be verified by municipal staff]
Project Location	88 Vivian Street, San Rafael, California APN: 008-092-02
Project Phase No.	N/A
Project Type and Description	Residential with 68 dwelling units
Total Project Site Area (acres)	2.408 acres
Total New and Replaced Impervious Surface Area	2.042 acres
Total Pre-Project Impervious Surface Area	2.314 acres
Total Post-Project Impervious Surface Area	2.042 acres

II. Setting

II.A. Project Location and Description

The project consists of 68 residential dwelling units located at 88 Vivian Road, in the City of San Rafael, California. The development includes private garages, private drive aisles, sidewalks, guest parking area, and common landscaped areas. The Project site is bounded by Vivian Street to the north-westerly side, Belvedere Street to the north-easterly side, and Commercial buildings to the south-easterly and south-westerly side.

Figure 1. Vicinity Map



II.B. Existing Site Features and Conditions

The site currently contains an existing closed bowling alley building of around 37,000 square feet and associated parking lot on a single lot, APN: 008-092-02. Based on USDS Soil Map, the site in soil type urban land-xerothents complex, which slopes at 0 to 9 percent. There are no swales or other natural drainage features, and there are no storm drains on site.

II.C. Opportunities and Constraints for Stormwater Control

Disposal of runoff to deep infiltration is not feasible on this site due to the high water table and low permeability of the clay soils. Buildings adjacent to the street proposes a bio-treatment planters for roof drainage. All onsite runoffs from the site eventually mitigates to downstream catch basins with proposed bio-filtration facility - Modular Wetland System for the treatment flow. Treated runoff will be mitigate out of the site via storm drain to Belvedere Street.

Refer to separate prepared hydrology and hydraulic study for additional proposed on-site runoff outlet information.

III. Low Impact Development Design Strategies

III.A. Optimization of Site Layout

The site will be rezoned to Residential from Commercial zoning district. The street widths, sidewalks, driveways are the minimum allowable consistent with the City standards and fire district requirement to minimize impervious surfaces.

III.B. Use of Permeable Pavements

Conventional concrete and asphalt are to be used to construct the street, sidewalks, and driveways. The underlaying clay soil condition would require a deep and large quantities of excavation and off-haul for the application of permeable pavements, which is not cost-effective for the proposed project site.

III.C. Dispersal of Runoff to Pervious Areas

Runoffs to pervious areas are maximized and grading design will disperse to nearby landscaped areas wherever possible. The landscaped area will be graded to retain a volume equal to one inch of rainfall to the maximum extend. The grading will not interfere with the overall flow paths direction runoffs around the building pads and outlet to the street. Portion of the roof runoff from the building facing the public street will be routed via downspout connection with drainage pipe to the bio-filtration facility.

III.D. Stormwater Control Measures

Runoff from the street will be routed to the street gutter to enter high-flowrate treatment area through curb inlet or storm drain system routing located at the low points of the site near the entrances from Vivian Street and Belvedere Street. Buildings adjacent to the street proposes a bio-treatment planters for roof drainage. The facilities are designed to the high-flowrate type bio-filters technical criteria for non-LID in the BASMAA Post-Construction Manual to minimize facility surface area. Equivalency Analysis for the Modular Wetlands Systems are provided to comply with the MS4 Permit Requirements as attached to this report. All drainage shall be confirmed with Final Engineering Site plan and maximize dispersion of runoff to nearby landscaped areas.

IV. Documentation of Drainage Design

IV.A. Descriptions of Each Drainage Management Area

IV.A.1. Drainage Management

Table 2. Drainage Management Areas

DMA Name	Name	Surface Type	Area (square feet)
A-RF	Homesites	Roof/ Roof Drain	12,074.61
A-PA	Street	Asphalt/ Concrete	16,088.78
A-HS	Hardscape	Asphalt/ Concrete	8,021.10
A-LS	Landscape	Ornamental Landscaping	9,715.50
A-BIO	Bio-filtration	Manufacturing specification	80.00
B-RF	Homesites	Roof/ Roof Drain	14,219.29
B-PA	Street	Asphalt/ Concrete	14,879.70
B-HS	Hardscape	Asphalt/ Concrete	3,602.61
B-LS	Landscape	Ornamental Landscaping	5,788.23
B-BIO	Bio-filtration	Manufacturing specification	80.00
C-RF	Homesites	Roof/ Roof Drain	2,082.33
C-BIO	Bio-filtration	Manufacturing specification	30.00
D-RF	Homesites	Roof/ Roof Drain	4,114.34
D-BIO	Bio-filtration	Manufacturing specification	60.00
E-RF	Homesites	Roof/ Roof Drain	4,114.34
E-BIO	Bio-filtration	Manufacturing specification	60.00
F-RF	Homesites	Roof/ Roof Drain	4,114.34
F-BIO	Bio-filtration	Manufacturing specification	60.00

G-RF	Homesites	Roof/ Roof Drain	4,114.34
G-BIO	Bio-filtration	Manufacturing specification	60.00
H-RF	Homesites	Roof/ Roof Drain	1,507.33
H-BIO	Bio-filtration	Manufacturing specification	30.00

IV.A.2. Drainage Management Area Descriptions

DMA A-RF, totaling 12,074.61 square feet, drains to street to downstream catch basin with Modular Wetland System via D-vert system.

DMA A-PA, totaling 16,088.78 square feet, drains via gutters to downstream catch basin with Modular Wetland System.

DMA A-HS, totaling 8,021.10 square feet, drains to street to downstream catch basin with Modular Wetland System

DMA A-LS, totaling 9,715.50 square feet, self-retaining landscape area.to be graded slightly concave to promote runoff retention wherever possible. Area will receive runoff from nearby building roofs.

DMA A-BIO, totaling 80.00 square feet, bio-filtration system that collects low flow from catch basin and drains through D-vert system to storm drain system to mitigate to downstream drainage system. Area will receive runoff from all upstream onsite tributary areas.

DMA B-RF, totaling 14,219.29 square feet, drains to street to downstream catch basin with Modular Wetland System via D-vert system.

DMA B-PA, totaling 14,879.70 square feet, drains via gutters to downstream catch basin with Modular Wetland System.

DMA B-HS, totaling 3,602.61 square feet, drains to street to downstream catch basin with Modular Wetland System

DMA B-LS, totaling 5,788.23 square feet, self-retaining landscape area.to be graded slightly concave to promote runoff retention wherever possible. Area will receive runoff from nearby building roofs.

DMA B-BIO, totaling 80.00 square feet, bio-filtration system that collects low flow from catch basin and drains through D-vert system to storm drain system to mitigate to downstream drainage system. Area will receive runoff from all upstream onsite tributary areas.

DMA C-RF, totaling 2,082.33 square feet, drains to Fiberglass Modular Wetland System via roof drain downspout system.

DMA C-BIO, totaling 30.00 square feet, bio-filtration system that collects low flow from catch basin and drains through D-vert system to storm drain system to mitigate to downstream drainage system. Area will receive runoff from nearby building roofs.

DMA D-RF, totaling 4,114.34 square feet, drains to Fiberglass Modular Wetland System via roof drain downspout system.

DMA D-BIO, totaling 60.00 square feet, bio-filtration system that collects low flow from catch basin and drains through D-vert system to storm drain system to mitigate to downstream drainage system. Area will receive runoff from nearby building roofs.

DMA E-RF, totaling 4,114.34 square feet, drains to Fiberglass Modular Wetland System via roof drain downspout system.

DMA E-BIO, totaling 60.00 square feet, bio-filtration system that collects low flow from catch basin and drains through D-vert system to storm drain system to mitigate to downstream drainage system. Area will receive runoff from nearby building roofs.

DMA F-RF, totaling 4,114.34 square feet, drains to Fiberglass Modular Wetland System via roof drain downspout system.

DMA F-BIO, totaling 30.00 square feet, bio-filtration system that collects low flow from catch basin and drains through D-vert system to storm drain system to mitigate to downstream drainage system. Area will receive runoff from nearby building roofs.

DMA G-RF, totaling 4,114.34 square feet, drains to Fiberglass Modular Wetland System via roof drain downspout system.

DMA G-BIO, totaling 60.00 square feet, bio-filtration system that collects low flow from catch basin and drains through D-vert system to storm drain system to mitigate to downstream drainage system. Area will receive runoff from nearby building roofs.

DMA H-RF, totaling 1,507.33 square feet, drains to Fiberglass Modular Wetland System via roof drain downspout system.

DMA H-BIO, totaling 30.00 square feet, bio-filtration system that collects low flow from catch basin and drains through D-vert system to storm drain system to mitigate to downstream drainage system. Area will receive runoff from nearby building roofs.

Tabulation and Sizing Calculations

Table 3. Areas Draining to Bio-filtration Facilities

<table>
<tr><th rowspan="2">DMA Name</th><th rowspan="2">DMA Area (square feet)</th><th rowspan="2">Post-project surface type</th><th rowspan="2">DMA Runoff factor</th><th rowspan="2">DMA Area × runoff factor</th><th colspan="3">Facility Name</th></tr>
<tr><th colspan="3">MWS-L-4-15-V</th></tr>
<tr><td>DMA-A-RF</td><td>12,074.61</td><td>Roof</td><td>1</td><td>12,074.61</td><td rowspan="3">Sizing factor</td><td rowspan="3">Minimum Facility Flowrate (cfs)</td><td rowspan="3">Proposed Facility Flowrate (cfs)</td></tr>
<tr><td>DMA-A-PA</td><td>16,088.78</td><td>Asphalt/ Concrete</td><td>1</td><td>16,088.78</td></tr>
<tr><td>DMA-A-HS</td><td>8,021.10</td><td>Asphalt/ Concrete</td><td>1</td><td>8,021.10</td></tr>
<tr><td colspan="4">Total></td><td>36,184.49</td><td>0.2 in/hr</td><td>0.1675</td><td>0.175</td></tr>
</table>

Refer to Attachment for spreadsheet calculation and bio-filtration facility specifications.

<table>
<tr><th rowspan="2">DMA Name</th><th rowspan="2">DMA Area (square feet)</th><th rowspan="2">Post-project surface type</th><th rowspan="2">DMA Runoff factor</th><th rowspan="2">DMA Area × runoff factor</th><th colspan="3">Facility Name</th></tr>
<tr><th colspan="3">MWS-L-4-15-V</th></tr>
<tr><td>DMA-B-RF</td><td>14,219.29</td><td>Roof</td><td>1</td><td>14,219.29</td><td rowspan="3">Sizing factor</td><td rowspan="3">Minimum Facility Flowrate (cfs)</td><td rowspan="3">Proposed Facility Flowrate (cfs)</td></tr>
<tr><td>DMA-B-PA</td><td>14,879.70</td><td>Asphalt/ Concrete</td><td>1</td><td>14,879.70</td></tr>
<tr><td>DMA-B-HS</td><td>3,602.61</td><td>Asphalt/ Concrete</td><td>1</td><td>3,602.61</td></tr>
<tr><td colspan="4">Total></td><td>32,701.60</td><td>0.2 in/hr</td><td>0.1514</td><td>0.175</td></tr>
</table>

Refer to Attachment for spreadsheet calculation and bio-filtration facility specifications.

DMA Name	DMA Area (square feet)	Post-project surface type	DMA Runoff factor	DMA Area × runoff factor	Facility Name		
					FG-MWS-L-3-5 (2 UNITS)		
DMA-C-RF	2,082.33	Roof	1	2,082.33	Sizing factor	Minimum Facility Flowrate (cfs)	Proposed Facility Flowrate (cfs)
Total>				2,082.33	0.2 in/hr	0.0096	0.054

Refer to Attachment for spreadsheet calculation and bio-filtration facility specifications.

DMA Name	DMA Area (square feet)	Post-project surface type	DMA Runoff factor	DMA Area × runoff factor	Facility Name		
					FG-MWS-L-3-5 (4 UNITS)		
DMA-D-RF	4,114.34	Roof	1	4,114.34	Sizing factor	Minimum Facility Flowrate (cfs)	Proposed Facility Flowrate (cfs)
Total>				4,114.34	0.2 in/hr	0.0190	0.108

Refer to Attachment for spreadsheet calculation and bio-filtration facility specifications.

DMA Name	DMA Area (square feet)	Post-project surface type	DMA Runoff factor	DMA Area × runoff factor	Facility Name		
					FG-MWS-L-3-5 (4 UNITS)		
DMA-E-RF	4,114.34	Roof	1	4,114.34	Sizing factor	Minimum Facility Flowrate (cfs)	Proposed Facility Flowrate (cfs)
Total>				4,114.34	0.2 in/hr	0.0190	0.108

Refer to Attachment for spreadsheet calculation and bio-filtration facility specifications.

DMA Name	DMA Area (square feet)	Post-project surface type	DMA Runoff factor	DMA Area × runoff factor	Facility Name		
					FG-MWS-L-3-5 (4 UNITS)		
DMA-F-RF	4,114.34	Roof	1	4,114.34	Sizing factor	Minimum Facility Flowrate (cfs)	Proposed Facility Flowrate (cfs)
Total>				4,114.34	0.2 in/hr	0.0190	0.108

Refer to Attachment for spreadsheet calculation and bio-filtration facility specifications.

DMA Name	DMA Area (square feet)	Post-project surface type	DMA Runoff factor	DMA Area × runoff factor	Facility Name		
					FG-MWS-L-3-5 (4 UNITS)		
DMA-G-RF	4,114.34	Roof	1	4,114.34	Sizing factor	Minimum Facility Flowrate (cfs)	Proposed Facility Flowrate (cfs)
Total>				4,114.34	0.2 in/hr	0.0190	0.108

Refer to Attachment for spreadsheet calculation and bio-filtration facility specifications.

DMA Name	DMA Area (square feet)	Post-project surface type	DMA Runoff factor	DMA Area × runoff factor	Facility Name		
					FG-MWS-L-3-5 (2 UNITS)		
DMA-H-RF	1,507.33	Roof	1	1,507.33	Sizing factor	Minimum Facility Flowrate (cfs)	Proposed Facility Flowrate (cfs)
Total>				1,507.33	0.2 in/hr	0.0070	0.054

Refer to Attachment for spreadsheet calculation and bio-filtration facility specifications.

V. Source Control Measures

V.A. Site activities and potential sources of pollutants

On-site activities that could potentially produce stormwater pollutants include:

- On-site Storm Drain Inlets
- Landscape/ Outdoor Pesticide Use/ Building and Ground Maintenance
- Roofing, gutters, and trim
- Plazas, sidewalks, and parking lots

V.B. Source Control Table

Table 4. Pollutant Sources and Source Control Measures

Potential source of runoff pollutants	Permanent source control BMPs	Operational source control BMPs
On-site Storm Drain Inlets	Mark all inlets with the words "No Dumping! Flows to Bay" or similar	Maintain and periodically repaint or replace inlet markings. Provide stormwater pollution prevention information to new site owners, lessees, or operators. See applicable operational BMPs in Fact Sheet SC-44, "Drainage System Maintenance," in the CASQA Stormwater Quality Handbooks at www.casqa.org/resources/bmphandbooks Include the following in lease agreements: "Tenant shall not allow anyone to discharge anything to storm drains or to store or deposit materials so as to create a potential discharge to storm drains."
Landscape/ Outdoor Pesticide Use/ Building and Ground Maintenance	Preserve existing native trees, shrubs, and ground cover to the maximum extent possible. Design landscaping to minimize irrigation and runoff, to promote surface infiltration where appropriate, and to minimize the use of fertilizers and pesticides that can contribute to stormwater pollution. Where landscaped areas are used to retain or detain stormwater, specify plants that are tolerant of	Maintain landscaping using minimum or no pesticides. See applicable operational BMPs in Fact Sheet SC-41, "Building and Grounds Maintenance," in the CASQA Stormwater Quality Handbooks at www.casqa.org/resources/bmphandbooks Provide IPM information to new owners, lessees and operators.

	saturated soil conditions. Consider using pest-resistant plants, especially adjacent to hardscape. To insure successful establishment, select plants appropriate to site soils, slopes, climate, sun, wind, rain, land use, air movement, ecological consistency, and plant interactions.	
Roofing, gutters, and trim	Condensate drain lines may discharge to landscaped areas if the flow is small enough that runoff will not occur. Condensate drain lines may not discharge to the storm drain system. Rooftop equipment with potential to produce pollutants shall be roofed and/or have secondary containment.	
Plazas, sidewalks, and parking lots		Sweep plazas, sidewalks, and parking lots regularly to prevent accumulation of litter and debris. Collect debris from pressure washing to prevent entry into the storm drain system. Collect washwater containing any cleaning agent or degreaser and discharge to the sanitary sewer not to a storm drain.

VI. Stormwater Facility Maintenance

VI.A. Ownership and Responsibility for Maintenance in Perpetuity

The property is currently owned by Ashton 3, LLC. The Owner will be responsible for the long-term maintenance of the project's storm water facilities and conformance to this storm water control plan after construction is complete.

The owner is aware of the maintenance responsibilities of the proposed BMPs. A funding mechanism is in place to maintain the BMPs. Maintenance Mechanism will be assigned to a Home Owners' Association or Property Owners Association.

VI.B. Summary of Maintenance Requirements for Each Stormwater Facility

The attachment includes specific BMP detail information pertaining to operation and maintenance guidelines.

Inspections will be conducted as follows:

- Annually and prior to the start of the rainy season
- Every (1) month during rainy season
- At any other time(s) or intervals of time specified in the contract documents

Repairs and/ or maintenance procedures shall be carried out at the soonest possible time.

VII. Construction Checklist

Table 5. Construction Plan Checklist

Reference Plan Page #	Source Control or Treatment Control Measure
Exhibit	Bio-filtration facility - Modular Wetland System
Grading/ SD plan	Catch Basins, Storm Drain Pump, Storm Drain Pipe

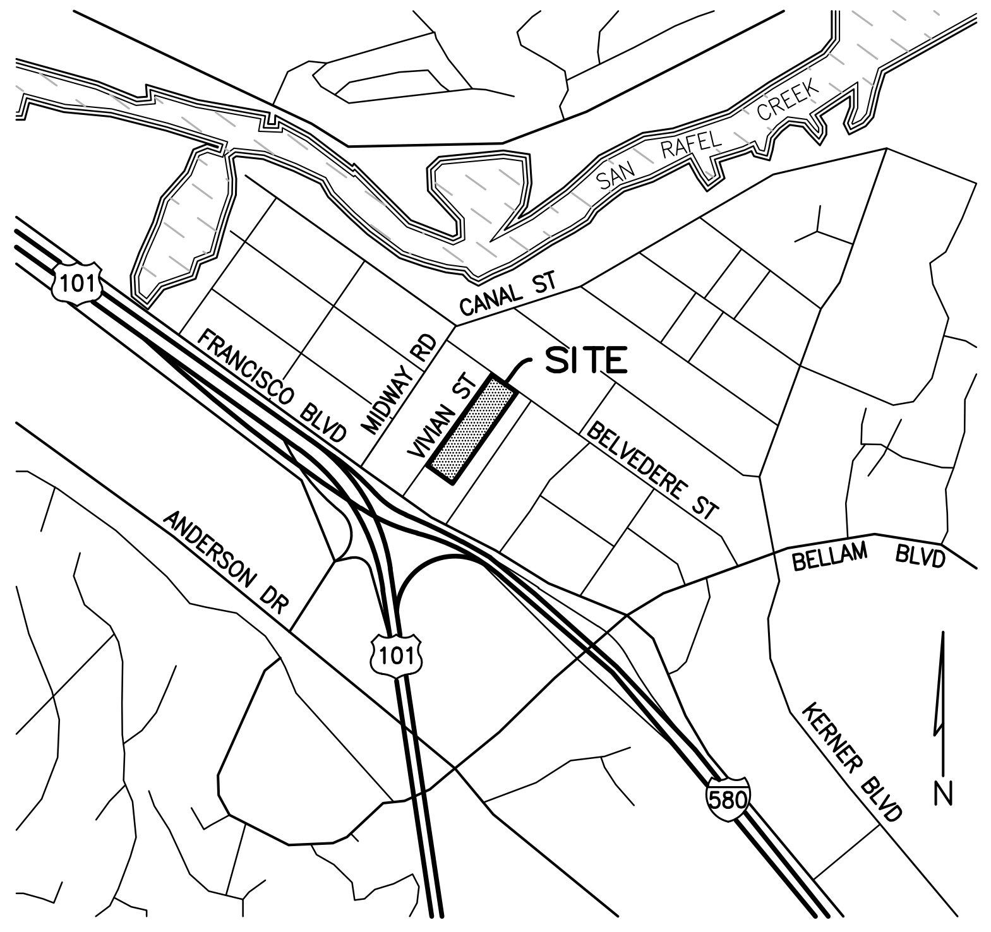
VIII. Certifications

The preliminary design of stormwater treatment facilities and other stormwater pollution control measures in this plan are in accordance with the current edition of the BASMAA *Post-Construction Manual*.

Attachments

Stormwater Control Plan Exhibit
Modular Wetland System Detail
Modular Wetland System Specification
Equivalency Analysis and Design Criteria for Modular Wetlands Systems
Modular Wetland System Maintenance Guidelines
Geotechnical Investigation

STORM WATER CONTROL PLAN EXHIBIT
88 VIVIAN STREET



PROPOSED CONDITION DMA SUMMARY										
ID	NAME	SURFACE TYPE	DMA-A (SF)	DMA-B (SF)	DMA-C (SF)	DMA-D (SF)	DMA-E (SF)	DMA-F (SF)	DMA-G (SF)	DMA-H (SF)
RF	HOMESITES	ROOF/ ROOF DRAIN TO BIO	12,074.61	14,219.29	2,082.33	4,114.34	4,114.34	4,114.34	4,114.34	1,507.33
PA	STREET	ASPHALT/CONCRETE	16,088.78	14,879.70	–	–	–	–	–	–
HS	HARDSCAPE	ASPHALT/CONCRETE	8,021.10	3,602.61	–	–	–	–	–	–
LS	LANDSCAPE	ORNAMENTAL LANDSCAPING	9,715.50	5,788.23	–	–	–	–	–	–
BIO	BIO-FILTRATION	MANUFACTURING SPECIFICATION	80.00	80.00	30.00	60.00	60.00	60.00	60.00	30.00

LEGEND:

— — —	DRAINAGE MANAGEMENT AREA (DMA) BOUNDARY
→	FLOW DIRECTION
░	PORTLAND CONCRETE CEMENT (PCC) PAVEMENT AREA
▒	ASPHALT CONCRETE (AC) PAVEMENT AREA
▨	ROOF TOP AREA
▩	BIO-FILTRATION AREA
░	LANDSCAPE

BEST MANAGEMENT PRACTICES:

SE-7	PRIVATE STREET SWEEPING
SD-10	SITE DESIGN & LANDSCAPE PLANNING
SD-11	ROOF RUNOFF CONTROLS
SD-12	EFFICIENT IRRIGATION
SD-13	STORM DRAIN SIGNAGE
BIO-1	HIGH-FLOW RATE BIO-FILTRATION AREA

SCALE: 1" = 20'

0 10 20 40

MARK	REVISIONS	APPR.	DATE

DESIGNED BY_______ DRAWN BY_______ CHECKED BY_______

CITY OF SAN RAFAEL

88 VIVIAN STREET

SHEET 1 OF 1

DWG: P:\A\AASHT-001\dwg\Sheets\EH\WQMP\EH-P-WQMP-PRELIM.dwg BY: klam Jan 17, 2022 - 2:42:30pm

PROJ: BWHX-028

ASHT-001 Stormwater Quality DMA Summary

Proposed Conditions

ID	NAME	SURFACE TYPE	DMA A (sf)	DMA B (sf)	DMA C (sf)	DMA D (sf)	DMA E (sf)	DMA F (sf)	DMA G (sf)	DMA H (sf)
RF	HOMESITES	ROOF DRAIN	12,074.61	14,219.29	2,082.33	4,114.34	4,114.34	4,114.34	4,114.34	1,507.33
PA	PAVEMENT	ASPALT/CONCRETE	16,088.78	14,879.70	-	-	-	-	-	-
HS	HARDSCAPE	ASPALT/CONCRETE	8,021.10	3,602.61	-	-	-	-	-	-
LS	LANDSCAPE	ORNAMENTAL LANDSCAPING	9,715.50	5,788.23	-	-	-	-	-	-
BIO	BIORETENTION	MANUFACTURING SPECIFICATION	80.00	80.00	30.00	60.00	60.00	60.00	60.00	30.00
		IMPERVIOUS AREA	36,184.49	32,701.60	2,082.33	4,114.34	4,114.34	4,114.34	4,114.34	1,507.33
		PERVIOUS AREA	9,795.50	5,868.23	30.00	60.00	60.00	60.00	60.00	30.00
		TOTAL	45,979.99	38,569.83	2,112.33	4,174.34	4,174.34	4,174.34	4,174.34	1,537.33

VAULT-BASED HIGH-FLOWRATE

Total Site Area:	104,896.84	sq ft.					**BIORETENTION FACILITIES**									
DMA Names	**Area**	**Self-Treating**	**Self-Retaining**	**Runoff Factor**	**Drains to Self-Retaining**	**Name of Receiving DMA**	**Facility 1**	**Facility 2**	**Facility 3**	**Facility 4**	**Facility 5**	**Facility 6**	**Facility 7**	**Facility 8**	**Facility 9**	**Facility 10**
DMA-A-RF	12,074.61			1		A-BIO	12,074.61									
DMA-A-PA	16,088.78			1		A-BIO	16,088.78									
DMA-A-HS	8,021.10			1		A-BIO	8,021.10									
DMA-A-LS	9,715.50		9,715.50													
DMA-A-BIO	80.00	80.00														
DMA-B-RF	14,219.29			1		B-BIO		14,219.29								
DMA-B-PA	14,879.70			1		B-BIO		14,879.70								
DMA-B-HS	3,602.61			1		B-BIO		3,602.61								
DMA-B-LS	5,788.23		5,788.23													
DMA-B-BIO	80.00	80.00														
DMA-C-RF	2,082.33			1		C-BIO			2,082.33							
DMA-C-BIO	30.00	30.00														
DMA-D-RF	4,114.34			1		D-BIO				4,114.34						
DMA-D-BIO	60.00	60.00														
DMA-E-RF	4,114.34			1		E-BIO					4,114.34					
DMA-E-BIO	60.00	60.00														
DMA-F-RF	4,114.34			1		F-BIO						4,114.34				
DMA-F-BIO	60.00	60.00														
DMA-G-RF	4,114.34			1		G-BIO							4,114.34			
DMA-G-BIO	60.00	60.00														
DMA-H-RF	1,507.33			1		H-BIO								1,507.33		
DMA-H-BIO	30.00	30.00														
Total DMAs (square feet)	**104,896.84**	**460.00**	**15,503.73**		**0**		**36,184.49**	**32,701.60**	**2,082.33**	**4,114.34**	**4,114.34**	**4,114.34**	**4,114.34**	**1,507.33**	**0.00**	**0.00**
						***Minimum Size (CFS)**	**0.1675**	**0.1514**	**0.0096**	**0.0190**	**0.0190**	**0.0190**	**0.0190**	**0.0070**	**0.0000**	**0.0000**
Total Facilities						**Treatment Flow**	0.175	0.175	0.054	0.108	0.108	0.108	0.108	0.054		
DMAs + Facilities	**OK**						**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**

***Required CFS is calculated with the factor of 2 in/hr per Technical Criteria for non-LID treatment facilities Document**

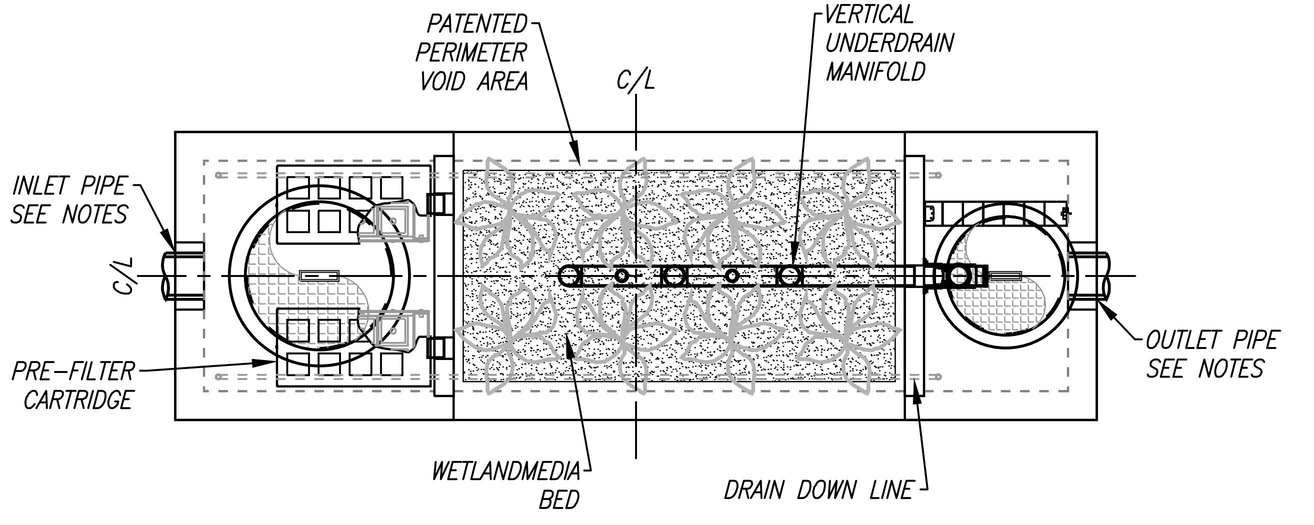
MWS LINEAR 2.0 HGL SIZING CALCULATIONS

			HGL HEIGHT																													
			SHALLOW MODELS																				STANDARD HEIGHT MODEL	HIGH CAPACITY MODELS								
MWS MODEL SIZE	WETLAND PERMITER LENGTH	LOADING RATE GPM/SF	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	**3.4**	3.5	3.6	3.65	3.70	3.75	3.80	3.85	3.90	3.95
MWS-L-4-4	6.70	1.0	0.022	0.023	0.025	0.026	0.028	0.029	0.031	0.032	0.034	0.035	0.037	0.038	0.040	0.042	0.043	0.045	0.046	0.048	0.049	0.051	**0.052**	0.054	0.055	0.056	0.057	0.058	0.058	0.059	0.060	0.061
~~**MWS-L-3-6**~~	~~10.00~~	~~1.0~~	~~0.032~~	~~0.035~~	~~0.037~~	~~0.039~~	~~0.042~~	~~0.044~~	~~0.046~~	~~0.048~~	~~0.051~~	~~0.053~~	~~0.055~~	~~0.058~~	~~0.060~~	~~0.062~~	~~0.065~~	~~0.067~~	~~0.069~~	~~0.072~~	~~0.074~~	~~0.076~~	~~**0.078**~~	~~0.081~~	~~0.083~~	~~0.084~~	~~0.085~~	~~0.087~~	~~0.088~~	~~0.089~~	~~0.090~~	~~0.091~~
MWS-L-4-6	9.30	1.0	0.030	0.032	0.034	0.036	0.038	0.041	0.043	0.045	0.047	0.049	0.051	0.053	0.055	0.058	0.060	0.062	0.064	0.066	0.068	0.070	**0.073**	0.075	0.077	0.078	0.079	0.080	0.081	0.082	0.083	0.084
MWS-L-4-8	14.80	1.0	0.048	0.051	0.054	0.058	0.061	0.065	0.068	0.071	0.075	0.078	0.082	0.085	0.088	0.092	0.095	0.099	0.102	0.105	0.109	0.112	**0.115**	0.119	0.122	0.124	0.126	0.127	0.129	0.131	0.132	0.134
MWS-L-4-13	18.40	1.0	0.059	0.063	0.068	0.072	0.076	0.080	0.084	0.089	0.093	0.097	0.101	0.106	0.110	0.114	0.118	0.122	0.127	0.131	0.135	0.139	**0.144**	0.148	0.152	0.154	0.156	0.158	0.160	0.163	0.165	0.167
MWS-L-4-15	22.40	1.0	0.072	0.077	0.082	0.087	0.093	0.098	0.103	0.108	0.113	0.118	0.123	0.129	0.134	0.139	0.144	0.149	0.154	0.159	0.165	0.170	**0.175**	0.180	0.185	0.188	0.190	0.193	0.195	0.198	0.200	0.203
MWS-L-4-17	26.40	1.0	0.085	0.091	0.097	0.103	0.109	0.115	0.121	0.127	0.133	0.139	0.145	0.151	0.158	0.164	0.170	0.176	0.182	0.188	0.194	0.200	**0.206**	0.212	0.218	0.221	0.224	0.227	0.230	0.233	0.236	0.239
MWS-L-4-19	30.40	1.0	0.098	0.105	0.112	0.119	0.126	0.133	0.140	0.147	0.153	0.160	0.167	0.174	0.181	0.188	0.195	0.202	0.209	0.216	0.223	0.230	**0.237**	0.244	0.251	0.255	0.258	0.262	0.265	0.269	0.272	0.276
MWS-L-4-21	34.40	1.0	0.111	0.118	0.126	0.134	0.142	0.150	0.158	0.166	0.174	0.182	0.189	0.197	0.205	0.213	0.221	0.229	0.237	0.245	0.253	0.261	**0.268**	0.276	0.284	0.288	0.292	0.296	0.300	0.304	0.308	0.312
MWS-L-6-8	18.80	1.0	0.060	0.065	0.069	0.073	0.078	0.082	0.086	0.091	0.095	0.099	0.104	0.108	0.112	0.116	0.121	0.125	0.129	0.134	0.138	0.142	**0.147**	0.151	0.155	0.157	0.160	0.162	0.164	0.166	0.168	0.170
MWS-L-8-8	29.60	1.0	0.095	0.102	0.109	0.115	0.122	0.129	0.136	0.143	0.149	0.156	0.163	0.170	0.177	0.183	0.190	0.197	0.204	0.211	0.217	0.224	**0.231**	0.238	0.245	0.248	0.251	0.255	0.258	0.262	0.265	0.268
MWS-L-8-12	44.40	1.0	0.143	0.153	0.163	0.173	0.183	0.194	0.204	0.214	0.224	0.234	0.245	0.255	0.265	0.275	0.285	0.296	0.306	0.316	0.326	0.336	**0.346**	0.357	0.367	0.372	0.377	0.382	0.387	0.392	0.397	0.402
MWS-L-8-16	59.20	1.0	0.190	0.204	0.217	0.231	0.245	0.258	0.272	0.285	0.299	0.312	0.326	0.340	0.353	0.367	0.380	0.394	0.408	0.421	0.435	0.448	**0.462**	0.476	0.489	0.496	0.503	0.509	0.516	0.523	0.530	0.537
MWS-L-8-20	74.00	1.0	0.238	0.255	0.272	0.289	0.306	0.323	0.340	0.357	0.374	0.391	0.408	0.425	0.442	0.459	0.476	0.493	0.509	0.526	0.543	0.560	**0.577**	0.594	0.611	0.620	0.628	0.637	0.645	0.654	0.662	0.671
MWS-L-10-20 or MWS-L-8-24	88.80	1.0	0.285	0.306	0.326	0.346	0.367	0.387	0.408	0.428	0.448	0.469	0.489	0.509	0.530	0.550	0.571	0.591	0.611	0.632	0.652	0.673	**0.693**	0.713	0.734	0.744	0.754	0.764	0.774	0.785	0.795	0.805
4'x'4 media cage	14.80	1.0	0.048	0.051	0.054	0.058	0.061	0.065	0.068	0.071	0.075	0.078	0.082	0.085	0.088	0.092	0.095	0.099	0.102	0.105	0.109	0.112	**0.115**	0.119	0.122	0.124						

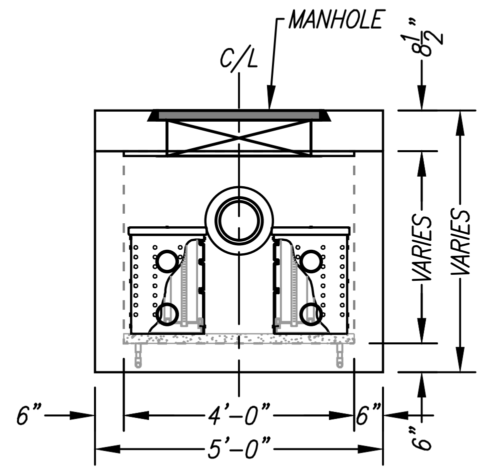
SITE SPECIFIC DATA

PROJECT NUMBER	ASHT-001		
PROJECT NAME	88 VIVIAN STREET		
PROJECT LOCATION	CITY OF SAN RAFAEL		
STRUCTURE ID	DMA-A		
TREATMENT REQUIRED			
VOLUME BASED (CF)	FLOW BASED (CFS)		
N/A	0.175		
PEAK BYPASS REQUIRED (CFS) – IF APPLICABLE	OFFLINE		
PIPE DATA	I.E.	MATERIAL	DIAMETER
INLET PIPE 1			
INLET PIPE 2	N/A	N/A	N/A
OUTLET PIPE			
	PRETREATMENT	BIOFILTRATION	DISCHARGE
RIM ELEVATION			
SURFACE LOAD	PEDESTRIAN		
FRAME & COVER	ø30"	OPEN PLANTER	ø24"
NOTES:			

* PRELIMINARY NOT FOR CONSTRUCTION



PLAN VIEW



LEFT END VIEW

INSTALLATION NOTES

1. CONTRACTOR TO PROVIDE ALL LABOR, EQUIPMENT, MATERIALS AND INCIDENTALS REQUIRED TO OFFLOAD AND INSTALL THE SYSTEM AND APPURTENANCES IN ACCORDANCE WITH THIS DRAWING AND THE MANUFACTURERS SPECIFICATIONS, UNLESS OTHERWISE STATED IN MANUFACTURERS CONTRACT.
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5. CONTRACTOR RESPONSIBLE FOR INSTALLATION OF ALL RISERS, MANHOLES, AND HATCHES. CONTRACTOR TO GROUT ALL MANHOLES AND HATCHES TO MATCH FINISHED SURFACE UNLESS SPECIFIED OTHERWISE.
6. VEGETATION SUPPLIED AND INSTALLED BY OTHERS. ALL UNITS WITH VEGETATION MUST HAVE DRIP OR SPRAY IRRIGATION SUPPLIED AND INSTALLED BY OTHERS.
7. CONTRACTOR RESPONSIBLE FOR CONTACTING BIO CLEAN FOR ACTIVATION OF UNIT. MANUFACTURERS WARRANTY IS VOID WITH OUT PROPER ACTIVATION BY A BIO CLEAN REPRESENTATIVE.

