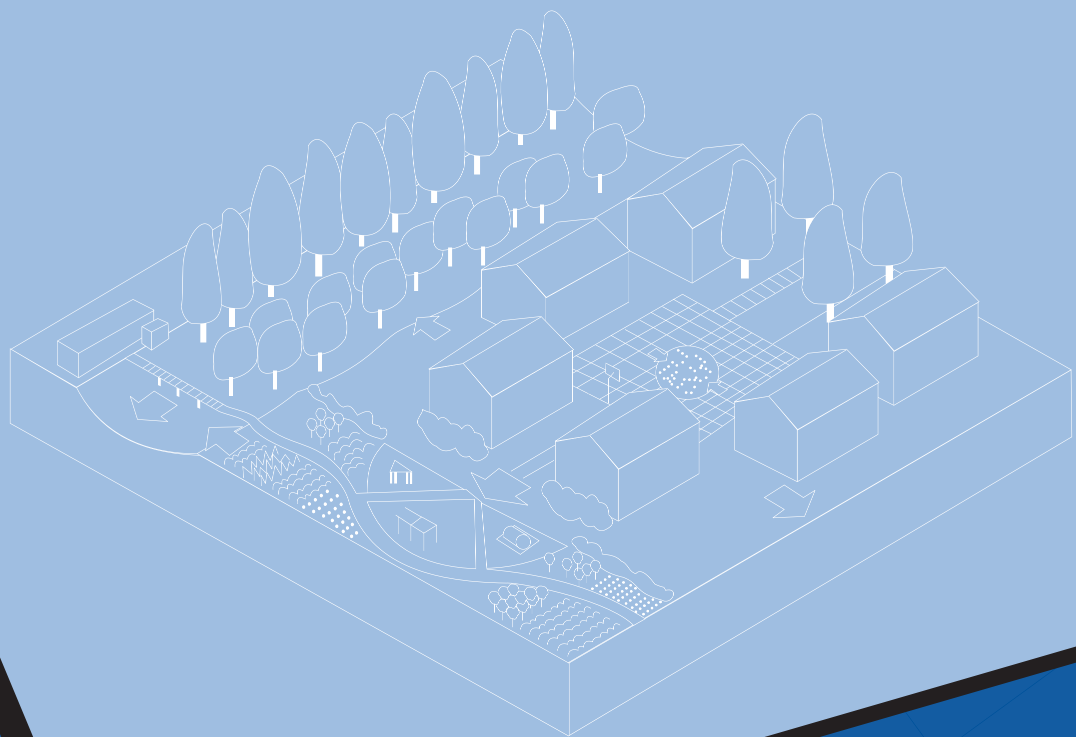

Using Site Design Techniques to Meet Development Standards for Stormwater Quality

A Companion Document to Start at the Source

May 2003

Bay Area Stormwater Management Agencies Association

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Table of Contents

Using Site Design Techniques to Meet Development Standards for Stormwater Quality

List of Tables

List of Figures

1 Introduction

1.1 Start at the Source Approach

To address stormwater quality during the planning and design phase of new development and redevelopment projects, the Bay Area Stormwater Management Agencies Association (BASMAA) developed *Start at the Source – Residential Site Planning and Design Guidance Manual for Stormwater Quality Protection* (BASMAA, 1997). This first edition introduced design concepts that could reduce the impact of new development and redevelopment on water quality by addressing pollutants at their source. The manual focused on implementation of Best Management Practices (BMPs) for complying with *qualitative* land development requirements contained within first and second generation NPDES stormwater permits. In 1999, BASMAA prepared a second edition titled *Start at the Source – Design Guidance Manual for Stormwater Quality Protection*. This second edition expanded on the first edition in two ways – by covering industrial/commercial and institutional development, and by providing more detailed technical information.

Recent stormwater permits have evolved to include more specific *quantitative* requirements regarding development and redevelopment. This document demonstrates ways to utilize the techniques described in BASMAA's second edition of *Start at the Source* to help comply with these quantitative permit requirements.

The development and redevelopment planning process involves not only planning, engineering, and landscape architect professionals, but also staff and elected and appointed officials from cities, counties, and local agencies. To address stormwater quality issues during the process, the *Start at the Source* approach aims to convey basic stormwater management concepts that can be adapted to site and project specific conditions.

Development and redevelopment projects that incorporate site design techniques such as detention, retention, and infiltration of runoff, like concave medians, permeable pavements, and conservation of natural areas, exhibit reduced runoff volumes and rates when compared to projects of similar magnitude where the techniques are not utilized. The runoff volume and rate reductions achieved with site design techniques translate directly to reductions in the amount of runoff that must be treated to comply with permit requirements and managed to protect streams from erosion. See Figure 1-1.

1.2 More Information

This manual does not provide detailed information on how to select or size specific site design techniques or other stormwater treatment measures. Sources for stormwater quality design information to supplement this manual include:

- California Stormwater Best Management Practice Handbooks (California Stormwater Quality Association, 2003)

- Urban Runoff Quality Management, WEF Manual of Practice No. 23, ASCE Manual and Report on Engineering Practice No. 87, 1998

These sources will help you complete the design calculations discussed in this document.

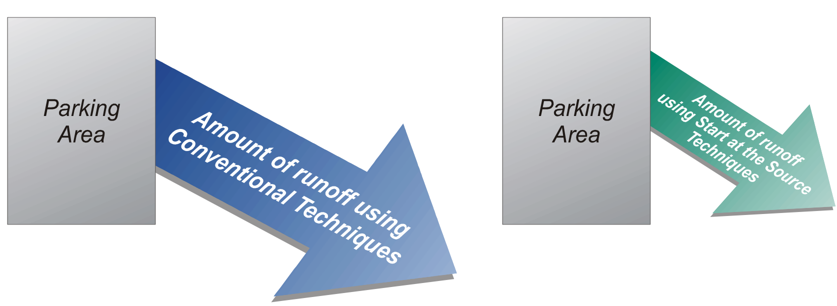


Figure 1-1
***Start at the Source* Reduces Post Development Runoff Volumes**

2 Current Land Development Requirements

2.1 Overview of General Requirements

Recently issued municipal stormwater discharge permits now contain quantitative requirements regarding stormwater controls for new development and redevelopment. Most new development and redevelopment projects must now treat runoff prior to being discharged to storm drains. The requirements set forth minimum standards for sizing newly constructed treatment controls. Sizing standards are prescribed for both:

- Volume-Based BMPs
- Flow-Based BMPs

Volume-based BMP design standards generally call for the capture and infiltration and / or treatment of the 80th to 85th percentile runoff volume. While this requirement may seem as if it calls for capturing the runoff from large, infrequent storms, in most areas it merely amounts to capturing the runoff from relatively small storms that occur several times per year. Such small storms produce more total runoff than larger more infrequent storms. See Figure 2-1. Local development requirements should be referenced for the specific percentile runoff volume that must be addressed.