GENERAL NOTES

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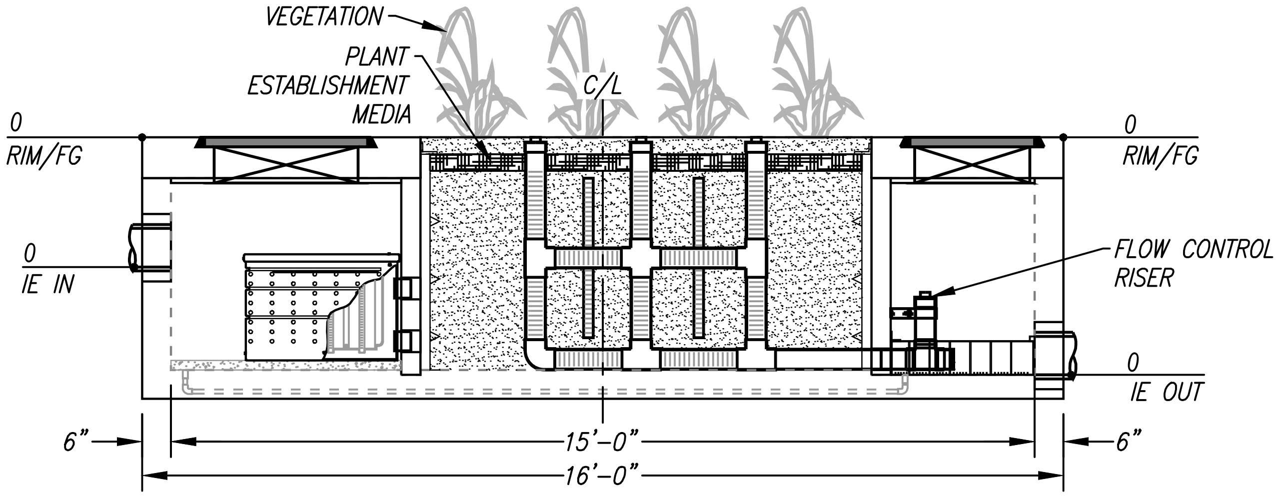
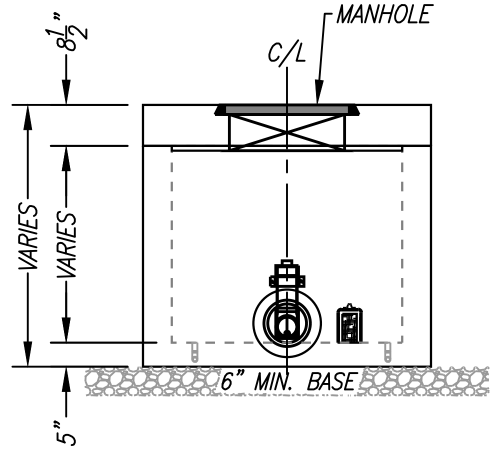


ELEVATION VIEW



RIGHT END VIEW

TREATMENT FLOW (CFS)	0.175
OPERATING HEAD (FT)	3.4
PRETREATMENT LOADING RATE (GPM/SF)	1.5
WETLAND MEDIA LOADING RATE (GPM/SF)	1.0

MODULAR WETLANDS

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PROPRIETARY AND CONFIDENTIAL:

Bio Clean
A Forterra Company

MWS-L-4-15-V
STORMWATER BIOFILTRATION SYSTEM
STANDARD DETAIL

5/23/19TOLEE

<table>
<tr><th colspan="4">SITE SPECIFIC DATA</th></tr>
<tr><td colspan="2">PROJECT NUMBER</td><td colspan="2">ASHT-001</td></tr>
<tr><td colspan="2">PROJECT NAME</td><td colspan="2">88 VIVIAN STREET</td></tr>
<tr><td colspan="2">PROJECT LOCATION</td><td colspan="2">CITY OF SAN RAFAEL</td></tr>
<tr><td colspan="2">STRUCTURE ID</td><td colspan="2">DMA-B</td></tr>
<tr><td colspan="4">TREATMENT REQUIRED</td></tr>
<tr><td colspan="2">VOLUME BASED (CF)</td><td colspan="2">FLOW BASED (CFS)</td></tr>
<tr><td colspan="2">N/A</td><td colspan="2">0.175</td></tr>
<tr><td colspan="3">PEAK BYPASS REQUIRED (CFS) – IF APPLICABLE</td><td>OFFLINE</td></tr>
<tr><td>PIPE DATA</td><td>I.E.</td><td>MATERIAL</td><td>DIAMETER</td></tr>
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<tr><td>INLET PIPE 2</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
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<tr><td>RIM ELEVATION</td><td colspan="3"></td></tr>
<tr><td>SURFACE LOAD</td><td colspan="3">PEDESTRIAN</td></tr>
<tr><td>FRAME & COVER</td><td>ø30"</td><td>OPEN PLANTER</td><td>ø24"</td></tr>
<tr><td colspan="4">NOTES:</td></tr>
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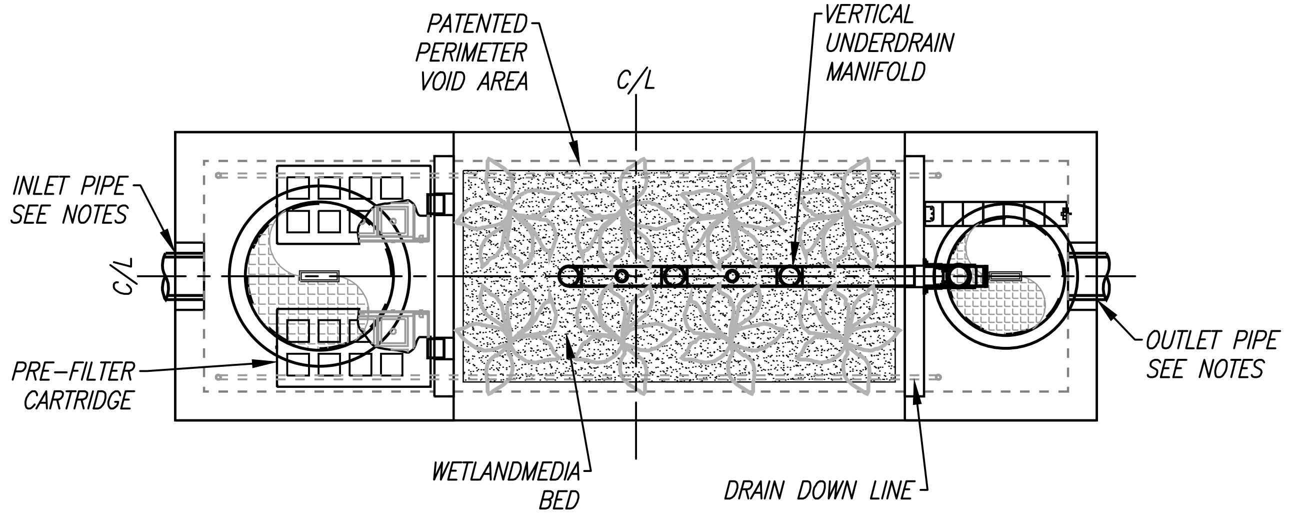
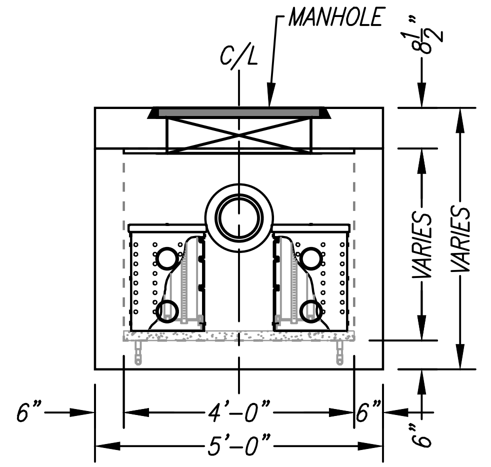


PLAN VIEW



LEFT END VIEW

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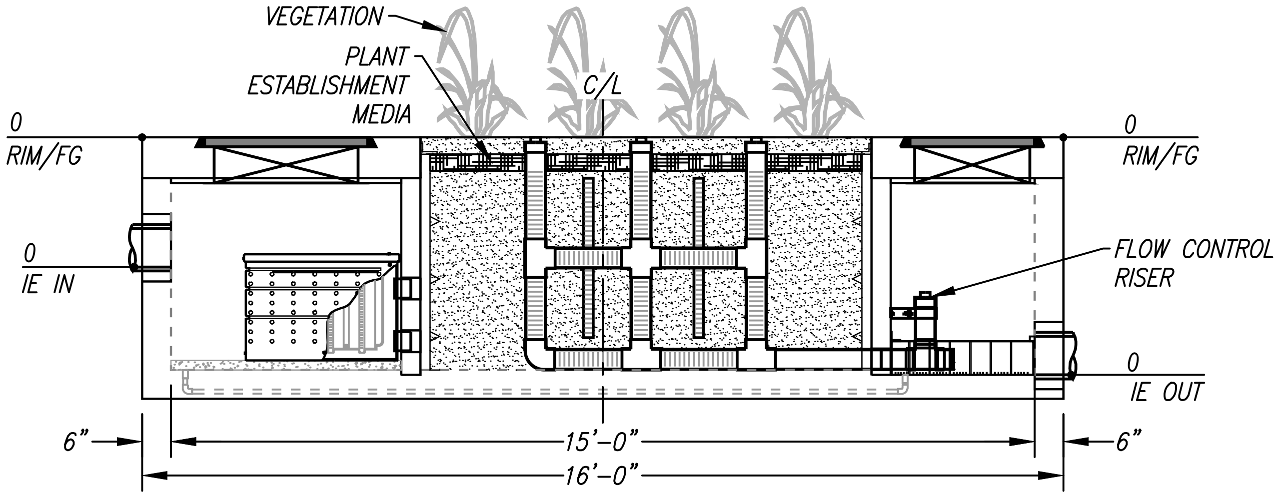
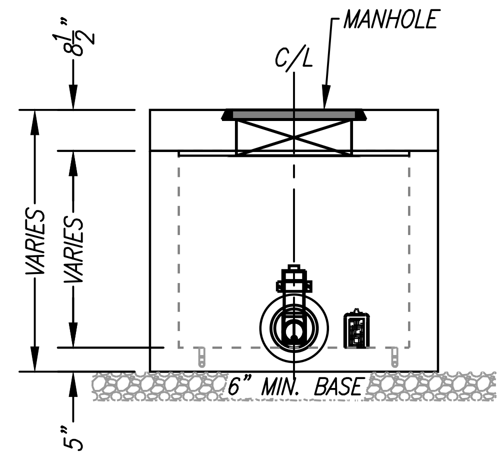


ELEVATION VIEW



RIGHT END VIEW

TREATMENT FLOW (CFS)	0.175
OPERATING HEAD (FT)	3.4
PRETREATMENT LOADING RATE (GPM/SF)	1.5
WETLAND MEDIA LOADING RATE (GPM/SF)	1.0

GENERAL NOTES

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5/23/19TOLFE

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PROPRIETARY AND CONFIDENTIAL:

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Bio Clean
A Forterra Company

MWS-L-4-15-V
STORMWATER BIOFILTRATION SYSTEM
STANDARD DETAIL

SITE SPECIFIC DATA

PROJECT NUMBER	
PROJECT NAME	
PROJECT LOCATION	
STRUCTURE ID	
TREATMENT REQUIRED	
TREATMENT FLOW (CFS)	
NOTES:	

	FG-MWS-L-3-5-2	FG-MWS-L-3-5-3
TREATMENT FLOW (CFS)	0.027	0.044
VAULT HEIGHT (FT)	2.0	3.0
MAX OPERATING HEAD (FT)	1.5	2.5
WETLAND MEDIA VOLUME (CY)	0.64	0.91
WETLAND MEDIA LOADING RATE (GPM/SF)	1.0	1.0
ORIFICE SIZE (DIA. INCHES)	0.91	1.02

INSTALLATION NOTES

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3. CONTRACTOR TO SUPPLY AND INSTALL ALL EXTERNAL CONNECTING PIPES.
4. DRIP OR SPRAY IRRIGATION REQUIRED ON ALL UNITS WITH VEGETATION.

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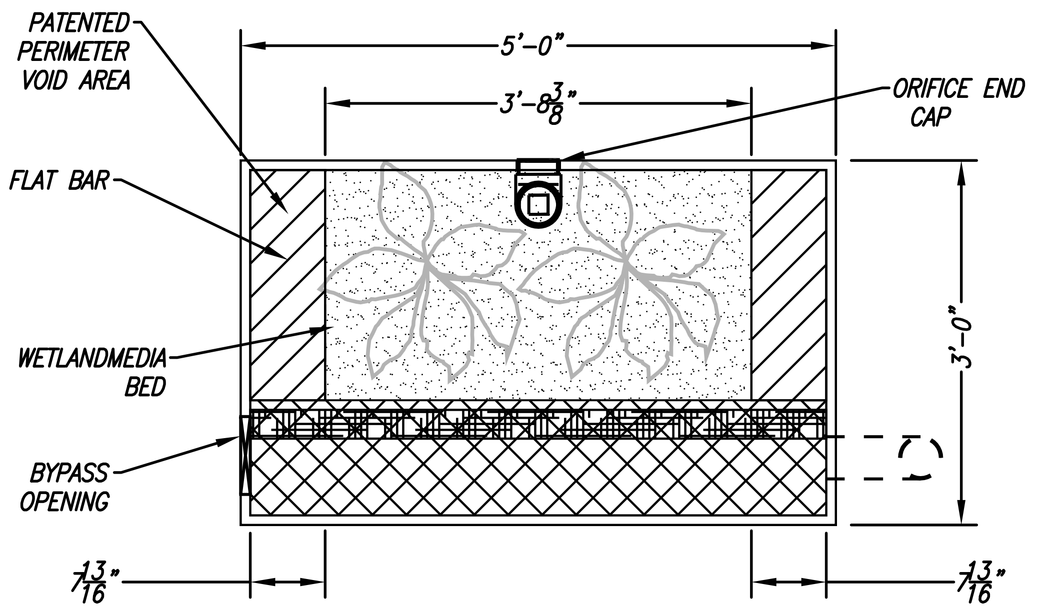
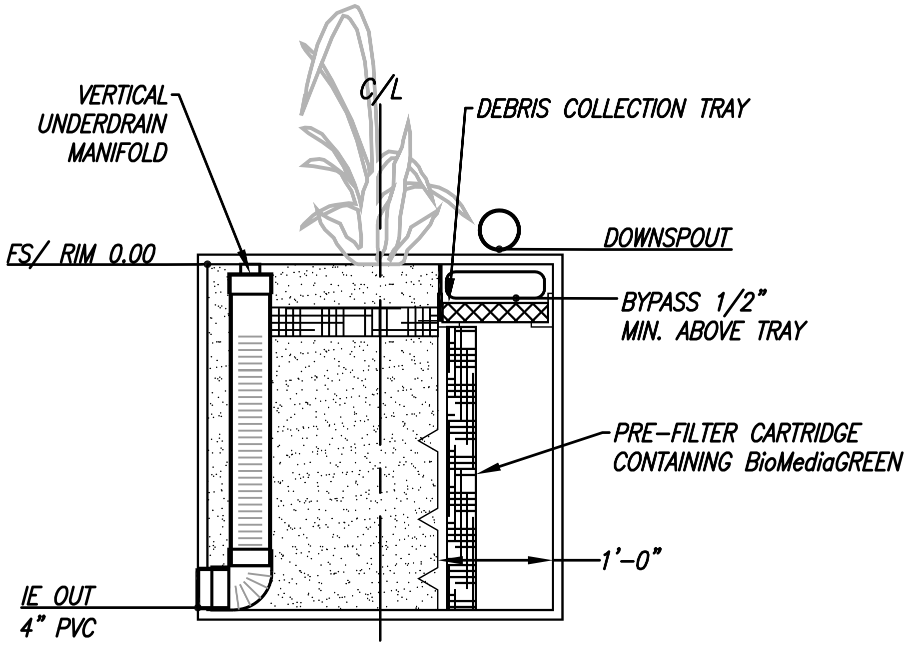
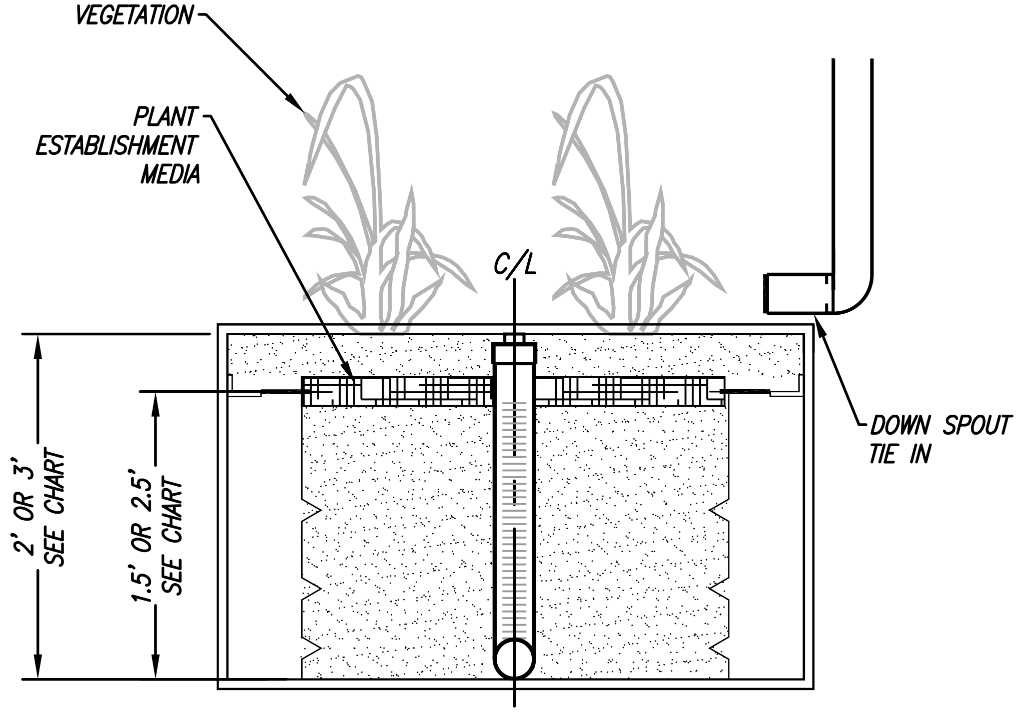


PLAN VIEW



LEFT END VIEW

BIOFILTRATION



ELEVATION VIEW

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Bio Clean
A Forterra Company

FIBERGLASS MWS LINEAR
STORMWATER BIOFILTRATION SYSTEM
FG-MWS-L-3-5

4/23/19SSERTICH

SPECIFICATIONS

MWS – Linear

Hybrid Stormwater Filtration System

MODULAR WETLANDS™

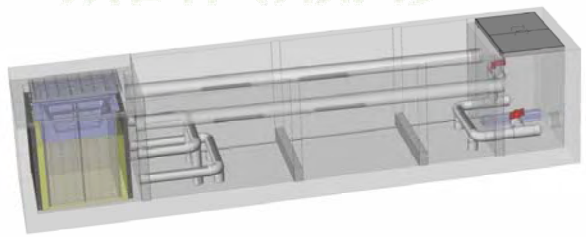
Modular Wetland Systems, Inc.
P.O. Box 869
Oceanside, CA 92049

www.modularwetlands.com
P 760-433-7640
F 760-433-3179

MWS – Linear

Hybrid Stormwater Filtration System

MODULAR WETLANDS



Save valuable space with small footprint for urban sites.

Improve BMP aesthetics with attractive native and tropical landscape plants.

Reduce lifetime costs with safer and less expensive maintenance

“The MWS – Linear hybrid stormwater treatment system is described as a self contained treatment train. This system utilizes an innovative combination of I treatment processes. Stormwater runoff flows into the system via pipe or curb/grate type catch basin opening. Polluted runoff first encounters a screening device to remove larger pollutants and then enters a hydrodynamic separation chamber which settles out the sediments and larger suspended solids. Next the runoff is treated by a revolutionary filter media, BioMediaGREEN that removes fines and associated pollutants, including bacteria. From there runoff enters of bioretention filter in the form of a subsurface flow vegetated gravel wetland. Within the wetland physical, chemical, and biological mechanisms remove the remaining particulate and dissolved pollutants. The purified runoff leaves the system via the discharge chamber. In the discharge chamber the rate of discharge is controlled by valves set to a desired rate”.

Tested Pollutant Removal Efficiencies:

TSS Removal	Dissolved Lead Removal	Dissolved Copper Removal	TPH	E. coli Removal	Turbidity Removal
98%	81%	92%	99%	60.2%	92%

“Nature and Harmony Working Together in Perfect Harmony”

SPECIFICATIONS – MWS- LINEAR

Track Record: The MWS- Linear Hybrid Stormwater Treatment System is manufactured by a company whom is regularly engaged in the engineering design and production of treatment systems for stormwater.

Coverage: The MWS- Linear is designed to treat the water quality volume or water quality flow. For flow based design, high flow bypass is internal, for volume based design, high flow bypass is external and prior to pre-detention system. For offline volume based designs the MWS - Linear has the ability to treat the entire water quality volume when used with pre-storage and properly sized.

Non-Corrosive Materials: The MWS – Linear is designed with non-corrosive materials. All internal piping is SD35 PVC. Catch basin filter components, including mounting hardware, fasteners, support brackets, filtration material, and support frame are constructed of non-corrosive materials (316 stainless steel, and UV protected/marine grade fiberglass). Fasteners are stainless steel. Primary filter mesh is 316 stainless steel welded screens. Filtration basket screens for coarse, medium and fine filtration is ¾" x 1 ¾"expanded, 10 x 10 mesh, and 35 x 35 mesh, respectively. No polypropylene, monofilament netting or fabrics shall be used in this system. Media Protective Panels are constructed of UV protected/marine grade fiberglass. Mounts are constructed of stainless steel. BioMediaGREEN is an inert rock substrate and is non-corrosive. Perimeter filter structure is constructed of lightweight injection molded plastic. Mounting brackets are constructed of SD40 PVC and are mounted with 3/8" diameter stainless steel redheads. Drain down filter cover is constructed of UV protected/marine grade fiberglass and stainless steel hinge and mount.

Weight: Each complete unit weighs approximately 29,000 to 40,000 pounds and requires a boom crane to install. Details of this are provided in the installation section of the MWS-Linear Design Kit.

Transportation: The Modular Wetland System – Linear is designed to be transported on a standard flat bed truck. The unit easily fits on a flat bed truck without the need of special permitting.

Alternative Technology Configurations: The Modular Wetland System – Linear is modular is design. Each module will be up to 22 feet long and 5 feet wide. The system can be made in lengths varying from 13 to 100s of feet long. For lengths longer than 22 feet the system will shipped in modules and assembled on site. The Modular Wetland System – Linear has many alternative configurations. This allows the system to be adapted to many site conditions. Runoff can enter the system through a pipe, and/or a built in curb or grate type opening.

Energy Requirements: The Modular Wetland System – Linear is completely passive and requires no external energy sources.

Buoyancy Issues: Buoyancy is only a an issue when ground water levels rise above the bottom of the Modular Wetland System – Linear's concrete structure. With 8.5 cubic yards of wetland media there is no concern of floatation. As a precaution a footing can also be built into the systems concrete structure.

Durability: The structure of the box will be precast concrete. The concrete will be 28 day compressive strength fc = 5,000 psi. Steel reinforcing will be ASTM A – C857. Structure will support an H20 loading as indicted by AASHTO. The joint between the concrete sections will ship lap and joint sealed with ram-nek. Filter (excluding oil absorbent media) and support structures are of proven durability. The filter and mounting structures are of sufficient strength to support water, sediment, and debris loads when the filter is full, with no slippage, breaking, or tearing. All filters are warranted for a minimum of five (5) years.

Oil Absorbent Media: The MWS – Linear utilizes both physical and biological mechanisms to capture and filter oil and grease. A skimmer and boom system will be positioned on the internal perimeter of the catch basin insert. The primary filtration media, BioMediaGreen, utilized in the perimeter and drain down filters, has excellent hydrocarbon removal abilities. Within the wetland filter biological processes capture and break down oil and grease. Much of the breakdown and transformation of oil and grease is performed by natural occurring bacteria.

Overflow Protection: The grate and curb type MWS – Linear are designed with an internal bypass consisting of two SD PVC pipes which direct high flows around the perimeter and wetland filter, directly into the discharge chamber. For the volume based vault type configuration, bypass should be located prior to the pre-detention system. For peak flows that exceed internal bypass capacity, external bypass is use.

Filter Bypass: Runoff will bypass filtration (BioMediaGREEN and wetland filter) components of the MWS - Linear. The system will still provide screening and settling during higher flow rates for internally bypassed flows. External bypass will bypass of treatment processes.

Pollutant Removal Efficiency: The MWS - Linear is capable of removing over 90% of the net annual total suspended solids (TSS) load based on a 20-micron particle size. Annual TSS removal efficiency models are based on documented removal efficiency performance from full-scale laboratory tests on BioMediaGreen and quarter-scale laboratory tests on the MWS – Linear flow based system.

POLLUTANT	REMOVAL EFFICIENCY
Trash & Litter	99%
TPH (mg/L)	99%
TSS (mg/L)	98%
E. Coli (MPN/100ml)	60%
Turbidity (NTU)	92%
Dissolved Metals (mg/L)	76%

Sil-Co-Sil 106. Mean particle diameter = 19 microns

Non-Scouring: During heavy storm events the runoff bypasses perimeter and wetland filter components. The system will not re-suspend solids at design flows.

Uniqueness: The Modular Wetland System – Linear is a complete self contained treatment train that incorporates capture, screening, sedimentation, filtration, bioretention, high flow bypass, and flow control into a single modular structure. This system provides four stages of treatment making it the only 4 stage treatment train stormwater filtration system, therefore making it unique to the industry. Other systems do not incorporate all the necessary attributes to make it a complete stormwater management device as with the Modular Wetland System – Linear. Therefore, no equal exists for this system.

Pretreatment & Preconditioning: Since the Modular Wetland System – Linear is a complete capture and treatment train stormwater management system no external pretreatment of preconditioning is necessary.

SPECIFICATIONS – BioMediaGREEN

BioMediaGREEN is a proprietary engineered filter media. Made of a unique combination of the inert naturally occurring material this product is non-combustible and do not pose a fire hazard, stable and non-reactive, and is also biodegradable. It is stable with no known adverse environmental effects.

This product has been tested in long-term carcinogenicity studies [inhalation and intraperitoneal injection (i.p.)] with no significant increase in lung tumors or abdominal tumors. Short-term biopersistent (inhalation and intra-tracheal injection) studies have shown that the products disappear very rapidly from the lung.

In October 2001, IARC classified this product as Group 3, "not classifiable as to its carcinogenicity to humans". The 2001 decision was based on the latest epidemiological studies and animal inhalation studies that show no relation between inhalation exposure and the development of tumors.

The product can typically be disposed of in an ordinary landfill (local regulations may apply). If you are unsure of the regulations, contact your local Public Health Department or the local office of the Environmental Protection Agency (EPA).

Coverage: When properly installed BioMediaGREEN Filter Blocks provide sufficient contact time, at rated flows, of passing contaminate water. The BioMediaGREEN material will capture and retain most pollutants that pass through it. The BioMediaGREEN material is made of a proprietary blend of inert substances. The BioMediaGREEN Filter Blocks can be used in different treatment devices, including but not limited to flume filters, trench drain filters, downspout filters, catch basin inserts, water polishing units, and hydrodynamic separators.

Non-Corrosive Materials: The BioMediaGreen material is made of non-corrosive materials.

Durability: The BioMediaGREEN material has been chosen for its proven durability, with an expected life of 2 plus years. The BioMediaGREEN material is of sufficient strength to support water, sediment, and debris loads when the media is at maximum flow; with no slippage, breaking, or tearing. The BioMediaGREEN material has been tested through rigorous flow and loading conditions.

Oil Absorbent Media: The BioMediaGREEN material has been proven to capture and retain hydrocarbons.

Pollutant Removal Efficiency: The BioMediaGREEN Filter Blocks are designed to capture high levels of Hydrocarbons including but not limited to oils & grease, gasoline, diesel, and PAHs. BioMediaGREEN Filter Blocks have the physical ability to block and filter trash and litter, grass and foliage, sediments, TSS, particulate and dissolved metals, nutrients, and bacteria.

BioMediaGREEN technology is based on a proprietary blend of synthetic inert natural substances aimed at removal of various stormwater pollutants. BioMediaGREEN was created to have a very porous structure capable of selectively removing pollutants while allowing high flow through rates for water. As pollutants are captured by its structure, BioMediaGREEN captures most pollutants and maintains porosity and filtering capabilities.

Field and laboratory tests have confirmed the BioMediaGREEN capability to capture large percentage of TSS, hydrocarbons, nutrients, and heavy metals. Microbial reduction efficiency will vary depending on colony size, flow rates and site specific conditions.

POLLUTANT	REMOVAL EFFICIENCY
Oil & Grease (mg/L)	90%
TPH (mg/L)	99%
TSS (mg/L)	85%
Turbidity (NTU)	99%
Total Phosphorus (mg/L)	69.6%
Dissolved Metals (mg/L)	75.6%

Sil-Co-Sil 106. Mean particle diameter = 19 microns

Replacement: Removal and replacement of the blocks is simple. Remove blocks from filtration system. Replace with new block of equal size.

Bio Clean

A Forterra Company

Fiberglass MWS Linear For Downspout Applications

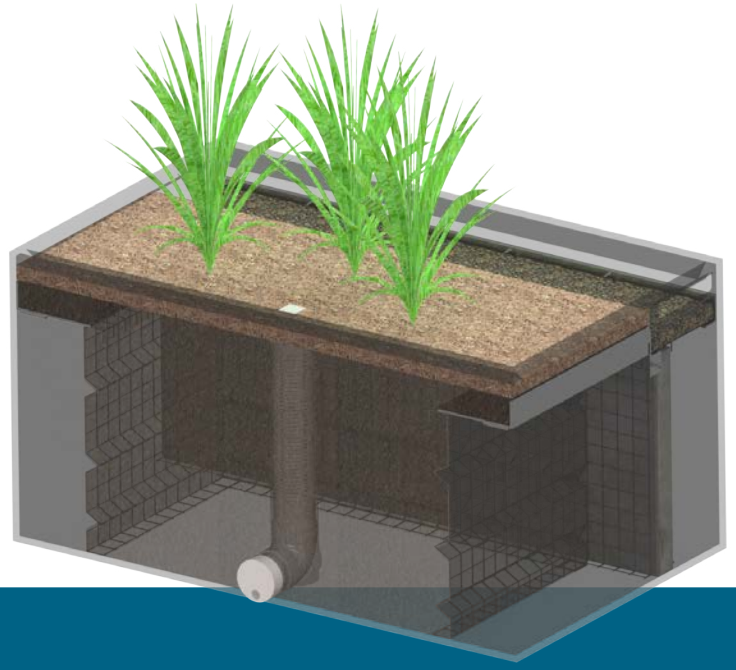
A Stormwater Biofiltration Solution

OVERVIEW

The Bio Clean Fiberglass MWS Linear™ is an adaptation of our flagship MWS Linear and is designed to be used specifically as an above-ground planter box for the treatment of roof runoff.

The system is lightweight, available in various sizes, and easy to install without the use of any heavy equipment. All models are available with high flow bypass.

The Fiberglass MWS Linear offers pretreatment to collect leaves and debris for easy removal. The advanced biofiltration chamber offers maximum treatment capacity in a minimal footprint, making it an excellent choice for industrial sites looking to meet permit benchmarks for various pollutants, including dissolved metals.



PERFORMANCE

86% REMOVAL OF DISSOLVED ZINC	65% REMOVAL OF DISSOLVED COPPER	85% REMOVAL OF TSS
64% REMOVAL OF TOTAL PHOSPHORUS	45% REMOVAL OF TOTAL KJELDAHL NITROGEN	• PROVEN IN THE FIELD TO REDUCE POLLUTANT CONCENTRATIONS BELOW INDUSTRIAL BENCHMARKS

ADVANTAGES

- LIGHTWEIGHT AND DURABLE FIBERGLASS CONSTRUCTION
- HIGH FLOW RATES AND MAXIMUM SURFACE AREA
- PROVEN POLLUTANT REMOVAL FOR TSS, BACTERIA, METALS, AND NUTRIENTS
- 8-YEAR WARRANTY
- CUSTOM SIZES AVAILABLE
- FITS IN SHALLOW CATCH BASINS
- MEETS LEED REQUIREMENTS
- EASILY RETROFITTED TO TREAT EXISTING BUILDING ROOF RUNOFF
- AVAILABLE IN VARIOUS TEXTURES AND COLORS
- CAN BE CONFIGURED FOR INFLOW PIPING, ALLOWING IT TO BE PUMPED TO
- NO NETS OR GEOFABRICS
- 15+ YEARS USER LIFE
- NO REPLACEMENT COSTS AS FOUND WITH FABRIC FILTERS

OPERATION

Half-Cut View

1. Trash and debris are separated (for easy removal) before entering the sediment storage chamber.
2. Runoff passes through the debris collection tray and enters the sediment storage chamber to capture TSS.
3. As water builds in the sediment storage chamber, it processes through the system's pre-filter cartridge containing BioMediaGREEN and patented horizontal flow biofiltration bed to remove dissolved and particulate metals and nutrients among other pollutants of concern.

SPECIFICATIONS

MODEL #	MODEL HEIGHT (ft.)	TREATMENT FLOW RATE (cfs)
FG-MWS-L-3-5	2.0	0.027
	3.0	0.044
FG-MWS-L-6-6	2.5	0.080
	3.5	0.120

INSTALLATION

All models are delivered fully assembled and can be installed in less than 15 minutes.

Once the unit is set in place, it is ready for operation.

MAINTENANCE

The debris collection tray allows for fast and easy maintenance. The sediment storage chamber is easily accessible for removal of accumulated material.

Bio Clean
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EQUIVALENCY ANALYSIS AND DESIGN CRITERIA for MODULAR WETLANDS SYSTEMS (MWS LINEAR)

Pursuant to:

Los Angeles County MS4 Permit (Order R4-2012-0175)

Prepared for

Bio Clean, a Forterra Company

Prepared by

Geosyntec consultants

engineers | scientists | innovators

621 SW Morrison Street, Suite 600
Portland, Oregon 97205

July 2018

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1 INTRODUCTION

The Los Angeles County MS4 Permit (Order No. R4-2012-0175) (MS4 Permit) requires that new development and redevelopment projects infiltrate 100 percent of the Stormwater Quality Design volume (SWQDv) on-site as the preferred approach unless technical infeasibility or alternative approaches apply (Provision 7.c). When it is not technically feasible to fully infiltrate the SWQDv, the MS4 Permit allows for on-site biofiltration to be used if it meets the specific criteria in Attachment H of the MS4 Permit. The MS4 Permit also allows for Los Angeles County Regional Water Quality Control Board (Regional Board) Executive Officer to approve alternate biofiltration design criteria.

The purpose of this report is to develop a design basis for Modular Wetland Systems Linear (MWS Linear) such that these systems will provide equivalent performance to biofiltration BMPs as defined in Attachment H of the MS4 Permit. This report is intended to serve as technical support for requests to the Executive Officer of the Regional Board for approval of alternative design criteria for MWS Linear systems. This report describes the basis for evaluating equivalency, details the design approach and equivalency criteria for MWS Linear systems to achieve equivalent performance to conventional biofiltration, and provides the supporting rationales for these equivalency criteria.

The remainder of this report is organized as follows:

2 BMP DESCRIPTIONS

2.1 Conventional Biofiltration

Biofiltration (also known as bioretention with underdrain) consists of shallow landscaped depressions that capture and filter stormwater runoff through engineered media. These facilities function as soil and plant-based filtration systems that remove pollutants through a variety of physical, biological, and chemical treatment processes. Biofiltration facilities normally consist of a ponding area, mulch layer, soils, and plantings (Figure 1). An optional gravel layer added below the planting soil coupled with an upturned elbow (or similar hydraulic control approach) can provide additional storage volume for infiltration. As stormwater passes through the planting soil pollutants are filtered, adsorbed, and biodegraded by the soil media, microorganisms living in the soil and optional gravel layer, and plants. Conventional biofiltration is typically designed as a “volume-based” BMP, meaning that is it sized based on capture of the runoff from a specific size of storm event (the SWQDv).

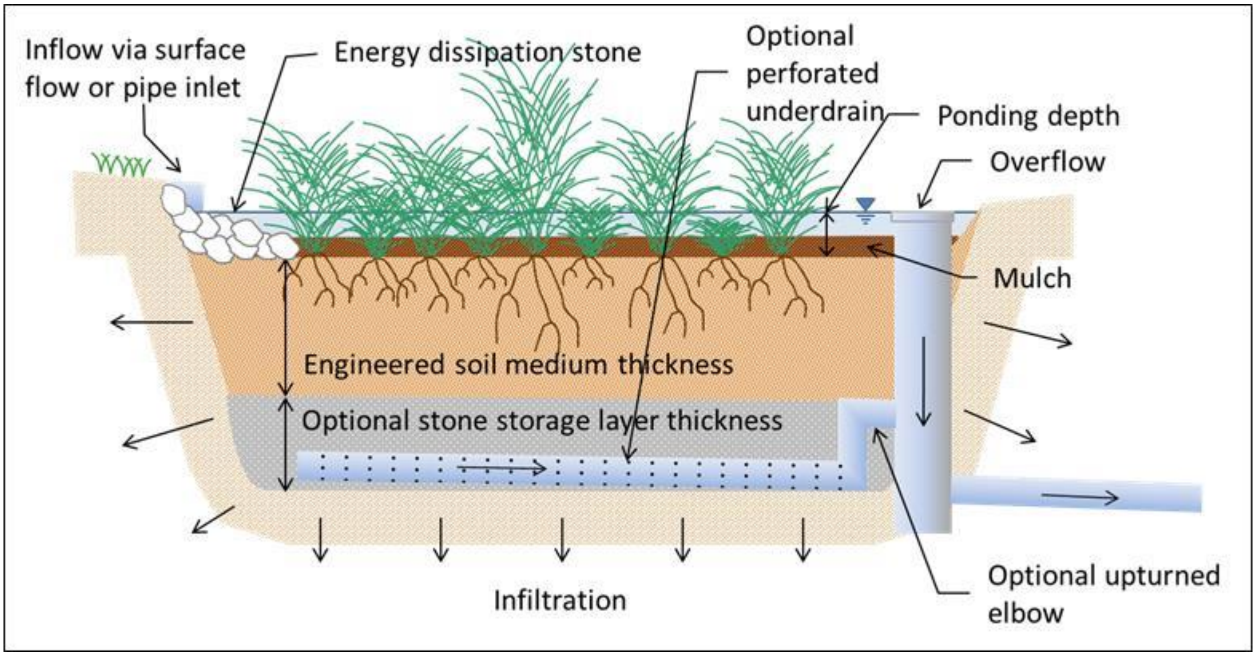


Figure 1: Cross sections of typical biofiltration system

2.2 MWS Linear

MWS Linear consist of a pre-treatment chamber, a horizontal flow biofiltration zone, and a discharge structure (Figure 2). The pre-treatment chamber separates trash and debris from smaller contaminants and includes pre-filter cartridges that utilize BioMediaGREEN filter material for reduction of TSS and hydrocarbons. This step helps to prevent clogging of the biofiltration media and acts as a small detention/equalization basin that can increase the effective time of concentration in small watersheds. The wetland biofiltration zone provides similar contaminant removal mechanisms to conventional biofiltration but uses a horizontal flow pattern to prevent clogging and improve filtration. The discharge structure provides flow control through the system. The flowrate of the system is limited by an orifice at the flow control structure. When the system fills, and the inflow rate exceeds the treated discharge rate through the orifice, flows in excess of the treatment capacity bypass treatment. MWS Linear units are available in a variety of configurations and sizes, but each has these common elements.

The MWS Linear technology has a General Use Level Designation (GULD) approved for Basic (TSS), Enhanced (dissolved metals), and Phosphorus treatment by the Washington State

Technology Assessment Protocol – Ecology (TAPE) program. It has approved treatment efficiencies and/or authorization for use as a BMP from Virginia Department of Environmental Quality, Maryland Department of the Environment, Rhode Island Department of Environmental Management, New York Department of Environmental Conservation, and City of Portland (Oregon) Environmental Services. These approvals are provided for reference only. The equivalency analysis presented in this report is based on an independent evaluation of MWS Linear performance. It is <u>not</u> contingent on approvals in other jurisdictions.

MWS units are typically designed as “flow-based” criteria, meaning that they are sized based on capture of the runoff from a specific rainfall rate (intensity) or runoff flowrate. However, the volume in the system upstream of the discharge structure provides some equalization of peak inflow rates.

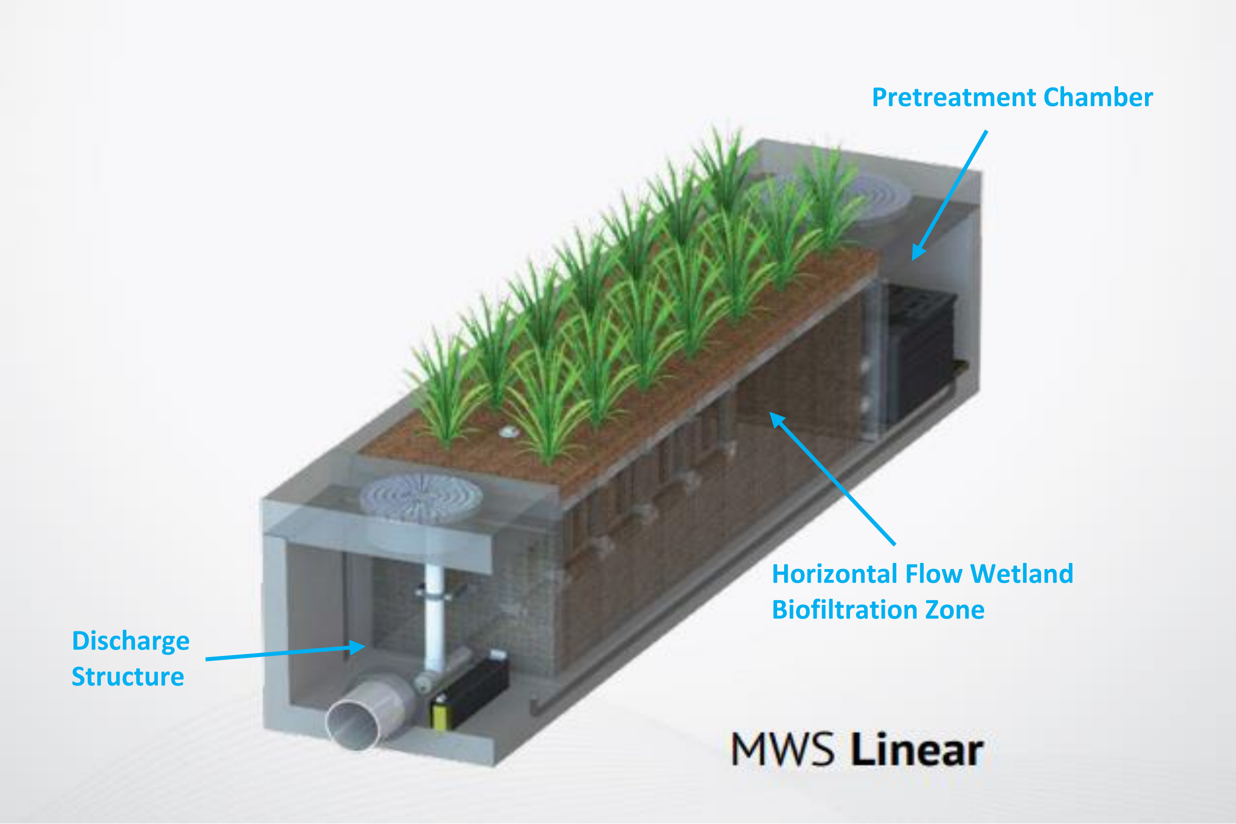


Figure 2: Typical MWS Linear Configuration

3 METHODOLOGY FOR EVALUATING EQUIVALENCY

3.1 Basis for Equivalency

The equivalency of MWS Linear to conventional biofiltration as described in Attachment H of the MS4 Permit was evaluated based on the following factors that influence pollutant load reduction performance of stormwater BMPs:

- **Capture efficiency:** The percent of long-term stormwater runoff volume that is treated by the BMP vs. bypassed.
- **Volume reduction:** The percent of long-term stormwater runoff volume that is removed from the system via infiltration or evapotranspiration and does not discharge directly to the storm sewer or surface waters.
- **Concentration reduction:** The difference in contaminant concentration between the raw stormwater runoff and the BMP-treated stormwater runoff.

The equivalency analysis consisted of three parts:

1) The baseline performance of conventional biofiltration was estimated, including representative estimates of capture efficiency, volume reduction, and concentration reduction provided by conventional designs.
2) Sizing criteria were developed for MWS Linear (with supplemental infiltration systems if needed) such that MWS Linear would provide equivalent load pollutant reduction performance to conventional biofiltration.
3) A design methodology for MWS Linear was developed to ensure consistent application of the equivalent sizing criteria in the design of MWS Linear systems.

3.2 Methods and Assumptions for Establishing Baseline for Conventional Biofiltration Performance

3.2.1 Hydrologic Performance (Capture Efficiency and Volume Reduction)

Attachment H of the MS4 Permit specifies several criteria that influence the hydrologic performance of the conventional biofiltration BMPs:

- 6 to 18-inch ponding area above media
- Optional layer of mulch
- 2 to 3 feet of engineered filter media (2 feet typical) with a design infiltration rate of 5 to 12 inches/hour; the Attachment H specification calls for a mix of 60 to 80% fine sand and 20 to 40% compost
- Gravel storage layer below the bioretention media to promote infiltration
- Underdrain placed near the top of the gravel layer (or an infiltration sump otherwise provided via an equivalent hydraulic control approach) in cases where underlying soil allows incidental infiltration
- Underdrain discharge to the storm drain system

- Capacity (including stored and filtered water) adequate to biofilter 150 percent of the portion of the SWQDv not reliably retained (i.e., infiltrated or evapotranspired).

Within the bounds established by these criteria, a range of actual conventional biofiltration designs could result as a function of site infiltration conditions as well as designer and local jurisdiction preferences. An example of potential design variability is illustrated in Appendix A. For this analysis, representative design assumptions were developed within the range of potential design assumptions. These assumptions are also presented in Appendix A with supporting rationales. Long-term continuous simulation SWMM 5.1 modeling was conducted using 18 years of 5-minute resolution precipitation data, as described in Appendix B, to estimate the long-term capture efficiency and volume reduction of the baseline biofiltration design scenario for a range of site infiltration rates. Biofiltration BMPs will tend to provide more volume reduction when installed in sites with higher incidental and allowable infiltration rates. Table 1 describes the baseline hydrologic performance of biofiltration BMPs.

Table 1. Conventional Biofiltration Hydrologic Performance

Site Soil Infiltration Rate, in/hr	Long-Term Capture Efficiency (percent of total runoff volume)	Long-Term Volume Reduction (percent of total runoff volume) (ET + Infiltration)
0	92 to 94%[1] (93% capture is representative)	4%
0.01		5%
0.05		10%
0.15		21%
0.30[2]		33%

1 - Capture efficiency varies slightly as a function of soil infiltration rate (and associated differences in design profile) and land use imperviousness. These differences are relatively minor and are less important than the variability in performance that may result from different design approaches and maintenance conditions that may be encountered. Therefore, a single baseline value of 93 percent long-term capture was used in this analysis.

2 - A maximum soil infiltration rate of 0.3 inches per hour was evaluated because for soil infiltration rates greater than 0.3 inches per hour the MS4 Permit requires that infiltration be evaluated.

3.2.2 Concentration Reduction

Pollutant concentration reduction performance for baseline biofiltration was evaluated based on analysis of bioretention with underdrain studies in the International Stormwater BMP Database. Analyses were conducted based on a screened subset of studies that were considered most representative of MS4 Permit Attachment H design criteria (16 studies). Additionally, four peer-reviewed research studies (Davis 2007; Li and Davis 2009; David et al., 2011; Gilbreath et al. 2012) not contained in the International BMP Database were added to the sample pool for analysis. Two of these studies were conducted in the San Francisco Bay area based on biofiltration design standards and media specifications very similar to Attachment H of the Los Angeles MS4 Permit. The two other additional studies were included due to their similarity to the MS4 Permit Attachment H design criteria. Note that this is the same set of conventional biofiltration studies that were considered in the Filterra Equivalency Analysis (Geosyntec Consultants, 2015). The resulting number of studies is adequate to estimate representative concentration reduction performance of conventional biofiltration.

Concentration reduction performance was characterized using a moving window bootstrapping method (Leisenring et al., 2009; see details in Appendix C) that accounts for the influence of influent concentration on effluent concentration and characterizes the relative uncertainty in performance estimates within each range of influent quality. Both the median and mean summary statistics were evaluated using these methods. Additionally, literature on the influence of biofiltration design variables on performance was summarized to support the criteria that were used to select the 20 BMP studies that were included in the screened dataset. The pollutant treatment evaluation was based on total suspended solids, total phosphorus, total nitrogen, total copper, and total zinc. Influent concentrations characteristic of single family, multi family, commercial, and light industrial land uses were applied to estimate effluent concentrations and concentration change.

Generally, biofiltration provides good removal of TSS, moderate removal of copper and zinc, and generally shows export of nutrients. Export of nutrients tends to be greater when influent concentrations are low. Details about pollutant treatment analyses are provided in Appendix C, and results of these analyses are provided in Appendix D.

3.3 Modular Wetland System Analysis to Determine Equivalent Design Criteria

This section provides information on how MWS Linear performance was analyzed to determine the conditions under which these systems provide equivalent performance to conventional biofiltration.

3.3.1 Capture Efficiency

Capture efficiency by MWS Linear is a function of the tributary area and runoff coefficient of the tributary area, the time of concentration of the associated watershed and internal equalization storage, and the design precipitation intensity used to size the MWS. A fully impervious catchment was used for all simulations. Continuous simulation with EPA SWMM 5.1 using the same 18 years of 5-minute resolution precipitation data (as was used for conventional biofiltration), as described in Appendix B, was used to determine the effect of time of concentration and MWS Linear sizing criteria on capture efficiency. The effect of time of concentration was determined by changing the modeled width of a one-acre catchment to match a range of time of concentrations. The treatment rate (and associated design precipitation intensity) of the unit was accounted for by using a flow rate-based flow splitter. The details of this analysis are provided in Appendix B. Figure 3 presents the results of the simulations.

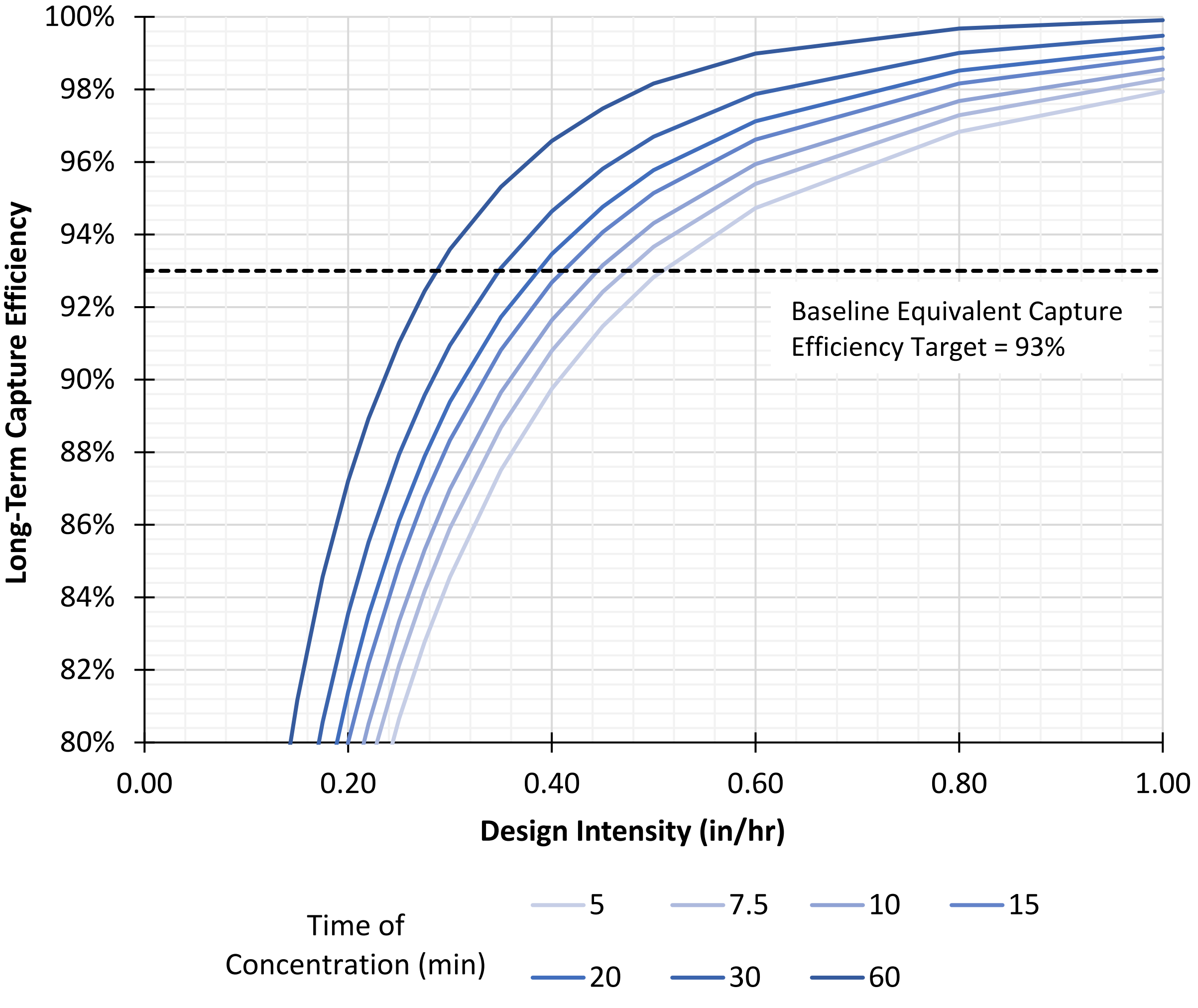


Figure 3: MWS Long-Term Capture Efficiency based on Design Intensity and Time of Concentration

3.3.2 Equalization Provided by Internal Storage

For MWS Linear, the storage within the system provides some equalization/detention prior to treatment. Because the systems are designed to limit flowrate via an orifice on the downstream end of the treatment train, the pretreatment forebay and storage within the wetland biofiltration cell must fill before bypass would occur. This was not explicitly modeled in SWMM because the ratios of storage volume to treatment flowrate vary by MWS Linear size model. The effect of this is akin to the hydrograph attenuation resulting from a longer time of concentration from the watershed. Therefore, as part of the design approach described in Section 4, this effect is accounted for by adding the detention time provided by the internal storage to the time of concentration of the watershed before looking up the required design intensity from the performance nomograph. This is a reasonable simplification.

3.3.3 Volume Reduction (MWS and Supplemental Infiltration Storage)

Volume reduction through MWS Linear is minor due to the small surface area and impermeable bottom of the treatment unit. Supplemental infiltration components may need to be added, either upstream, downstream, or underneath of the MWS Linear, to provide equivalent volume reduction to what conventional biofiltration would typically achieve under the same site conditions. Volume reduction is a function of the storage volume provided and the infiltration rate of the underlying soil. EPA SWMM 5.1 was used to conduct long-term continuous simulation to model supplemental infiltration compartments to determine the magnitude of volume reduction that would be provided if these were paired with an MWS Linear unit. A range of soil infiltration values were used to determine the long-term volume reduction of a supplemental infiltration compartment based upon the volume of the infiltration component. Infiltration component sizing was based on various fractions of the SWQDv. The details of this analysis are presented in Appendix B, and results are presented in Figure 4.

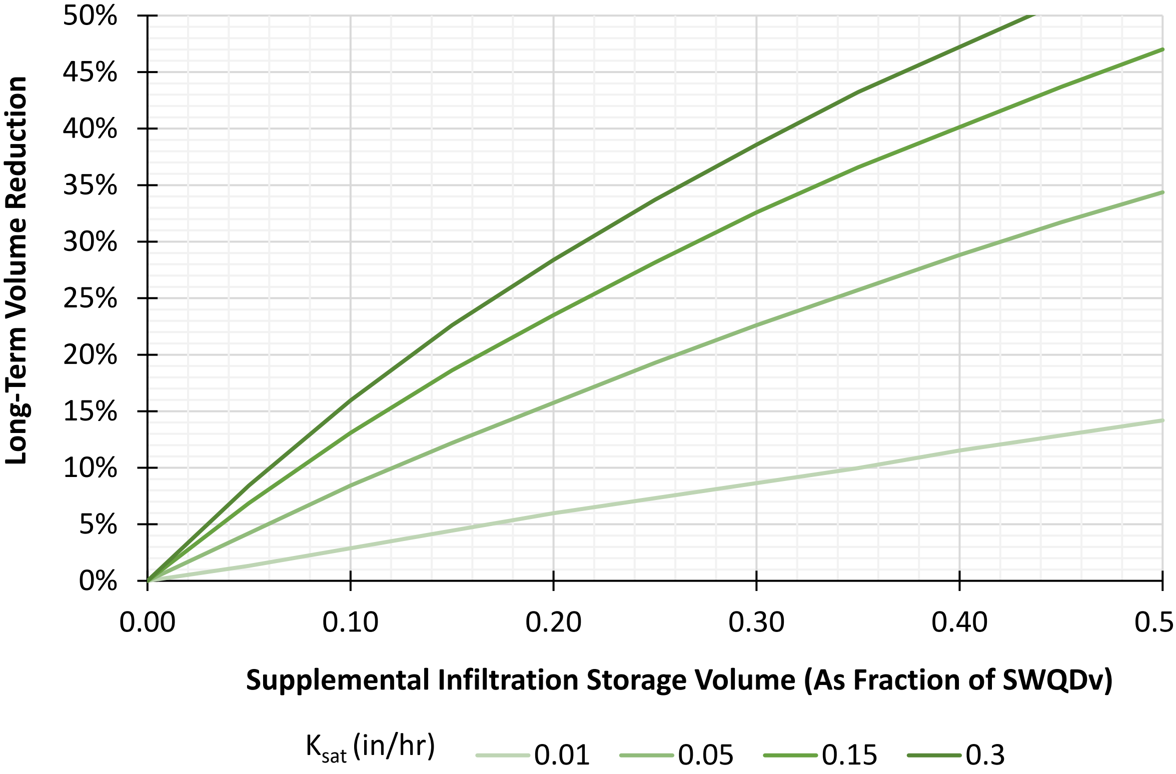


Figure 4: Volume Reduction Provided by a Supplemental Infiltration Compartment

3.3.4 Pollutant Treatment

MWS Linear performance data were analyzed using the same moving window bootstrapping methods used for conventional biofiltration. Data from two third party studies were utilized in this analysis. This analysis sought to determine whether MWS Linear performance is reasonably similar to the treatment performance of conventional biofiltration BMPs under representative ranges of influent quality.

The water quality equivalency analysis as described in Appendix C and D indicates that MWS Linear have similar or superior pollutant removal performance compared to conventional biofiltration. The bullets summarize findings:

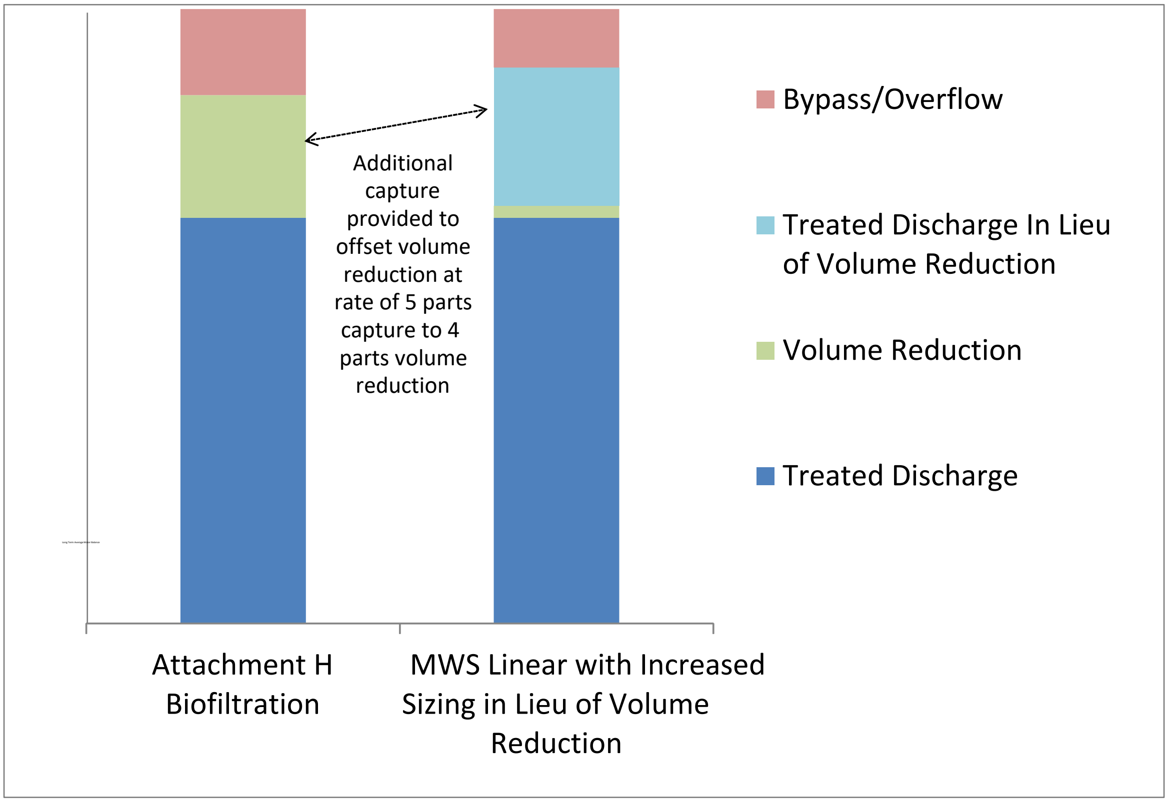
- **Total Suspended Sediment:** Both MWS Linear and conventional biofiltration performed well for TSS. Based on achieved effluent quality, MWS Linear provided somewhat better performance than conventional biofiltration. TSS removal efficiencies were greater than 75% for all evaluated land use influent concentrations, typically better than 80%.
- **Metals (Copper and Zinc):** Performance was generally similar between MWS Linear and conventional biofiltration for copper and zinc. MWS Linear showed better performance for some representative influent concentrations and conventional biofiltration showed better concentration reductions for others. In general, both provided moderate concentration reductions of metals. MWS Linear exhibited removal efficiencies generally greater than 40% for copper and 50% for zinc for all evaluated land use influent concentrations.
- **Nutrients (Nitrogen and Phosphorus):** Variable nitrogen removal was evident for both conventional biofiltration and MWS Linear. There are relatively few total nitrogen samples for MWS Linear, especially for influent concentrations greater than 2 mg/L. The bootstrap regression plots (Appendix D) show comparable performance between conventional biofiltration and MWS Linear. For influent concentrations below 0.5 mg/L, conventional biofiltration exported phosphorus. Superior phosphorus performance was evident for MWS, with removal efficiencies exceeding 55% for all evaluated land use influent concentrations. This is likely a function of the low nutrient media included in the system.

Given these findings, MWS Linear are expected to provide similar or better pollutant concentration reduction across the representative site conditions considered. Notably, MWS Linear does not exhibit phosphorus export as is consistently observed in conventional biofiltration similar to Attachment H criteria.

3.3.5 Additional Capture In Lieu of Volume Reduction

For MWS Linear applications with minor deficiencies in volume reduction compared to conventional biofiltration, an alternative option to supplemental infiltration is to provide treatment of long-term runoff in excess of the 93% required for equivalency with conventional biofiltration.

As a simple approach for minor volume reduction deficiencies, the pollutant treatment performance of MWS Linear systems for TSS was used. Based on a representative removal efficiency of 80 percent, a BMP must treat and discharge 5 parts of water for every 4 parts of water that would be lost to infiltration or ET. This means that for every 1 percent of volume reduction deficit, 1.25 percent of long-term volume must be treated. This translates to 0.25 percent additional capture for every 1 percent of volume reduction deficit. This concept is illustrated in Figure 5. Calculations of required additional capture efficiency are provided in Table 2.



Additional capture provided to offset volume reduction at rate of 5 parts capture to 4 parts volume reduction

Figure 5. Illustration of Additional Capture In Lieu of Volume Reduction (Not to scale)

Table 2. Additional Capture Efficiency In lieu of Volume Reduction

Site Soil Infiltration Rate, in/hr	Attachment H Biofiltration Long-Term Volume Reduction[1, 2]	MWS Linear Long-Term Volume Reduction[1] (ET only)	Volume Reduction Deficit	Additional Required Capture Efficiency in Lieu of Volume Reduction[3]	Adjusted Target Capture Efficiency
0	3.7%	0.7%	3.0%	0.8%	93.8%
0.01	5.0%	0.7%	4.3%	1.1%	94.1%
0.05	10.3%	0.7%	9.6%	2.4%	95.4%
0.15	21.2%	0.7%	20.5%	5.1%	98.1%
0.30	33.4%	0.7%	32.7%	8.2%	N/A

1 – Based on modeling of ET from pores and standing water.

2 – Includes infiltration losses, where feasible

3 – Required additional capture calculated at a rate of 1 part additional for every 4-parts volume reduction deficit.

4 DESIGN METHODOLOGY AND EQUIVALENCY CRITERIA

This section explains how to apply the equivalency relationships developed in Section 3. Applying this design methodology is expected to result in equivalent treatment to a conventional biofiltration basin as described in Appendix H of the MS4 Permit.

Step 1: Characterize Site and Determine Key Attributes

The first steps in developing an equivalent design are to assess the location-specific characteristics of each proposed MWS Linear:

- Delineate the drainage area to the MWS Linear.
- Estimate the imperviousness of the tributary area; use this value to estimate a runoff coefficient for the drainage area using a method acceptable to the local jurisdiction.
- Calculate the drainage area time of concentration (T_c) using methods acceptable to the local jurisdiction.
- Determine local 85th percentile, 24-hour precipitation depth for the project location. This should be determined from the Los Angeles County 85th percentile precipitation isohyetal map (http://dpw.lacounty.gov/wrd/hydrologygis/). If the isohyetal map gives a value less than 0.75 in, use 0.75 in per the MS4 Permit.
- Calculate the site "scaling factor" (f*)* as the ratio of the project-specific 85th percentile, 24-hour storm event to the LAX 85th percentile, 24-hour storm event (1.0").
- Determine the long-term reliable infiltration rate of the soils underlying the future BMP location using appropriate methods, subject to the approval of the reviewing agency.

This information is applied in the following steps.

Step 2: Adjust the Drainage Area Time of Concentration to Account for Internal Detention Storage (Total Effective Time of Concentration for Drainage Area plus Storage)

The time of concentration of the tributary watershed can be augmented by the detention storage provided within the MWS, including the pre-treatment chamber and the void space within the wetland biofiltration cell. Both storage volumes are upstream of the outlet control orifice and are available to incoming water (the BioMediaGreen pre-treatment media has a higher flowrate than the outlet control orifice).

Table 3 shows the detention time adjustment for each MWS Linear model. This should be added to the Tc computed in Step 1. Note: Before knowing the required treatment flowrate, it will not be possible to select an MWS Linear model number. The first time through this process, select a minimum Tc adjustment of 9 minutes. After completing subsequent steps, if the selected model has a longer Tc, then revisit this step.

Table 3: MWS Model Selection Chart and Detention Time Calculation for MWS Linear® Models

Model #	Dimensions	Pre-treatment Chamber Volume (ft^3)	Wetland Biofiltration Chamber Effective Void Volume (ft^3)	Treatment Flow Rate (cfs)	Detention Time Adjustment to T_c (min)
MWS-L-4-4	4′ x 4′	19.6	11.3	0.052	10
MWS-L-4-6	4′ x 6′	19.6	18.6	0.073	9
MWS-L-4-8	4′ x 8′	33.6	27.0	0.115	9
MWS-L-4-13	4′ x 13′	54.4	38.2	0.144	11
MWS-L-4-15	4′ x 15′	56	50.4	0.175	10
MWS-L-4-17	4′ x 17′	54.4	62.7	0.206	9
MWS-L-4-19	4′ x 19′	54.4	74.9	0.237	9
MWS-L-4-21	4′ x 21′	54.4	87.2	0.268	9
MWS-L-8-8	8′ x 8′	70	53.9	0.23	9
MWS-L-8-12	8′ x 12′	112	80.9	0.346	9
MWS-L-8-16	8′ x 16′	168	107.9	0.462	10
MWS-L-8-20	8′ x 20′	168	134.9	0.577	9
MWS-L-8-24	8′ x 24′	192	161.8	0.693	9

Step 3: Select Design Approach for MWS Linear for Equivalent Long-Term Performance

MWS Linear must be designed to provide equivalent capture efficiency to conventional biofiltration. Additionally, because MWS Linear systems do not allow for infiltration, the design of MWS Linear must mitigate for deficiency in volume reduction compared to conventional biofiltration. Two options are available for meeting this requirement:

> **Option A:** Provide a supplemental infiltration chamber either upstream, downstream, or underneath of the MWS unit. This is feasible in any condition where infiltration is allowable but requires supplemental BMPs.
>
> **Option B:** Increase the size of the MWS unit to provide a higher capture efficiency in lieu of infiltration. This is most feasible when soils have very low permeability or infiltration is infeasible for other reasons, such that conventional BMPs would achieve relatively little incidental infiltration and therefore volume reduction.

Note that both options may not be feasible for a specific site. Step 4A provides guidance on Option A; Step 4B provides guidance on Option B.

Step 4A: MWS Linear Sizing with Supplemental Retention Storage (Option A)

This option involves selecting an MWS Linear model that achieves equivalent long-term capture efficiency to conventional biofiltration and sizing a supplemental retention system to achieve equivalent long-term volume reduction.

1. Based on the adjusted Tc from Step 2, select the required design precipitation intensity to achieve equivalent long-term capture efficiency.

Table 4: Design Precipitation Intensity to Achieve Equivalent Long-Term Capture Efficiency (supplemental infiltration provided separately)

Adjusted Time of Concentration (min)	Design Precipitation Intensity (in/hr)
5	0.51
7.5	0.47
10	0.44
15	0.41
20	0.39
30	0.35
60	0.29

2. Apply the Rational Method (Equation 1) to determine the design flowrate (Q) required for the MWS.

$$Q = CiA \times (\frac{1\,ft}{12\,in}) \times (\frac{1\,h}{3600\,s}) \times f \qquad (1)$$

Where,

Q = design flow rate (cfs)
C = runoff coefficient
i = design precipitation intensity (in/hr)
A = catchment area (ft^2)
f = site scaling factor

3. Consult Table 3 to select an MWS Linear model that equals or exceeds the required treatment flowrate.

4. Consult Table 5 to determine the fraction of the SWQDv that must be infiltrated to provide equivalent volume reduction to conventional biofiltration. For long-term reliable infiltration rates greater than 0.3 in/hr, full infiltration of the SWQDv must be considered.

Table 5: Supplemental Infiltration Volume for Equivalent Long-Term Volume Reduction

Estimated Long-Term Reliable Infiltration Rate below Site, inches per hour	Long-Term Volume Reduction Deficit, % of Long-Term Runoff	Required Supplemental Infiltration Storage Volume as Fraction of Local SWQDv, unitless[1,2]
0	3.0%	Not feasible; See Option B
0.01	4%	0.15
0.05	10%	0.12
0.15	21%	0.17
0.3	33%	0.24

1 – Values are not expected to follow a continually increasing trend.

2 - A 2.0-foot effective storage depth is assumed for supplemental storage.

5. Multiply the site-specific SWQDv for the MWS drainage area by the required supplemental infiltration storage volume fraction in Table 5 . This table assumes that the supplemental infiltration basin will be 2.0 ft in depth. Shallower or deeper storage would require different sizing factors. Supplemental calculations could be provided to demonstrate that an alternative storage configuration would provide equivalent long-term volume reduction.

Step 4B: MWS Linear Sizing for Excess Capture In Lieu of Volume Reduction

This option involves increasing the size of MWS Linear to achieve a higher level of capture efficiency in lieu of providing supplemental volume reduction.

1. Use Table 6 to determine the design rainfall intensity. The adjusted Tc from Step 2 should be used. For times of concentration less than 5 min, round up to 5 min. Interpolation between values in this table would be permissible.
2. Apply the Rational Method (Equation 1) to determine the design flowrate (Q) required for the MWS.
3. Select an MWS Linear Model from Table 3 to provide the required treatment flowrate.

Table 6: Adjusted Design Intensity to Provide Additional Capture In Lieu of Volume Reduction (Option B)

Adjusted Time of Concentration (min)	**Reliable Infiltration Rate at Site**			
	0 in/hr (ET only) Capture Efficiency Target = 93.8%	**0.01 in/hr** Capture Efficiency Target = 94.1%	**0.05 in/hr** Capture Efficiency Target = 95.4%	**0.15 in/hr** Capture Efficiency Target = 98.1%
	Adjusted MWS Design Precipitation Intensities, in/hr			
5	0.55	0.57	0.66	N/A
7.5	0.51	0.53	0.60	0.96
10	0.48	0.49	0.57	0.90
15	0.44	0.45	0.52	0.79
20	0.41	0.42	0.48	0.74
30	0.37	0.38	0.43	0.64
60	0.31	0.31	0.35	0.50

NA = additional capture is not a viable option to offset volume reduction in these cases.

5 DISCUSSION AND CONCLUSIONS

5.1 Key Observations and Findings

5.1.1 Capture Efficiency and Volume Reduction

Overall, if MWS Linear units are designed based on the methodology and criteria presented in Section 4 and effectively operated and maintained, these systems are expected to result in similar performance compared to conventional biofiltration. The following bullets summarize key findings from this analysis:

- The baseline level of capture efficiency and volume reduction provided by conventional biofiltration BMPs, if effectively designed per Attachment H of the MS4 Permit, is relatively high. This establishes a relatively high baseline standard for MWS Linear systems to meet in providing equivalent performance.
- There is substantial leeway within the MS4 Permit Attachment H criteria and local implementation guidance that is expected to result in significant design variations of conventional biofiltration throughout Los Angeles County. These variations result in variations in hydrologic performance. Additionally, variations in operations and maintenance conditions over time (i.e., decline in media rates, reduction in active storage volume from sedimentation) are also expected to influence performance.
- It is possible to design MWS units to match the capture efficiency of conventional biofiltration BMPs. This requires larger sizes of MWS units than was required for treatment control BMPs under the previous MS4 Permit. This also requires a commitment to regular maintenance consistent with MWS standard maintenance requirements.

- MWS units alone are not expected to match the volume reduction performance provided by effectively designed conventional biofiltration. However, it is possible for MWS systems to mitigate for deficiency in volume reduction via either a supplemental infiltration basin or by increasing the size of the MWS unit to increase capture efficiency, thereby providing equivalent TSS load reductions.

5.1.2 Water Quality Treatment

The water quality equivalency analysis as described in Appendix C and D indicates that MWS Linear have similar or better pollutant removal performance compared to conventional biofiltration. This is summarized in Section 3.3.4 above. Notably, MWS Linear has not exhibited phosphorus export as is consistently observed in conventional biofiltration systems that include compost similar to Attachment H criteria. MWS Linear does not include compost.

5.2 Reliability and Limitations

There are several uncertainties that could influence the reliability of the findings presented in this report. These are addressed in the paragraphs below.

Modeled hydrologic performance estimates. Performance estimates were based on models which were not calibrated. This introduces some uncertainty. However, this uncertainty was mitigated by applying identical input parameters and modeling approaches for conventional biofiltration and MWS units, as appropriate. This has the effect of offsetting most sources of bias.

Treatment performance estimates for conventional biofiltration. Treatment performance estimates were based on peer reviewed studies from the International Stormwater BMP Database and other peer reviewed third party studies that were selected to be representative of the BMPs being compared. Due to the limited documentation of these studies, it was not possible to quantitatively evaluate whether performance estimates are specifically representative of the MS4 Permit's Attachment H guidelines. Additionally, performance has been observed to vary greatly from site to site, indicative of the importance of design factors such as sizing, media composition, and sources of media components. The conventional biofiltration datasets analyzed are believed to provide reliable information about the range of potential performance that may be expected from conventional biofiltration in Los Angeles County; however, they are not intended to be used as a predictive tool for any one variation of biofiltration design. Reliability of these data was improved through the application of robust statistical methods that account for the influence of influent concentration and provide a quantification of uncertainty.

Treatment performance estimates for MWS units. MWS units have been evaluated in third-party field studies with representative stormwater conditions; however, none of these sites were in Los Angeles County. Additionally, the sample size of MWS datasets is still somewhat low in comparison to conventional biofiltration BMPs. These factors are mitigated to a large extent by the standardized design that accounts differences in rainfall intensity and ensures consistency in treatment processes. These factors improve the transferability of findings between regions. Additionally, the reliability of MWS performance data was improved by applying the same robust statistical methods as used for conventional biofiltration, which helps adjust for differences in influent quality between studies.

TSS removal as a surrogate for additional capture in lieu of volume reduction. For small deficiencies in volume reduction, a TSS treatment removal rate of 80 percent was used to calculate required additional capture efficiency in lieu of volume reduction. A multi-parameter approach would be more complex and would need to account for the export of nutrients in conventional biofiltration as well as variability in treatment performance with influent contraction. Given that this approach is only intended to offset minor volume reduction (up to about 20%), this is considered a reasonable approach.

Sensitivity to site conditions. The effectiveness of volume reduction processes is particularly sensitive to estimates of a BMPs underlying infiltration rate. It is often not possible to anticipate with certainty what the long-term infiltration rate will be after construction. This limitation is largely mitigated for this analysis because the uncertainty in infiltration rate influences the design and performance of conventional biofiltration and MWS with supplemental infiltration storage similarly. Additionally, estimating the BMP location infiltration rate is now a standard part of developing a BMP plan for a site, so the reliability of approaches for developing this estimate should improve with time.

Variability in design and construction process. The analyses and criteria presented in this report assume that the BMPs will be designed, constructed, and maintained according to typical standards and manufacturer guidelines. It is inherent that the design of conventional biofiltration BMPs provides a greater degree of freedom and associated professional judgment as part of preparing design calculations, design drawings, and specifications that proprietary BMPs such as MWS Linear units. This introduces a wider potential range of resulting designs for conventional biofiltration: some may perform better than average, some may perform worse. In comparison, there is likely to be substantially less variability in the design and construction of MWS units as compared to biofiltration BMPs.

Sensitivity to operations and maintenance. Both types of systems are susceptible to decline in performance over time. **Neither BMP type will continue to function as designed if not regularly and effectively maintained.**

Overall, the analyses are believed to result in reliable design assumptions. Where substantial uncertainties exist, these are mostly offset for the purpose of estimating equivalency, because they effect both conventional biofiltration and MWS Linear similarly.

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APPENDIX A – CONVENTIONAL BIOFILTRATION DESIGN ASSUMPTIONS FOR PERFORMANCE MODELING

The following criteria from the MS4 Permit Attachment H were important for evaluating pollutant load reduction performance of "conventional biofiltration" scenarios:

- 6 to 18-inch ponding area above media
- Optional layer of mulch
- 2 to 3 feet of engineered filter media (2 feet typical) with a design infiltration rate of 5 to 12 inches/hour; the Attachment H specification calls for a mix of 60 to 80% fine sand and 20 to 40% compost
- Gravel storage layer below the bioretention media to promote infiltration
- Underdrain placed near the top of the gravel layer (or an infiltration sump otherwise provided via an equivalent hydraulic control approach) in cases where underlying soil infiltration rates allow
- Underdrain discharge to the storm drain
- Total physical water storage volume sized to be equal to at least the stormwater quality design volume (SWQDv = runoff volume from the 85th percentile, 24-hour storm event)
- Capacity (including stored and filtered water) adequate to biofilter 150 percent of the portion of the SWQDv not reliably retained.

Within the bounds established by these criteria, a range of actual biofiltration designs could result as a function of site infiltration conditions as well as designer and local jurisdiction preferences. An example of potential design variability is illustrated in Table A.1 below. For this analysis, representative design assumptions were developed within the range of potential design assumptions. These assumptions are also presented in Table A.1 with supporting rationales.

Table A.1 Biofiltration Design Assumptions from Various Sources and Selected Representative Design Assumptions

Design Assumption	**Design References**					**Selected Representative Design Assumption**	**Rationale for Selected Design Assumption**
	MS4 Permit Attachment H	Los Angeles County LID Manual, static method	Los Angeles County LID Manual, routing method	City of Los Angeles LID Manual	Ventura County TGM		
Ponding Depth, ft	0.5 to 1.5	0.5 to **1.5**	0.5 to **1.5**	0.5 to **1.5**	0.5 to **1.5**	1.5	Many designers will utilize deepest depth allowable because of space efficiency.
Media Depth, ft	2 to 3	**2** to 3	**2** to 3	**2** to 3	**2** to 3	2	Typical design approach is to use minimum depth due to cost of media.
Gravel "sump" depth below underdrain, ft	Not specified; narrative	Not specified, narrative	Not specified, narrative	At least 1 feet; up to **2** feet if soils allow incidental infiltration	**0.5** minimum below underdrain	Depth that would drain in 24 hours. For example, 1.5 ft if site infiltration rate estimated at just less than 0.3 in/hr	Approach produces a reasonable design that considers infiltration rates; Attachment H states that volume infiltrated within 24 hours can be considered retained.
Media Filtration Rate, in/hr	5 to 12	**5** to 12	**5** to 12	**5** to 12	1 to 12 **(5)**	5	Representative of long-term operation after some clogging
Allowable Routing Period for Biofiltration Treatment, hrs	Not specified	Routing is not part of simple method	Allows routing of **24-hour** design hydrograph from LA County HydroCalc model	**3** hours, unless using a routing model	Depth up to ponding depth (**1.5 ft**) can be considered routed	6 hours[1]	Based on evaluation of storm durations for events similar to design event. See footnote 1.
Resulting Footprint Factor at 0.3 in/hr Infiltration Rate, in/hr (% of impervious area)	Not enough information to calculate	5 to 10%	1.4%	2.4% (1.4% with routing similar to LA County)	2.8%	2.0%	Calculated based on assumptions.

Note: where a range of guidance is allowed, the bolded number indicates the value that was used in calculations. The design values were selected based on developing the most economical and space-efficient design that meets the applicable criteria.

1 – The allowable routing period was estimated based on the typical storm duration associated with events similar to the 85th percentile, 24-hour storm depth (1.0 inches at LAX). This was estimated in two ways. For days with precipitation totals between 0.9 and 1.1 inches, the total number of hours with rainfall was tabulated (average = 11 hours; 10th percentile = 6 hours). This does not consider dry periods between hours with rainfall, therefore is somewhat conservative in estimating the time available for routing biofiltered water during a given day. For unique precipitation events, separated by 6-hour dry period (potentially spanning across breaks in calendar days), with precipitation totals between 0.9 and 1.1 inches, the total storm durations were tabulated (average = 16 hours; 10th percentile = 7 hours). Based on this analysis, a 6-hour routing period is defensible and conservative in estimating the amount of water that can be routed through a biofiltration system during typical storm events similar to the design storm event.

APPENDIX B – SWMM MODELING METHODOLOGY AND ASSUMPTIONS

The relative performance of MWS Linear and conventional biofiltration was determined using the following data inputs and modeled site conditions:

- Rainfall: Los Angeles International Airport, 2000-2018, ASOS
- ET: CIMIS Zone 4
- Catchment imperviousness: 100%
- Catchment slope: 3%
- Area: 1 acre

For conventional biofiltration the sizing and design criteria described in Appendix A were followed, including underlying soil infiltration rates of 0, 0.01, 0.05, 0.15, and 0.30 in/hr.

For MWS Linear, all combinations of the following sizing and design criteria were evaluated:

- Time of concentration: 5, 7.5, 10, 15, 20, 30, and 60 min
- Design rainfall intensity: 20 values spanning 0.02 - 1.00 in/hr

Supplemental infiltration compartments were evaluated using the following sizing and design criteria:

- Time of concentration: 5 min (not a sensitive parameter for a volume-based BMP)
- Unit depth: 2 ft
- Underlying soil infiltration rate: 0.01, 0.05, 0.15, and 0.30 in/hr
- Percent of runoff depth, using the 24-hr, 85th percentile rainfall depth: 10 increments spanning 5% -50%.

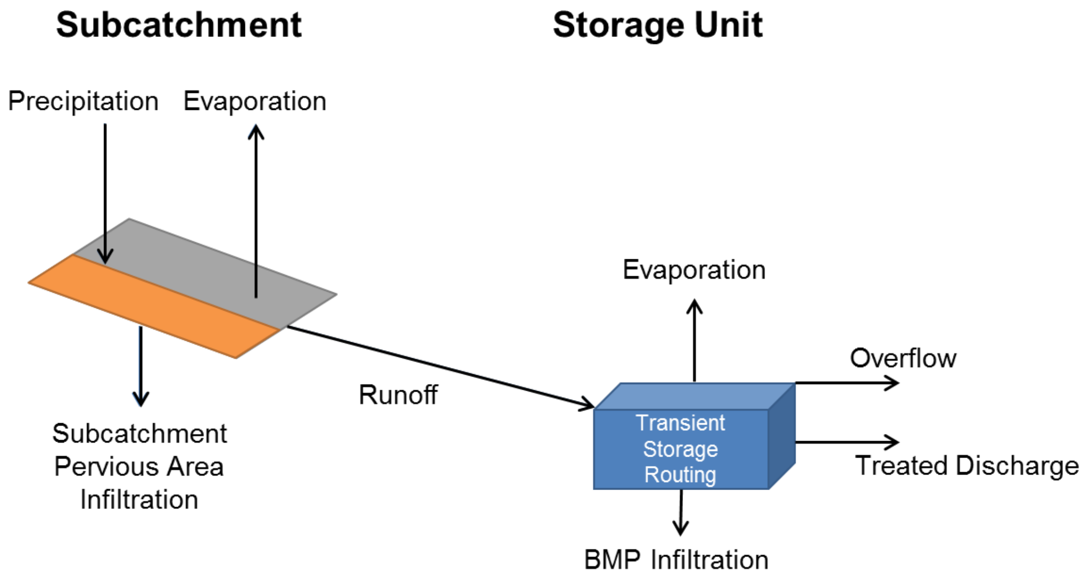
Overview of SWMM Analysis Framework

SWMM was used to estimate the long-term capture efficiency and volume reduction from conventional biofiltration and MWS Linear for each scenario. SWMM simulates surface runoff, evaporation, infiltration, and flow routing. A conceptual representation of the SWMM model framework used for this analysis is provided in Figure B.1. Within this framework, parameters were adjusted for each scenario to account for soil condition and BMP sizing and design attributes.