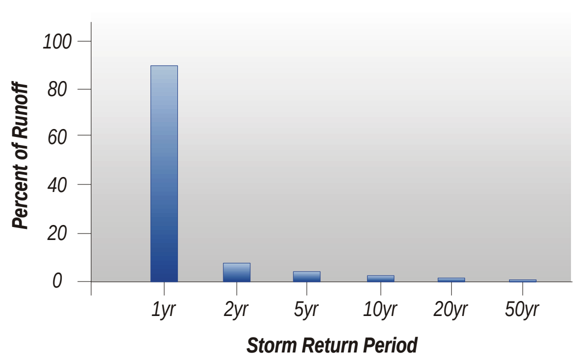


Figure 2-1
Small Storms Add Up

Flow-based BMP design standards generally call for the capture and infiltration and / or treatment of runoff flows produced by the 85th percentile hourly rainfall intensity plus a safety factor. As mentioned above, this requires treating flows from only small, frequent storm events.

Start at the Source provides many site design techniques directly applicable to meeting these land development requirements.

2.2 Volume-Based BMP Design Standards

According to current municipal permits, treatment BMPs whose primary mode of action depends on volume capacity to remove pollutants, such as retention or infiltration structures, shall be designed to treat a volume of stormwater runoff equal to:

- The maximized stormwater quality capture volume for the area, based on historical rainfall records, determined using the formula and volume capture coefficients set forth in Urban Runoff Quality Management, WEF Manual of Practice No. 23 / ASCE Manual of Practice No. 87, (1998), pages 175-178; <u>or</u>
- 80 percent of the volume of annual runoff, determined by using local rainfall data in accordance with methodology set forth in Appendix D of the California Stormwater Best Management Practices New Development and Redevelopment Handbook (2003). The BMP Handbooks have recently been revised.

2.3 Flow Based BMP Design Standards

Current municipal stormwater permits also require that treatment BMPs whose primary mode of action depends on flow capacity, such as swales, sand filters, or wetlands, be sized to treat:

- 10% of the 50-year design flow rate; <u>or</u>
- The flow of runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the applicable area, based on historical records of hourly rainfall depths; <u>or</u>
- The flow of runoff resulting from a rain event equal to at least 0.2 inches per hour intensity.

2.4 Which Design Approach to Use?

Some BMPs are designed based on volume, flow, or a combination of both. The design basis is dependent upon the primary mode of action for the specific BMP. For example, the design of extended detention (dry) ponds requires a volume-based design approach, vegetated swales require a flow-based design approach, and concave medians require a combination of volume-based and flow-based design approaches. Table 3-1 lists various site design and landscape techniques and indicates whether a volume-based approach, flow-based approach, or both, is appropriate for the design of each technique.

In determining which design approach to use, apply the locally approved design standards to the BMP design guidance found in the references noted in Section 1.2.

3 Site Design for Stormwater Quality Protection

3.1 Site Design for Stormwater Quality Protection

Reducing the amount of runoff required to be captured and infiltrated and/or treated may be achieved by applying the following design philosophies during the planning and design stage of development:

- **Zero Discharge Areas** – areas that have been designed to infiltrate or retain the volume of runoff requiring treatment
- **Self-Treating Areas** – areas that have been designed to provide "self-treatment" without additional BMPs
- **Runoff Reduction Areas** – areas that have been designed using alternative materials or surfaces that may reduce the volume of runoff

Figure 3-1 conceptually illustrates how these philosophies may be used to reduce treatment requirements during development and redevelopment. The design philosophies are explained in detail in the following sections.

The site design techniques do not require radical changes in design methods or development planning. The techniques may simply be incorporated into the standard features of a development, requiring only small changes or refinements in design. For example, an area reserved to meet landscaping requirements can also be used to meet stormwater treatment requirements. The key is to incorporate these changes early on in the planning and design process. Appropriately applied, these techniques can reduce runoff volume and flow rate, which reduces the infrastructure necessary to treat and convey stormwater.

Table 3-1 presents a list of site design and landscaping techniques and indicates whether they are applicable for use in Zero Discharge Areas, Self-Treating Areas, and Runoff Reduction Areas. Several different techniques may be implemented within the same design philosophy. Some techniques may be used to implement more than one design philosophy. Where feasible, combinations of multiple techniques may be incorporated into new development and redevelopment projects to minimize the amount of treatment required.