In SWMM, subcatchment elements are used to generate a runoff hydrograph. Input data defining the surface characteristics include subcatchment area, imperviousness, width, depression storage, surface roughness, surface slope, and infiltration parameters. SWMM performs a mass balance of inflows and outflows to determine runoff from a subcatchment. The inflows to this mass balance are precipitation and any runoff directed from another subcatchment. The outflows from the mass balance include evaporation, infiltration, and runoff. The runoff parameters assumed for this analysis are discussed in this Appendix.

A variety of hydraulic flow routing elements exist in SWMM, but fundamentally the program includes nodes (i.e., storage units, manholes, and outfalls) and links (i.e., conduits, pipes, pumps, weirs, orifices, and outlets). For traditional biofiltration a storage unit was to represent the storage and routing attributes of BMPs. The elements defining the storage volume and related discharge were adjusted based on the various sizing and design criteria evaluated in the equivalency scenarios, the details of which are discussed in this Appendix. For MWS Linear, storage was not modeled explicitly. MWS Linear, a simple flow divider was used to represent the treatment capacity of the system. For runs considering the supplemental infiltration storage compartment, this compartment was modeled as a storage unit.

SWMM was run in continuous simulation mode over an 18-year period (January 2000-March 2018). A continuous hydrograph of runoff was generated and routed through the model representations of BMPs. The results were tracked and reported in terms of long-term runoff volume, long-term volume lost in the BMP, long-term volume bypassing or overflowing the BMP, and long-term volume treated in the BMP. The 18-year period of record was selected based on the availability of high quality 5-minute resolution precipitation data, which are important for representing urban catchments with short time of concentration. To ensure comparability, the same forcing data (rainfall, ET) were applied to conventional biofiltration scenarios and MWS Linear scenarios.



Capture Efficiency (fraction of runoff) = 1- (Overflow/Runoff)

Volume Reduction (fraction of runoff) = 1- (Treated Discharge + Overflow)/(Runoff)

Figure B.1. Schematic SWMM modeling framework in support of equivalency analysis

Meteorological Inputs

Precipitation

Long-term modeling used 5-minute data obtained from the Automated Surface Observation System (ASOS). This data was compared to National Climatic Data Center (NCDC) hourly precipitation data to ensure quality, as NCDC data sets undergo a greater level of quality review than ASOS data sets. While the NCDC data spans 1948-2015 and the ASOS model spans only 2000-2018, the ASOS data was selected over the NCDC data because the improved temporal resolution is important for small catchments. Both ASOS and NCDC rainfall data were obtained from gauges located at Los Angeles International Airport.

Comparison of NCDC and ASOS data resulted in the elimination of 14 ASOS data points (for a total of 70 minutes of data out of the 17+ years of available) that were determined to be artificially high. Otherwise, ASOS and NCDC data agreed well. The 85th percentile, 24-hour depth was determined using NCDC data for days with rainfall greater than 0.1 inches. This value was slightly higher for the NCDC data (1.01") than for the ASOS data (0.94"), which can be attributed to the difference in the length of available data sets (Table B.1).

Table B.1: LAX Storm Water Quality Design Volume

Data	Gage Location	85th Percentile 24-Hour Depth (in)
NCDC (1948-2015)	Los Angeles Airport (045114)	1.01
ASOS (2000-2018)	Los Angeles Airport (KLAX)	0.94

Evapotranspiration

Evapotranspiration (ET) values for Zone 4 as defined in the California Irrigation Management Information System (CIMIS) were used for all SWMM models (Table B.2). ET values used in the model were set to 60% of the reference ET values to account for mixed urban conditions and shading conditions based on guidance provided by CIMIS (CDWR, 2015). ET values have little influence on modeled outputs in SWMM.

Table B.2: CIMIS Zone 4 Evapotranspiration Values

Month	Evapotranspiration Rate (in/month)	Evapotranspiration Rate (in/day)	60% Evapotranspiration Rate (in/day)
January	1.86	0.05	0.06
February	2.24	0.08	0.08
March	3.41	0.12	0.11
April	4.5	0.17	0.15
May	5.27	0.22	0.17
June	5.7	0.26	0.19

Month	Evapotranspiration Rate (in/month)	Evapotranspiration Rate (in/day)	60% Evapotranspiration Rate (in/day)
July	5.89	0.28	0.19
August	5.58	0.25	0.18
September	4.5	0.19	0.15
October	3.41	0.13	0.11
November	2.4	0.07	0.08
December	1.86	0.05	0.06

Runoff Parameters

The key SWMM parameters used to estimate surface runoff from the impervious catchment are subcatchment area, width, depression storage, surface roughness, surface slope. The majority of surface characteristics were kept constant for both BMP systems and across all land use types. For MWS Linear simulations the width parameter (defines the overland flow length for runoff to travel), was adjusted to reflect differences in time of concentrations. Drainage widths were set to correspond with times of concentration of 5, 7.5, 10, 15, 20, 30, and 60 minutes in a 1-acre catchment via Equation B.1 (Table B.3):

$$T_c = \frac{0.93 \times L^{0.6} \times n^{0.6}}{I^{0.4} \times S^{0.3}} \tag{B.1}$$

Where,

T_c= time of concentration (min)
L = length (ft)
n = Manning’s n (0.12, corresponding to impervious surface Manning’s n)
S = Slope (ft/ft) (0.03)
I = intensity (in/hr; set to the 85th percentile rainfall intensity at the corresponding time of concentration, as determined by ASOS data; Table B.3)

Table B.3: Rainfall Intensities Used to Determine Catchment Width

Time of Concentration (min)	85th Percentile Rainfall Intensity (in/hr)	Path Length Associated with Tc (ft)	SWMM Catchment Width to Represent Tc (ft)
5	0.24	92	474
7.5	0.24	181	241
10	0.24	292	149
15	0.20	508	86
20	0.18	765	57
30	0.16	1391	31
60	0.12	3644	12

Infiltration over the catchment was not modeled because the scenarios considered only 100 percent impervious catchments. This was done for both conventional biofiltration and MWS simulations. Runoff coefficients are applied as part of the design process.

Table B.4: EPA SWMM Parameters Used to Model BMPs

SWMM Runoff Parameters	**Units**	**Values**	**Source/Rationale**
Wet time step	seconds	60	Set to 20% of the time steps of precipitation input data (300 seconds)
Dry time step	seconds	14,400	Equivalent to 4 hours.
Period of Record		January 2000-March 2018	Availability of ASOS data
Percent of Impervious Area	percent	100	Representative of typical fully developed area draining to MWS; actual imperviousness would be used by designer to calculate runoff coefficient.
Impervious Manning's n	unitless	0.012	James and James, 2000
Drainage area	acres	1	Hypothetical for purpose of analysis
Width	feet	*Conventional biofiltration:* 174 ft *MWS Linear:* Variable to represent different time of concentrations (Table B.3)	*Conventional biofiltration:* Typical assumption for urban drainage patters (equates to 250-ft path length). Performance of volume-based BMPs is not sensitive to catchment width. *MWS Linear:* Calculated as described above.

SWMM Runoff Parameters	Units	Values	Source/Rationale
Slopes	ft/ft	0.03 (represents average of roofs, landscaping, and streets)	Professional judgment; actual slope would be used by designer to calculate Tc.
Evaporation	in / month	60% of reference ET values (Table B.4)	CIMIS (CWDR, 2015)
Depression storage, impervious	inches	0.02	James and James, 2000

Supplemental Infiltration Unit

Catchment parameters were kept the same for supplemental infiltration unit modeling as for MWS Linear runoff modeling (Table B.5). Catchment width was kept constant for all runs, using the conservative value associated with a time of concentration of 5 minutes. The unit was modeled with a constant depth and a total volume based upon a fraction of the SWQDv (Table B.1) (equal to the runoff from a 1.0" event).

Table B.5: EPA SWMM Parameters Used to Model Supplemental Infiltration

SWMM Runoff Parameters	Units	Values	Source/Rationale
Catchment Width	feet	473.6	Width of a 1 ac catchment with a 5 min time of concentration
Storage Unit Depth	ft	2.0	Typical value
Storage Unit Saturated Hydraulic Conductivity (in/hr)	in/hr	Varies by site condition: 0.01, 0.05, 0.1, 0.15, and 0.30	Allows for analysis of different underlying soil types

<u>BMP Representation</u>

Conventional Biofiltration

Conventional biofiltration was simulated using a storage unit with outlets to represent infiltration losses (if present) and treated discharge, and a weir to simulate overflow/bypass. The elevations of these elements within the storage unit were used to represent the design profiles of these systems. Storage compartments were divided in to: evaporation storage (i.e., water stored in soil that is not freely drained); infiltration storage (i.e., water stored below the lowest outlet that can either infiltration or ET only); and freely drained storage (i.e., water that can drain through the underdrains of the system at a rate controlled by the media hydraulic conductivity).

Sizing criteria for the conventional biofiltration system was based on the runoff from the 85th percentile, 24-hour storm depth (1.0 for LAX). For each scenario, this depth was applied to the catchment area to compute an estimated runoff volume. Storage profiles for the conventional biofiltration system were established to represent typical profiles for conventional biofiltration consistent with what is required by Attachment H of the MS4 Permit, which are presented in Appendix A of this report. The storage profiles included equivalent storage volumes provided in the ponding depth, media depth (divided between ET storage and freely drained storage), gravel layer, and placement of the underdrain system specific to the site conditions. Based on the equivalent storage depth in these profiles and the design storm runoff volume, the required footprints were calculated. For gravel, a porosity of 0.4 was assumed. For media, a porosity of 0.4 in/in was assumed, divided as 0.15 in/in soil suction storage (i.e. ET storage) and 0.25 in/in freely drained storage. The profiles used for this analysis and the typical footprints are presented in Table B.6.

For estimating long-term volume reduction and baseline capture efficiency, the entire pore volume was assumed to be immediately available. However, because water takes time to travel through the soil column, it is possible for a biofiltration BMP to overflow before the entire soil poor volume is utilized. Based on analysis of flow monitoring data, Davis et al. (2011) found that the volume immediately available within a storm is better represented by the bowl volume (surface ponding) and the freely drained pores within the root zone (approximately the top 1 foot of soil). To check whether this condition influenced long term capture efficiency, parallel model runs were conducted where the storage volume equaled the bowl volume plus freely drained pores in the soil root zone, and the drawdown time was adjusted for only this volume. The result was that this condition reduced capture efficiency by approximately 2 percent. This indicates that this condition controls performance relatively rarely but is not negligible.

Table B.6 Summary of Conventional Biofiltration Profiles

Infiltration Rate, in/hr	Retention Sump Depth (as gravel depth)[1], ft	Effective Water Storage in Retention Sump (ft)	Media Depth, ft	Effective Water Storage in Media[2], ft	Ponding Depth, ft	Total Effective Water Depth (ft)	Approximate Footprint Sizing Factor (Los Angeles)[3]
0.3	1.5	0.60	2	0.8	1.5	2.9	1.9%
0.15	0.75	0.30	2	0.8	1.5	2.6	2.1%
0.05	0.25	0.10	2	0.8	1.5	2.4	2.2%
0.01	0.05	0.02	2	0.8	1.5	2.32	2.3%
0	0	0.00	2	0.8	1.5	2.3	2.3%

1 Sump storage was determined based on the depth of water that would infiltrate in 24 hours based on guidance provided in Attachment H.

2 Media storage depth represented as 0.3 ft suction storage and 0.5 ft freely drained storage.

3 Expressed as BMP footprint as percent of tributary area.

MWS Linear

MWS Linear primarily operates as a flow-based BMP. Therefore, systems were modeled using only a flow rate-based flow divider, with the cutoff flow corresponding to a range of design rainfall intensities. Design rainfall intensities were converted to design maximum flow rates using the Rational Method Equation (Equation B.2):

$$Q = CiA \tag{B.2}$$

Where,

Q = flow rate (ft^3/hr)
C = runoff coefficient (0.90)
i = rainfall intensity (in/hr)
A = catchment area (43,560 ft^2, corresponding to 1 acre)

Twenty increments of design intensities ranging from 0.02 inches/hour up to 1.0 inches/hour were established to represent a range of potential MWS Linear sizing criteria to achieve equivalency. For each scenario, the design intensity was applied to the catchment area and imperviousness to calculate the runoff flowrate.

A representative ET loss from MWS Linear was calculated for an example scenario by adding a storage unit to the treated flow stream to represent the MWS Linear unit. The storage unit was sized by assuming a 1-acre catchment with a 10 min T_c, resulting in an 8 ft by 16 ft MWS Linear model. The storage unit was modeled with an evaporation factor of 1.0 and a media pore storage ratio of 0.15 in/in. The resulting ET loss was 1 percent.

Supplemental Infiltration Unit

Supplemental infiltration was modeled as a storage unit with a pervious underlying soil and an outlet. The infiltration unit was sized based on a percentage of the runoff volume from the 85th percentile, 24-hour depth. Every combination of ten sizes of basin (5%-50% of the SWQDv in 5% increments) and four infiltration rates (0.01, 0.05, 0.15, and 0.30 in/hr) were modeled. The depth of the unit was assumed to be 2 ft.

APPENDIX C – DATASETS AND ANALYSIS METHODS FOR POLLUTANT TREATMENT EVALUATION

Data Development and Analysis Framework

BMP performance is a function of BMP type, BMP design parameters, influent water quality characteristics, and other factors. As part of the MWS Linear equivalency analysis it was necessary to develop a statistical description of BMP performance, that accounted for the difference between conventional biofiltration and MWS Linear, and for the influence of land use runoff quality (i.e., BMP influent quality) on the expected BMP performance. The data development and analysis framework used for this project included four steps:

1) Compile and review data from monitoring studies of conventional biofiltration systems; then screen these studies to identify studies that are reasonably representative of conventional biofiltration designs that would meet the MS4 Permit requirements, particularly focusing on factors that would influence treated effluent quality.
2) Compile and review monitoring data from full-scale MWS Linear monitoring studies.
3) Apply a common statistical analysis framework to analyze the data from both datasets.
4) Determine representative land use runoff quality.
5) Based on results from step 3 and 4, estimate the effluent quality expected for conventional biofiltration compared to MWS Linear for each pollutant for a range of land use-based influent quality.

Compilation and Screening of Conventional Biofiltration Studies

Note, this analysis is equivalent to the analysis conducted as part of evaluating Filterra equivalency (Geosyntec, 2015). Based on review of the International BMP Database, limited new information about conventional biofiltration performance was available at the time of publication. It is possible that 2 to 3 additional studies are available that would have similar design parameters to Attachment H of the MS4 Permit. New data from two to three new studies would be unlikely to influence findings from the 20 studies that were used in the 2015 Filterra equivalency analysis, this previous assessment of baseline performance was not revised.

As of 2015, the International Stormwater BMP Database (www.bmpdatabase.org) included storm event monitoring data from 28 peer-reviewed studies of bioretention BMPs with underdrains. These data were used as the primary source for characterizing the treatment performance of conventional biofiltration BMPs in this study. In addition to the 28 studies from the International BMP Database, four peer-reviewed research studies (Davis 2007; Li and Davis 2009; David et al., 2011; Gilbreath et al. 2012) not contained in the International BMP Database were added to the sample pool for analysis. Two of these studies were conducted in the San Francisco Bay area, which has biofiltration design standards and media specifications nearly identical to Attachment H of the Los Angeles MS4 Permit. The two other additional studies were included due to their similarity to Attachment H design criteria and rigor of their analytical methods.

Screening Process for Developing Conventional Biofiltration Sample Pool

In general, the bioretention BMPs in the International BMP Database are representative of the range of designs that could meet the MS4 Permit Attachment H requirements. Most of the bioretention studies in the BMP Database were completed fairly recently (most between 2000 and 2015) and have typically been designed, constructed, and/or monitored under the supervision of experienced researchers. Many of these systems have been designed with BMP profiles (i.e., ponding depth, media depth), media filtration rates, and media composition that are similar to the criteria in Attachment H. However, where design attributes indicated that performance would be expected to be poorer than Attachment H designs and/or representativeness could not be evaluated, these studies were screened out of the analysis pool for this study. Systems that were expected to achieve similar or better performance than a typical BMP designed per Attachment H were kept in the pool; this is a conservative approach when evaluating MWS equivalency because it tends to establish a higher baseline for comparison than if these BMPs were excluded.

Screening criteria were developed based on professional judgment, as informed by review of literature and BMP performance studies. Our understanding of the influence of design parameters on bioretention performance was informed by studies in the BMP Database (see various summary reports at www.bmpdatabase.org), a recent evaluation by Roseen and Stone (2013), and review of recent bioretention media research in Washington State. A summary of the relevant findings is provided in the paragraphs below.

Roseen and Stone (2013) conducted an evaluation of biofiltration performance to determine how design criteria and media composition influence performance. As part of their research, they compiled site, design, and performance data for 80 field bioretention systems and 114 lab columns/mesocosms. Data from the International BMP Database were included in this pool as well as other research studies. Performance data were compiled as study summaries (e.g., study median influent, effluent, and removal efficiency). Roseen and Stone then utilized design information to categorizing systems into groups based on common combinations of factors. They then conducted a statistical evaluation of how performance was influenced by design factors such as presence/absence of mulch layers, use of compost in media, infiltration rate of media, ratio of tributary to biofiltration area, presence/absence of pretreatment, presence/absence of internal storage layers, etc. Roseen and Stone found that the presence of compost in mixes strongly influences the variability in performance and potential export of pollutants, including phosphorus, nitrogen, and copper. Systems without compost and/or with a high fraction of sand tended to provide the most consistent and best performance for these pollutants. Systems with an internal water storage zone tended to perform better for nutrients than systems without an internal water storage zone. Finally, they found that media flowrate and depth of media bed tended to have an influence on performance. Beyond these findings, the influence of other parameters was less conclusive.

Recent bioretention studies, many in Washington State (Herrera 2014b, 2015a, 2015b), have identified the potential severity of pollutant export of nitrogen, phosphorus, and copper from conventional biofiltration systems and have evaluated the potential sources of these issues. This research also found that some sand products can also contain elevated levels of phosphorus and copper. These studies are relevant because the standard biofiltration media specifications for Western Washington are very similar to Attachment H, calling for 60 to 65 percent sand and 35 to 40 percent compost. It should also be noted that the compost certification criteria in Washington State (Washington Department of Ecology, 2014) allow for half as much metals content as allowed in the Attachment H specification, therefore should theoretically have less potential for export of metals than compost meeting the Attachment H specification.

Based on these literature findings and best professional judgment, the following criteria were applied as part of screening bioretention studies:

- Systems with media filtration rates substantially higher than 12 inches per hour were excluded – while higher rate media has been found to provide good performance in some cases, the general trends observed by Roseen and Stone (2013) indicated a decline in performance for some parameters with increased infiltration rates.
- Systems with sizing factors (BMP area as fraction of tributary area) substantially smaller than the 3 to 5 percent (20:1 to 30:1 ratio of tributary area to BMP area) were excluded – this parameter is related to media filtration rate and is an indicator of the degree of hydraulic loading.
- Systems that were observed to have very infrequent underdrain discharge (i.e., mostly infiltration) were excluded – for these designs, the effluent that was sampled for water quality was likely not representative of the entire storm event.
- Systems with internal water storage zones were kept in the pool of data; these systems are believed to provide better control of nutrients than systems without internal water storage; Attachment H does not require internal water storage to be provided.
- Based on the findings of Roseen and Stone (2013) as well as recent research in Washington State, mixes with less compost and a higher fraction of sand than the Attachment H specification were kept in the sample pool because they are believed to provide more reliable performance and less potential for export of pollutants on average than a 70-30 sand/compost mix.
- Systems that contained media with experimental components were excluded.
- Finally, systems were excluded if there was not enough design information reported to be able to evaluate representativeness, and/or any other factors were noted by the original study researchers that were believed to contribute to poorer performance than average. For example, some studies were noted as underperforming studies due to construction issues, premature clogging, etc.

Overall, the screening that was applied is believed to improve the representativeness of the sample pool and generally increase the average performance of the sample pool compared to the entire pool of studies contained in the International BMP Database. As discussed above, establishing a higher baseline level of performance for conventional biofiltration is conservative in the context of this evaluation.

Screening Results

Table C.2 summarizes the number of data points for each constituent after applying screening to remove unrepresentative studies and without screening.

Table C.2. Summary of data points by parameter for conventional biofiltration BMPs

Constituent	Number of Screened Data Pairs	Number of Unscreened Data Pairs
Total Suspended Solids	234	354
Total Phosphorus	242	384
Total Nitrogen	71	184
Total Copper	190	216
Total Zinc	200	252

Inventory of Bioretention Studies and Screening Results/Rationales

Table C.4 (located at the end of this Appendix) provides an inventory of studies of bioretention with underdrains from the International BMP Database, screening results, and brief rationales for screening.

Compilation of MWS Linear Monitoring Studies

Data were compiled from two MWS Linear monitoring studies conducted in 2013 and 2014. The data from these two studies were found to cover the range of influent pollutant concentrations for the representative land uses. Both monitoring studies were based on full-scale field applications, were conducted by third-party entities, and employed flow weighted influent and effluent sampling of representatively sized MWS Linear systems under actual storm events. The following studies were used in this assessment with the number of data points included presented in Table C.3:

- **Herrera (2014a):** This assessment followed the Washington State Technology Acceptance Protocol-Ecology (TAPE) certification requirements. Storm event sampling of an MWS Linear system was conducted at the Albina Maintenance Facility in Portland, Oregon. Monitoring was conducted by Herrera Environmental Consultants. The sample results reported by the original researches were used in this evaluation.
- **United States Army Engineer Research and Development Center (USARDC, 2013):** Two MWS linear systems were evaluated by the US Army Research and Development Center at a site in Fort Hood, Texas. In addition to TSS and total zinc (reported below), total copper samples were obtained at this site. Total copper data were not included in this evaluation because four of six effluent samples were below the detection limit.

Table C.3. Inventory of evaluated MWS Linear studies and data points by parameter

Pollutant (total count of data pairs)	Data Pairs by Study	Reference
Total Suspended Solids (n = 47)	29	(Herrera, 2014)
	18	(USARDC, 2013)
Total Phosphorus (n=25)	25	(Herrera, 2014)
Total Nitrogen (n = 28)	28	(Herrera, 2014)
Total Copper (n = 29)	29	(Herrera, 2014)
Total Zinc (n = 47)	29	(Herrera, 2014)
	18	(USARDC, 2013)

Data Analysis Method

The most common ways to characterize BMP performance include (1) removal efficiency (percent removal) in various forms, and (2) effluent probability. In general, the effluent probability approach is recommended for evaluating BMP performance and applying BMP performance to pollutant load models (Geosyntec and Wright Water, 2009). This method involves conducting a statistical comparison of influent and effluent quality to determine if effluent is significantly different from influent. If effluent is significantly different from influent, then the effluent quality is characterized by a statistical distribution developed from all effluent data points. Probability plots are prepared indicating the probability that a certain effluent quality is achieved.

However, to isolate differences in performance between two BMP types, the effluent probability method requires the assumption that the influent quality was similar between the studies of the two BMP types being compared. This assumption is generally reliable for categorical analysis of BMPs in the International BMP Database because of the large number of studies in the most categories in the Database. However, when comparing BMP types with a relatively limited number of study sites (such as the MWS Linear dataset), this assumption may not be reliable.

To address these challenges and help ensure a valid comparison between conventional biofiltration and MWS Linear, a moving bootstrap method (Leisenring et al., 2009) was applied to both datasets. This method characterizes influent-effluent relationships such that the BMPs compared do not need to have been studied under conditions with similar influent quality. In this approach, all data pairs are used to form the total sample population. Then for each increment of influent quality, a subsample of the overall population is formed including only those data pairs that lie within a certain span of the selected influent quality. Applying bootstrap principles (Singh and Xie, 2008), the median or mean and the confidence interval around the median or mean is computed. Then a new increment of influent quality is selected, and the process is repeated with a new subsample population until a statistical description of effluent quality has been developed for each increment of influent quality over the range of the data. A minimum span of 5 was set for calculation of confidence intervals.

Resulting tables and plots from this analysis are presented in Appendix D.

Land Use Stormwater Quality Inputs and Assumptions

Representative stormwater runoff concentrations for the land use condition used in this analysis were developed based on the land use stormwater quality monitoring data reported in the Los Angeles County 1994-2000 Integrated Receiving Water Impacts Report, 2000 and Los Angeles County 2000-2001 Stormwater Monitoring Report, 2001(LA County 2000; LA County 2001). The median and mean runoff quality values from this dataset were used as representative influent water quality conditions for evaluating BMP performance. These concentrations represent only one land use monitoring station in one geographic area; actual conditions for a given drainage area in a given region are anticipated to vary. Beyond the range of water quality presented in this table, this analysis did not attempt to characterize the uncertainty/variability in runoff water quality. This simplification is considered appropriate for evaluating equivalency in BMP performance.

Land use runoff quality is reported in Appendix D.

Table C.4. Inventory of conventional biofiltration studies from the International BMP Database and screening rationale

Source	Site Name	Sponsoring Entity	State	City	Selected?	Selection/Rejection Reasons
Int. BMP Database	Rocky Mount Grassed Bioretention Cell 1	North Carolina State	NC	Rocky Mount	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Int. BMP Database	Rocky Mount Mulch/Shrub Bioretention Cell 1	North Carolina State	NC	Rocky Mount	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Int. BMP Database	CHS_BioFilter	The Thomas Jefferson Planning District Commission	VA	Charlottesville	Yes	Aligns with Att. H; Has internal water storage zone, underdrain, and mulch layer (0.25 feet)
Int. BMP Database	Parks & Forestry Bioretention	City of Overland Park	KS	Overland Park	Yes	Aligns with Att. H; Has internal water storage zone, underdrain, and mulch layer
Int. BMP Database	Bioretention 6	Johnson County	KS	Shawnee	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Int. BMP Database	G2	North Carolina State	NC	Greensboro	Yes	Aligns with Att. H; Has underdrain, and mulch layer (7-10 cm)
Int. BMP Database	G1	North Carolina State	NC	Greensboro	Yes	Aligns with Att. H; Has underdrain, and mulch layer (7-10 cm)
Int. BMP Database	L1	North Carolina State	NC	Louisburg	Yes	Aligns with Att. H; Appropriate loading ratio
Int. BMP Database	Bioretention 3B	Johnson County	KS	Shawnee	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Int. BMP Database	Parking Lot Bioretention Cell	City of Fort Collins	CO	Fort Collins	Yes	Aligns with Att. H; Has internal water storage zone and mulch layer
Int. BMP Database	Bioretention Cells	Johnson County SMP	KS	Overland Park	Yes	Aligns with Att. H; Has internal water storage zone, underdrain, and mulch layer
Int. BMP Database	Bioretention Cell	Johnson County SMP	KS	Overland Park	Yes	Aligns with Att. H; Has internal water storage zone and underdrain

Source	Site Name	Sponsoring Entity	State	City	Selected?	Selection/Rejection Reasons
Int. BMP Database	Bioretention System (D1)	UNH/Cooperative Institute for Coastal and Estuarine Environmental Technology	NH	Durham	Yes	Aligns with Att. H; Has pretreatment, internal water storage zone, underdrain, and mulch layer
Int. BMP Database	UDFCD Rain Garden	Urban Drainage and Flood Control District	CO	Lakewood	Yes	Aligns with Att. H; Has internal water storage zone, underdrain, and compost layer
Int. BMP Database	Hal Marshall Bioretention Cell	City of Charlotte, North Carolina	NC	Charlotte	Yes	Aligns with Att. H; Has underdrain, and mulch layer
Int. BMP Database	Rocky Mount Grassed Bioretention Cell 2	The Cooperative Institute for Coastal and Estuarine Environmental Technology	NC	Rocky Mountain	Yes	Aligns with Att. H; Has internal water storage zone and underdrain
Li and Davis (2009)	Bioretention Cell 1	Prince George's County Department of Environmental Resources/ U of MD	MD	College Park	Yes	Aligns with Att. H
Li and Davis (2009)	Bioretention Cell 2	Prince George's County Department of Environmental Resources/U of MD	MD	Silver Spring	Yes	Aligns with Att. H
Davis (2007)	Bioretention Cell 1	Prince George's County Department of Environmental Resources/U of MD	MD	College Park	Yes	Aligns with Att. H
David et al. (2011)	Daly City Library Rain Gardens	San Francisco Estuary Institute	CA	Daly City	Yes	Aligns with Att. H
Gilbreath et al. (2012)	San Pablo Ave Green Streets	San Francisco Estuary Institute	CA	El Cerrito	Yes	Aligns with Att. H
Int. BMP Database	Bioretention Area	Virginia Department of Conservation and Recreation	VA	Charlottesville	No	Not enough design info provided
Int. BMP Database	Small Cell	North Carolina Department of Transportation	NC	Knightdale	No	Infiltration rate low; noted to be underperforming BMP by study researchers
Int. BMP Database	BRC_B	North Carolina State	NC	Nashville	No	Infiltration too low and undersized
Int. BMP Database	North cell	North Carolina State	NC	Raleigh	No	Media very different from Att. H
Int. BMP Database	WA Ecology Embankment at SR 167 MP 16.4	Washington State Dept. of Transportation	WA	Olympia	No	Linear design; lateral flow; not representative of typical biofiltration design

Source	Site Name	Sponsoring Entity	State	City	Selected?	Selection/Rejection Reasons
Int. BMP Database	Bioretention Cell	Delaware Department of Transportation	DE	Dover	No	Design is very different from Att. H
Int. BMP Database	East 44th St. Pond	City of Tacoma	WA	Tacoma	No	No design data
Int. BMP Database	Tree Filter	UNH/Cooperative Institute for Coastal and Estuarine Environmental Technology	NH	Durham	No	Design is very different from Att. H
Int. BMP Database	BRC_A	North Carolina State University	NC	Raleigh	No	Infiltration rate very low; noted to be a partially clogged/failing system
Int. BMP Database	Cub_Run_Bioretention	Fairfax County	VA	Fairfax	No	No design data provided
Int. BMP Database	South cell	North Carolina State University (BAE)	NC	Raleigh	No	Design is very different from Att. H
Int. BMP Database	R Street	City of Tacoma	WA	Tacoma	No	No design data provided

APPENDIX D – RESULTS OF POLLUTANT TREATMENT DATA ANALYSIS

The data analysis methods described in Appendix C were applied to the datasets described in Appendix C. The following pages present tabular and graphical results of this analysis.

Table D.1 compares the mean and median summary statistics and confidence intervals from the moving window bootstrap analysis between the conventional biofiltration datasets and the MWS Linear datasets. The screened dataset refers to the 20 studies described in Appendix C that were considered representative of MS4 Permit Attachment criteria. The unscreened dataset includes all bioretention studies available in the International BMP Database as of 2015. These datasets are described in Appendix C.

Figure D.1 shows plots of the data analysis results based on the median statistic. Figure D.2 shows plots of the data analysis results based on the mean statistic.

Table D.1 Summary Statistics of Moving Window Bootstrap Analysis – Bioretention and MWS Studies

Median Statistics

Land Use	Pollutant	Units	Median Representative Runoff Quality	Traditional Biofiltration Effluent (Screened)		Traditional Biofiltration Effluent (Unscreened)		MWS Linear Effluent	
				Median	95th Percentile UCL on Median	Median	95th Percentile UCL on Median	Median	95th Percentile UCL on Median
Commercial	TSS	mg/L	53	12	13.7	11	12	12.8	17.2
	Total Phosphorus	mg/L	0.27	**0.46**	0.55	0.26	0.37	0.08	0.14
	Total Nitrogen	mg/L	2.3	1.6	2.9	1.19	1.52	1.77	2.75
	Copper	µg/L	22	12	15	12	14	10.3	12.9
	Zinc	µg/L	192	35	44	36	40	48.8	72.8
High Density Single Family Residential	TSS	mg/L	61	12	15	12	13	13	17.2
	Total Phosphorus	mg/L	0.32	**0.47**	0.55	0.28	0.43	0.1	0.19
	Total Nitrogen	mg/L	2	1.6	2.9	1.2	1.5	1.41	1.56
	Copper	µg/L	11	5.3	5.9	5.3	6.4	6.5	8
	Zinc	µg/L	66	20	27	18	26	39.5	53.5
Light Industrial	TSS	mg/L	129	16	18	16	18	17	19.4
	Total Phosphorus	mg/L	0.3	**0.47**	0.55	0.27	0.42	0.09	0.17
	Total Nitrogen	mg/L	2.4	1.6	2.9	1.2	1.5	1.8	2.75
	Copper	µg/L	21	12	15	12	13.85	10	12.6
	Zinc	µg/L	366	35	44	36	40	48.8	73.6
Multi-family Residential	TSS	mg/L	24	10.8	12.5	9.9	9.9	4.05	5.7
	Total Phosphorus	mg/L	0.14	**0.39**	0.45	**0.21**	0.25	0.04	0.05
	Total Nitrogen	mg/L	1.5	**1.6**	2.9	1.2	1.5	0.94	1.04
	Copper	µg/L	12	5.6	6.1	5.6	6.6	7	9
	Zinc	µg/L	89	20	27	18	26	39.5	53.5

Mean Statistics

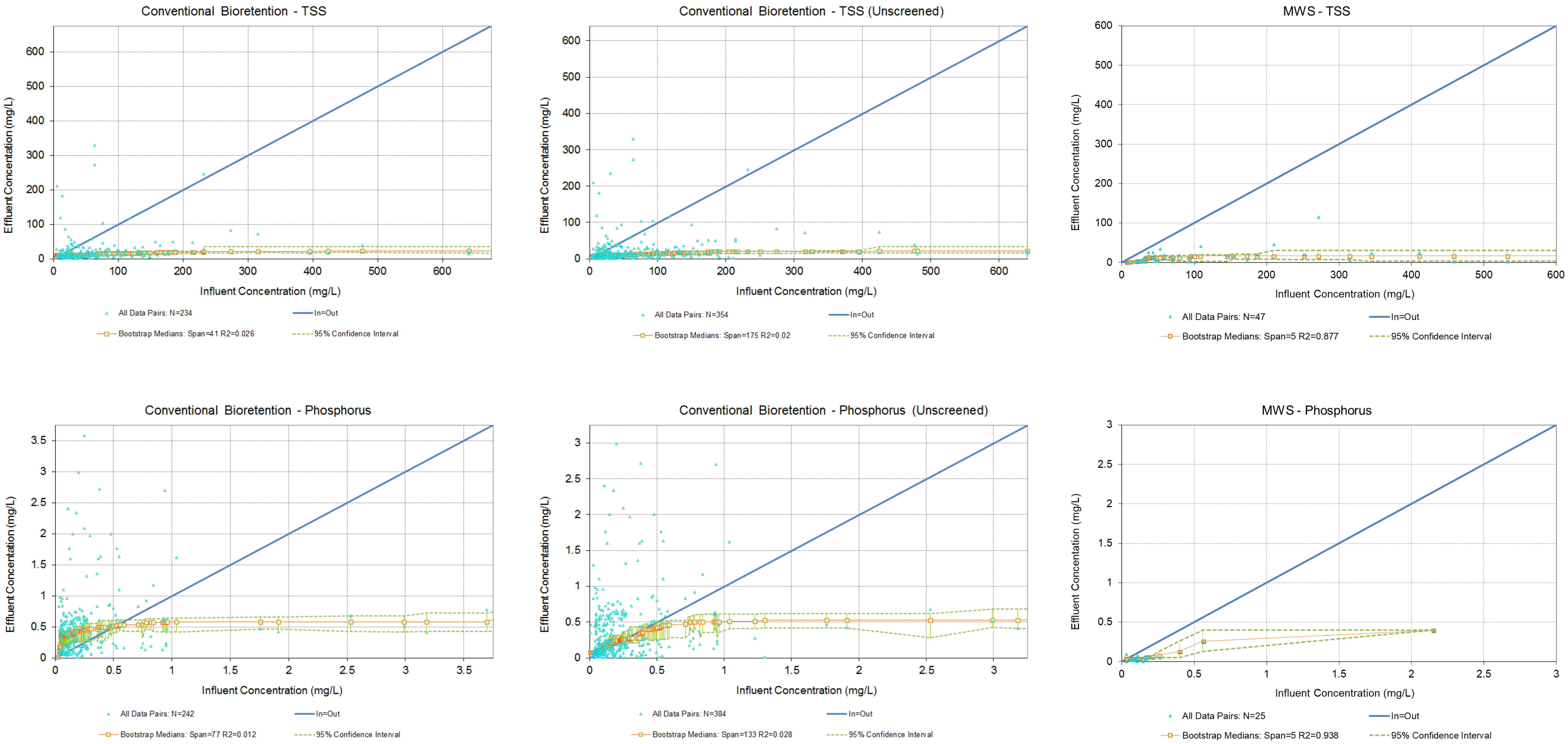
Land Use	Pollutant	Units	Median Representative Runoff Quality	Traditional Biofiltration Effluent (Screened)		Traditional Biofiltration Effluent (Unscreened)		MWS Linear Effluent	
				Mean	95th Percentile UCL on Mean	Mean	95th Percentile UCL on Mean	Mean	95th Percentile UCL on Mean
Commercial	TSS	mg/L	66	28	49	25	39	14.1	6.24
	Total Phosphorus	mg/L	0.39	**0.8**	1.3	**0.65**	1	0.17	0.27
	Total Nitrogen	mg/L	3.6	2.9	4.3	2.1	2.8	2.28	2.8
	Copper	µg/L	39	19	29	16	24	20.6	33
	Zinc	µg/L	241	65	145	59	108	49.4	70.9
High Density Single Family Residential	TSS	mg/L	95	28	49	25	39	14.1	2.3
	Total Phosphorus	mg/L	0.39	**0.8**	1.3	**0.65**	1	0.17	0.27
	Total Nitrogen	mg/L	3	2.9	4.3	2.1	2.8	2.28	2.80
	Copper	µg/L	15	13	21	13	19	8.75	8.75
	Zinc	µg/L	79	33	50	32	46	39.5	55.1
Light Industrial	TSS	mg/L	240	46	105	40	87	28.5	10.6
	Total Phosphorus	mg/L	0.41	**0.8**	1.3	**0.65**	1	0.18	0.28
	Total Nitrogen	mg/L	3.1	2.9	4.3	2.1	2.8	2.28	2.8
	Copper	µg/L	32	19	29	16	24	15.5	33
	Zinc	µg/L	639	**NA**	NA	59	108	80	110
Multi-family Residential	TSS	mg/L	46	18	28	18	27	14.1	4.92
	Total Phosphorus	mg/L	0.2	**0.8**	1.3	**0.6**	1	0.07	0.09
	Total Nitrogen	mg/L	2.1	**2.9**	4.3	2.1	2.8	2.01	2.64
	Copper	µg/L	12	10	15	9	14	7	8.75
	Zinc	µg/L	146	45	90	32	46	46.3	66

NA: Average values could not be computed because the land use average influent was outside the range of influent observed in monitoring studies.

Red bold indicates median or mean effluent concentrations are greater than influent concentration. This is indicative of the potential for pollutant export.

Blue indicates upper confidence interval of effluent concentration is greater than the influent concentration. This is not a conclusive indicator but is provided for reference.

Figure D.1 Moving Window Bootstrap Plots of Medians



Screened Biofiltration Dataset

Unscreened Biofiltration Dataset

MWS Dataset

Figure D.1 Moving Window Plots of Medians (Cont.)

Screened Biofiltration Dataset

Unscreened Biofiltration Dataset

MWS Dataset

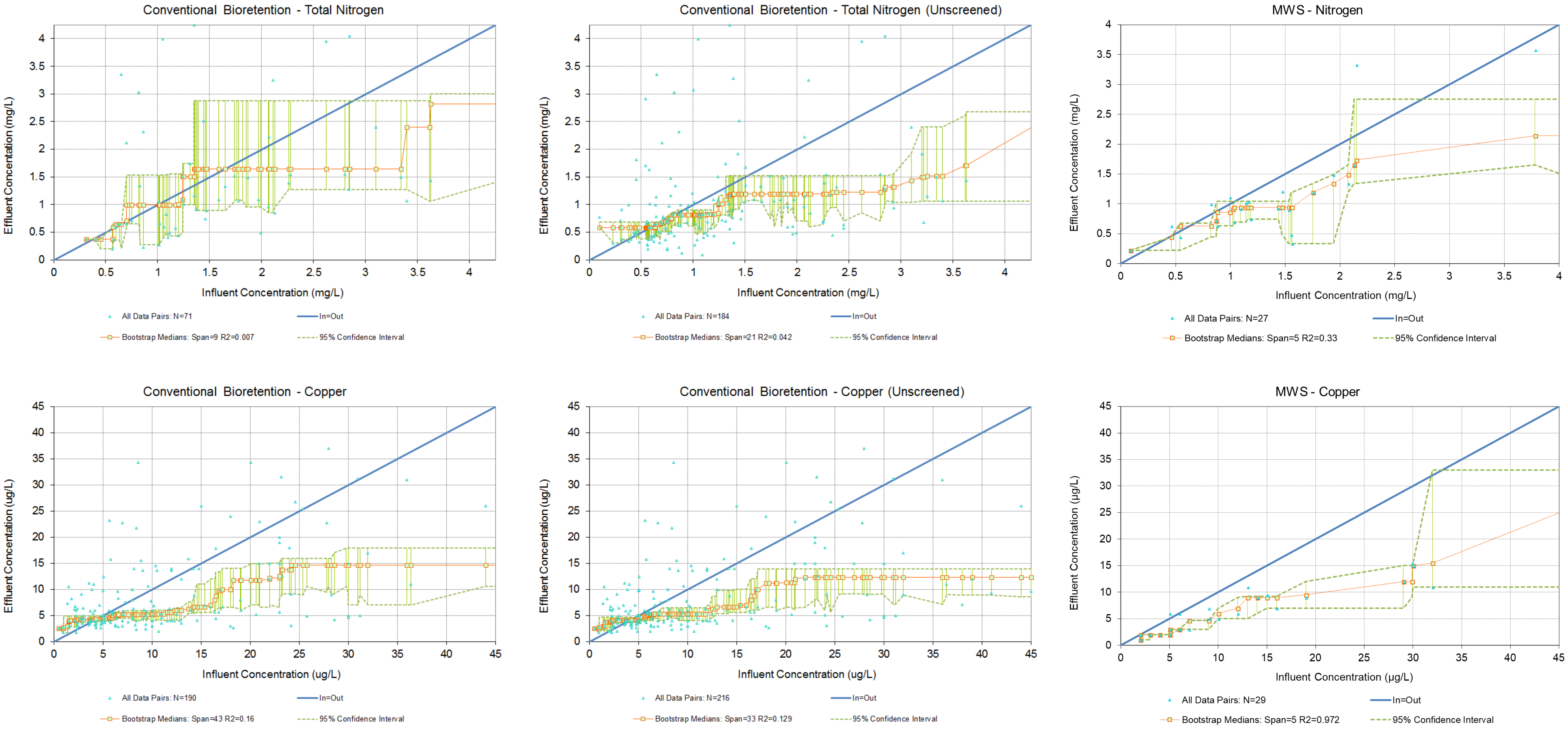
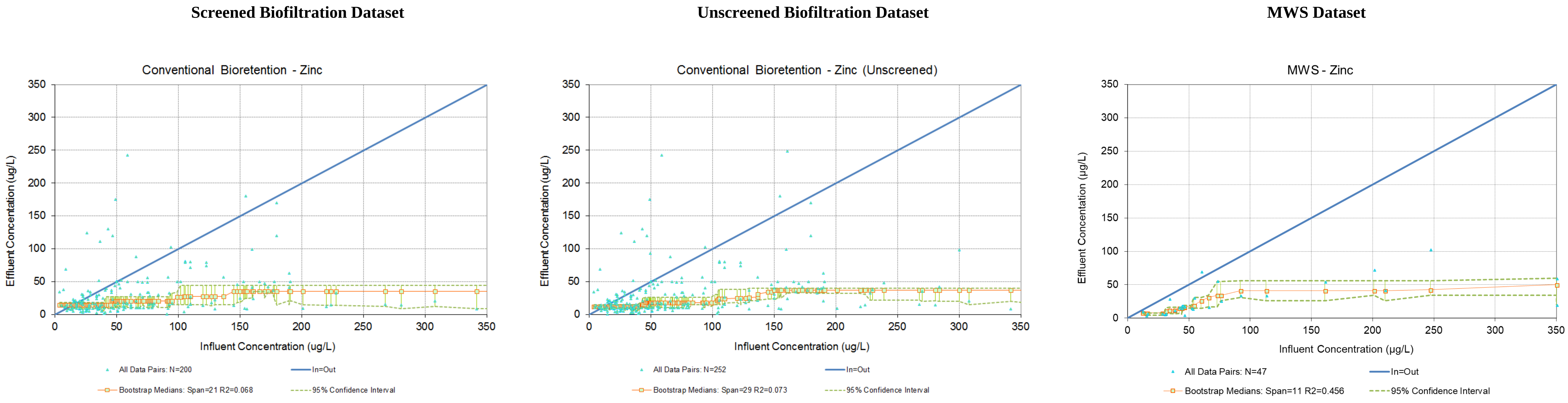


Figure D.1 Moving Window Plots of Medians (Cont.)


Screened Biofiltration Dataset

Unscreened Biofiltration Dataset

MWS Dataset

Figure D.2 Moving Window Bootstrap Plots of Means

Screened Biofiltration Dataset

Unscreened Biofiltration Dataset

MWS Dataset

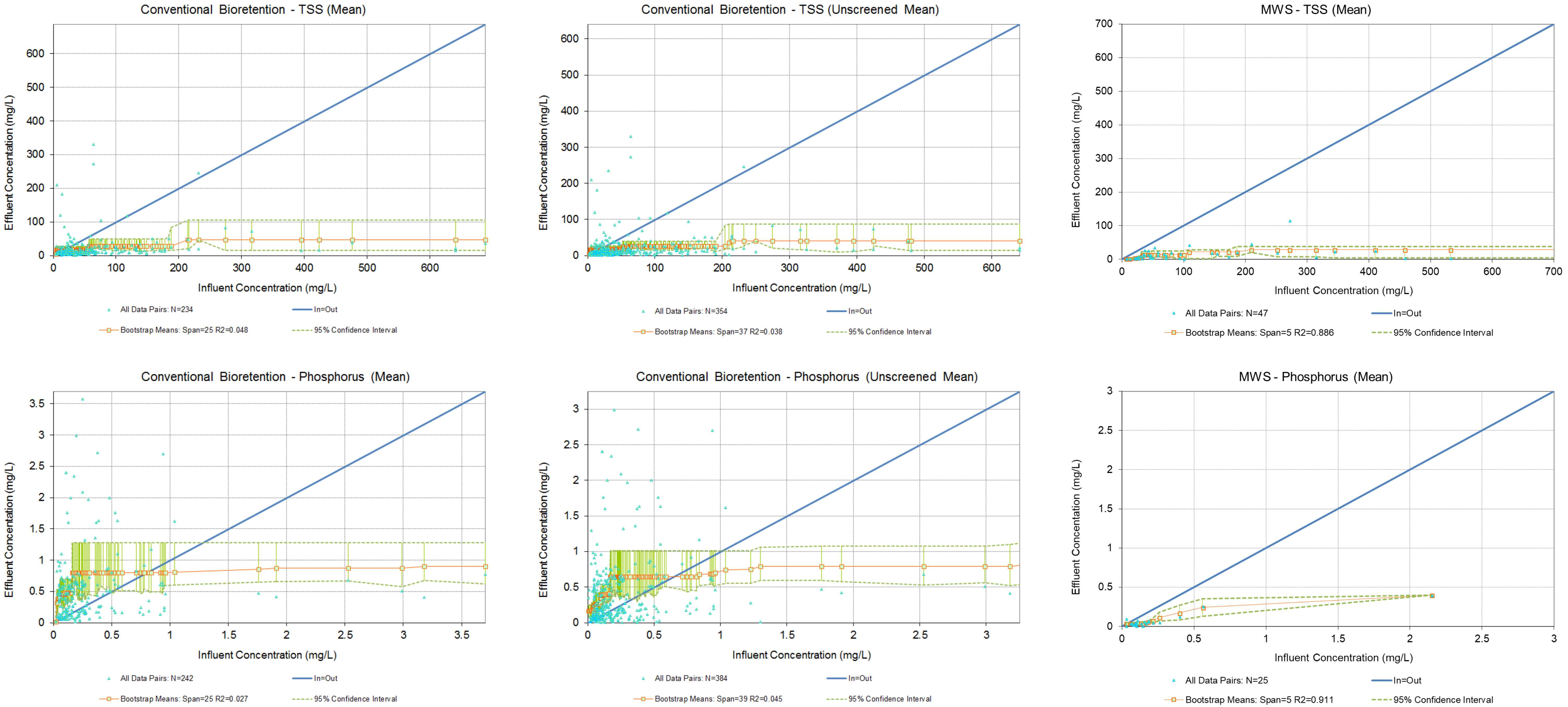


Figure D.2 Moving Window Plots of Means (Cont.)

Screened Biofiltration Dataset | **Unscreened Biofiltration Dataset** | **MWS Dataset**

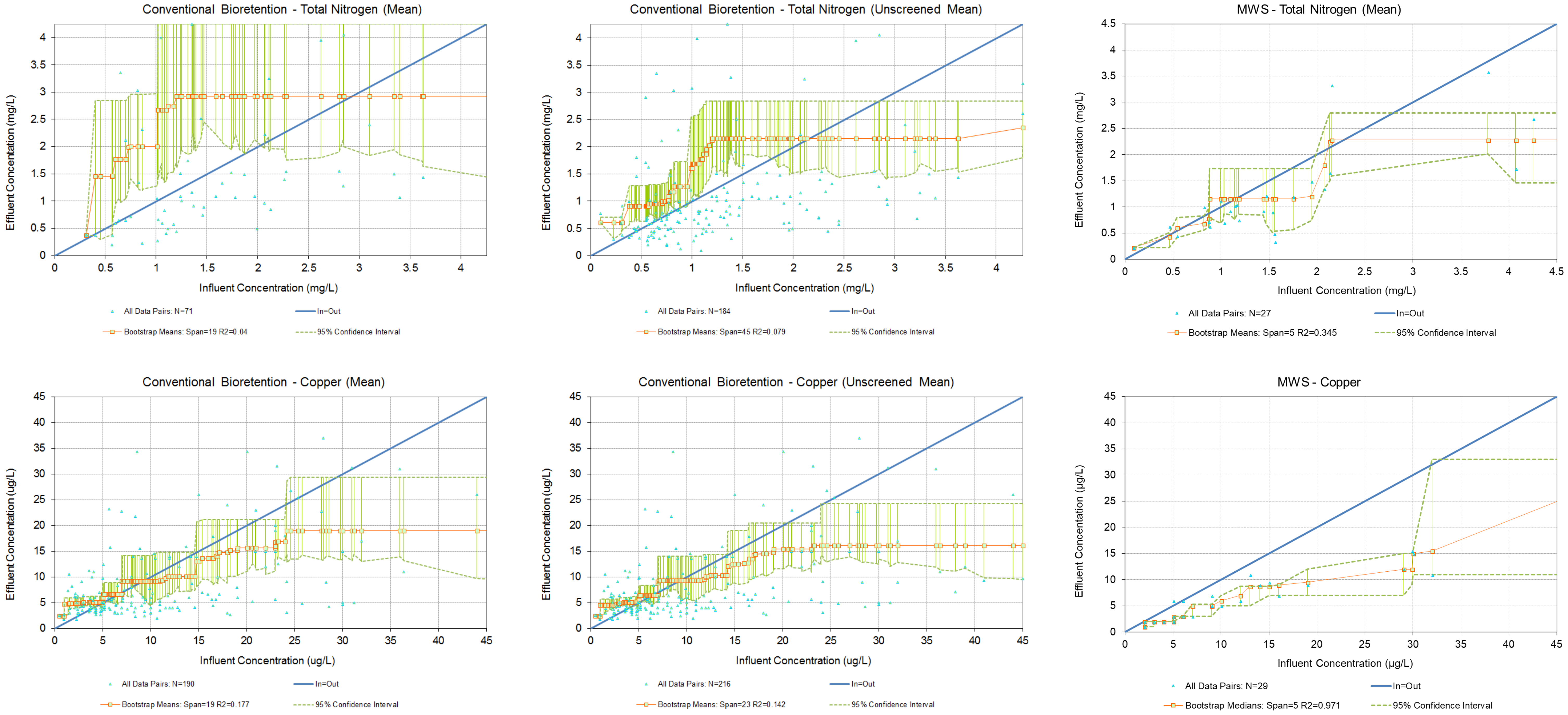
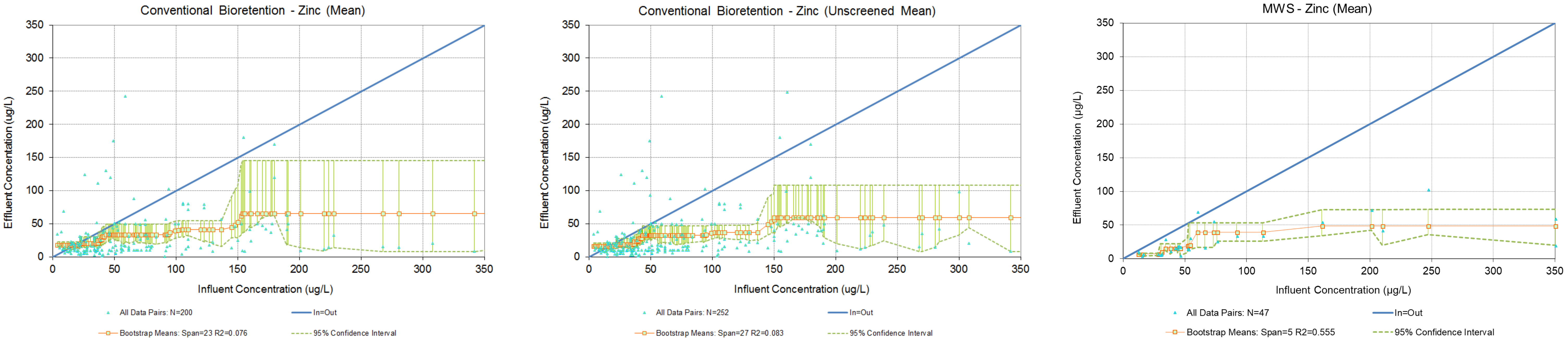


Figure D.2 Moving Window Plots of Means (Cont.)



Screened Biofiltration Dataset

Unscreened Biofiltration Dataset

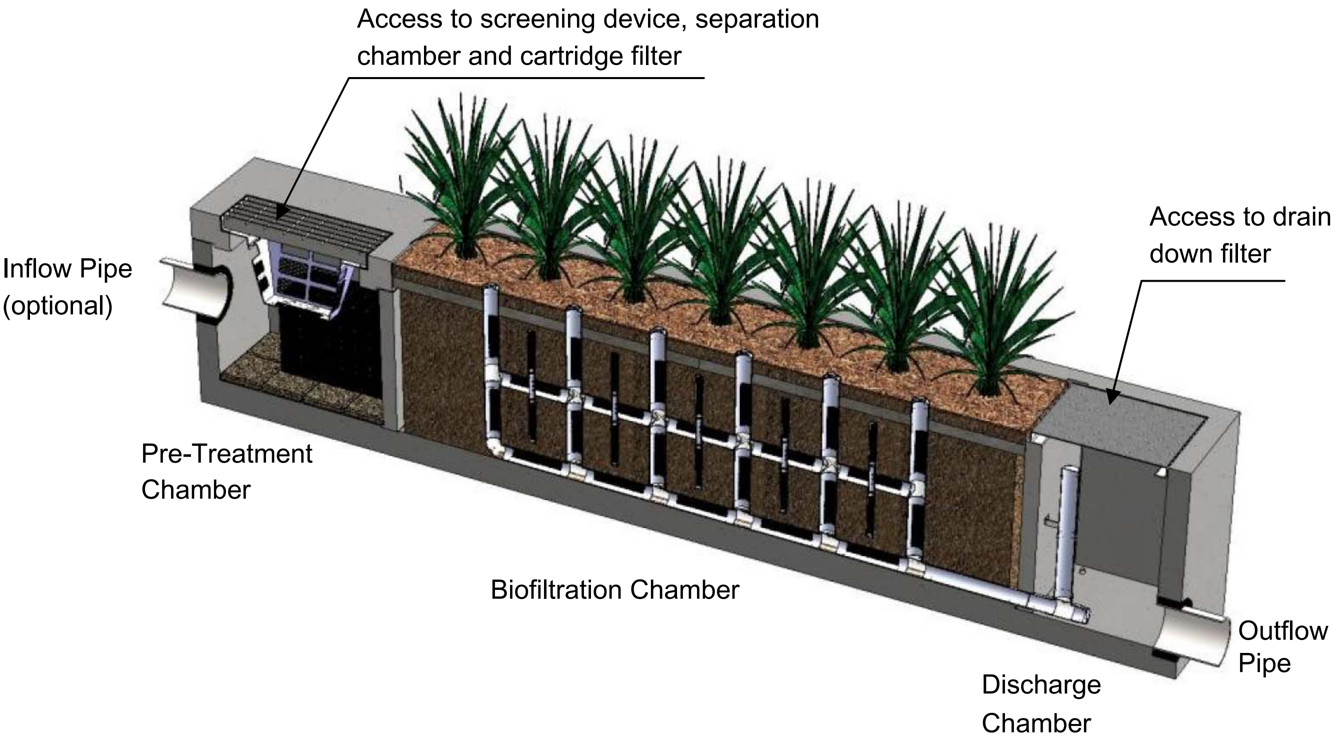
MWS Dataset

Maintenance Guidelines for
Modular Wetland System - Linear

Maintenance Summary

- Remove Trash from Screening Device – average maintenance interval is 6 to 12 months.
    - (*5 minute average service time*).
- Remove Sediment from Separation Chamber – average maintenance interval is 12 to 24 months.
    - (*10 minute average service time*).
- Replace Cartridge Filter Media – average maintenance interval 12 to 24 months.
    - (*10-15 minute per cartridge average service time*).
- Replace Drain Down Filter Media – average maintenance interval is 12 to 24 months.
    - (*5 minute average service time*).
- Trim Vegetation – average maintenance interval is 6 to 12 months.
    - (*Service time varies*).

System Diagram



Maintenance Procedures

Screening Device

1. Remove grate or manhole cover to gain access to the screening device in the Pre-Treatment Chamber. Vault type units do not have screening device. Maintenance can be performed without entry.
2. Remove all pollutants collected by the screening device. Removal can be done manually or with the use of a vacuum truck. The hose of the vacuum truck will not damage the screening device.
3. Screening device can easily be removed from the Pre-Treatment Chamber to gain access to separation chamber and media filters below. Replace grate or manhole cover when completed.

Separation Chamber

1. Perform maintenance procedures of screening device listed above before maintaining the separation chamber.
2. With a pressure washer spray down pollutants accumulated on walls and cartridge filters.
3. Vacuum out Separation Chamber and remove all accumulated pollutants. Replace screening device, grate or manhole cover when completed.

Cartridge Filters

1. Perform maintenance procedures on screening device and separation chamber before maintaining cartridge filters.
2. Enter separation chamber.
3. Unscrew the two bolts holding the lid on each cartridge filter and remove lid.
4. Remove each of 4 to 8 media cages holding the media in place.
5. Spray down the cartridge filter to remove any accumulated pollutants.
6. Vacuum out old media and accumulated pollutants.
7. Reinstall media cages and fill with new media from manufacturer or outside supplier. Manufacturer will provide specification of media and sources to purchase.
8. Replace the lid and tighten down bolts. Replace screening device, grate or manhole cover when completed.

Drain Down Filter

1. Remove hatch or manhole cover over discharge chamber and enter chamber.
2. Unlock and lift drain down filter housing and remove old media block. Replace with new media block. Lower drain down filter housing and lock into place.
3. Exit chamber and replace hatch or manhole cover.

Maintenance Notes

1. Following maintenance and/or inspection, it is recommended the maintenance operator prepare a maintenance/inspection record. The record should include any maintenance activities performed, amount and description of debris collected, and condition of the system and its various filter mechanisms.

2. The owner should keep maintenance/inspection record(s) for a minimum of five years from the date of maintenance. These records should be made available to the governing municipality for inspection upon request at any time.

3. Transport all debris, trash, organics and sediments to approved facility for disposal in accordance with local and state requirements.

4. Entry into chambers may require confined space training based on state and local regulations.

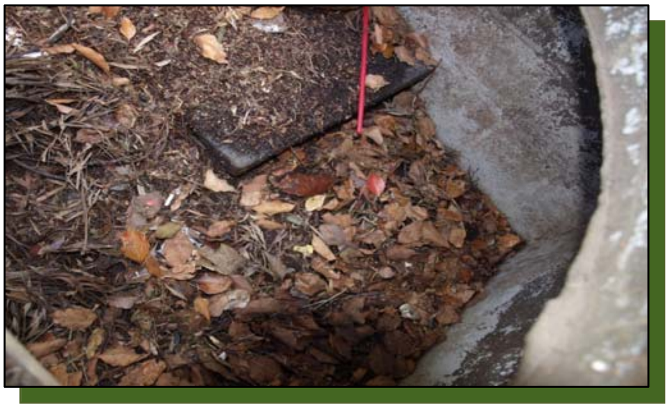
5. No fertilizer shall be used in the Biofiltration Chamber.

6. Irrigation should be provided as recommended by manufacturer and/or landscape architect. Amount of irrigation required is dependent on plant species. Some plants may require irrigation.

Maintenance Procedure Illustration

Screening Device

The screening device is located directly under the manhole or grate over the Pre-Treatment Chamber. It's mounted directly underneath for easy access and cleaning. Device can be cleaned by hand or with a vacuum truck.

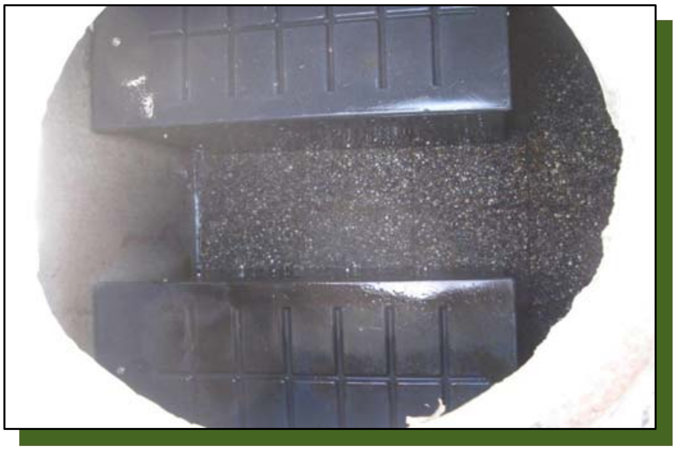


Separation Chamber

The separation chamber is located directly beneath the screening device. It can be quickly cleaned using a vacuum truck or by hand. A pressure washer is useful to assist in the cleaning process.

Cartridge Filters

The cartridge filters are located in the Pre-Treatment chamber connected to the wall adjacent to the biofiltration chamber. The cartridges have removable tops to access the individual media filters. Once the cartridge is open media can be easily removed and replaced by hand or a vacuum truck.



Drain Down Filter

The drain down filter is located in the Discharge Chamber. The drain filter unlocks from the wall mount and hinges up. Remove filter block and replace with new block.

Trim Vegetation

Vegetation should be maintained in the same manner as surrounding vegetation and trimmed as needed. No fertilizer shall be used on the plants. Irrigation per the recommendation of the manufacturer and or landscape architect. Different types of vegetation requires different amounts of irrigation.

Inspection Form

Modular Wetland System, Inc.
P. 760.433-7640
F. 760-433-3176
E. Info@modularwetlands.com

www.modularwetlands.com

Inspection Report
Modular Wetlands System

Project Name ______________________

Project Address ______________________ (city) (Zip Code)

Owner / Management Company ______________________

Contact ______________________ Phone (   )   –

Inspector Name ______________________ Date ____/____/______ Time __________ AM / PM

Type of Inspection ☐ Routine ☐ Follow Up ☐ Complaint ☐ Storm Storm Event in Last 72-hours? ☐ No ☐ Yes

Weather Condition ______________________ Additional Notes ______________________

For Office Use Only
(Reviewed By)
(Date) Office personnel to complete section to the left.

Inspection Checklist

Modular Wetland System Type (Curb, Grate or UG Vault): __________ Size (22', 14' or etc.): __________

Structural Integrity:	**Yes**	**No**	**Comments**
Damage to pre-treatment access cover (manhole cover/grate) or cannot be opened using normal lifting pressure?			
Damage to discharge chamber access cover (manhole cover/grate) or cannot be opened using normal lifting pressure?			
Does the MWS unit show signs of structural deterioration (cracks in the wall, damage to frame)?			
Is the inlet/outlet pipe or drain down pipe damaged or otherwise not functioning properly?			
Working Condition:			
Is there evidence of illicit discharge or excessive oil, grease, or other automobile fluids entering and clogging the unit?			
Is there standing water in inappropriate areas after a dry period?			
Is the filter insert (if applicable) at capacity and/or is there an accumulation of debris/trash on the shelf system?			
Does the depth of sediment/trash/debris suggest a blockage of the inflow pipe, bypass or cartridge filter? If yes, specify which one in the comments section. Note depth of accumulation in in pre-treatment chamber.			Depth:
Does the cartridge filter media need replacement in pre-treatment chamber and/or discharge chamber?			Chamber:
Any signs of improper functioning in the discharge chamber? Note issues in comments section.			
Other Inspection Items:			
Is there an accumulation of sediment/trash/debris in the wetland media (if applicable)?			
Is it evident that the plants are alive and healthy (if applicable)? Please note Plant Information below.			
Is there a septic or foul odor coming from inside the system?			

Waste:	**Yes**	**No**
Sediment / Silt / Clay		
Trash / Bags / Bottles		
Green Waste / Leaves / Foliage		

Recommended Maintenance	
No Cleaning Needed	
Schedule Maintenance as Planned	
Needs Immediate Maintenance	

Plant Information	
Damage to Plants	
Plant Replacement	
Plant Trimming	

Additional Notes: ______________________

Maintenance Report

Modular Wetland System, Inc.
P. 760.433-7640
F. 760-433-3176
E. Info@modularwetlands.com

www.modularwetlands.com

Cleaning and Maintenance Report
Modular Wetlands System

Project Name ______________________________

Project Address ______________________________ (city) (Zip Code)

Owner / Management Company ______________________________

Contact ____________________ Phone ( ) –

Inspector Name ____________________ Date ____ / ____ / ______ Time ________ AM / PM

Type of Inspection ☐ Routine ☐ Follow Up ☐ Complaint ☐ Storm Storm Event in Last 72-hours? ☐ No ☐ Yes

Weather Condition ____________________ Additional Notes ____________________

For Office Use Only

(Reviewed By)

(Date)

Office personnel to complete section to the left.

Site Map #	GPS Coordinates of Insert	Manufacturer / Description / Sizing	Trash Accumulation	Foliage Accumulation	Sediment Accumulation	Total Debris Accumulation	Condition of Media 25/50/75/100 (will be changed @ 75%)	Operational Per Manufactures' Specifications (If not, why?)
	Lat: Long:	MWS Catch Basins						
		MWS Sedimentation Basin						
		Media Filter Condition						
		Plant Condition						
		Drain Down Media Condition						
		Discharge Chamber Condition						
		Drain Down Pipe Condition						
		Inlet and Outlet Pipe Condition						

Comments:

GEOTECHNICAL INVESTIGATION

Vivian Street Townhomes
88 Vivian Street
San Rafael, California

PREPARED FOR:

ASHTON 3, LLC
5 HOYA STREET
RANCHO MISSION VIEJO, CALIFORNIA 92694

ASHTON 3

PREPARED BY:

GEOCON CONSULTANTS, INC.
6671 BRISA STREET
LIVERMORE, CALIFORNIA 94550

GEOCON

GEOCON PROJECT NO. E9226-04-01 **JANUARY 2021**

GEOCON
CONSULTANTS, INC.
GEOTECHNICAL ■ ENVIRONMENTAL ■ MATERIALS

Project No. E9226-04-01
January 22, 2021

Ashton 3, LLC
5 Hoya Street
Rancho Mission Viejo, California 92694

Attention: Mr. Taylor Ashton

Subject: 88 VIVIAN STREET
SAN RAFAEL, CALIFORNIA
GEOTECHNICAL INVESTIGATION

Dear Mr. Ashton:

In accordance with your authorization, we have performed a geotechnical investigation for subject site in San Rafael, California. Our investigation was performed to observe the soil and geologic conditions that may impact site development for the proposed townhome project. The accompanying report presents the results of our investigation and geotechnical conclusions and recommendations. The findings of this study indicate the site is suitable for development as planned provided the recommendations of this report are implemented during design and construction.

If you have any questions regarding this report, or if we may be of further service, please contact the undersigned at your convenience.

Sincerely,

GEOCON CONSULTANTS, INC.

DRAFT

Andre E. Ashour, PE
Senior Project Engineer

DRAFT

Shane Rodacker, GE
Senior Engineer

(1/e-mail) Addressee

TABLE OF CONTENTS

GEOTECHNICAL INVESTIGATION

1. PURPOSE AND SCOPE

This report presents the results of a geotechnical investigation for a proposed townhome development at 88 Vivian Street in San Rafael, California (see Vicinity Map, Figure 1). The purpose of this investigation was to evaluate the subsurface soil and geologic conditions in the areas of the planned development and provide conclusions and recommendations pertaining to the geotechnical aspects of project design and construction, based on the conditions encountered during our study.

The scope of this investigation included field exploration, laboratory testing, engineering analysis and the preparation of this report. Our field exploration consisted of four soil borings drilled on November 19, 2020 to maximum depths of about 25 feet and three Cone Penetrometer Tests (CPTs) advanced on November 10, 2020 to depths ranging from about 82 to about 90 feet below the existing grade. Seismic shear wave velocity measurements were collected from one of the CPTs. The locations of our explorations are depicted on the Site Plan, Figure 2. A detailed discussion of our field investigation, boring logs and CPT profiles are presented in Appendix A.

Laboratory tests were performed on selected soil samples obtained during the investigation to evaluate pertinent physical properties for engineering analyses. In addition, three soil samples were submitted to our laboratory for screening-level corrosion testing. Laboratory test results are presented in Appendix B. Figures related to our site-specific ground motion hazard analysis are presented in Appendix C. Our liquefaction analysis is included as Appendix D.

The opinions expressed herein are based on analysis of the data obtained during the investigation and our experience with similar soil and geologic conditions. References reviewed to prepare this report are provided in the *List of References* section.

If project details vary significantly from those described herein, Geocon should be contacted to determine the necessity for review and possible revision of this report.

2. SITE CONDITIONS AND PROJECT DESCRIPTION

The site is a 2.41-acre parcel (Marin Co. APN 008-092-02) on the southeastern side of Vivian Street. The site is currently occupied by the one- to two-story Country Club Bowl building with at-grade parking in the southwestern portion of the parcel. The site is relatively flat with ground surface elevations of approximately 5 feet above Mean Seal Level (MSL) per web-based mapping. Existing development in the immediate site vicinity generally consists of one- to two-story industrial, multi-family, and commercial buildings.

Based on the site development plan that you provided, we understand that all existing improvements will be razed, and the site will be redeveloped as a 66-unit multifamily residential community. The new residential structures (townhomes) will be up to three stories in height with no subterranean levels. Landscaping, at-grade asphalt parking and driveways, utilities and other improvements necessary for the site development are also expected. Grading plans were not provided; we understand that cuts and fills to attain design subgrade elevation will be minimal.

3. GEOLOGIC SETTING

San Rafael is located within the Coast Ranges Geomorphic Province of California, which is characterized by a series of northwest trending mountains and valleys along the north and central coast of California. Topography is controlled by the predominant geological structural trends within the Coast Range that generally consist of northwest trending synclines, anticlines and faulted blocks. The dominant structure is a result of both active northwest trending strike-slip faulting, associated with the San Andreas Fault system, and east-west compression within the province.

The San Andreas Fault (SAF) is a major right-lateral strike-slip fault that extends from the Gulf of California in Mexico to Cape Mendocino in northern California. The SAF forms a portion of the boundary between two tectonic plates on the surface of the earth. To the west of the SAF is the Pacific Plate, which moves north relative to the North American Plate, located east of the fault. In the San Francisco Bay Area, movement across this plate boundary is concentrated on the SAF but also distributed, to a lesser extent, across several other faults including the Hayward, Calaveras and Rodgers Creek faults, among others. Together, these faults are referred to as the SAF system.

Basement rock west of the SAF is generally granitic, while to the east it consists of a chaotic mixture of highly deformed marine sedimentary, submarine volcanic and metamorphic rocks of the Franciscan Complex. Both are typically Jurassic to Cretaceous in age (205 to 65 million years old). Overlying the basement rocks are Cretaceous (about 140 to 65 million years old) marine, as well as Tertiary (about 65 to 1.6 million years old) marine and non-marine sedimentary rocks with some continental volcanic rock. These Cretaceous and Tertiary rocks have typically been extensively folded and faulted largely because of movement along the SAF system, which has been ongoing for about the last 25 million years, and regional compression during the last about 4 million years. The inland valleys, as well as the structural depression within which San Francisco Bay is located, are filled with unconsolidated to semi-consolidated deposits of Quaternary age (about the last 1.6 million years). Continental deposits (alluvium) consist of unconsolidated to semi-consolidated sand, silt, clay and gravel, while the bay deposits typically consist of soft organic-rich silt and clay (bay mud) or sand.

Available geologic mapping by the United States Geological Survey (USGS) indicates the site vicinity is in an area of artificial fill over Quaternary-age marine and marsh deposits (Bay Mud).

4. GEOLOGIC HAZARDS

4.1 Faulting and Seismicity

Geologists and seismologists recognize the greater San Francisco Bay Area as one of the most active seismic regions in the United States. The significant earthquakes that occur in the Bay Area are associated with crustal movements along well-defined active fault zones that generally trend in a northwesterly direction.

The San Francisco Bay Area is seismically dominated by the presence of the active San Andreas Fault System. In the theory of plate tectonics, the San Andreas Fault System is a transform fault that forms the boundary between the northward moving Pacific Plate (west of the fault) and the southward moving North American Plate (east of the fault). In the Bay Ares, the movement is distributed across a complex system of strike-slip, right lateral parallel and subparallel faults, which include the San Andreas, Hayward and Calaveras Faults, among others.

The table below presents approximate distances to active faults within approximately 25 miles of the site based on web-based mapping by CGS, as previously published by Caltrans. WGS 84 site coordinates are N 37.9634°, W 122.5081°.

TABLE 4.1
REGIONAL FAULT SUMMARY

Fault Name	Distance to Site (miles)	Maximum Earthquake Magnitude, M_w
Hayward (North)	7¾	7.3
San Andreas	8¾	8.0
San Gregorio	10¼	7.4
Rodgers Creek	14½	7.3
Contra Costa Shear Zone	19	6.5
West Napa	19½	6.6
Concord	22¾	6.6
Green Valley	24	6.8

The faults tabulated above and numerous other faults in the Bay Area are sources of potential ground motion. However, earthquakes that might occur on other faults within the northern and central California area are also potential generators of significant ground motion and could subject the site to intense ground shaking. The faults and distances tabulated above are intended to acquaint the reader with the seismic setting of the site; this information is not intended to be a basis for our ground motion hazard analysis.

4.2 Surface Fault Rupture

The site is not within a currently established State of California Earthquake Fault Zone for surface fault rupture hazards. No active or potentially-active faults are known to pass directly beneath the site. Therefore, the potential for surface rupture due to faulting occurring beneath the site during the design life of the proposed development is considered low. By definition, an active fault is one with surface displacement within the last 11,000 years. A potentially-active fault has demonstrated evidence of surface displacement with the past 1.6 million years. Faults that have not moved in the last 1.6 million years are typically considered inactive.

4.3 Specific Ground Motion Hazard Analysis

A site-specific ground motion hazard analyses was performed in accordance with ASCE 7-16 Chapter 21 and Section 1613A of the 2019 CBC using online applications developed by USGS.

4.3.1 Site- Specific Shear Wave Velocity

On November 10, 2020, Middle Earth Geo Testing Inc. performed seismic CPT (SCPT) soundings in CPT-1. The SCPT soundings measured the shear waves generated at the ground surface at approximately 5-foot intervals to a depth of about 82 feet below the existing ground surface. The SCPT profile is included herein as Figure C4.

Based on the results of the SCPT, the site-specific soil shear wave velocity for the upper 30 meters feet of soil (Vs30) is estimated as 110 meters/second. In accordance with Section 1613A.3.2 of the 2019 California Building Code and Table 20.3-1 of ASCE 7-16, the estimated soil shear wave velocity falls within the boundaries of a Site Class “E”.

Although there are liquefiable soils underlying the site, we assume that the proposed townhome structures will have a fundamental period of less than 0.5 seconds and therefore will not require a site-response analysis.

4.3.2 Probabilistic Seismic Hazard Analysis

The risk-targeted Maximum Considered Earthquake (MCER) probabilistic response spectrum consists of the spectral response accelerations which are expected to achieve a 1 percent probability of collapse within a 50-year period, evaluated at 5 percent damping.

The mean spectral response accelerations having a 2 percent chance of exceedance in 50 years were evaluated at 5 percent damping using the USGS Unified Hazard Tool (UHT). The Dynamic U.S. 2014 (v4.2.0) edition was used within the analysis, which is based on the UCERF-3 fault model. The soil underlying the site was modeled as a Site Class “D/E” with a corresponding average shear wave velocity (VS30) of 180 meters per second. The site class definition is based on the SCPT data, which indicates a VS30 of approximately 110 meters per second or Site Class “E”. The lowest VS30 value available in the USGS UHT is Site Class “D/E”; therefore, 180 meters per second value was used for VS30 within the probabilistic analysis.

The web application uses the ground motion prediction equations (GMPEs) from the NGA-West 2 project: Abrahamson-et al. (2014) NGA West 2, Boore et al. (2014) NGA West 2, Campbell-Bozorgnia (2014) NGA West 2, and Chiou-Youngs (2014) NGA West 2. Each GMPE was assigned an equal weight and the mean value of the four GMPEs was evaluated. The mean spectral accelerations were rotated to maximum direction using the period specific ratios from Shahi et al. (2013 & 2014).

The GMPE of Campbell and Borzorgnia requires that the depth to where the shear wave velocity reaches 2.5 kilometers per second (Z2.5) be defined. Additionally, the GMPEs of Abrahamson-et al., Boore et al. and Chiou-Youngs require that the depth to where the shear wave velocity reaches 1 kilometer per second (Z1.0) be defined. The values of Z2.5 and Z1.0 are internally calculated by the Uniform Hazard Tool.

The MCE uniform hazard response spectra was adjusted to risk-targeted spectral accelerations corresponding to a 1 percent chance of collapse in 50 years by using the USGS Risk-Targeted Ground Motion Calculator and following ASCE 7-16 Section 21.2.1.2 Method 2.

The risk-targeted Maximum Considered Earthquake (MCER) probabilistic response spectrum is provided on Figure C1.

4.3.3 Deterministic Seismic Hazard Analysis

In order to define the deterministic scenario events, deaggregation of the uniform hazard probabilistic response spectrum was performed using the USGS UHT. The inversion approach used by UCERF-3 allows for a large number of variations for each source scenario, including multi-fault ruptures. Therefore, deaggregation of UCERF-3 consists of the contributions from multi-fault ruptures rather than individual source contributions. To address this, the UHT aggregates the contributions on a per-fault-section basis, with rupture contributions only ever counted once. The UHT deaggregation contributor list shows the fault sections which contribute most to hazard at a site and report a mean earthquake magnitude for each section identified by a 'parent' fault name and section index. Based on the deaggregation, we have considered scenario events with the greatest contribution to the deterministic ground motions.

The input values used to evaluate the deterministic scenario events are provided in the following table.

TABLE 4.3.3
INPUT VALUES TO EVALUATE DETERMINISTIC SCENARIO EVENTS

Parameter	Scenario 1	Scenario 2	Reference
Parent Fault Name	San Andreas (North Coast)	Hayward (North)	
Scenario Name	N. San Andreas: SAO+SAN+SAP+SAS	Hayward: RC+HN+HS+HE	BSSC Online Scenario Catalog
Earthquake Magnitude	8.04	7.58	BSSC Online Scenario Catalog
Fault Mechanism	Strike-Slip	Strike-Slip	
Fault Dip	88.2	76.6	BSSC 2014 [1]
Fault Width	11.8 km	10.58 km	BSSC 2014 [1]
Rake	180	178.2	BSSC 2014 [1]
Z_{TOR}	1.1 km	2.04 km	BSSC 2014 [1]
Rrup	15.90 km	13.09 km	Derived from Rx and Fault Type
Rjb	15.86 km	12.93 km	Derived from Rx and Fault Type
Rx	15.86 km	12.93 km	USGS Quartenary Faults & Folds Database
Vs30	180 m/s	180 m/s	Average Site Class D/E Value
$Z_{1.0}$	0.038 km	0.038 km	Bay Area Seismic Velocity Model, Release 8.3.0
$Z_{2.5}$	0.855 km	0.855 km	Bay Area Seismic Velocity Model, Release 8.3.0

1. BSSC 2014, aka. UCERF3_EventSet_All on GitHub

The deterministic median and standard deviation (sigma) for the scenario events were evaluated using the USGS NSHMP-HAZ-WS Response Spectra online application. The deterministic analysis used the same four GMPEs, equally weighted, to generate the median and standard deviation of the ground motion which were then used to calculate the 84th percentile at 5% damping. The geometric median spectral accelerations were rotated to maximum direction using the period specific ratios from Shahi et al. (2013 & 2014).

The deterministic scenarios were compared and a combination of events controls the deterministic spectrum. The fault source resulting in the highest spectral accelerations from 0 to 0.02 seconds would be a magnitude 8.04 event on the San Andreas fault; from 0.03 to 0.4 seconds would be a magnitude 7.58 event on the Hayward fault; and from 0.5 to 10 seconds would be a magnitude 8.04 event on the San Andreas fault.

The largest spectral ordinate of the deterministic spectra was compared to 1.5Fa, with Fa determined using Table 11.4.1. Based on this comparison, a scale factor was applied uniformly across all periods of the deterministic spectrum such that the largest ordinate is not less than 1.5Fa. The scaled 84th percentile maximum rotated component deterministic response spectra is provided on Figure C2.