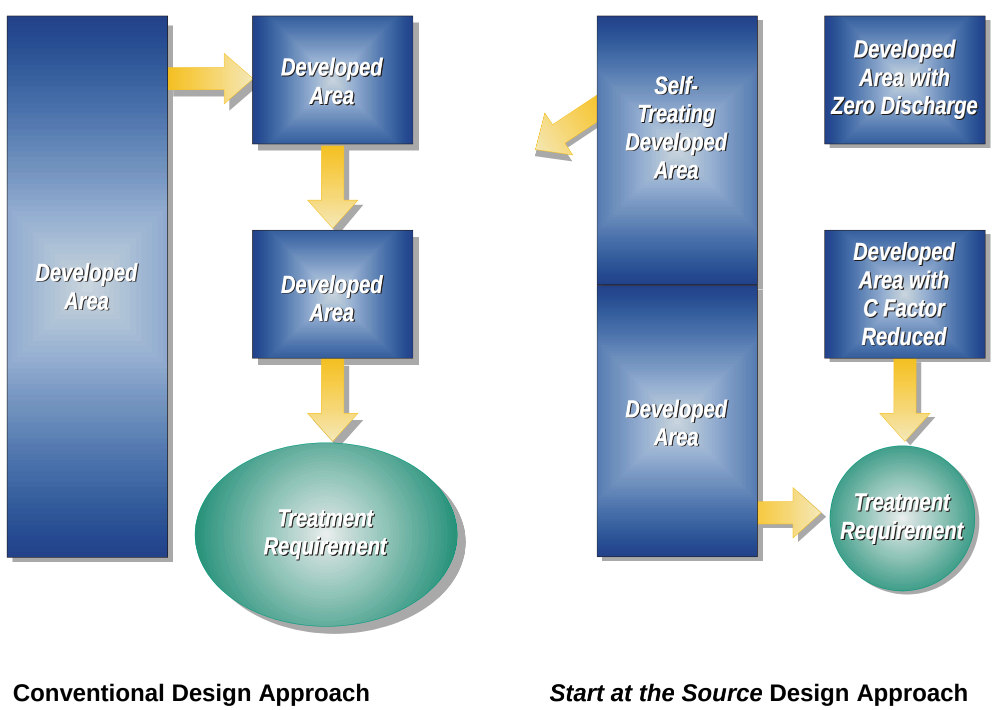


Figure 3-1
Reducing the Size of Treatment Requirements

Table 3-1
Site Design and Landscaping Techniques

	Design Criteria		Design Philosophy [1,2]		
Site Design and Landscape Techniques	**Volume-Based Design**	**Flow-Based Design**	**Zero Discharge**	**Self – Treating**	**Runoff Reduction**
Permeable pavements					
Pervious concrete	X				X
Pervious asphalt	X				X
Turf block	X			X	X
Un-grouted brick [3]	X				X
Un-grouted natural stone [3]	X				X
Un-grouted concrete unit pavers [3]	X				X
Unit pavers on sand	X				X
Crushed aggregate	X				X
Cobbles	X				X
Wood mulch	X				X
Streets					
Urban curb/swale system	X	X			X
Rural swale system	X	X			X
Dual drainage systems	X	X			X
Concave median	X	X	X	X	X
Pervious island	X	X		X	X
Parking lots [4]					
Hybrid surface parking lot	X				X
Pervious parking grove	X				X
Pervious overflow parking	X			X	X
Driveways [4]					
Not directly connected impervious driveway		X			X
Paving only under wheels	X			X	X
Flared driveways	X				X
Buildings					
Dry-well	X		X	X	X
Cistern	X	X	X	X	X
Foundation planting	X	X			X
Pop-up drainage emitters		X			X
Blue roofs [5]	X		X	X	X
Green roofs [5]	X		X	X	X
Landscape					
Grass/vegetated swales	X	X		X	X
Extended detention (dry) ponds	X		X	X	X
Wet ponds	X		X	X	X
Bio-retention areas	X		X	X	X
Fountains	X		X		

Notes:
(1) The above site design and landscape techniques may be applicable to more than one design philosophy; for example, turf block may be used as part of a self-treating area or runoff reduction area.
(2) These techniques must be designed and located properly to achieve the desired treatment requirement reduction.
(3) The open area between brick, stone, and pavers design techniques is critical, as the spaces provide perviousness.
(4) Options for parking lot and driveway surface treatments are covered under permeable pavements. See Start at the Source for details.
(5) Green roofs are vegetative, landscaped rooftops. Blue roofs are rooftops designed to detain or retain stormwater.

4 Zero Discharge Areas

4.1 Design Philosophy

An area within a development or redevelopment project can be designed to infiltrate or retain the volume of runoff requiring treatment from that area.

The term "zero discharge" in this philosophy applies at stormwater treatment design storm volumes. For example, consider an area that functionally captures and then infiltrates the 80th percentile storm volume. If permits require treatment of the 80th percentile storm volume, the area generates no *treatment-required* runoff.

Site design techniques available for designing areas that produce no treatment-required runoff include:

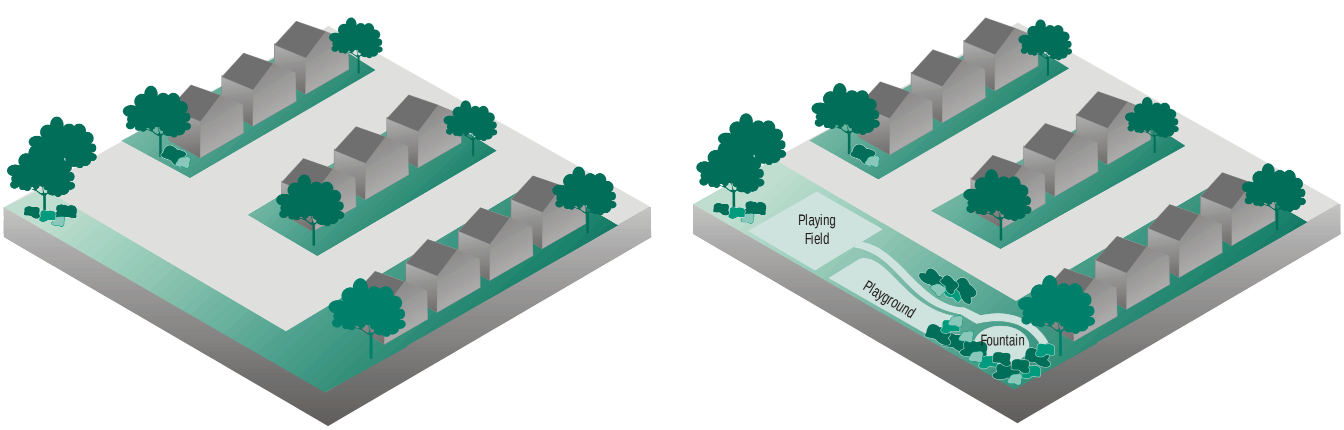
- Retention Ponds
- Wet Ponds
- Infiltration Areas
- Large Fountains
- Retention Rooftops
- Green and / or Blue Roofs

Infiltration areas, ponds, fountains, and green / blue roofs can provide "dual use" functionality as stormwater retention measures and development amenities. Retention ponds and infiltration areas can double as playing fields or parks. Wet ponds and infiltration areas can serve dual roles when meeting landscaping requirements.