4.3.4 Site-Specific Response Spectrum

The lesser of the probabilistic and deterministic MCE_R response spectrums is the Site-Specific MCE_R. Two thirds of the Site-Specific MCE_R is the Design Earthquake (DE) Response Spectrum, provided the results are not less than 80 percent of the modified General Design Response Spectrum determined by ASCE 7-16 Section 11.4.6 with F_a and F_v determined as specified in Section 21.3.

Graphical representations of the analyses are presented on Figures C1 and C2. The Site-Specific Design Earthquake response spectrum at 5 percent damping is presented on graphically on Figure C2 and in tabular form on Figure C3.

4.3.5 Mapped Acceleration Parameters

The following table summarizes the mapped acceleration parameters obtained from the 2019 California Building Code (CBC; Based on the 2018 International Building Code [IBC] and ASCE 7-16), Chapter 16A Structural Design, and Section 1613A Earthquake Loads. The data was calculated using the online application *Seismic Design Maps*, provided by OSHPD. The short spectral response uses a period of 0.2 second.

TABLE 4.3.5
MAPPED SPECTRAL ACCELERATIONS

Parameter	Value	2019 CBC Reference
Site Class	E	Section 1613.2.2
MCE_R Ground Motion Spectral Response Acceleration – Class B (short), S_S	1.5g	Figure 1613.2.1(1)
MCE_R Ground Motion Spectral Response Acceleration – Class B (1 sec), S_1	0.6g	Figure 1613.2.1(2)
Site Coefficient, F_A	1.2	Table 1613.2.3(1)
Site Coefficient, F_V	2*	Table 1613.2.3(2)
Site Class Modified MCE_R Spectral Response Acceleration (short), S_{MS}	1.8g	Section 1613.2.3 (Eqn 16-36)
Site Class Modified MCE_R Spectral Response Acceleration – (1 sec), S_{M1}	1.2g*	Section 1613.2.3 (Eqn 16-37)
5% Damped Design Spectral Response Acceleration (short), S_{DS}	1.2g	Section 1613.2.4 (Eqn 16-38)
5% Damped Design Spectral Response Acceleration (1 sec), S_{D1}	0.8g*	Section 1613.2.4 (Eqn 16-39)
T_S	0.67 sec	ASCE 7-16 Chapter 11

Note:

*Per Section 11.4.8 of ASCE/SEI 7-16, a ground motion hazard analysis shall be performed for projects for Site Class “E” sites with Ss greater than or equal to 1.0g and for Site Class “D” and “E” sites with S1 greater than 0.2g. Section 11.4.8 also provides exceptions which indicates that the ground motion hazard analysis may be waived provided the exceptions are followed. Using the code based values presented in the table above, in lieu of a performing a ground motion hazard analysis, requires the exceptions outlined in ASCE 7-16 Section 11.4.8 be followed.

4.3.6 Site-Specific Seismic Design Criteria

In accordance with the ASCE 7-16 Section 21.4, site-specific design acceleration parameters shall be derived using the results of the site-specific ground motion hazard analysis.

The parameter S_{DS} shall be taken as equal to 90 percent of the maximum spectral acceleration obtained from the site-specific analysis at any period within the range from 0.2 to 5 seconds, inclusive. The parameter S_{D1} shall be taken as the maximum value of the product of the spectral acceleration and period for periods from 1 to 5 seconds, inclusive. The values of S_{MS} and S_{M1} shall be taken as 1.5 times the site-specific values of S_{DS} and S_{D1}. The site-specific design acceleration parameters shall not be less than 80 percent of the general seismic design values determined by ASCE 7-16 Section 11.4.

The following table presents the site-specific seismic design parameters based on the site-specific ground motion hazard analysis.

TABLE 4.3.6
SITE-SPECIFIC DESIGN ACCELERATION PARAMETERS

Parameter	Value
Site Class Modified MCER Spectral Response Acceleration (short), S_{MS}	1.440g
Site Class Modified MCER Spectral Response Acceleration – (1 sec), S_{M1}	1.920g
5% Damped Design Spectral Response Acceleration (short), S_{DS}	0.96g
5% Damped Design Spectral Response Acceleration (1 sec), S_{D1}	1.280g

4.3.7 Site-Specific Peak Ground Acceleration

The site-specific Maximum Considered Earthquake (MCE_G) geometric mean peak ground acceleration was evaluated in accordance with ASCE 7-16 Section 21.5.

The probabilistic geometric mean peak ground acceleration and the deterministic 84th percentile geometric mean peak ground acceleration were analyzed using the same approaches as described above. The analysis used the same Site Class and scenario earthquake.

The deterministic MCE_G shall not be less than $0.5F_{PGA}$, where F_{PGA} is determined from ASCE 7-16 Table 11.8-1 with the value of PGA taken as 0.5g. The site-specific MCE_G peak ground acceleration is taken as the lesser of the probabilistic and deterministic MCE_G, provided the value is not less than 80 percent of the value of PGAM as determined by ASCE 7-16 Equation 11.8.1.

TABLE 4.3.7
ASCE 7-16 SITE-SPECIFIC PEAK GROUND ACCELERATION

Parameter	Value	ASCE 7-16 Reference
Site-Specific MCE_G Peak Ground Acceleration, PGA_M	0.481g	Section 21.5

4.4 Liquefaction

The site is not currently mapped by the California Geological Survey (CGS) for liquefaction hazards as such mapping has not been performed in the project area; however, web-based mapping by the USGS indicates the entire site possesses a “very high” susceptibility to liquefaction. Liquefaction is a phenomenon in which saturated cohesionless soils are subject to a temporary loss of shear strength due to pore pressure buildup under the cyclic shear stresses associated with intense earthquakes. Primary factors that trigger liquefaction are: moderate to strong ground shaking (seismic source), relatively clean, loose granular soils (primarily poorly graded sands and silty sands), and saturated soil conditions (shallow groundwater). Due to the increasing overburden pressure with depth, liquefaction of granular soils is generally limited to the upper 50 feet of a soil profile.

We used the computer software program *CLiq* (Version 2.2.0.35, Geologismiki) and the in-situ soil parameters measured in the CPT soundings to evaluate liquefaction potential at the site. The software utilized the 2014 methodology of Boulanger and Idriss (2014) and also considered the potential for dry sand settlements above groundwater. Our evaluation incorporated an earthquake moment magnitude (M_w) of 7.3 (overall all sources) and a groundwater depth of 4 feet. Per 2019 CBC, we used a ground motion (peak ground acceleration) of 0.481g in our analysis.

Liquefaction analyses typically evaluate the potential for liquefaction in soils to depths of 50 feet. As a conservatism, we evaluated liquefaction potential for the full depth of the Bay Mud encountered in our CPTs, based on the geologic recency of those deposits.

Consequences of liquefaction can include ground surface settlement, ground loss (sand boils) and lateral slope displacements (lateral spreading). For liquefaction-induced sand boils or fissures to occur, pore water pressure induced within liquefied strata must exert enough force to break through overlying, non-liquefiable layers. Based on methodology recommended by Youd and Garris (1995), which advanced original research by Ishihara (1985), a capping layer of non-liquefiable soil can prevent the occurrence of sand boils and fissures. Based on the presence of the non-liquefiable layer that mantles the site and the depth to liquefiable layers, the potential for ground loss due to sand boils or fissures in a seismic event is considered low.

The likely consequence of potential liquefaction at the site is settlement. Our analysis indicates that, if liquefaction and cyclic softening were to occur, total ground surface settlements on the order of ½ inch or less may result. Selected output from our liquefaction analysis is presented in Appendix D.

4.5 Landslides

There are no known landslides near the site, nor is the site in the path of any known or potential landslides. We do not consider the potential for a landslide to be a significant hazard to this project.

4.6 Tsunamis and Seiches

Based on mapping published by the California Emergency Management Agency and CGS, the site would not be inundated during an extreme tsunami.

Seiches are large waves generated in enclosed bodies of water in response to ground shaking. No major water-retaining structures are located immediately up gradient from the project site. Flooding from a seismically induced seiche is considered unlikely.

5. SOIL AND GROUNDWATER CONDITIONS

5.1 Surface Materials

Pavement within the project limits generally consists of approximately 2 to 6 inches of asphalt concrete over 5½ to 9 inches of aggregate base materials. Based on visual observations, the existing surface pavements are in poor condition with severe cracking, potholes, and patching.

5.2 Artificial Fill

Below surface materials, artificial fill was encountered in our soil borings and was observed to be variable throughout the project limits to depths ranging from 5½ to 6½ feet below existing surface grades. The fill materials comprise stiff to hard clay (CL) with various amounts of silt, sand and gravel; loose to medium dense clayey sand (SC) with various amounts of silt and gravel; and medium dense gravel (GC/GM) with various amount of sand and clay/silt. The artificial fill materials may differ from those than encountered in our borings. The fills may contain constituents not encountered in our borings or reported herein. Based on our laboratory test results, the clayey soils within the artificial fills possess moderate plasticity and should be considered moderately expansive.

5.3 Bay Mud

Bay Mud deposits were encountered beneath the artificial fills in all our soil borings and CPT locations. As encountered in our CPT soundings, the Bay Mud deposits extend to depths of approximately 42 to 62 feet below existing grade at CPT locations CPT-3 and CPT-1, respectively. As observed in our borings, the deposits consisted of very soft, organic rich fat clay (CH). Our laboratory testing indicates the Bay Mud deposits are highly compressible and weak, consistent with our prior experience and typical Bay Mud properties.

5.4 Older Alluvium

Based on our review of the information obtained in our CPT soundings, it appears soil conditions at the site transition from Bay Mud to an older alluvial deposit extend to depths of approximately 82 to 90 feet below the existing surface grades at CPT location CPT-1 and CPT-3, respectively– the maximum depths extended. The soil types within this alluvial unit were not directly observed due to our CPT-based field exploration.

5.5 Groundwater

Groundwater was encountered at depths of approximately 4 to 5 feet in our borings at the time drilling. Actual groundwater levels will fluctuate with variations in rainfall, temperature and other factors and may be higher or lower than observed during our study. Additionally, it is not uncommon for perched groundwater conditions to develop where none previously existed, especially in or atop fine-grained soils that are subjected to irrigation or precipitation.

5.6 Soil Corrosion Screening

Soil samples obtained during our field exploration were subjected to laboratory testing for minimum resistivity, pH, and chloride and water-soluble sulfate. The laboratory test results and published screening levels are presented in Appendix B. Soil corrosivity should be considered in the design of buried metal pipes, underground structures, etc.

Water-soluble sulfate test results on selected samples of site soils indicate an S0 exposure classification for sulfate attack on normal portland cement concrete (PCC) as defined in Chapter 318, Table 19.3.1.1 of the ACI Building Code Requirements for Structural Concrete. ACI does not set forth requirements for S0 sulfate exposure classification. In addition, none of the two soil samples tested would be classified as corrosive to buried metal improvements based on Caltrans criteria.

Geocon does not practice in the field of corrosion engineering and mitigation. If corrosion sensitive improvements are planned, it is recommended that a corrosion engineer be retained to evaluate corrosion test results and incorporate the necessary precautions to avoid premature corrosion of buried metal pipes and concrete structures in direct contact with the soils.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 General

6.1.1 No overriding geotechnical constraints were encountered during our investigation that would preclude the project as presently proposed. Primary geotechnical considerations are the presence of highly compressible Bay Mud deposits within the upper approximately 42 to 62 feet below existing grade and the potential for strong seismic shaking. A layer of lightweight fill material will be required below the proposed townhomes to mitigate settlement from building loads.

6.1.2 Based on the subsurface conditions at the site and the anticipated structural loading, post-tension foundation systems, used in conjunction with the remedial grading described herein, can be used to support the planned townhome buildings. Post-construction settlements due to static foundation loads should in order of 1¾ inch or less with differential settlements of 1 inch or less across a horizontal distance of 50 feet.

6.1.3 Any changes in the design, location or elevation, as outlined in this report, should be reviewed by this office. Geocon should be contacted to determine the necessity for review and possible revision of this report.

6.1.4 The proposed project redevelops a site with past episodes of grading and construction. As such, unknown underground improvements and areas of undocumented fill materials (not discussed herein) may be present. If encountered, supplemental recommendations will be provided during site development.

6.1.5 All references to relative compaction and optimum moisture content in this report are based on the latest edition of ASTM D 1557.

6.2 Soil and Excavation Characteristics

6.2.1 Based on the soils conditions encountered in our field explorations, we anticipate the onsite soils can be excavated with moderate effort using conventional excavation equipment. We do not anticipate excavations at the site will generate oversize material (greater than 6 inches in nominal dimension). Any artificial fills encountered at the site are undocumented and may contain constituents not reported herein.

6.2.2 It is the responsibility of the contractor to ensure that all excavations and trenches are properly shored and maintained in accordance with applicable Occupation Safety and Health Administration (OSHA) rules and regulations to maintain safety and maintain the stability of adjacent existing improvements.

6.2.3 The existing soils encountered at the site should be considered “expansive” as defined by 2019 CBC. However, the recommendations of this report assume proposed building foundation systems will derive support in properly compacted non expansive fills (i.e., lightweight fill).

6.3 Materials for Fill

6.3.1 Excavated soils generated from cut operations at the site should be suitable for use as engineered fill in structural areas provided, they do not contain deleterious matter, organic material, or cementations larger than 6 inches in maximum dimension.

6.3.2 Import fill material should be primarily granular with a “low” expansion potential (Expansion Index less than 50), a Plasticity Index less than 15, be free of organic material and construction debris, and not contain rock larger than 6 inches in greatest dimension.

6.3.3 Lightweight fill (LWF), where required, should have maximum unit weight of 30 pounds per cubic foot (pcf). LWF materials include, but are not limited to, foamed concrete or expanded polystyrene (EPS), low-density cellular concrete (LDCC), and lightweight aggregate (LWA). In our experience, LDCC is the most common of the listed LWF materials.

6.3.4 Environmental characteristics and corrosion potential of import soil materials may also be considered. Proposed import materials should be sampled, tested, and approved by Geocon prior to transportation to the site.

6.4 Grading

6.4.1 All clearing operations and earthwork (including over-excavation, scarification, and recompaction) should be observed and all fills tested for recommended compaction and moisture content by representatives of Geocon.

6.4.2 Structural areas should be considered as areas extending a minimum of 5 feet horizontally from a foundation or beyond the outside dimensions of buildings, including footings and overhangs carrying structural loads, and where not restricted by property boundaries.

6.4.3 A preconstruction conference should be held at the site prior to the beginning of grading operations with the owner, contractor, civil engineer and geotechnical engineer in attendance. Special soil handling requirements can be discussed at that time.

6.4.4 Site preparation should begin with removal of any surface and subsurface structures including all foundations, flatwork, and pavement. Within landscaped area, all surface vegetation should be stripped and all the trees, root balls and shrubs should be removed such that no roots larger than approximately 1 inch in diameter remain within proposed building footprints. All active or inactive utilities within the construction area should be protected, relocated, or abandoned. Any pipelines to be abandoned that are greater than 2 inches and less than 18 inches in diameter should be removed or filled with sand-cement slurry. Utilities larger than 18 inches in diameter should be removed. Excavations or depressions resulting from site clearing operations, or other existing excavations or depressions, should be restored with engineered fill in accordance with the recommendations of this report.

6.4.5 After demolition and the removal of existing improvements, the existing subgrade within building pad areas should be over-excavated to a depth of 3 feet below the existing surface grade or two feet below proposed pad grade, whichever is deeper, and replaced with LWF meeting the requirements of Section 6.3.3. The exposed subgrade should be scarified to a depth of 8 to 12 inches, moisture conditioned to at least 2% above optimum and compacted to at least 90% relative compaction before placing LWF.

6.4.6 The existing soils outside of building pad areas should be over-excavated to a depth of approximately 1 foot. The exposed bottom should be scarified 8 to 12 inches, moisture conditioned to at least 2% above optimum moisture and recompacted to at least 90% relative compaction (at near optimum moisture where fill materials are predominantly sands or gravels).

6.4.7 The exposed bottom surfaces and bottom processing should be observed by our representatives on a full-time basis. Supplemental recommendations may be provided based on-site conditions during grading. Deeper over-excavations may be needed in some areas.

6.4.8 If grading commences in winter or spring, or in periods of precipitation, excavated and in-place soils may be wet. Earthwork contractors should be aware of potential compaction/workability difficulties. The most effective site preparation alternatives will depend on site conditions prior to and during grading operations; we should evaluate site conditions at those times and provide supplemental recommendations, if necessary.

6.4.9 All engineered fills should be placed in layers no thicker than will allow for adequate bonding and compaction (typically 8 inches). Fill soils should be placed, moisture conditioned to minimum 2 percent above optimum moisture content (near optimum moisture where fill materials are predominantly sands or gravels) and compacted to at least 90% relative compaction.

6.5 Temporary Excavations

6.5.1 We anticipate that the majority of the site will be classified as Cal-OSHA “Type C” soil when encountered in excavations during site development and construction. Excavation sloping, benching, the use of trench shields, and the placement of trench spoils should conform to the latest applicable Cal-OSHA standards. The contractor should have a Cal-OSHA-approved “competent person” onsite during excavation to evaluate trench conditions and make appropriate recommendations where necessary.

6.5.2 All onsite excavations must be conducted in such a manner that potential surcharges from existing structures, construction equipment, and vehicle loads are resisted. The surcharge area may be defined by a 1:1 projection down and away from the bottom of an existing foundation or vehicle load. Penetrations below this 1:1 projection will require special excavation measures such as sloping and possibly shoring.

6.5.3 It is the contractor’s responsibility to provide sufficient and safe excavation support as well as protecting nearby utilities, structures, and other improvements that may be damaged by earth movements.

6.5.4 Temporary excavations such as utility trench sidewalls within the dune sands should remain near vertical to depths of at least 3 feet below ground surface, although some sloughing and caving may occur, particularly if clean sandy or gravelly soils, undocumented fills or groundwater are encountered. Excavations greater than approximately 3 feet in height or those that are surcharged by adjacent traffic or structures may require sloping or shoring measures in order to provide a stable excavation.

6.5.5 Temporary excavations should be protected from rainfall and erosion. Surface runoff should be directed away from excavations or slopes.

6.6 Underground Utilities

6.6.1 Underground utility trenches should be backfilled with properly compacted material. The material excavated from the trenches should be adequate for use as backfill provided it does not contain deleterious matter, vegetation or rock larger than six inches in maximum dimension. Trench backfill should be placed in loose lifts not exceeding eight inches and compacted to at least 90% relative compaction to minimum 2 percent above optimum moisture content.

6.6.2 Bedding and pipe zone backfill typically extends from the bottom of the trench excavations to a minimum of six inches above the crown of the pipe. Pipe bedding material should consist of crushed aggregate, clean sand or similar open-graded material. Proposed bedding and pipe zone materials should be reviewed by Geocon prior to construction; materials such as ¾-inch drain rock may require wrapping with filter fabric to mitigate the potential for piping. Bedding and backfill should also conform to the requirements of the governing utility agency.

6.7 Post-Tensioned Slabs

6.7.1 We understand that thickened post-tensioned slabs in engineered fill may be used in slab-on-grade areas for the new apartment buildings. Post-tensioned (PT) slab thickness, reinforcement and crack control spacing should be designed by the project structural engineer. PT slabs should be designed to accommodate the estimated settlements discussed in Section 6.1.2.

6.7.2 PT slab contact pressure should be generally limited to 350 psf for dead plus live loads. We recognize that isolated areas of higher contact pressure may exist at wall or column locations. When available, PT slab contact pressures should be reviewed by Geocon to confirm the settlement estimates provided herein. Supplemental recommendations may be provided after our review.

6.7.3 We anticipate post-tensioned slabs will be designed using a modulus of subgrade reaction. We recommended that a modulus of subgrade reaction of 120 pounds per cubic inch (pci) be utilized. The modulus of subgrade reaction is based on the square-foot plate load method and should be adjusted as needed to account for slab size. The modulus should be reduced in accordance with the following equation:

$$K_R = K\left[\frac{B+1}{2B}\right]^2$$

Where: K_R = reduced subgrade modulus

K = unit subgrade modulus

B = foundation width in feet

If applicable, the reduced modulus of subgrade reaction value calculated above should be adjusted to account for the rectangularity of the mat foundation per the following:

$$\mathrm{K_R} = \frac{\mathrm{K_{(BxB)}}\left(1+\frac{\mathrm{B}}{2\mathrm{L}}\right)}{1.5}$$

Where: K_R = reduced subgrade modulus

$K_{(BxB)}$ = subgrade modulus scaled for square mat size

B = mat foundation width in feet

L = mat foundation length in feet

6.7.1 Mat foundation design will require iteration(s) between the geotechnical engineer and structural engineers to review the estimated settlement and foundation contact pressures. Differential settlement will be controlled by mat rigidity.

6.7.4 Post-tensioned foundations should be embedded in accordance with the recommendations of the structural engineer. If a post-tensioned mat foundation system is planned, the slab should possess a thickened edge with a minimum width of 12 inches. The thickened edge should extend below the crushed rock underlayment layer.

6.7.5 The thickness of post-tensioned foundation systems should be determined by the project structural engineer. Based on our experience with similar projects and soils conditions, we anticipate the post-tensioned slab thicknesses will be on the order of 10 to 12 inches.

6.7.6 Our experience indicates that post-tensioned slabs are susceptible to excessive edge lift, regardless of the underlying soil conditions. Placing reinforcing steel at the bottom of the perimeter footings and the interior stiffener beams may mitigate this potential. Because of the placement of the reinforcing tendons in the top of the slab, the resulting eccentricity after tensioning reduces the ability of the system to mitigate edge lift. The structural engineer should design the foundation system to reduce the potential of edge lift occurring for the proposed structures.

6.7.7 During the construction of the post-tension foundation system, the concrete should be placed monolithically. Under no circumstances should cold joints be allowed to form between the footings/grade beams and the slab during the construction of the post-tension foundation system.

6.7.8 The use of isolated footings, which are located beyond the perimeter of the building and support structural elements connected to the building, are not recommended. Where this condition cannot be avoided, the isolated footings should be connected and tied to the building foundation system with grade beams.

6.7.9 Consideration should be given to connecting patio slabs to the building foundation to reduce the potential for future separation to occur.

6.7.10 Post-tensioned slabs should be underlain by at least 3 inches of ½-inch or ¾-inch crushed rock with no more than 5 percent passing the No. 200 sieve to serve as a capillary break.

6.7.11 Where post-tensioned foundation systems are designed and constructed as recommended herein, post-construction settlement due to dead + live loads should be approximately 1¾ inch or less with differential settlements of less than 1 inch across a horizontal distance of 50 feet.

6.8 Shallow Foundations

6.8.1 Shallow foundations (footings) founded in engineered fill may be used for ancillary site structures such as short retaining walls, screen walls, or trash enclosures. The following recommendations are based on the assumption that the soils within 4 feet of finish grade will consist of moderate expansive materials.

6.8.2 It is recommended that conventional shallow footings have a minimum embedment depth of 12 inches below lowest adjacent pad grade. Strip footings should be at least 12 inches wide. Spread column footings should be at least 3 feet square.

6.8.3 Footings proportioned as recommended may be designed for an allowable soil bearing pressure of 2,000 pounds per square foot (psf). The allowable bearing pressure is for dead + live loads and may be increased by up to one-third for transient loads due to wind or seismic forces.

6.8.4 The allowable passive pressure used to resist lateral movement may be assumed to be equal to a fluid weighing 300 pounds per cubic foot (pcf) for footings poured neat against properly compacted fills or undisturbed natural soils. The allowable passive pressure assumes a horizontal surface extending at least 5 feet or 3 times the surface generating the passive pressure, whichever is greater. The allowable coefficient of friction to resist sliding is 0.30 for concrete against soil. Combined passive resistance and friction may be utilized for design provided that the frictional resistance is reduced by 50%. Where not protected by flatwork or pavement, the upper 1 foot of soil should be neglected when calculating passive resistance to lateral loads.

6.8.5 Minimum reinforcement for continuous footings should consist of four No. 4 steel reinforcing bars; two placed near the top of the footing and two near the bottom. Spread column footing reinforcement should be specified by the structural engineer.

6.8.6 The foundation dimensions and minimum reinforcement recommendations presented herein are based upon soil conditions only and are not intended to be used in lieu of those required for structural purposes.

6.8.7 Underground utilities running parallel to footings should not be constructed in the zone of influence of footings. The zone of influence may be taken to be the area beneath the footing and within a 1:1 (horizontal:vertical) plane extending out and down from the bottom edge of the footing.

6.8.8 The use of isolated footings that are located beyond the perimeter of the building and support structural elements connected to the building are not recommended. Where this condition cannot be avoided, the isolated footings should be connected and tied to the building foundation system with grade beams.

6.8.9 The foundation subgrade should be sprinkled as necessary to maintain a moist condition without significant shrinkage cracks as would be expected in any concrete placement. Our representative should observe all footing excavations prior to placing reinforcing steel.

6.9 Retaining Wall Design

6.9.1 Lateral earth pressures may be used in the design of retaining walls and buried structures. Lateral earth pressures against these facilities may be assumed to be equal to the pressure exerted by an equivalent fluid. The unit weight of the equivalent fluid depends on the design conditions. Table 6.9 summarizes the weights of the equivalent fluid based on the different design conditions.

TABLE 6.9
RECOMMENDED LATERAL EARTH PRESSURES

Condition	Equivalent Fluid Density
Active	50 pcf
At-Rest	65 pcf

6.9.2 Unrestrained walls should be designed using the active case. Unrestrained walls are those that are allowed to rotate more than 0.01H (where H is the height of the wall). Walls restrained from movement such as basement walls should be designed using the at-rest case. The above soil pressures assume level backfill under drained conditions within an area bounded by the wall and a 1:1 plane extending upward from the base of the wall and no surcharges within that same area.

6.9.3 Retaining wall foundations should be designed as continuous strip footings in accordance with Section 6.8.

6.9.4 Unless hydrostatic conditions are incorporated into design, retaining walls greater than 2 feet tall (retained height) should be provided with a drainage system adequate to prevent the buildup of hydrostatic forces and should be waterproofed as required by the project architect. Positive drainage for retaining walls should consist of a vertical layer of permeable material positioned between the retaining wall and the soil backfill. The permeable material may be composed of a composite drainage geosynthetic or a natural permeable material such as crushed gravel at least 12 inches thick and capped with at least 12 inches of native soil. A geosynthetic filter fabric should be placed between the gravel and the soil backfill. Provisions for removal of collected water should be provided for either system by installing a perforated drainage pipe along the bottom of the permeable material that leads to suitable drainage facilities.

6.10 Concrete Slabs-on-Grade

6.10.1 Concrete slabs-on-grade subject to vehicular loading are pavements should be designed in accordance with the recommendations in Section 6.12 of this report.

6.10.2 Concrete slabs-on-grade for structures should be a minimum of 4 inches thick and minimum slab reinforcement should consist of No. 3 steel reinforcing bars placed 24 inches on center in both horizontal directions. Steel reinforcing should be positioned vertically near the slab midpoint.

6.10.3 Interior slabs should also be underlain by 3 inches of ½-inch or ¾-inch crushed rock with no more than 5 percent passing the No. 200 sieve to serve as a capillary break. The crushed rock should be subjected to several passes with a walk-behind vibratory compactor or similar equipment prior to placing a vapor barrier or rebar for the slab-on-grade.

6.10.4 The slab-on-grade dimensions and minimum reinforcement recommendations presented herein are based upon soil conditions only and are not intended to be used in lieu of those required for structural purposes.

6.10.5 Crack control joints for slabs-on-grade should be spaced at intervals not greater than 8 feet and should be constructed using saw-cuts or other methods as soon as practical following concrete placement. Crack control joints should extend a minimum depth of one-fourth the slab thickness. Construction joints should be designed by the project structural engineer.

6.10.6 The recommendations of this report are intended to reduce the potential for cracking of slabs due to soil movement. However, even with the incorporation of the recommendations presented herein, foundations, stucco walls, and slabs-on-grade may exhibit some cracking due to soil movement. The occurrence of concrete shrinkage cracks is independent of the supporting soil characteristics. Their occurrence may be reduced and/or controlled by limiting the slump of the concrete, proper concrete placement and curing, and by the placement of crack control joints at periodic intervals, in particular, where re-entrant slab corners occur.

6.11 Moisture Protection Considerations

6.11.1 A vapor barrier is not required beneath slabs-on-grade (including post-tensioned slabs) for geotechnical purposes. Further, the migration of moisture through concrete slabs or moisture otherwise released from slabs is not a geotechnical issue. However, for the convenience of the owner, we are providing the following general suggestions for consideration by the owner, architect, structural engineer, and contractor. The suggested procedures may reduce the potential for moisture-related floor covering failures on concrete slabs-on-grade, but moisture problems may still occur even if the procedures are followed. If more detailed recommendations are desired, we recommend consulting a specialist in this field. If a vapor barrier is used beneath mat slab foundations, we should review the geotechnical design parameters presented herein.

6.11.2 A vapor barrier meeting ASTM E 1745-09 Class C requirements may be placed directly below the slab, without a sand cushion. To reduce the potential for punctures, a higher quality vapor barrier (15 mil, Class A or B) should be used. The vapor barrier, if used, should extend to the edges of the slab, and should be sealed at all seams and penetrations.

6.11.3 The concrete water/cement ratio should be as low as possible. The water/cement ratio should not exceed 0.45 for concrete placed directly on the vapor barrier. Midrange plasticizers could be used to facilitate concrete placement and workability.

6.11.4 Proper finishing, curing, and moisture vapor emission testing should be performed in accordance with the latest guidelines provided by the American Concrete Institute, Portland Cement Association, and ASTM.

6.12 Pavement Recommendations

6.12.1 The upper 12 inches of pavement subgrade should be scarified, moisture conditioned to minimum 2 percent above optimum moisture content (at near optimum moisture where fill materials are predominantly sands or gravels) and compacted to at least 95% relative compaction. Prior to placing aggregate base, the finished subgrade should be proof-rolled with a laden water truck (or similar equipment with high contact pressure) to verify stability.

6.12.2 Sidewalk, curb and gutter, and driveway encroachments should be designed and constructed in accordance with City of San Rafael requirements, as applicable.

6.12.3 We recommend the following asphalt concrete (AC) pavement sections for design to establish subgrade elevations in pavement areas. The project civil engineer should determine the appropriate Traffic Index (TI) based on anticipated traffic conditions. The flexible pavement sections below are based on estimated design TIs and an R-Value of 5 for the subgrade soils. We can provide additional sections based on other TIs if necessary.

TABLE 6.12.3
FLEXIBLE PAVEMENT SECTION RECOMMENDATIONS

Location	Estimated Traffic Index (TI)	AC Thickness (inches)	AB Thickness (inches)
Parking Stalls	4.5	3	8
Driveways	6.0	3½	12½
Heavy-Duty	7.0	4	15½

Note: The recommended flexible pavement sections are based on the following assumptions:

1. AB: Class 2 AB with a minimum R-Value of 78 and meeting the requirements of Section 26 of the latest Caltrans Standard Specifications.
2. AB is compacted to 95% or higher relative compaction at or near optimum moisture content. Prior to placing AB, the subgrade should be proof-rolled with a loaded water truck to verify stability.
3. AC: Asphalt concrete conforming to local agency standards or Section 39 of the latest Caltrans Standard Specifications.

6.12.4 The AC sections in Table 6.12.3 are final, minimum thicknesses. If staged pavements are used, the construction bottom AC lift should be at least 2 inches thick. Following construction, the finish top AC lift should be at least 1.5 inches thick.

6.12.5 Unless specifically designed and evaluated by the project structural engineer, where concrete paving will be utilized for support of vehicles, we recommend the concrete be a minimum of 6 inches thick and reinforced with No. 3 steel reinforcing bars placed 24 inches on center in both horizontal directions. In addition, doweling, reinforcing steel or other load-transfer mechanism should be provided at joints if desired to reduce the potential for vertical offset. The concrete should have a minimum 28-day compressive strength of 3,500 psi.

6.12.6 We recommend that at least 6 inches of Class 2 Aggregate Base (Class 2 AB) be used below rigid concrete pavements. The aggregate base should be compacted to at least 95% relative compaction near optimum moisture content.

6.12.7 In general, we recommend that concrete pavements be designed, constructed and maintained in accordance with industry standards such as those provided by the American Concrete Pavement Association.

6.12.8 The performance of pavements is highly dependent upon providing positive surface drainage away from the edge of pavements. Ponding of water on or adjacent to the pavement will likely result in saturation of the subgrade materials and subsequent cracking, subsidence and pavement distress. If planters are planned adjacent to paving, it is recommended that the perimeter curb be extended at least 6 inches below the bottom of the aggregate base to minimize the introduction of water beneath the paving. Alternatives such as plastic moisture cut-offs or modified drop-inlets may also be considered in lieu of deepened curbs.

6.12.9 Asphalt pavement section recommendations for driveways and parking areas are based on Caltrans design procedures. It should be noted that most rational pavement design procedures are based on projected street or highway traffic conditions and, hence, may not be representative of vehicular loading that occurs in parking lots and driveways. Pavement proximity to landscape irrigation, reduced traffic speed and short turning radii increase the potential for pavement distress to occur in parking lots even though the volume of traffic is significantly less than that of an adjacent street. The Caltrans *Highway Design Manual* indicates that the resulting pavement sections for parking lots are minimized to keep initial costs down but are reasonable because additional AC surfacing can be added later, if needed, and generally without incurring traffic hazards or traffic handling problems. It is generally not economically feasible to design and construct the entire parking lot and driveways for the unique loading conditions previously described. Periodic maintenance of the pavement in these areas, therefore, should be anticipated.

6.12.10 We recommend that all retaining wall designs be reviewed by Geocon to confirm the incorporation of the recommendations provided herein. In particular, potential surcharges from adjacent structures and other improvements should be reviewed by Geocon.

6.13 Exterior Slabs

6.13.1 Exterior slabs, not subject to traffic loads, should be at least 4 inches thick and reinforced with No. 3 steel reinforcing bars placed 18 inches on center in both horizontal directions, positioned near the slab midpoint. We recommend that at least 6 inches of Class 2 Aggregate Base (AB) compacted to at least 95% relative compaction be used below exterior concrete slabs. Prior to placing AB, the subgrade should be scarified 8 inches, moisture conditioned 2% above optimum and properly compacted to at least 90% relative compaction(at near optimum moisture where fill materials are predominantly sands or gravels).

6.13.2 The slab-on-grade dimensions and minimum reinforcement recommendations presented herein are based upon soil conditions only and are not intended to be used in lieu of those required for structural purposes.

6.13.3 Crack control joints for slabs-on-grade should be spaced at intervals not greater than 8 feet for 4-inch slabs and should be constructed using saw-cuts or other methods as soon as practical following concrete placement. Crack control joints should extend a minimum depth of one-fourth the slab thickness. Construction joints should be designed by the project structural engineer.

6.13.4 The recommendations of this report are intended to reduce the potential for cracking of slabs due to soil movement. However, even with the incorporation of the recommendations presented herein, foundations, stucco walls, and slabs-on-grade may exhibit some cracking due to soil movement. This is common for project areas that contain expansive soils since designing to eliminate potential soil movement is cost prohibitive. The occurrence of concrete shrinkage cracks is independent of the supporting soil characteristics. Their occurrence may be reduced and/or controlled by limiting the slump of the concrete, proper concrete placement and curing, and by the placement of crack control joints at periodic intervals, in particular, where re-entrant slab corners occur.

6.14 Surface Drainage

6.14.1 Proper surface drainage is critical to the future performance of the project. Uncontrolled infiltration of irrigation excess and storm runoff into the soils can adversely affect the performance of the planned improvements. Saturation of a soil can cause it to lose internal shear strength and increase its compressibility, resulting in a change to important engineering properties. Proper drainage should be maintained at all times.

6.14.2 All site drainage should be collected and transferred to the street in non-erosive drainage devices. Drainage should not be allowed to pond anywhere on the site, and especially not against any foundations or retaining walls. Drainage should not be allowed to flow uncontrolled over any descending slope. The proposed structures should be provided with roof gutters. Discharge from downspouts, roof drains and scuppers not permitted onto unprotected soils within five feet of the building perimeter. Planters which are located adjacent to foundations should be sealed or properly drained to prevent moisture intrusion into the materials providing foundation support. Landscape irrigation within five feet of the building perimeter footings should be kept to a minimum to just support vegetative life.

6.14.3 Positive site drainage should be provided away from structures, pavement, and the tops of slopes to swales or other controlled drainage structures. The building pad and pavement areas should be fine graded such that water is not allowed to pond. Final soil grade should slope a minimum of 2% away from structures.

6.14.4 We recommend implemented measures to reduce infiltrating surface water near buildings and slabs-on-grade. Such measures may include:

- Selecting drought-tolerant plants that require little or no irrigation, especially within 3 feet of buildings, slabs-on-grade, or pavements.
- Using drip irrigation or low-output sprinklers.
- Using automatic timers for irrigation systems.
- Appropriately spaced area drains.
- Hard-piping roof downspouts to appropriate collection facilities.

7. FURTHER GEOTECHNICAL SERVICES

7.1 Plan and Specification Review

7.1.1 We should review project plans and specifications prior to final design submittal to assess whether our recommendations have been properly implemented and evaluate if additional analysis and/or recommendations are required.

7.2 Testing and Observation Services

7.2.1 The recommendations provided in this report are based on the assumption that we will continue as Geotechnical Engineer of Record throughout the construction phase and provide compaction testing and observation services and foundation observations throughout the project. It is important to maintain continuity of geotechnical interpretation and confirm that field conditions encountered are similar to those anticipated during design. If we are not retained for these services, we cannot assume any responsibility for others interpretation of our recommendations, and therefore the future performance of the project.

LIMITATIONS AND UNIFORMITY OF CONDITIONS

The recommendations of this report pertain only to the site investigated and are based upon the assumption that the soil conditions do not deviate from those disclosed in the investigation. If any variations or undesirable conditions are encountered during construction, or if the proposed construction will differ from that anticipated herein, Geocon Consultants, Inc. should be notified so that supplemental recommendations can be given. The evaluation or identification of the potential presence of hazardous or corrosive materials was not part of the geotechnical scope of services provided by Geocon Consultants, Inc.

This report is issued with the understanding that it is the responsibility of the owner, or of his representative, to ensure that the information and recommendations contained herein are brought to the attention of the architect and engineer for the project and incorporated into the plans, and the necessary steps are taken to see that the contractor and subcontractors carry out such recommendations in the field.

The findings of this report are valid as of the present date. However, changes in the conditions of a property can occur with the passage of time, whether they are due to natural processes or the works of man on this or adjacent properties. In addition, changes in applicable or appropriate standards may occur, whether they result from legislation or the broadening of knowledge. Accordingly, the findings of this report may be invalidated wholly or partially by changes outside our control. Therefore, this report is subject to review and should not be relied upon after a period of three years.

Our professional services were performed, our findings obtained, and our recommendations prepared in accordance with generally accepted geotechnical engineering principles and practices used in the site area at this time. No warranty is provided, express or implied.

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Vivian Street Townhomes

88 Vivian Street
San Rafael, California

VICINITY MAP

E9226-04-01	January 2021	Figure 1

LEGEND:

B5 ⊗ Approximate Boring Location

CPT-3 ⦿ Approximate CPT Location

0 80
Scale in Feet

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SITE PLAN

E9226-04-01	January 2021	Figure 2

APPENDIX A

APPENDIX A
FIELD EXPLORATION

Fieldwork for our investigation included a site visit, subsurface exploration, and soil sampling. The locations of our exploratory borings and CPTs are shown on the Site Development Plan, Figure 2. Soil boring logs and CPT profiles for our exploration are presented as figures in this Appendix A. The borings and CPTs were located by pacing from existing reference points. Therefore, the exploration locations shown on Figure 2 are approximate.

Our field exploration included four exploratory soil borings to depths ranging from 15 to 25 feet below existing grade. Our borings were performed by Clear Heart Drilling under Geocon supervision on November 19, 2020 using a track-mounted DR8K drill rig equipped with 7-inch OD hollow-stem and 4-inch OD solid flash augers. Sampling in the borings was accomplished using an auto hammer 140-pound hammer (hammer efficiency of about 80%) with a 30-inch drop. Samples were obtained with a 3-inch outside-diameter (OD), split spoon (California Modified) sampler, and a 2-inch OD, Standard Penetration Test (SPT) sampler. The number of blows required to drive the sampler the last 12 inches (or fraction thereof) of the 18-inch sampling interval were recorded on the boring logs. The blow counts shown on the boring logs should not be interpreted as standard SPT "N" values; corrections have not been applied.

Our exploration also included three CPT soundings to maximum depths of approximately 90 feet below existing grade utilizing a truck-mounted CPT rig with a down-pressure capacity of approximately 20 tons. The CPTs were performed on November 10, 2020 by Middle Earth Geo Testing using an integrated electronic cone system under Geocon supervision. The cone has a tip area of 15 square centimeters, a friction sleeve area of 225 square centimeters, and a ratio of friction sleeve area to tip end area equal to 0.8. The cone bearing (Q_c) and sleeve friction (F_s) were measured and recorded during tests at approximately 2-inch depth intervals. The CPT data consisting of cone bearing, sleeve friction, friction ratio and equivalent standard penetration blow counts (N) versus penetration depth below the existing ground surface for each location has been recorded and is presented in this appendix.

Subsurface conditions encountered in the exploratory boring were visually examined, classified and logged in general accordance with the American Society for Testing and Materials (ASTM) Practice for Description and Identification of Soils (Visual-Manual Procedure D2488). This system uses the Unified Soil Classification System (USCS) for soil designations. The log depicts soil and geologic conditions encountered and depths at which samples were obtained. The log also includes our interpretation of the conditions between sampling intervals. Therefore, the logs contain both observed and interpreted data. We determined the lines designating the interface between soil materials on the logs using visual observations, drill rig penetration rates, excavation characteristics and other factors. The transition between materials may be abrupt or gradual. Where applicable, the field logs were revised based on subsequent laboratory testing. Upon completion, our soil borings and CPT boreholes were backfilled per Marin County permit requirements.

UNIFIED SOIL CLASSIFICATION

MAJOR DIVISIONS					TYPICAL NAMES
COARSE-GRAINED SOILS MORE THAN HALF IS COARSER THAN NO. 200 SIEVE	**GRAVELS** MORE THAN HALF COARSE FRACTION IS LARGER THAN NO.4 SIEVE SIZE	CLEAN GRAVELS WITH LITTLE OR NO FINES	GW	▨	WELL GRADED GRAVELS WITH OR WITHOUT SAND, LITTLE OR NO FINES
			GP	▨	POORLY GRADED GRAVELS WITH OR WITHOUT SAND, LITTLE OR NO FINES
		GRAVELS WITH OVER 12% FINES	GM	▨	SILTY GRAVELS, SILTY GRAVELS WITH SAND
			GC	▨	CLAYEY GRAVELS, CLAYEY GRAVELS WITH SAND
	SANDS MORE THAN HALF COARSE FRACTION IS SMALLER THAN NO.4 SIEVE SIZE	CLEAN SANDS WITH LITTLE OR NO FINES	SW	▨	WELL GRADED SANDS WITH OR WITHOUT GRAVEL, LITTLE OR NO FINES
			SP	▨	POORLY GRADED SANDS WITH OR WITHOUT GRAVEL, LITTLE OR NO FINES
		SANDS WITH OVER 12% FINES	SM	▨	SILTY SANDS WITH OR WITHOUT GRAVEL
			SC	▨	CLAYEY SANDS WITH OR WITHOUT GRAVEL
FINE-GRAINED SOILS MORE THAN HALF IS FINER THAN NO. 200 SIEVE	**SILTS AND CLAYS** LIQUID LIMIT 50% OR LESS		ML	▥	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTS WITH SANDS AND GRAVELS
			CL	▨	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, CLAYS WITH SANDS AND GRAVELS, LEAN CLAYS
			OL	▤	ORGANIC SILTS OR CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS LIQUID LIMIT GREATER THAN 50%		MH	▨	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS, FINE SANDY OR SILTY SOILS, ELASTIC SILTS
			CH	▨	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
			OH	▨	ORGANIC CLAYS OR CLAYS OF MEDIUM TO HIGH PLASTICITY
	HIGHLY ORGANIC SOILS		PT	▨	PEAT AND OTHER HIGHLY ORGANIC SOILS

BORING/TRENCH LOG LEGEND

☐ — No Recovery

▯ — Shelby Tube Sample

▩ — Bulk Sample

◧ — SPT Sample

■ — Modified California Sample

▼ — Groundwater Level (At Completion)

▽ — Groundwater Level (Seepage)

PENETRATION RESISTANCE

SAND AND GRAVEL			SILT AND CLAY			
RELATIVE DENSITY	BLOWS PER FOOT (SPT)*	BLOWS PER FOOT (MOD-CAL)*	CONSISTENCY	BLOWS PER FOOT (SPT)*	BLOWS PER FOOT (MOD-CAL)*	COMPRESSIVE STRENGTH (tsf)
VERY LOOSE	0 - 4	0 - 6	VERY SOFT	0 - 2	0 - 3	0 - 0.25
LOOSE	5 - 10	7 - 16	SOFT	3 - 4	4 - 6	0.25 - 0.50
MEDIUM DENSE	11 - 30	17 - 48	MEDIUM STIFF	5 - 8	7 - 13	0.50 - 1.0
DENSE	31 - 50	49 - 79	STIFF	9 - 15	14 - 24	1.0 - 2.0
VERY DENSE	OVER 50	OVER 79	VERY STIFF	16 - 30	25 - 48	2.0 - 4.0
			HARD	OVER 30	OVER 48	OVER 4.0

*NUMBER OF BLOWS OF 140 LB HAMMER FALLING 30 INCHES TO DRIVE LAST 12 INCHES OF AN 18-INCH DRIVE

MOISTURE DESCRIPTIONS

FIELD TEST	APPROX. DEGREE OF SATURATION, S (%)	DESCRIPTION
NO INDICATION OF MOISTURE; DRY TO THE TOUCH	S<25	DRY
SLIGHT INDICATION OF MOISTURE	25≤S<50	DAMP
INDICATION OF MOISTURE; NO VISIBLE WATER	50≤S<75	MOIST
MINOR VISIBLE FREE WATER	75≤S<100	WET
VISIBLE FREE WATER	100	SATURATED

QUANTITY DESCRIPTIONS

APPROX. ESTIMATED PERCENT	DESCRIPTION
<5%	TRACE
5 - 10%	FEW
11 - 25%	LITTLE
26 - 50%	SOME
>50%	MOSTLY

GRAVEL/COBBLE/BOULDER DESCRIPTIONS

CRITERIA	DESCRIPTION
PASS THROUGH A 3-INCH SIEVE AND BE RETAINED ON A NO. 4 SIEVE (#4 TO 3")	GRAVEL
PASS A 12-INCH SQUARE OPENING AND BE RETAINED ON A 3-INCH SIEVE (3"-12")	COBBLE
WILL NOT PASS A 12-INCH SQUARE OPENING (>12")	BOULDER

BEDDING SPACING DESCRIPTIONS

THICKNESS/SPACING	DESCRIPTOR
GREATER THAN 10 FEET	MASSIVE
3 TO 10 FEET	VERY THICKLY BEDDED
1 TO 3 FEET	THICKLY BEDDED
3 ⅝-INCH TO 1 FOOT	MODERATELY BEDDED
1 ¼-INCH TO 3 ⅝-INCH	THINLY BEDDED
⅜-INCH TO 1 ¼-INCH	VERY THINLY BEDDED
LESS THAN ⅜-INCH	LAMINATED

STRUCTURE DESCRIPTIONS

CRITERIA	DESCRIPTION
ALTERNATING LAYERS OF VARYING MATERIAL OR COLOR WITH LAYERS AT LEAST ¼-INCH THICK	STRATIFIED
ALTERNATING LAYERS OF VARYING MATERIAL OR COLOR WITH LAYERS LESS THAN ¼-INCH THICK	LAMINATED
BREAKS ALONG DEFINITE PLANES OF FRACTURE WITH LITTLE RESISTANCE TO FRACTURING	FISSURED
FRACTURE PLANES APPEAR POLISHED OR GLOSSY, SOMETIMES STRIATED	SLICKENSIDED
COHESIVE SOIL THAT CAN BE BROKEN DOWN INTO SMALLER ANGULAR LUMPS WHICH RESIST FURTHER BREAKDOWN	BLOCKY
INCLUSION OF SMALL POCKETS OF DIFFERENT SOIL, SUCH AS SMALL LENSES OF SAND SCATTERED THROUGH A MASS OF CLAY	LENSED
SAME COLOR AND MATERIAL THROUGHOUT	HOMOGENOUS

CEMENTATION/INDURATION DESCRIPTIONS

FIELD TEST	DESCRIPTION
CRUMBLES OR BREAKS WITH HANDLING OR LITTLE FINGER PRESSURE	WEAKLY CEMENTED/INDURATED
CRUMBLES OR BREAKS WITH CONSIDERABLE FINGER PRESSURE	MODERATELY CEMENTED/INDURATED
WILL NOT CRUMBLE OR BREAK WITH FINGER PRESSURE	STRONGLY CEMENTED/INDURATED

IGNEOUS/METAMORPHIC ROCK STRENGTH DESCRIPTIONS

FIELD TEST	DESCRIPTION
MATERIAL CRUMBLES WITH BARE HAND	WEAK
MATERIAL CRUMBLES UNDER BLOWS FROM GEOLOGY HAMMER	MODERATELY WEAK
⅛-INCH INDENTATIONS WITH SHARP END FROM GEOLOGY HAMMER	MODERATELY STRONG
HAND-HELD SPECIMEN CAN BE BROKEN WITH **ONE** BLOW FROM GEOLOGY HAMMER	STRONG
HAND-HELD SPECIMEN CAN BE BROKEN WITH **COUPLE** BLOWS FROM GEOLOGY HAMMER	VERY STRONG
HAND-HELD SPECIMEN CAN BE BROKEN WITH **MANY** BLOWS FROM GEOLOGY HAMMER	EXTREMELY STRONG

IGNEOUS/METAMORPHIC ROCK WEATHERING DESCRIPTIONS

DEGREE OF DECOMPOSITION	FIELD RECOGNITION	ENGINEERING PROPERTIES
SOIL	DISCOLORED, CHANGED TO SOIL, FABRIC DESTROYED	EASY TO DIG
COMPLETELY WEATHERED	DISCOLORED, CHANGED TO SOIL, FABRIC MAINLY PRESERVED	EXCAVATED BY HAND OR RIPPING (Saprolite)
HIGHLY WEATHERED	DISCOLORED, HIGHLY FRACTURED, FABRIC ALTERED AROUND FRACTURES	EXCAVATED BY HAND OR RIPPING, WITH SLIGHT DIFFICULTY
MODERATELY WEATHERED	DISCOLORED, FRACTURES, INTACT ROCK-NOTICEABLY WEAKER THAN FRESH ROCK	EXCAVATED WITH DIFFICULTY WITHOUT EXPLOSIVES
SLIGHTLY WEATHERED	MAY BE DISCOLORED, SOME FRACTURES, INTACT ROCK-NOT NOTICEABLY WEAKER THAN FRESH ROCK	REQUIRES EXPLOSIVES FOR EXCAVATION, WITH PERMEABLE JOINTS AND FRACTURES
FRESH	NO DISCOLORATION, OR LOSS OF STRENGTH	REQUIRES EXPLOSIVES

IGNEOUS/METAMORPHIC ROCK JOINT/FRACTURE DESCRIPTIONS

FIELD TEST	DESCRIPTION
NO OBSERVED FRACTURES	UNFRACTURED/UNJOINTED
MAJORITY OF JOINTS/FRACTURES SPACED AT 1 TO 3 FOOT INTERVALS	SLIGHTLY FRACTURED/JOINTED
MAJORITY OF JOINTS/FRACTURES SPACED AT 4-INCH TO 1 FOOT INTERVALS	MODERATELY FRACTURED/JOINTED
MAJORITY OF JOINTS/FRACTURES SPACED AT 1-INCH TO 4-INCH INTERVALS WITH SCATTERED FRAGMENTED INTERVALS	INTENSELY FRACTURED/JOINTED
MAJORITY OF JOINTS/FRACTURES SPACED AT LESS THAN 1-INCH INTERVALS; MOSTLY RECOVERED AS CHIPS AND FRAGMENTS	VERY INTENSELY FRACTURED/JOINTED

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KEY TO LOGS

PROJECT NO. **E9226-04-01** PROJECT NAME: **Vivian St. Townhomes**

BORING B1

ELEV. (MSL.) __________ DATE COMPLETED **11/19/2020**

ENG./GEO. **AA** DRILLER **Clear Heart Drilling**

EQUIPMENT **DR8k Track Rig w/ 7" HSA** HAMMER TYPE **Auto-hammer**

DEPTH IN FEET	SAMPLE NO.	LITHOLOGY	GROUNDWATER	SOIL CLASS (USCS)	MATERIAL DESCRIPTION	PENETRATION RESISTANCE (BLOWS/FT.)	DRY DENSITY (P.C.F.)	MOISTURE CONTENT (%)
0					Approximately 2 inches of AC			
1				CL	Approximately 9 inches of AB			
	B1-1.5				FILL	45		
2	B1-2				Hard, damp, black to dark brown, CLAY with (f) sand			5.3
3				SC	Medium dense, wet, brown, Clayey SAND with trace (f) gravel			
4			▼			20		
5	B1-4.5							12.4
6				CH	BAY MUD			
	B1-6.5				Very soft, gray, wet, fat CLAY	3		
7	B1-7				-some organics at the top		57.1	67.4
8					-pp<¼			
9	B1-8.5-10.5						42.4	110.0
10					-pp<¼			
11								
12								
13								
14								
15								
16								
17								
18								
19						0		
20	B1-19.5				-pp<¼		54	74.3

END OF BORING AT APPROXIMATELY 20 FEET
GROUNDWATER INITIALLY ENCOUNTERED AT APPROXIMATELY 4 FEET
BACKFILLED WITH NEAT GROUT CEMENT

Figure A2, Log of Boring B1, Page 1 of 1

SAMPLE SYMBOLS

☐ ... SAMPLING UNSUCCESSFUL	◧ ... STANDARD PENETRATION TEST	■ ... DRIVE SAMPLE (UNDISTURBED)
☒ ... DISTURBED OR BAG SAMPLE	◩ ... CHUNK SAMPLE	▼ ... WATER TABLE OR SEEPAGE

NOTE: THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING OR TRENCH LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

PROJECT NO. **E9226-04-01** PROJECT NAME: **Vivian St. Townhomes**

BORING B2

ELEV. (MSL.) ____________ DATE COMPLETED **11/19/2020**

ENG./GEO. **AA** DRILLER **Clear Heart Drilling**

EQUIPMENT **DR8k Track Rig w/ 7" HSA** HAMMER TYPE **Auto-hammer**

DEPTH IN FEET	SAMPLE NO.	LITHOLOGY	GROUNDWATER	SOIL CLASS (USCS)	MATERIAL DESCRIPTION	PENETRATION RESISTANCE (BLOWS/FT.)	DRY DENSITY (P.C.F.)	MOISTURE CONTENT (%)
0					Approximately 3 inches of AC			
					Approximately 9 inches of AB			
1	B2-1.5-2.5			CL	FILL Moist, dark brown, CLAY with (f) sand	21		
2	B2-2.5-3.5			GC	Medium dense, moist, olive, GRAVEL with (m) sand, clay, and silt			
3				CL	Stiff, moist, brown, (f-m) Sandy CLAY			
4	B2-4-5					13		12.3
5			▼					
6								
7	B2-6.5 B2-7			CH	BAY MUD Soft, moist, gray and olive, fat CLAY -pp<¼	9		
8								
9	B2-9.5				-very soft, gray -pp<¼	0		
10								
11								
12								
13								
14	B2-14.5				-pp<¼	0	49.0	83.1
15								
16								
17								
18								
19								
20								
21								
22								
23								
24	B2-24.5				-pp<¼	0	64.3	54.2
25					END OF BORING AT APPROXIMATELY 25 FEET GROUNDWATER INITIALLY ENCOUNTERED AT APPROXIMATELY 5 FEET BACKFILLED WITH NEAT GROUT CEMENT			

Figure A3, Log of Boring B2, Page 1 of 1

GEOCON BORING LOG W/FIG# STARTING W/ A2 E9226-04-01 BORING LOGS.GPJ 12/22/20

GEOCON

SAMPLE SYMBOLS

☐ ... SAMPLING UNSUCCESSFUL	◧ ... STANDARD PENETRATION TEST	■ ... DRIVE SAMPLE (UNDISTURBED)
☒ ... DISTURBED OR BAG SAMPLE	◪ ... CHUNK SAMPLE	▼ ... WATER TABLE OR SEEPAGE

NOTE: THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING OR TRENCH LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

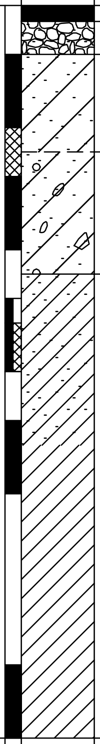
PROJECT NO. **E9226-04-01** PROJECT NAME: **Vivian St. Townhomes**

BORING B3

ELEV. (MSL.) ____________ DATE COMPLETED **11/19/2020**

ENG./GEO. **AA** DRILLER **Clear Heart Drilling**

EQUIPMENT **DR8k Track Rig w/ 4" SFA** HAMMER TYPE **Auto-hammer**



DEPTH IN FEET	SAMPLE NO.	LITHOLOGY	GROUNDWATER	SOIL CLASS (USCS)	MATERIAL DESCRIPTION	PENETRATION RESISTANCE (BLOWS/FT.)	DRY DENSITY (P.C.F.)	MOISTURE CONTENT (%)
0					Approximately 4 inches of AC Approximately 8 inches of AB			
1	B3-1-3			CL	FILL			
2	B3-1.5-2.5				Medium stiff, moist, brown/olive, CLAY with (f) sand -pp=1¼	12	116.9	15.1
3				SC	Loose, wet, dark brown/black, Clayey (f-m) SAND with trace (f) gravel			
4			▼			10		
5	B3-4.5-5							12.5
6				CH	BAY MUD Very soft, wet, black/olive/gray, fat CLAY with trace (f) sand -pp<¼			
7	B3-6.5-7.5					2		47.2
8								
9					-gray, no sand -pp<¼	0		
10	B3-9.5							
11								
12								
13								
14						0		
15	B3-14.5						51.1	82.4

END OF BORING AT APPROXIMATELY 15 FEET
GROUNDWATER INITIALLY ENCOUNTERED AT
APPROXIMATELY 4 FEET
BACKFILLED WITH NEAT GROUT CEMENT

Figure A4, Log of Boring B3, Page 1 of 1

GEOCON

SAMPLE SYMBOLS

☐ ... SAMPLING UNSUCCESSFUL
▨ ... DISTURBED OR BAG SAMPLE
◧ ... STANDARD PENETRATION TEST
◪ ... CHUNK SAMPLE
■ ... DRIVE SAMPLE (UNDISTURBED)
▼ ... WATER TABLE OR SEEPAGE

NOTE: THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING OR TRENCH LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

PROJECT NO. **E9226-04-01** PROJECT NAME: **Vivian St. Townhomes**

BORING B4

ELEV. (MSL.) ________ DATE COMPLETED **11/19/2020**

ENG./GEO. **AA** DRILLER **Clear Heart Drilling**

EQUIPMENT **DR8k Track Rig w/ 7" HSA** HAMMER TYPE **Auto-hammer**

DEPTH IN FEET	SAMPLE NO.	LITHOLOGY	GROUNDWATER	SOIL CLASS (USCS)	MATERIAL DESCRIPTION	PENETRATION RESISTANCE (BLOWS/FT.)	DRY DENSITY (P.C.F.)	MOISTURE CONTENT (%)
0					Approximately 6 inches of AC			
					Approximately 5½ inches of AB			
1	B4-1-3			CL	FILL Stiff, moist, brown, (f) Sandy CLAY and trace (f) gravel			
2								
3								
	B4-3.5						128.4	13.4
4	B4-4			GM	Medium dense, moist, brown, Silty (f-c) GRAVEL with (f-m) sand	29		8.1
5			▼					
6				CH	BAY MUD Very soft to soft, wet, gray, fat CLAY			
7						2		
8								
9					-pp<¼	2		
	B4-9.5						50.8	81.0
10								
11								
12								
13								
14								
15								
16								
17								
18								
19						0		
	B4-19.5				-very soft		56.1	69.1
20					END OF BORING AT APPROXIMATELY 20 FEET GROUNDWATER INITIALLY ENCOUNTERED AT 5 FEET BACKFILLED WITH NEAT GROUT CEMENT			

Figure A5, Log of Boring B4, Page 1 of 1

GEOCON

SAMPLE SYMBOLS

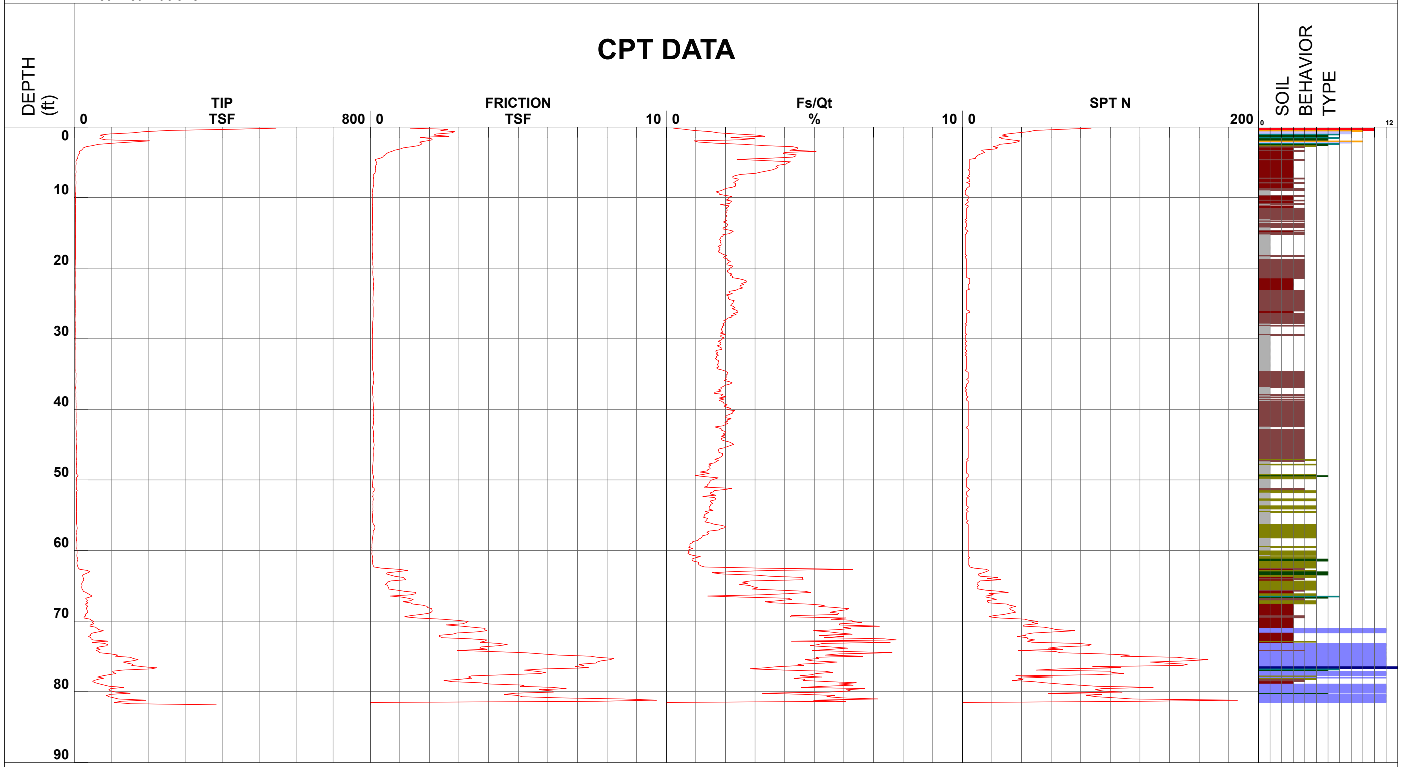
☐ ... SAMPLING UNSUCCESSFUL
◧ ... STANDARD PENETRATION TEST
■ ... DRIVE SAMPLE (UNDISTURBED)
☒ ... DISTURBED OR BAG SAMPLE
◪ ... CHUNK SAMPLE
▼ ... WATER TABLE OR SEEPAGE

NOTE: THE LOG OF SUBSURFACE CONDITIONS SHOWN HEREON APPLIES ONLY AT THE SPECIFIC BORING OR TRENCH LOCATION AND AT THE DATE INDICATED. IT IS NOT WARRANTED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT OTHER LOCATIONS AND TIMES.

Geocon Inc.

Project	Vivian Street Townhome	Operator	BH-AJ	Filename	SDF(364).cpt
Job Number	E9226-04-01	Cone Number	DDG1496	GPS	
Hole Number	CPT-01	Date and Time	11/10/2020 8:04:44 AM	Maximum Depth	81.86 ft
EST GW Depth During Test		5.00 ft			

Net Area Ratio .8



CPT DATA

■ 1 - sensitive fine grained

■ 2 - organic material

■ 3 - clay

■ 4 - silty clay to clay

■ 5 - clayey silt to silty clay

■ 6 - sandy silt to clayey silt

■ 7 - silty sand to sandy silt

■ 8 - sand to silty sand

■ 9 - sand

■ 10 - gravelly sand to sand

■ 11 - very stiff fine grained (*)

■ 12 - sand to clayey sand (*)

Cone Size 15cm squared

S*Soil behavior type and SPT based on data from UBC-1983

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CONE PENETROMETER TEST DATA - CPT-1

Project: Vivian Street Townhomes
Project No. E9226-04-01
Date: January 2021

FIGURE A6

Middle Earth
GEO TESTING INC.

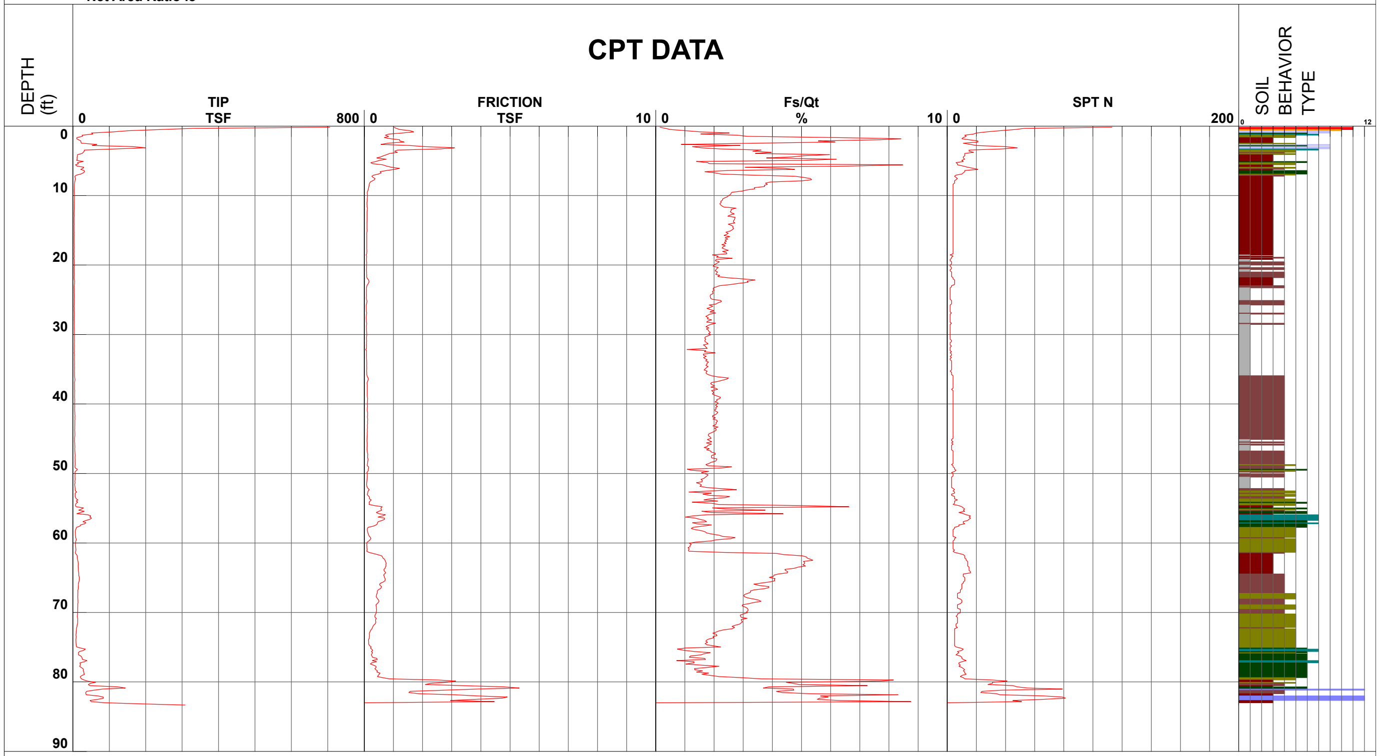
Geocon Inc.

Project Vivian Street Townhome
Job Number E9226-04-01
Hole Number CPT-02
EST GW Depth During Test 4.00 ft

Operator BH-AJ
Cone Number DDG1496
Date and Time 11/10/2020 11:01:20 AM

Filename SDF(365).cpt
GPS
Maximum Depth 83.33 ft

Net Area Ratio .8



■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

Cone Size 15cm squared

S*Soil behavior type and SPT based on data from UBC-1983

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CONE PENETROMETER TEST DATA - CPT-2

Project: Vivian Street Townhomes
Project No. E9226-04-01
Date: January 2021

FIGURE A7

Geocon Inc.

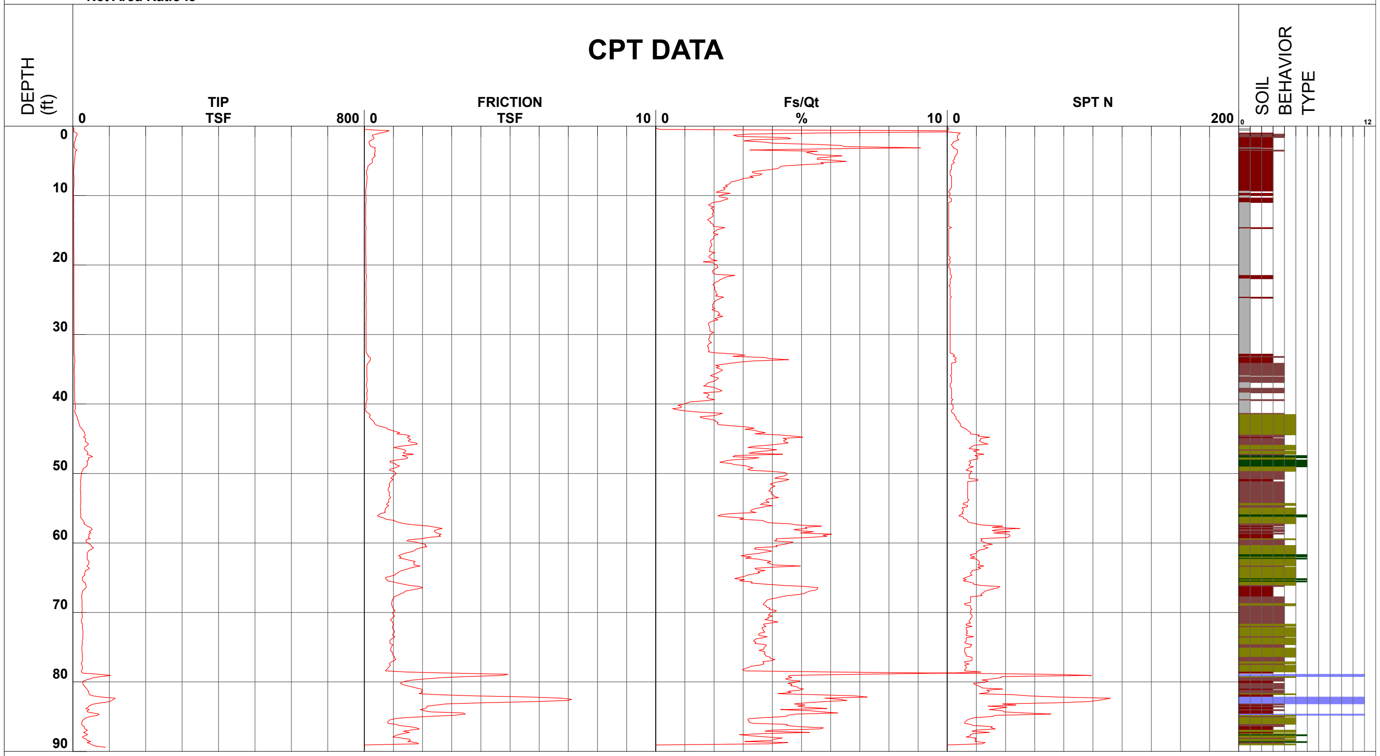
Middle Earth GEO TESTING INC.

Project Vivian Street Townhome
Job Number E9226-04-01
Hole Number CPT-03
EST GW Depth During Test 7.00 ft

Operator BH-AJ
Cone Number DDG1496
Date and Time 11/10/2020 2:08:57 PM

Filename SDF(366).cpt
GPS
Maximum Depth 89.40 ft

Net Area Ratio .8



■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay

■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt

■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand

■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

Cone Size 15cm squared

S*Soil behavior type and SPT based on data from UBC-1983

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CONE PENETROMETER TEST DATA - CPT-3

Project: Vivian Street Townhomes
Project No. E9226-04-01
Date: January 2021

FIGURE A8

APPENDIX B

APPENDIX B
LABORATORY TESTING

Laboratory tests were performed in accordance with generally accepted test methods of the American Society for Testing and Materials (ASTM) or other suggested procedures. Selected samples were tested for in-situ dry density and moisture content, grain size distribution, plasticity, expansion index, and screening-level corrosion parameters. The results of our testing are summarized in tabular format below and the following figures. In-situ dry density and moisture content test results are included on the boring logs in Appendix A.

TABLE B-I
SUMMARY OF LABORATORY ATTERBERG LIMITS TEST RESULTS
ASTM D 4318

Sample No.	Liquid Limit	Plastic Limit	Plasticity Index
B2/B3/B4-1-3.5	41	17	24
B2-7	93	36	57
B3-14.5	98	34	64

TABLE B-II
SUMMARY OF LABORATORY EXPANSION INDEX TEST RESULTS
ASTM D 4829

Sample No.	Moisture Content		Dry Density* (pcf)	Expansion Index
	Before Test (%)	After Test (%)		
B2/B3/B4-1-3.5	9.3	19.2	112.9	60

*Before saturation.

TABLE B-III
SUMMARY OF LABORATORY GRAIN SIZE ANALYSIS – NO. 200 WASH
ASTM D1140

Boring No.	Sample Depth (feet)	Fraction Passing No. 200 Sieve (%)
B1	4.5	25.6
B2	4-5	55.5
B3	4.5-5	32.3

TABLE B-IV
SUMMARY OF SOIL CORROSION PARAMETERS
(CTM 643, CTM 417, CTM 422)

Boring No. (sample depth in feet)	Soil Type (USCS Classification)	Resistivity (ohm-cm)	pH	Chloride (ppm)	Sulfate (ppm)
B1 (1-1.5)	Sandy CLAY(Fill/CL)	950	7.5	154	25
B2/B3/B4(1-3.5')	Sandy CLAY/Clayey SAND(Fill/CL/SC)	1,000	7.6	198	21

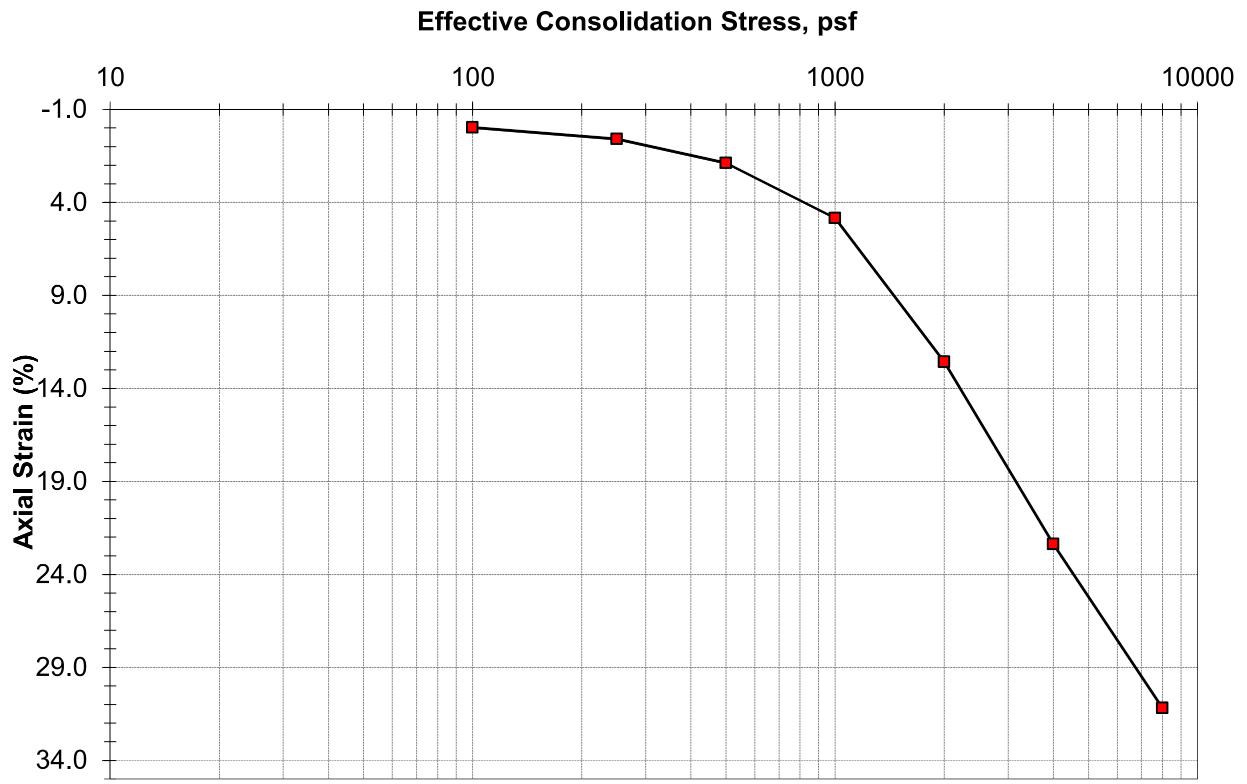
*Caltrans considers a site corrosive to foundation elements if one or more of the following conditions exist for the representative soil samples at the site:

- The pH is equal to or less than 5.5.
- Chloride concentration is equal to or greater than 500 parts per million (ppm) or 0.05%.
- Sulfate concentration is equal to or greater than 2,000 ppm (0.2%)

**According to the American Concrete Institute 318 Chapter 19, Type II cement may be used where sulfate levels are below 2,000 ppm (0.2%)

CONSOLIDATION TEST - ASTM D2435
STRESS VERSUS STRAIN

Project Name	Vivian Street Townhomes
Geocon Project Number	E9226-04-01
Boring Number	B1
Sample Number	B1-8.5-10.5
Sample Description	Very Dark Gray Fat CLAY



Axial Load, psf	Void Ratio	Axial Strain, %
initial	3.196	0.00
100	3.197	-0.03
250	3.171	0.60
500	3.117	1.88
1000	2.993	4.84
2000	2.669	12.57
4000	2.257	22.37
8000	1.888	31.19

Measurement	Initial	Final
Height (in.)	0.750	0.516
Moisture Content (%)	110.0	65.8
Dry Density (pcf)	42.4	61.6
Saturation (%)	98	99

Note:
Gs = 2.85 (assumed)

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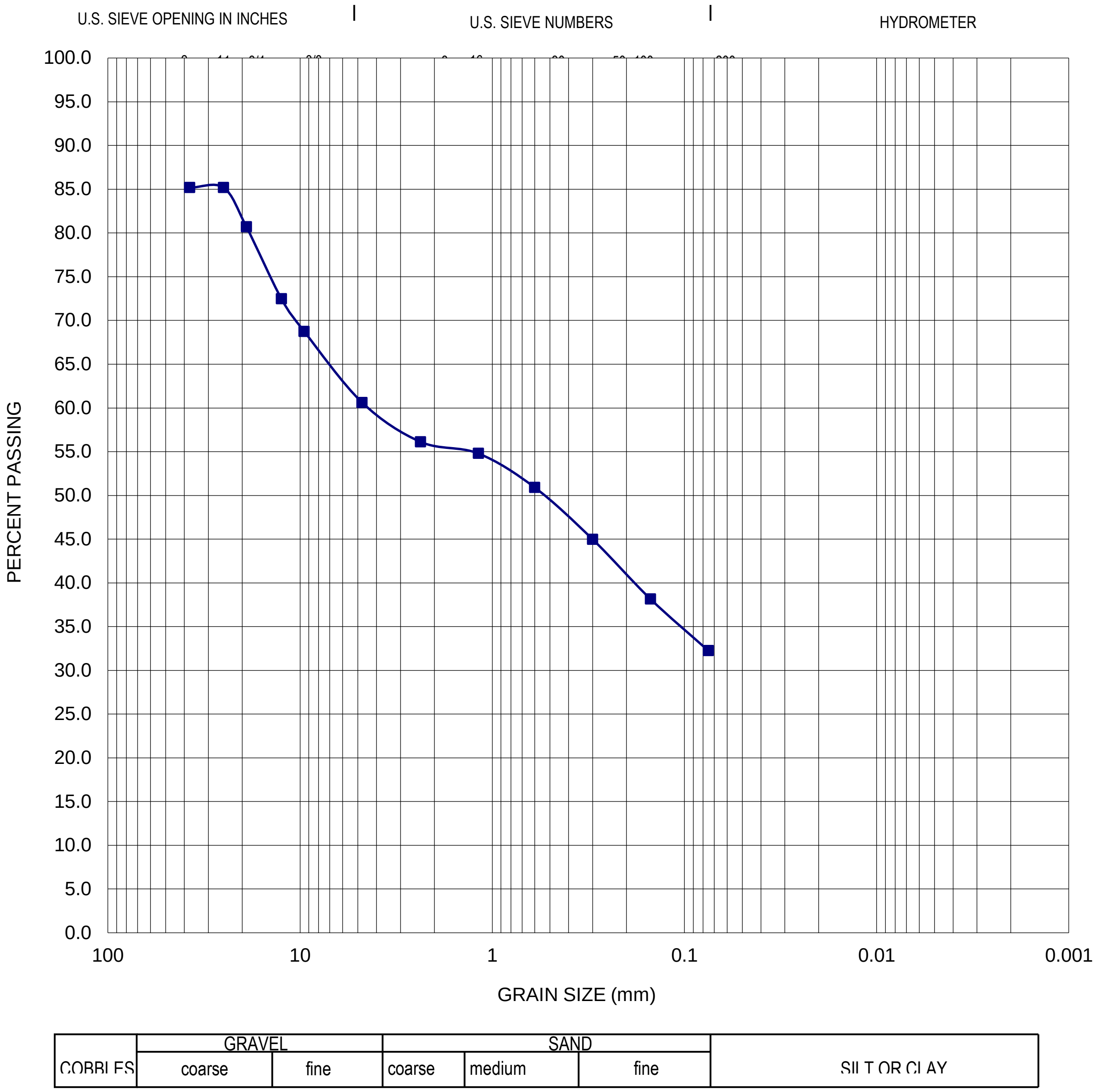
Figure B1