When several "zero discharge" areas are incorporated into a development design, significant reductions in volumes requiring treatment may be realized.

"Zero discharge" areas such as wet ponds, retention ponds, and infiltration areas can be designed to provide treatment over and above the storm volume captured and infiltrated. For example, after a wet pond area has captured its required storm volume, additional storm volume may be treated via settling prior to discharge from the pond. In this case, the "zero discharge" area converts automatically into a treatment device for runoff from other areas, providing settling for storm volumes beyond treatment requirements. Another example is a grassy infiltration area that converts into a treatment swale after infiltrating its area-required treatment volume. The grassy infiltration area in this example becomes a treatment swale for another area within the development.

Figure 4-1 illustrates a residential tract, and a tract incorporating Zero Discharge Area techniques (infiltration areas). The Zero Discharge Area designed tract represents a design to infiltrate (i.e., achieve zero discharge from) a portion of the tract's runoff, reducing total runoff from the tract.



Conventional Design Approach **Start at the Source Design Approach**

Figure 4-1
Zero Discharge Area Usage

4.2 Zero Discharge Area Example

The following example problem compares sizing a retention basin using conventional design methods, to sizing the basin using *Start at the Source* design techniques. Figure 4-2 represents a conventionally designed residential tract with a retention basin.

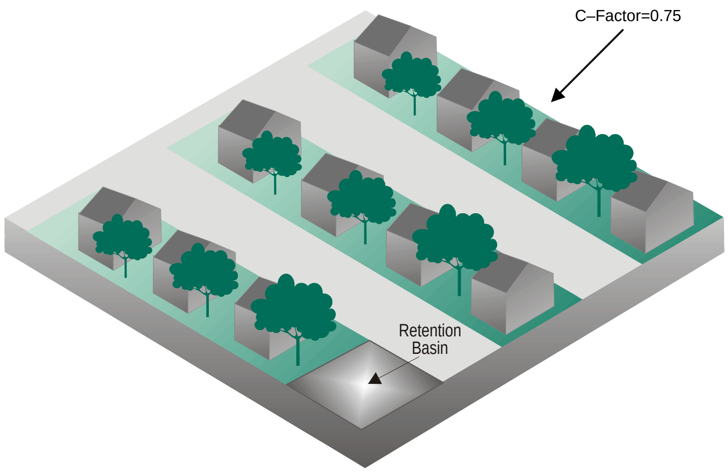


Figure 4-2
Conventional Design

Conventionally Designed Residential Tract:

Assume a 10-acre residential tract has a coefficient of runoff (C-Factor) of C=0.75

Start at the Source Designed Residential Tract:

- Redesign the 10-acre residential tract using the Zero Discharge Area *Start at the Source* technique. Figure 43 represents the residential tract with a 2-acre Zero Discharge Area incorporated into the development. To accommodate the Zero Discharge Area, the residential units were constructed at a higher density, resulting in a C-factor increase in the remaining 8-acre portion of the tract. Assume the redesign is comprised of:

- 2-acre portion with Zero Discharge Areas (fountains, playgrounds, wetlands, parks) with a runoff coefficient of C = 0.00

- 8-acre portion with a runoff coefficient of C = 0.85

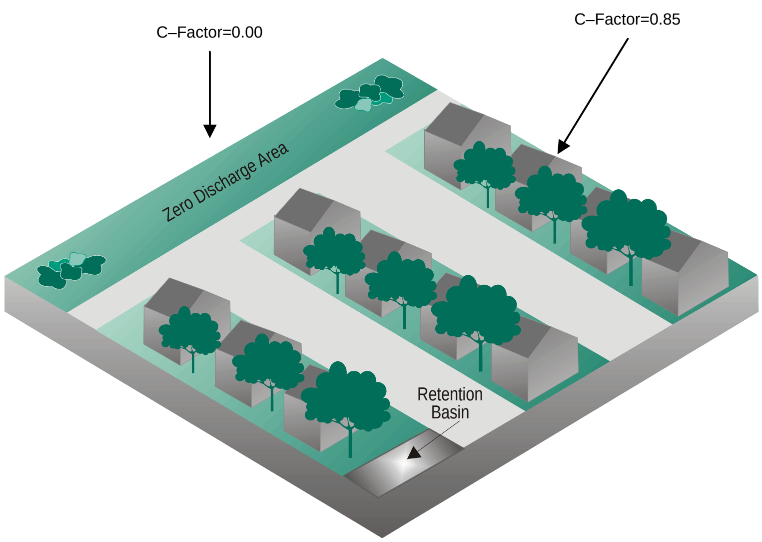


Figure 4-3
Start at the Source Design Approach

Calculating Retention Basin Size – Conventional Design:

Using Figure 4-4, San Jose Capture Curve developed using techniques set forth in the California Storm Water BMP Handbooks (CDM, et al. 2003):