Boring: B4

Depth To Sample: 4'

Sieve Date: 12/7/2020

Tested and Computed by: AC

Test Data

Sieve Number	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
% Passing	85.2	85.2	80.7	72.5	68.7	60.6	56.1	54.8	50.9	45.0	38.1	32.2

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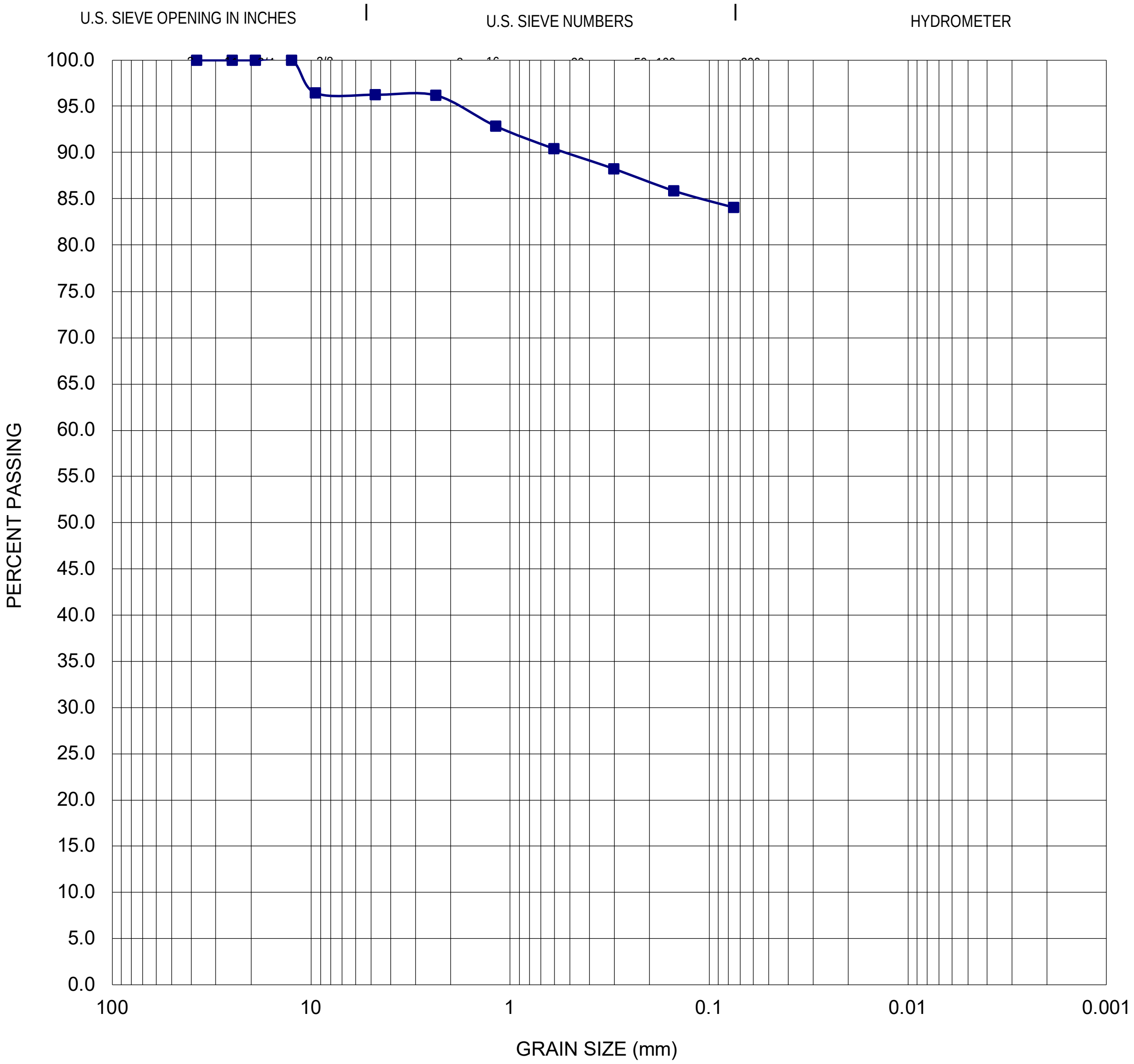
Particle Size Analysis - ASTM D422

Project: Vivian St. Townhomes

Location: San Rafael, CA

Project No.: E9226-04-01

Figure B2



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Boring: B2/B3

Depth To Sample: 1'-3.5'

Sieve Date: 12/4/2020

Tested and Computed by: TG

Test Data

Sieve Number	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
% Passing	100.0	100.0	100.0	100.0	96.5	96.2	96.2	92.9	90.4	88.3	85.9	84.1

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Particle Size Analysis - ASTM D422

Project: Vivian St. Townhomes

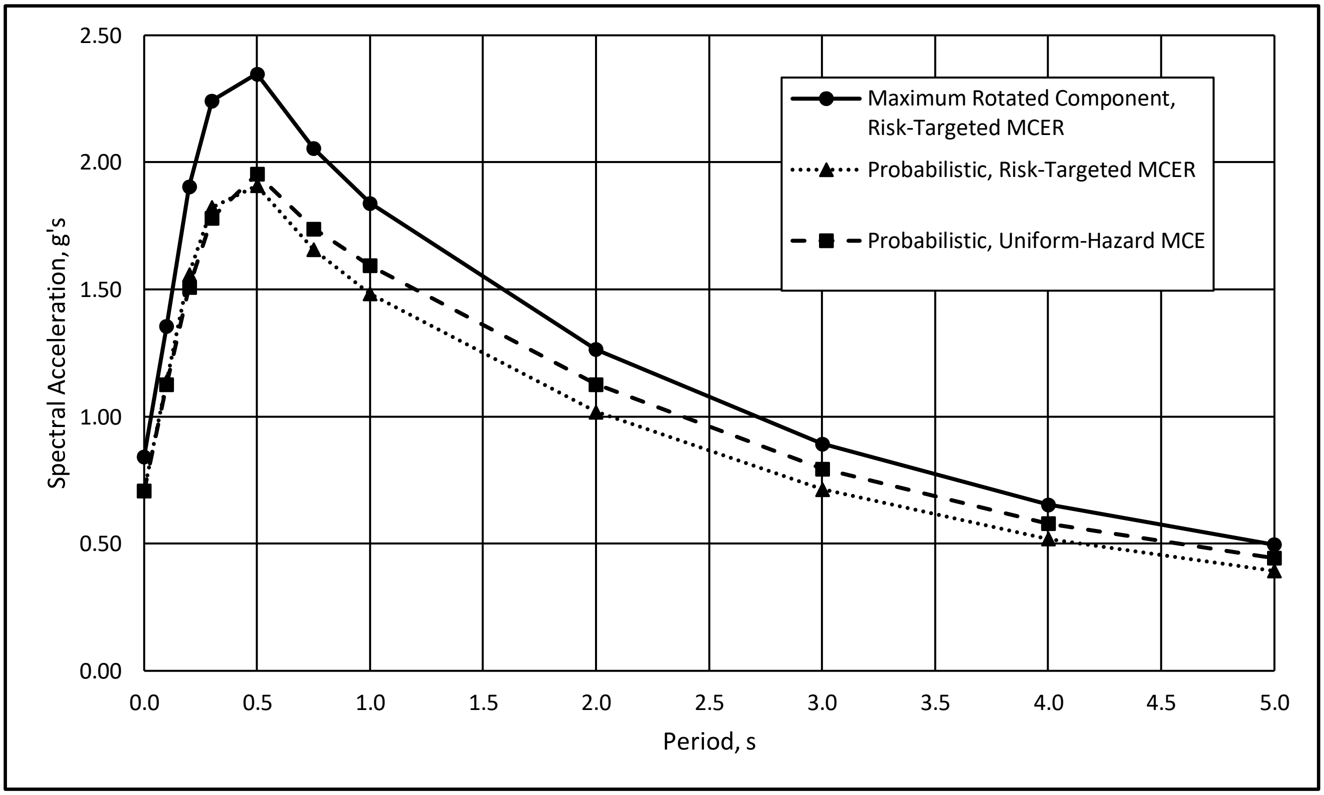
Location: San Rafael, CA

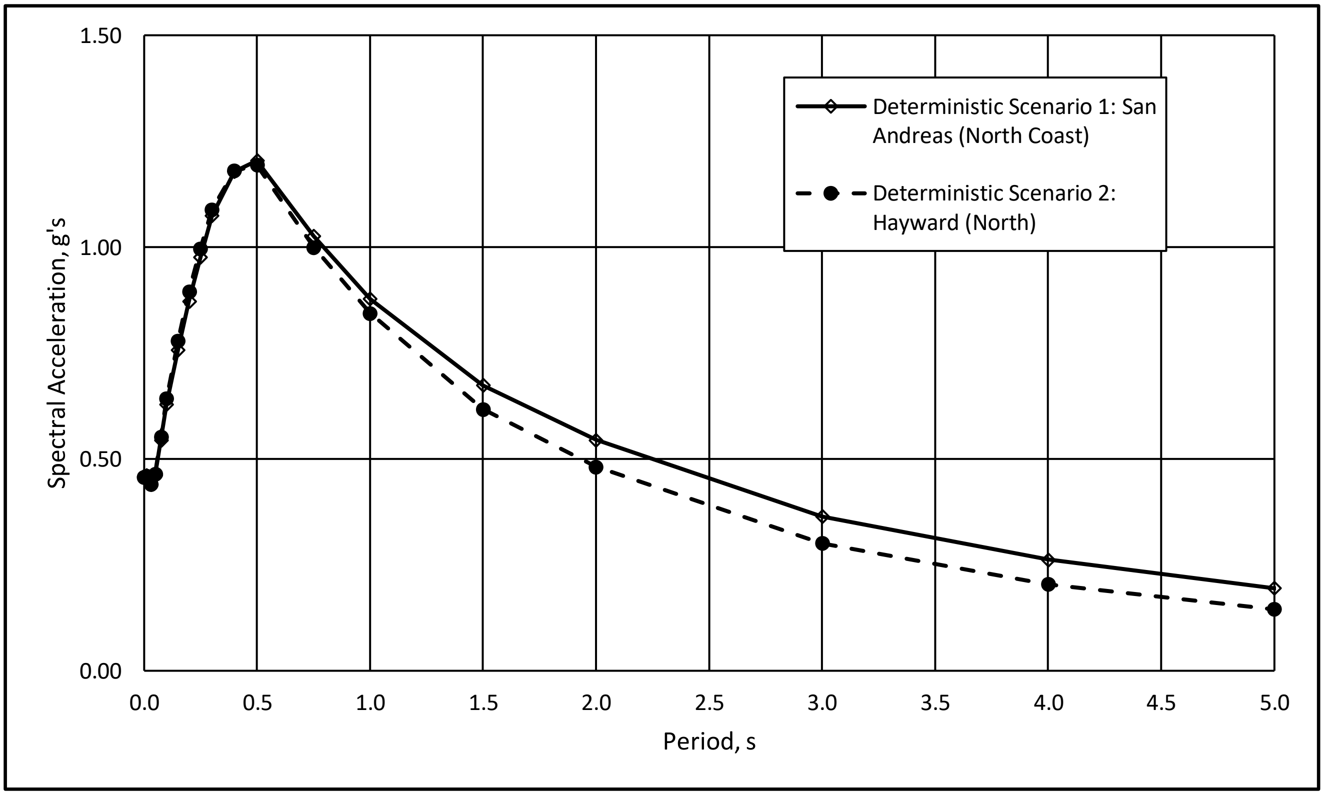
Project No.: E9226-04-01

Figure B3

APPENDIX C

APPENDIX C
GROUND MOTION HAZARD ANALYSIS





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DESIGN RESPONSE SPECTRUM

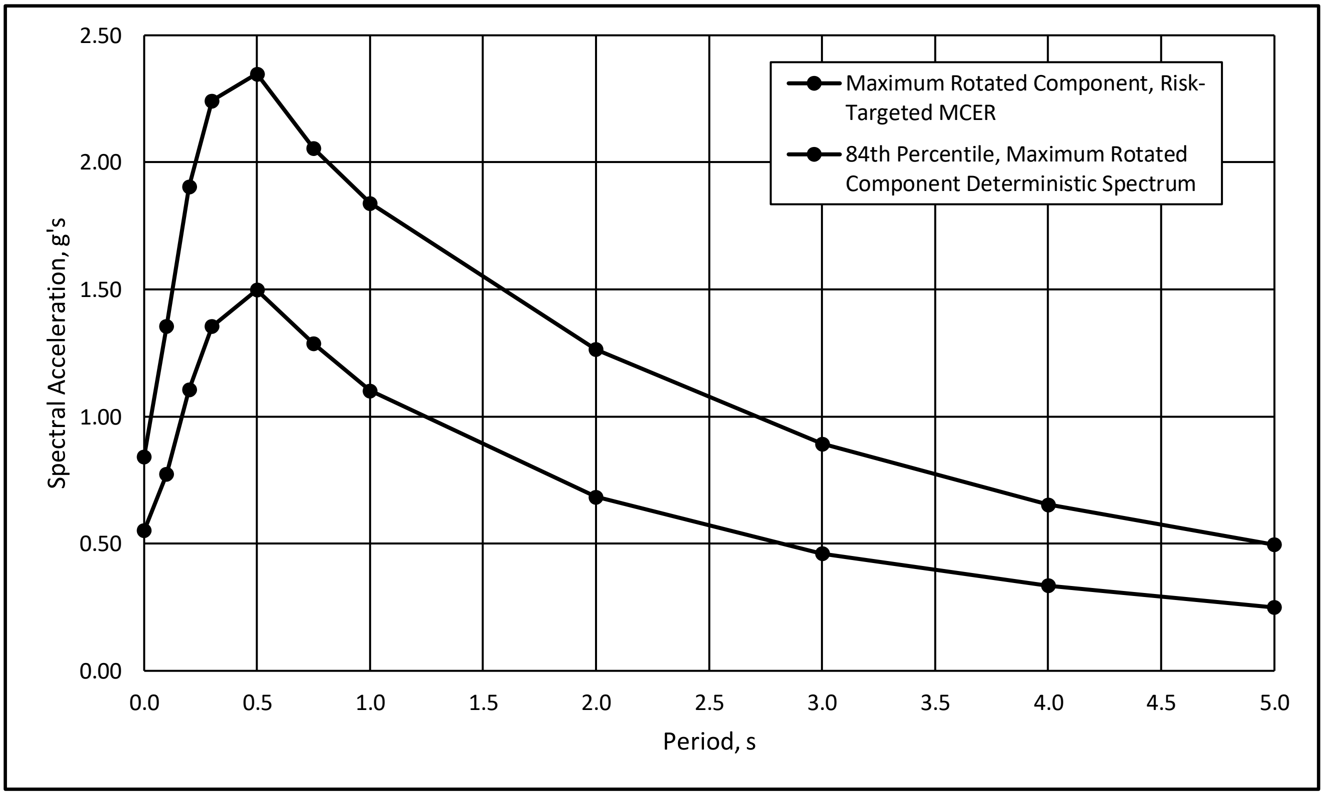
Checked by: JA

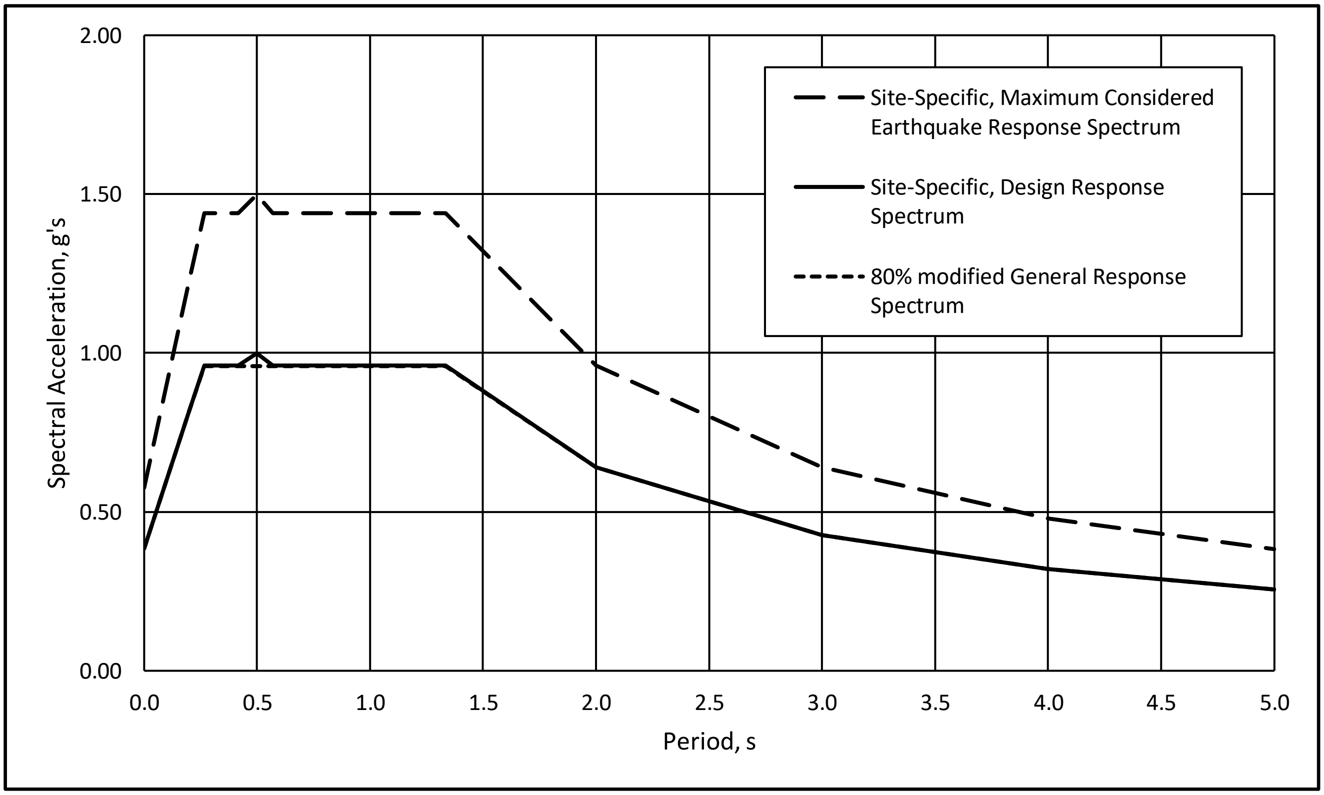
Project No.: E9226-04-01

Vivian Street Townhomes
San Rafael, CA

Dec 20

Figure C1





GEOCON

DESIGN RESPONSE SPECTRUM

Checked by: JA

Project No.: E9226-04-01

Vivian Street Townhomes
San Rafael, CA

Dec 20

Figure C2

Spectral Period (seconds)	Probabilistic Uniform-Hazard	Risk-Targeted, Probabilistic	Risk Factor, Cr	Maximum-Rotated Componet Scale Factor	MRC, Risk-Targeted Probablistic	84th Percentile, Deterministic	Site-Specific Design Earthquake	80% Modifed General Response Spectrum	Site-Specific Maximum Considered Earthquake
0.00	0.708	0.708	1.000	1.190	0.843	0.552	0.384	0.384	0.576
0.10	1.126	1.139	1.011	1.190	1.355	0.774	0.600	0.600	0.900
0.20	1.509	1.560	1.034	1.220	1.903	1.106	0.816	0.816	1.224
0.27	--	--	--	--	--	--	0.960	0.960	1.440
0.30	1.782	1.823	1.023	1.230	2.242	1.355	0.960	0.960	1.440
0.42	--	--	--	--	--	--	0.960	0.960	1.440
0.50	1.954	1.909	0.977	1.230	2.348	1.500	1.000	0.960	1.500
0.57	--	--	--	--	--	--	0.960	0.960	1.440
0.75	1.739	1.657	0.953	1.240	2.055	1.287	0.960	0.960	1.440
1.00	1.594	1.484	0.931	1.240	1.840	1.102	0.960	0.960	1.440
1.33	--	--	--	--	--	--	0.960	0.960	1.440
2.00	1.127	1.019	0.905	1.240	1.264	0.684	0.640	0.640	0.960
3.00	0.795	0.714	0.898	1.250	0.893	0.461	0.427	0.427	0.640
4.00	0.580	0.519	0.894	1.260	0.654	0.335	0.320	0.320	0.480
5.00	0.444	0.394	0.887	1.260	0.497	0.249	0.256	0.256	0.384

SM_S = 1.440 g

SM_1 = 1.920 g

SD_S = 0.960 g

SD_1 = 1.280 g

Reference: ASCE 7-16 21.4 DESIGN ACCELERATION PARAMETERS

Where the site-specific procedure is used to determine the design ground motion in accordance with Section 21.3, the parameter S_{DS} shall be taken as 90% of the maximum spectral acceleration, S_a, obtained from the site-specific spectrum, at any period within the range from 0.2 to 5 s, inclusive. The parameter S_{D1} shall be taken as the maximum value of the product, TS_a, for periods from 1 to 2 s for sites with $v_{s,30}$ > 1,200 ft/s ($v_{s,30}$ > 365.76 m/s) and for periods from 1 to 5 s for sites with $v_{s,30}$ ≤ 1,200 ft/=s ($v_{s,30}$ ≤ 365.76 m/s). The parameters S_{MS} and S_{M1} shall be taken as 1.5 times S_{DS} and S_{D1}, respectively. The values so obtained shall not be less than 80% of the values determined in accordance with Section 11.4.3 for S_{MS} and S_{M1} and Section 11.4.5 for S_{DS} and S_{D1}.

"--" Indicates that spectral period was not used at that calculation step

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DESIGN RESPONSE SPECTRUM

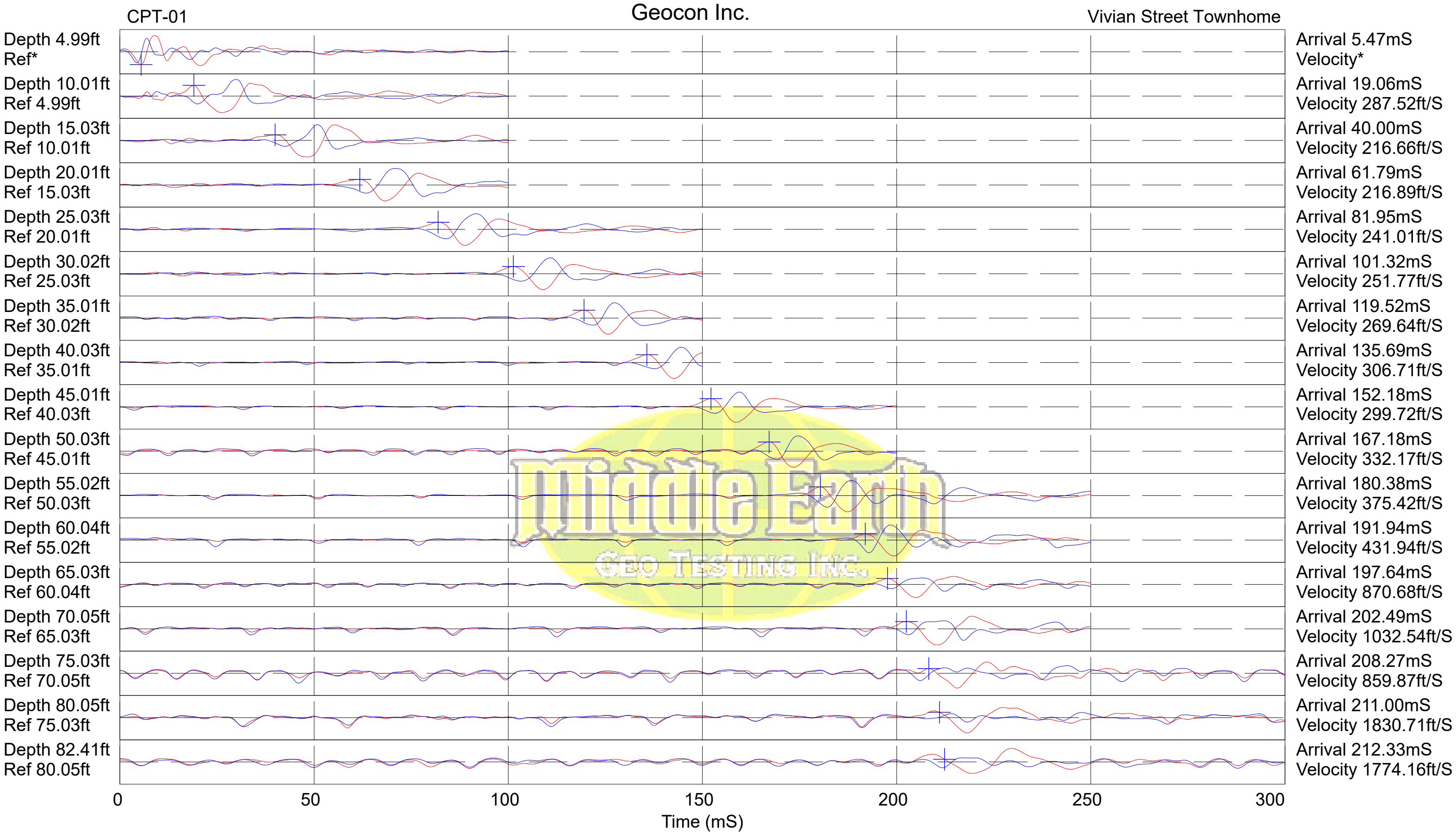
Checked by: JA

Project No.: E9226-04-01

Vivian Street Townhomes
San Rafael, CA

Dec 20

Figure C3



Hammer to Rod String Distance (ft): 5.83

* = Not Determined

COMMENT:

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Shear Velocity Sounding Profile(SCPT-1)

Project: Vivian Street Townhomes
Project No. E9226-04-01
Date: January 2021

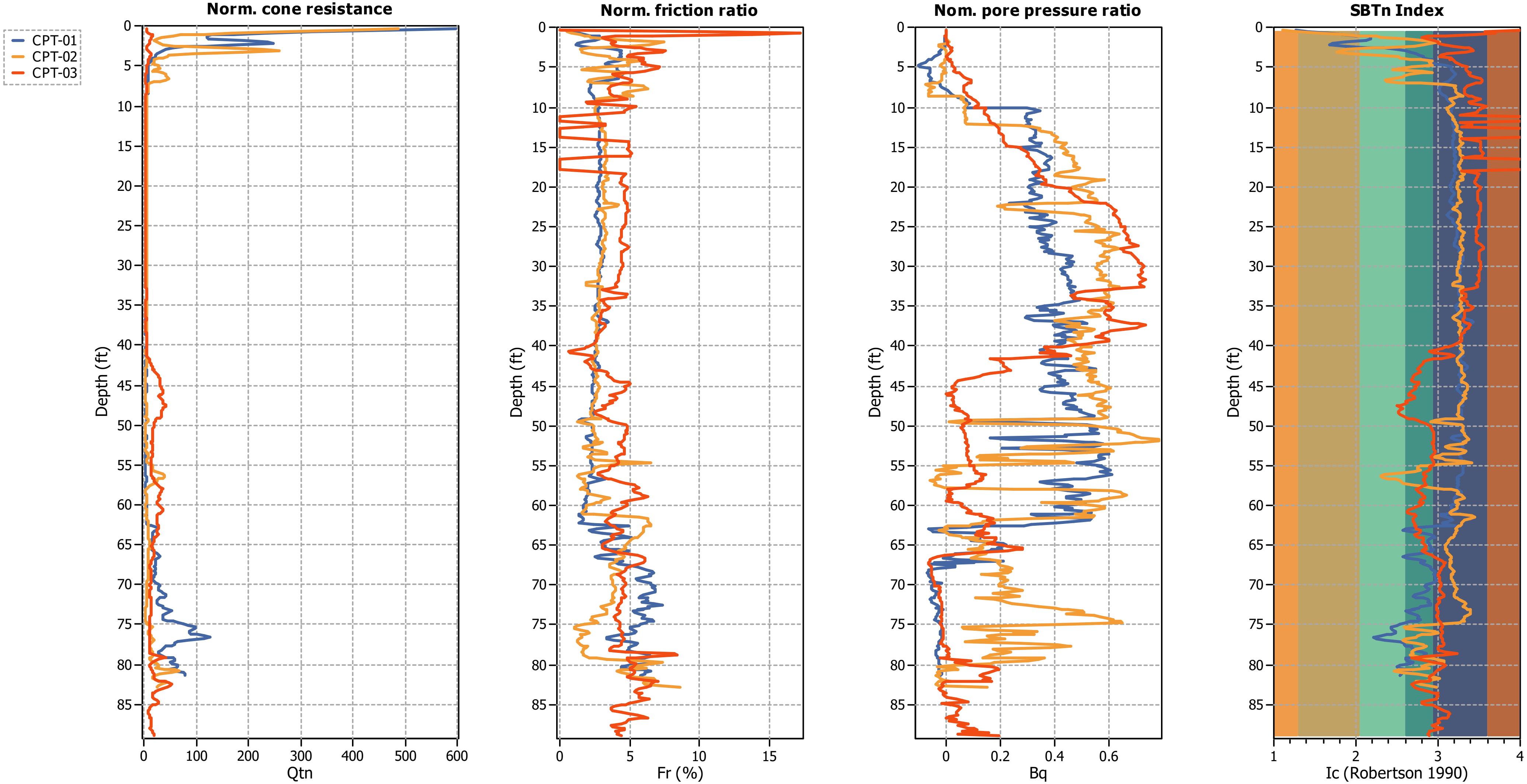
FIGURE C4

APPENDIX D

APPENDIX D
LIQUEFACTION ANALYSIS

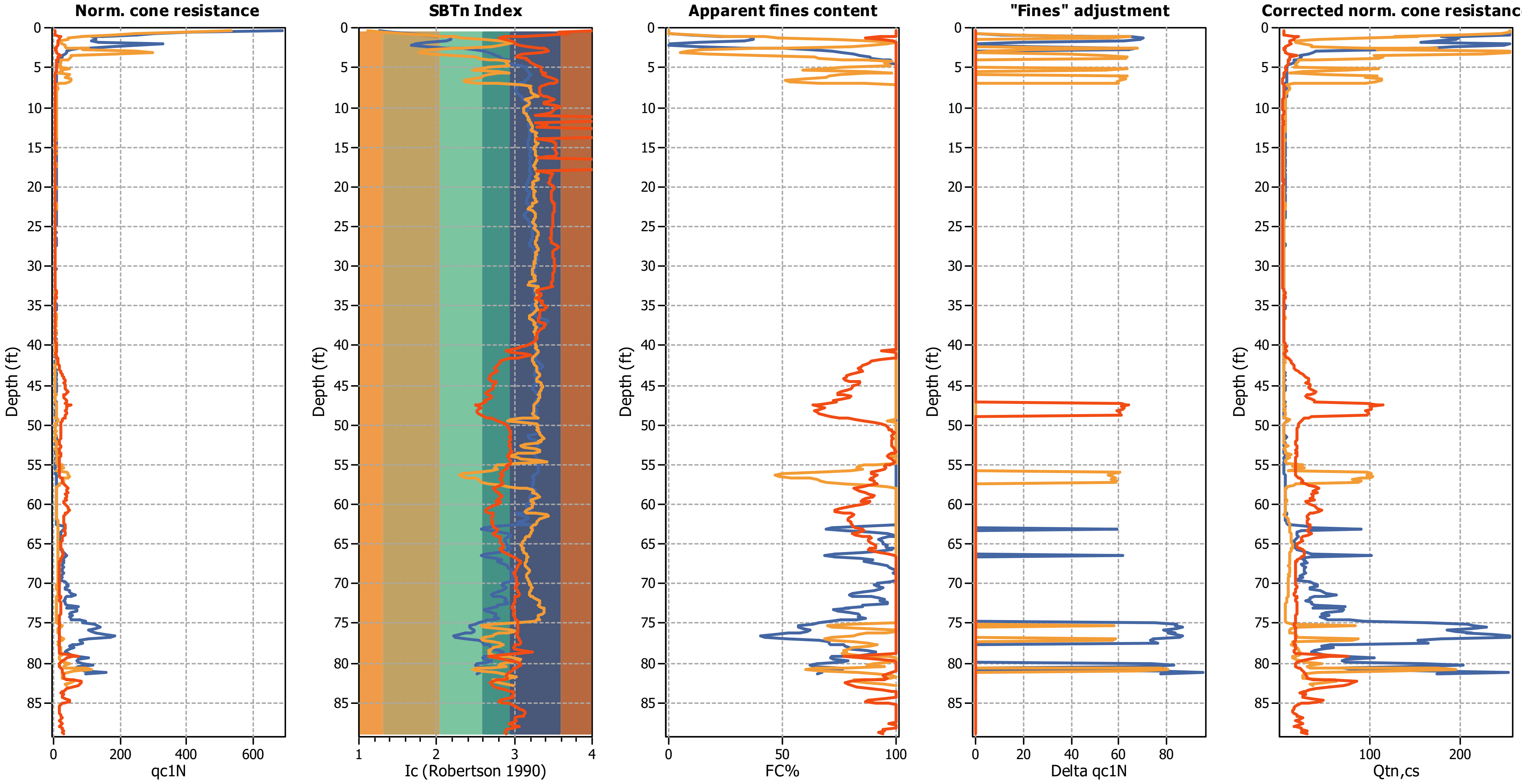
Project: Vivian Street Townhomes

Overlay Normalized Plots



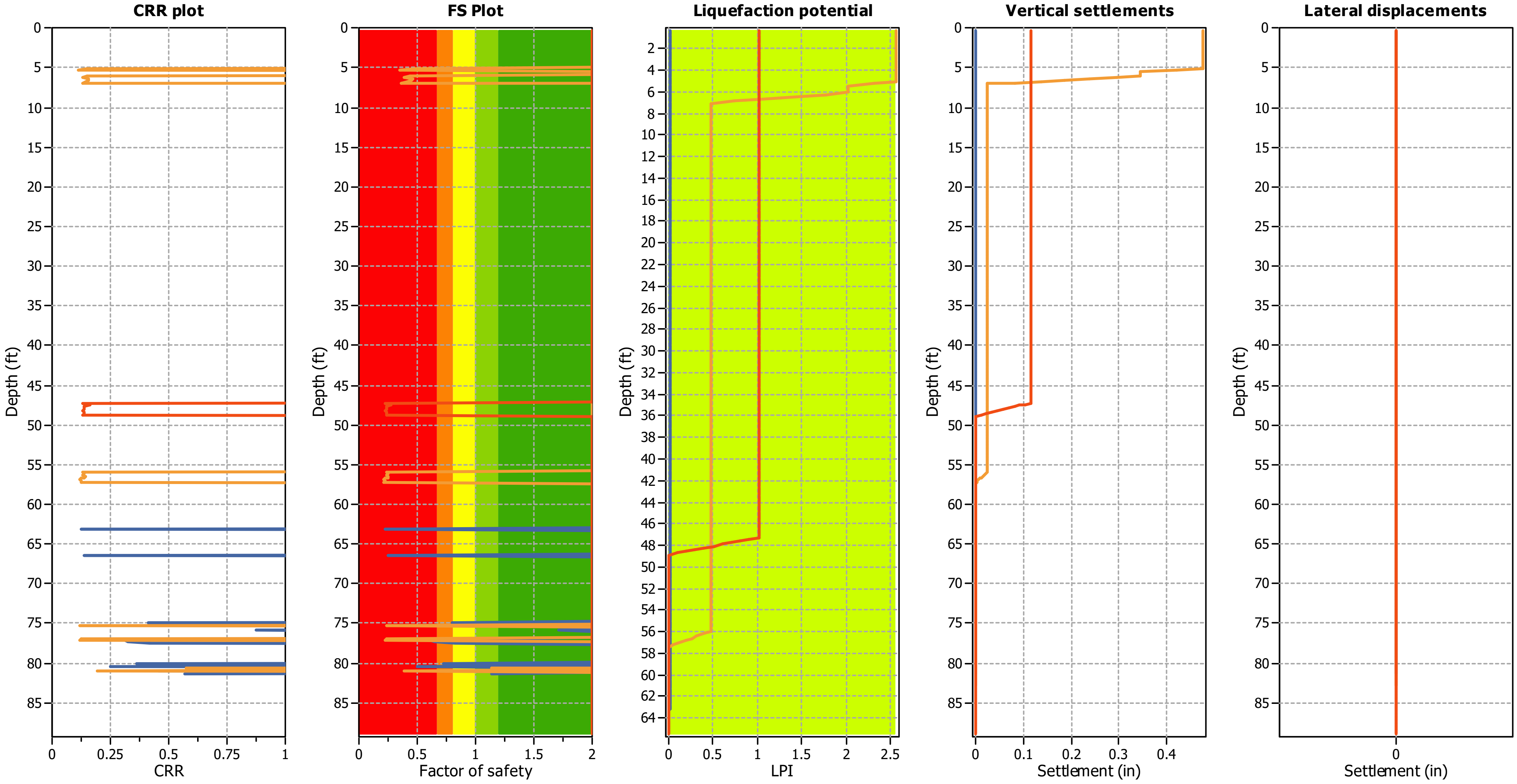
Project: **Vivian Street Townhomes**

Overlay Intermediate Results



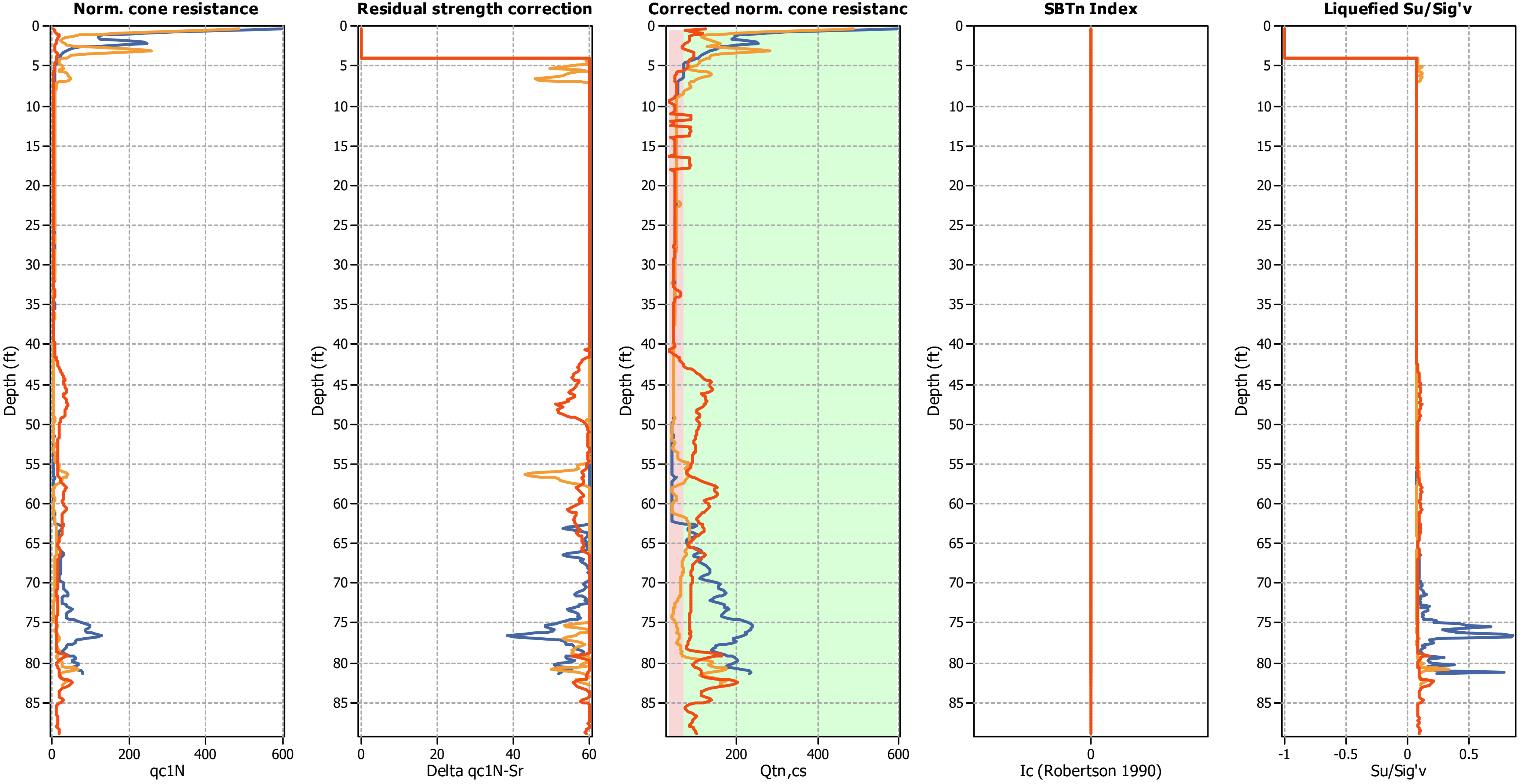
Project: Vivian Street Townhomes

Overlay Cyclic Liquefaction Plots



Project: **Vivian Street Townhomes**

Overlay Strength Loss Plots



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