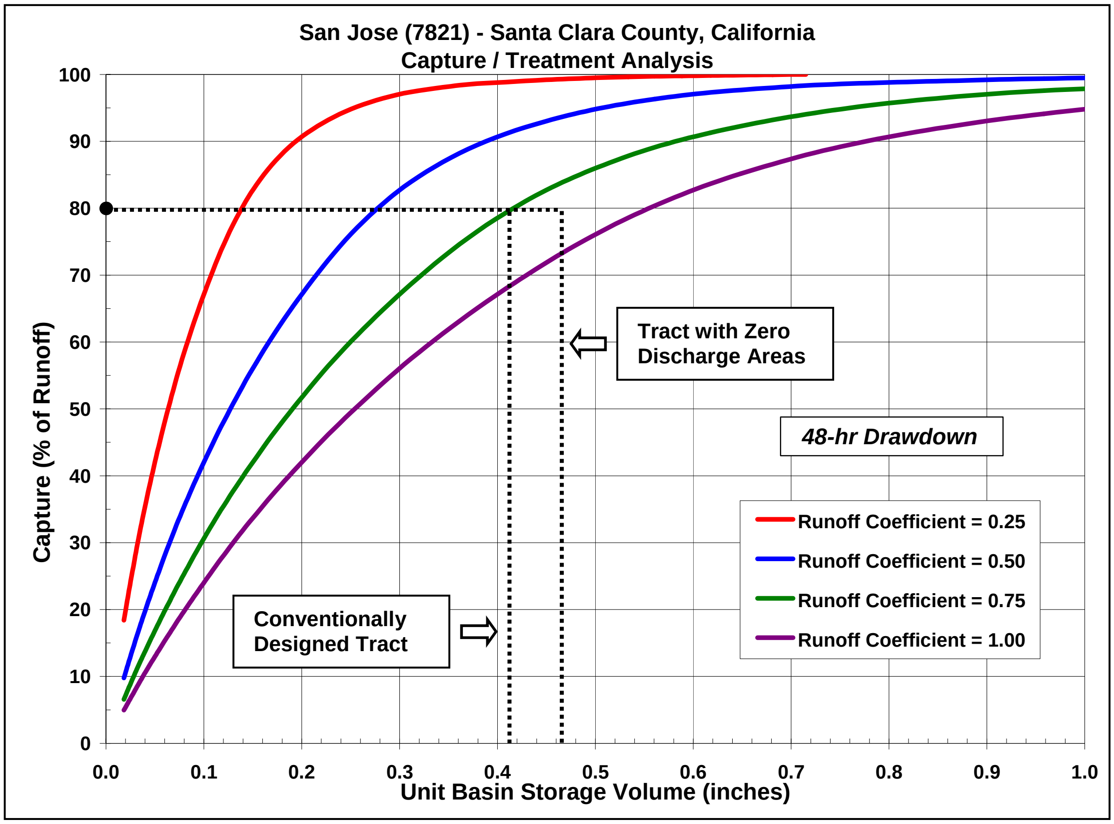


Figure 4-4
San Jose Capture Curve (California Stormwater BMP Handbooks)

By choosing the curve corresponding to a runoff coefficient of C=0.75, the Unit Basin Storage Volume is determined to be 0.41 inches, at the 80th percentile capture. Calculate the capacity of the retention basin required to treat runoff from the 10-acre residential tract:

$$\text{Volume:} \quad \forall_{\text{Basin}} = 10 \text{ acres} \times 0.41 \text{ inches} = 4.10 \text{ acre-inches}$$

Calculating Retention Basin Size – *Start at the Source* Design:

Using Figure 4-4 San Jose Capture Curve, by interpolation, the appropriate curve corresponding to a runoff coefficient of C = 0.85, would lie between the C=0.75 curve and the C=1.0 curve. For the 80th percentile capture, the Unit Basin Storage Volume is 0.46 inches.

Though use of the *Start at the Source* design technique has increased the required Unit Basin Storage Volume from 0.41 inches to 0.46 inches, the technique has reduced the total acreage of the residential tract that will produce treatment-required runoff from 10 acres to 8 acres.

Calculate the capacity of the retention basin required to treat runoff from the 8-acre portion of the tract (2-acres has zero treatment-required runoff).

$$\text{Volume:} \quad \forall_{\text{Basin}} = 8 \text{ acres} \times 0.46 \text{ inches} = 3.68 \text{ acre-inches}$$

By designing the 10-acre residential parcel using the *Start at the Source* design approach, a **10.2% reduction in treatment requirement** can be achieved.

5 Self-Treating Areas

5.1 Design Philosophy

Developed areas may provide "self-treatment" of runoff if properly designed and drained.

Self-treating site design techniques include:

- Conserved Natural Spaces
- Large Landscaped Areas (including parks and lawns)
- Grass / Vegetated Swales
- Turf Block Paving Areas

The infiltration and bio-treatment inherent to such areas provides the treatment control necessary. These areas therefore act as their own BMP, and no additional BMPs to treat runoff should be required.

As illustrated in Figure 5-1, site drainage designs must direct runoff from self-treating areas away from other areas of the site that require treatment of runoff. Otherwise, the volume from the self-treating area will only add to the volume requiring treatment from the impervious area.

Likewise under this philosophy, self-treating areas receiving runoff from treatment-required areas would no longer be considered self-treating, but rather would be considered as the BMP in place to treat that runoff. These areas could remain as self-treating, or partially self-treating areas, if adequately sized to handle the excess runoff addition.

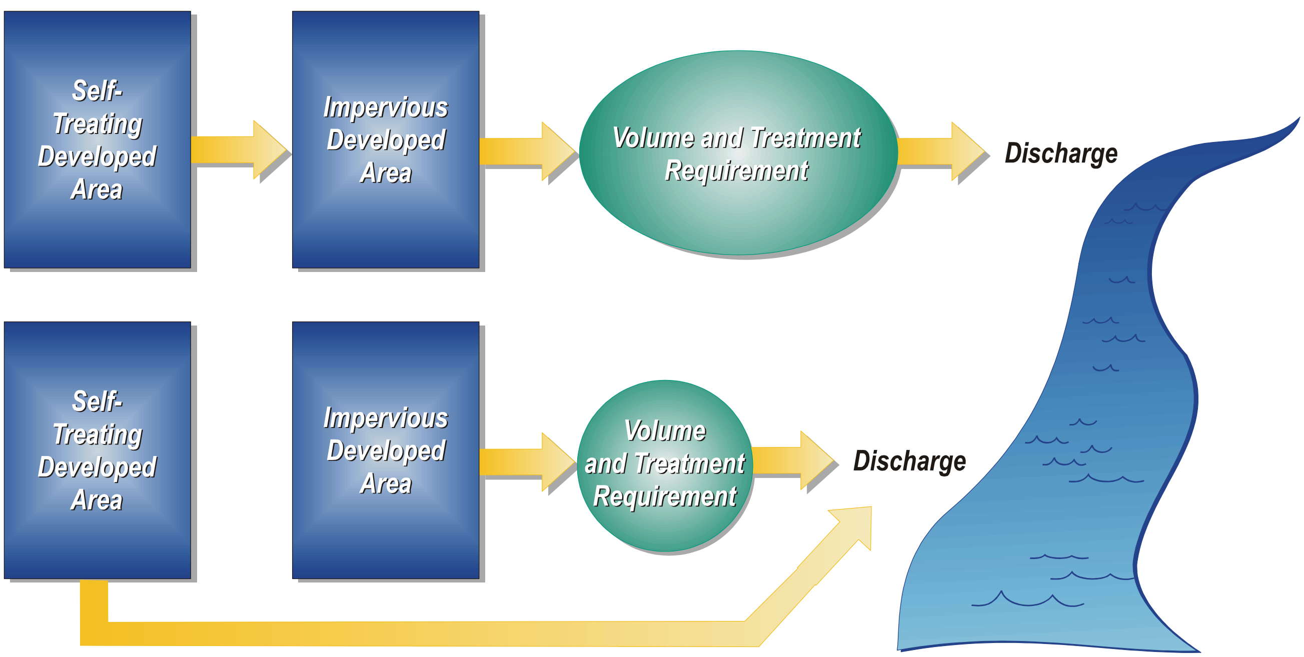
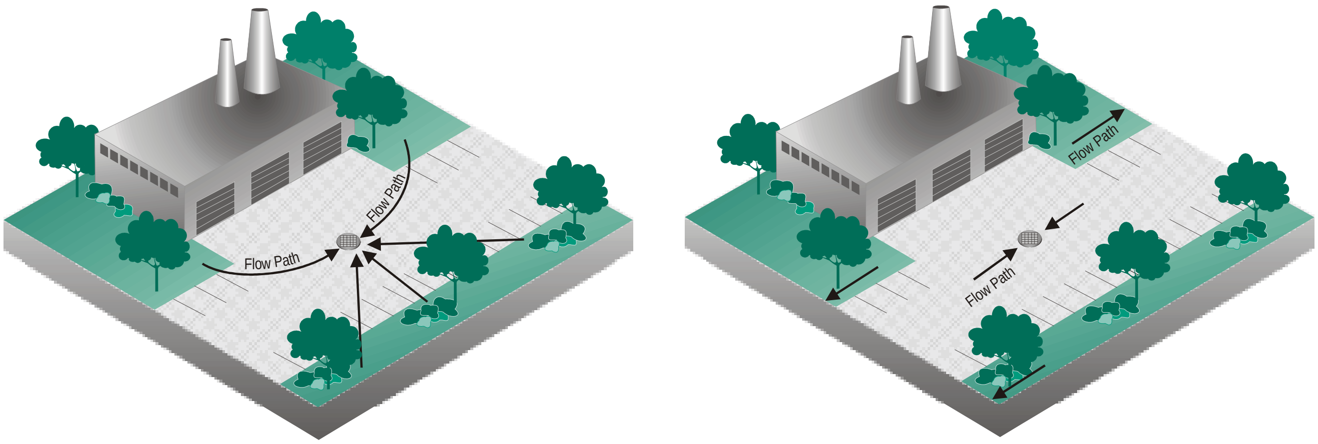


Figure 5-1
Self-Treating Area Usage

5.2 Self-Treating Area Example

The following example problem compares sizing a retention basin using conventional design methods, to sizing the basin using *Start at the Source* design techniques. Figure 5-2 represents a conventionally designed commercial/industrial lot and a commercial/industrial lot designed using the Self-Treating Area *Start at the Source* design approach. Assume the example lot is one of many similar lots making up a 100-acre commercial industrial site.



Conventional Design Approach **Start at the Source Design Approach**

Figure 5-2
Commercial/Industrial Site vs. Commercial/Industrial Site with Self-Treating Areas

Conventionally Designed Commercial/Industrial Site:

Assume a 100-acre commercial/industrial area comprised of:

- 80 acres with a runoff coefficient of 0.95 (roofs, parking lots, etc.)
- 20 acres with a runoff coefficient of 0.50 (landscape areas)

$$C_{combined} = \frac{(80 \text{ acres} \times 0.95) + (20 \text{ acres} \times 0.50)}{100 \text{ acres}} = 0.86$$

Commercial/Industrial Site Using *Start at the Source* Techniques (Self-Treating Areas):

100-acre commercial/industrial area comprised of:

- 80 acres with a runoff coefficient of 0.95 (roofs, parking lots, etc.)
- 20 acres of self-treating areas (landscape buffers, grassy areas, etc.) Note: These 20-acres do not drain to the retention basin as they are self treating. All runoff draining to the retention basin is from roofs, parking lots, etc.

Calculating Retention Basin Size – Conventional Design:
Using Figure 5-3, San Jose Capture Curve developed using techniques set forth in the California Storm Water BMP Handbooks (CDM, et al. 2003):

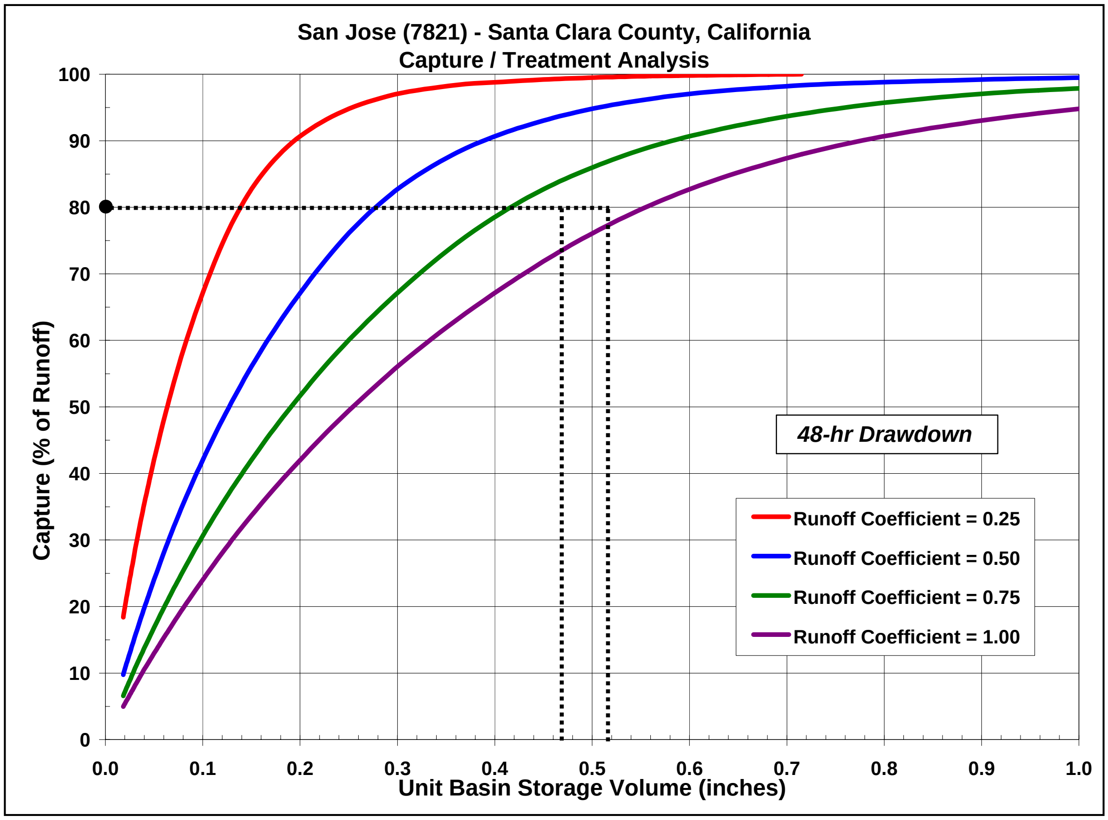


Figure 5-3
San Jose Capture Curve (California Stormwater BMP Handbooks)

By interpolation, the appropriate curve corresponding to a runoff coefficient of C combined = 0.86, would lie between the C=1.0 curve and the C=0.75 curve. For the 80th percentile runoff capture, the Unit Basin Storage Volume is 0.47 inches.

The capacity of the retention basin required to treat runoff from the 100-acre commercial/industrial area is calculated as follows:

$$\forall_{Basin} = 100 \text{ acres} \times 0.47 \text{ inches} = 47 \text{ acre-inches}$$

Calculating Retention Basin Size – *Start at the Source* Design:
Using Figure 5-3, San Jose Capture Curve:

By interpolation, the appropriate curve corresponding to a runoff coefficient of 0.95, would lie between the C=1.0 curve and the C=0.75 curve. For the 80th percentile runoff capture, the Unit Basin Storage Volume is 0.52 inches.

The capacity of the retention basin required to treat runoff from the 80-acre commercial/industrial area (excludes the 20-acres of self-treating areas) is calculated as follows:

$$\forall_{Basin} = 80 \text{ acres} \times 0.52 \text{ inches} = 41.6 \text{ acre-inches}$$

By designing the 100-acre commercial/industrial area using the *Start at the Source* design approach, an **11.5% reduction in treatment requirement** can be achieved.

6 Runoff Reduction Areas

6.1 Design Philosophy

Using alternative surfaces with a lower coefficient of runoff or "C-Factor" helps reduce runoff from developed areas. The C-Factor is a representation of a surface's ability to produce runoff. Surfaces that produce higher volumes of runoff are represented by higher C-Factors, such as impervious surfaces. Surfaces that produce smaller volumes of runoff are represented by lower C-Factors, such as more pervious surfaces. See Table 6-1 for typical C-Factor values for various surfaces during small storms.

Table 6-2 compares the C-Factors of conventional paving surfaces to alternative, lower C-Factor paving surfaces. By incorporating more pervious, lower C-Factor surfaces into a development, lower volumes of runoff are produced. Lower volumes and rates of runoff translate directly to lower treatment requirements.

Site design techniques may be used to reduce the C-Factor of a developed area, reducing the amount of runoff requiring treatment, including:

- Pervious Concrete
- Pervious Asphalt
- Turf Block
- Brick (un-grouted)
- Natural Stone
- Concrete Unit Pavers
- Crushed Aggregate
- Cobbles
- Wood Mulch

Other site design techniques such as disconnecting impervious areas, preservation of natural areas, and designing concave medians may be used to reduce the overall C-Factor of development areas.

Table 6-1
Estimated C-Factors for Various Surfaces During Small Storms

Paving Surface	*C-Factor*
Concrete	0.80
Asphalt	0.70
Pervious Concrete	0.60
Cobbles	0.60
Pervious Asphalt	0.55
Natural Stone without Grout	0.25
Turf Block	0.15
Brick without Grout	0.13
Unit Pavers on Sand	0.10
Crushed Aggregate	0.10
Grass	0.10
Grass Over Porous Plastic	0.05
Gravel Over Porous Plastic	0.05

Note: C-Factors for frequent small storms used to size water quality BMPs are likely to differ (be lower) than C-Factors developed for infrequent, large storms used to size flood control facilities. The above C-Factors were produced by selecting the lower end of the best available C-Factor range for each paving surface. These C-Factors are only appropriate for small storm treatment design, and should not be used for flood control sizing. Where available, locally developed small storm C-Factors for various surfaces should be utilized.

Table 6-2
Conventional Paving Surface Small Storm C-Factors vs. Alternative Paving C-Factors

Conventional Paving Surface C-Factors	*Reduced C-Factor Paving Alternatives*
Asphalt Parking Area (0.70)	Crushed Aggregate (0.10)
Concrete Patio/Plaza (0.80)	Decorative Unit Pavers on Sand (0.10)
	Turf Block Overflow Parking Area (0.15)
	Pervious Asphalt (0.55)
	Pervious Concrete (0.60)

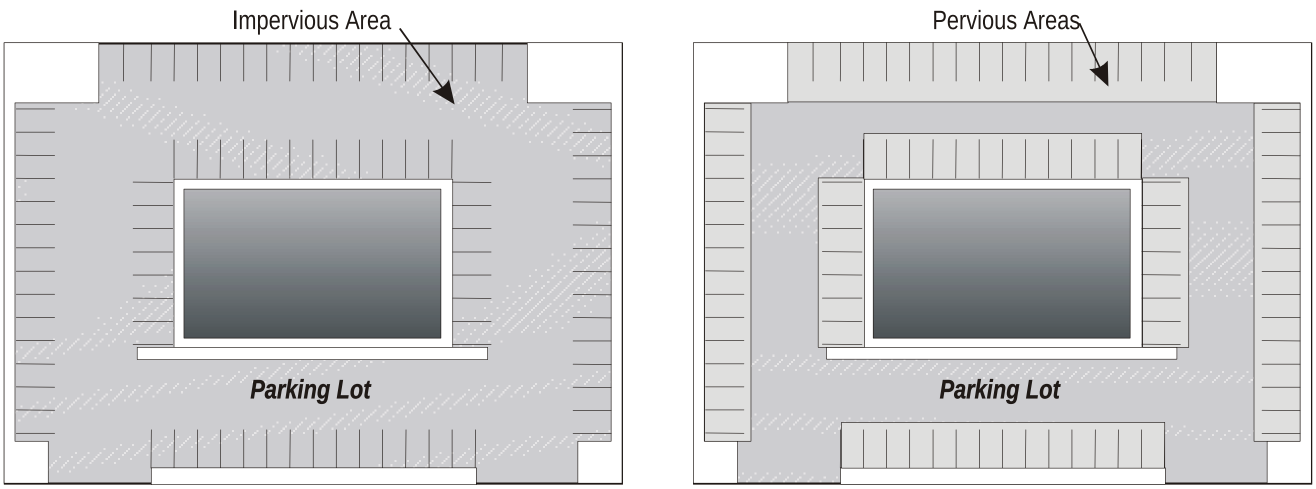


Figure 6-1
Impervious Parking Lot vs. Parking Lot with Some Pervious Surfaces

6.2 Runoff Reduction Area Example

The following example problem compares sizing a treatment swale using conventional design methods, to sizing the swale using *Start at the Source* design techniques.

Conventionally Designed Paved Parking Lot:
1-acre parking lot with a C-Factor of 0.80

Paved Parking Lot Using *Start at the Source* Techniques (Porous Pavement – See Figure 6-2):
1-acre parking lot with a C-Factor of 0.60

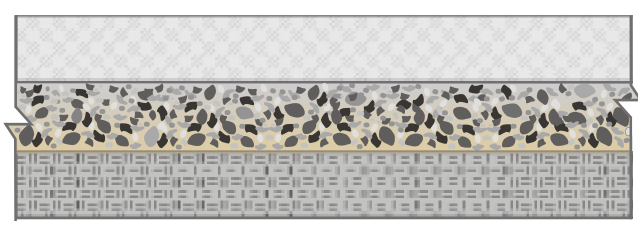


Figure 6-2
Porous Pavement

Calculating Swale Size:
Using the Urban Runoff Quality Management ASCE / WEF Manual guidelines for Selection and Design of Passive Treatment Controls:

Step 1: Determine Runoff
Using the Rational Method Q = CIA to solve for Q, given a rainfall intensity of 0.2 inches / hour

Where Q = Flow (cubic feet / second, cfs)

C = Runoff Coefficient

I = Rainfall Intensity (inch / hour)

A = Total Site Area (acres)

Calculating Runoff – Conventional Design:

Q = CIA
= 0.80 × 0.2 inches/hour × 1 acre
= 0.16 cubic feet/second

Calculating Runoff – *Start at the Source* Design:

Q = CIA
= 0.60 × 0.2 inches/hour × 1 acre
= 0.12 cubic feet/second

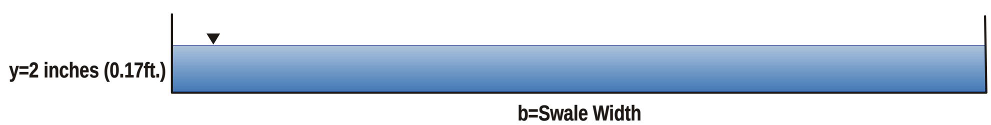
Step 2: Determine swale slope
Assume 1% or 0.01

Step 3: Select vegetation cover
Assume grass-lined swale

Step 4: Determine vegetation height
Assume 2 inches or 0.17 feet

Step 5: Select Manning's n value
Manning's n = 0.20, for routinely mowed grass-lined channels

Step 6: Select cross-sectional shape of swale
A typical swale cross-section is parabolic or trapezoidal in shape. The 2-inch (0.17 ft) flow depth in this example allows a rectangular cross-sectional approximation.



Step 7 Use Manning's equation to determine swale width
Manning's equation: $Q = 1.49 / n \times R^{2/3} \times S^{1/2} \times A$

Where Q = Flow

n = Manning's n

R = Hydraulic Radius = A / (b + 2y) for rectangular channels

S = Slope of swale

A = Cross-sectional Area = b × y for rectangular channels

y = Flow Depth = Vegetation Height for Treatment Swale

b = Swale Width

Using Manning's equation to solve for Swale Width, b:

Swale Width = 4.3 feet (Conventional Design)

Swale Width = 3.3 feet (*Start at the Source* Design)

Step 8: Determine flow velocity

Flow Velocity – Conventional Design:

Velocity = Runoff / Cross-sectional Area
= Q / A
= 0.16 cfs / (0.17 feet × 4.3 feet)
= 0.22 feet/second

Flow Velocity – *Start at the Source* Design:

Velocity = Runoff / Cross-sectional Area
= Q / A
= 0.12 cfs / (0.17 feet × 3.3 feet)
= 0.21 feet/second

Step 9: Determine swale length

Using Urban Runoff Quality Management Manual guidelines (p195), assume swale detention time of 7 minutes = 420 seconds

Swale Length – Conventional Design:

Length = Velocity × Detention Time
= 0.22 feet/second × 420 seconds
= 92.4 feet

Swale Length – *Start at the Source* Design:

Length = Velocity × Detention Time
= 0.21 feet/second × 420 seconds
= 88.2 feet

Step 10: Determine swale size (surface area)

Swale Size – Conventional Design:

Swale Size = Swale Length × Swale Width
= 92.4 feet × 4.3 feet
= 397 square feet

Swale Size – *Start at the Source* Design:

Swale Size = Swale Length × Swale Width
= 88.2 feet × 3.3 feet
= 291 square feet

By designing the parking lot using the *Start at the Source* design approach, a **27% reduction in treatment requirement** can be achieved**.**