QUANTIFYING THE PROBLEM: CALCULATION

In the most traditional sense the stormwater management would be a responsibility of the Department of Environmental Protection, hence of the sanitation engineers. One expects the entire sewer system, with its network of trunks, pipes, connectors and ultimately the WPCP, to be designed / sized to cope with the demand. Wastewater treatment plants are built to treat stormwater runoff; in fact, the Red Hook WPCP has the wet weather capacity of 120 mgd. However, the sewershed residents are experiencing flooding even during frequent rain events that are not considered extreme.

As a matter of fact, the FF research findings support this concern. During community organization meetings, the team asked attendees to share firsthand experiences in their neighborhoods. The team later mapped these trouble areas within the sewershed. The problem reports did not always correspond to the topographically challenging or low-lying elevations. The team inferred that the identified trouble areas might be indicative of the below-ground infrastructure's inadequacy.

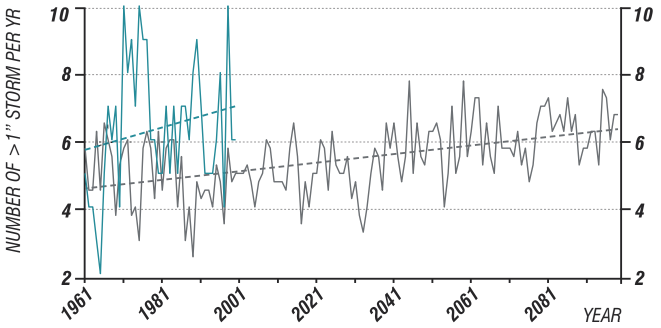
Simulating the system with computer modeling techniques would have been one way to visualize the behavior of runoff through the existing infrastructure and to reveal local deficiencies. However, required information on sewer infrastructure is not made available to the public. After assessing available data, including that of the Red Hook WPCP's finite capacity, weather data, and surface analysis, the FF team concluded to focus on the 'ground', above ground, and building surfaces for further investigations.

Current challenges are greater than anticipated:

_Metro New York is experiencing extreme weather events more frequently than predicted *(See Graph 1, Graph 2)*

_There is uneven growth/population density: The urban transformation that is taking place across Metro New York is not uniformly distributed; instead, it is concentrated in certain neighborhoods. These areas that are experiencing unprecedented population growth further strain the century-old system that was designed for lesser population and density *(See Graph 3)*

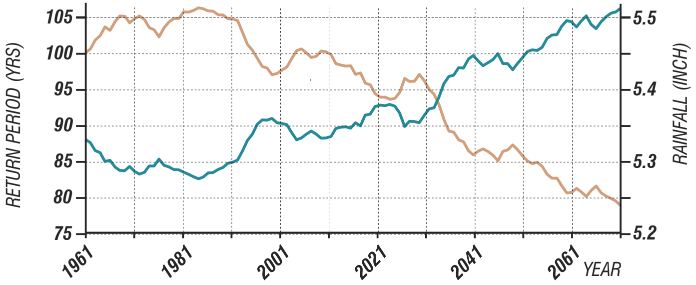
Faced with the fact that *'it floods when it rains'*, and that *'the City is not in attainment of the Clean Water Act'*, the team felt strongly that a thorough review of DEP's approach to stormwater management was a necessary first step. In order to understand the gap that exists between DEP's plans for stormwater management and the status quo on the streets, the team began examining several calculation methodologies. Through a comparative analysis of DEP's methodology vis a vis the methodology implemented by German Standards, the team developed a unique approach to quantifying the problem.



GRAPH 1: The observed and projected number of rainfall events exceeding 1", average for New York State

Based on the current trends, climate models indicate that annual precipitation and its frequency in New York will increase by 5 to 10 percent by 2080. The rate of increase in the observed precipitation far exceeds that of the projected.

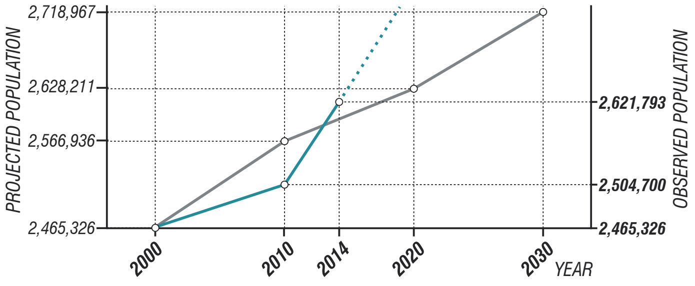
Observed *Projected*



GRAPH 2: Projected rainfall and return period of the 100-year storm

With increased rainfall frequency and amount, storms that would now occur every 100 years are likely to become more frequent, recurring on average of every 80 years by the end of the century

Return period of the current 100-yr storm
Amount of rainfall during a 100-yr storm



GRAPH 3: The observed and projected population for Brooklyn

Observed Population
Projected Population

Climate data source:
Northeast Regional Climate Center
ClimAID, NYSERDA

Population data source:
NYC Department of City Planning

NEW YORK CITY CALCULATION METHODOLOGY

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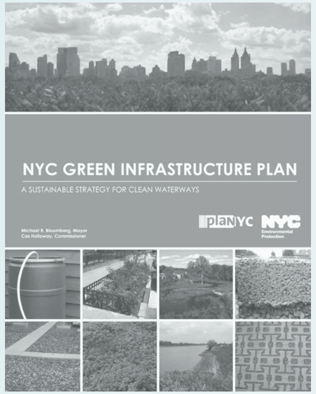
EXCERPT 1: New York City Green Infrastructure Plan (DEP, 2010)



Executive Summary:

3. Control runoff from 10% of impervious surfaces through green infrastructure

Green Infrastructure is at the core of this plan. The City's goal is to capture the first inch of rain fall on 10% of the impervious areas in combined sewer watersheds through detention or infiltration techniques over 20 years. By preventing one inch of precipitation from becoming runoff that surges into the sewers over 10% of each combined sewer watershed's impervious area, goal by achieving 1.5% impervious area capture by 2015, an additional 2.5% by 2020, an additional 3% by 2025, and the remaining 3% by 2030.

The strategies to achieve the 10% goal vary depending on the type of land use (see Table 1). DEP's initial analysis shows that there are significant opportunities to incorporate green infrastructure in 52% of the land in CSO areas of the City, well more than needed to meet the 10% capture goal over 20 years. The remaining 48% of the City's land area consists of existing development, where stormwater retrofits may also be appropriate but are more difficult and expensive to build. For a highly urbanized city, the goal of 10% capture over 20 years is ambitious but achievable.

data source:
NYC Department of Environmental Protection

"

FF Notes:

Our Comparative Analysis began with a look at the 2011 NYC GI Plan by the Department of Environmental Protection. The Plan outlines a sewershed-scale strategy that categorizes potential typologies for stormwater management infrastructure with the following breakdown for reaching the goal of managing 10% of the combined-sewer area:

_3% impervious area capture by street trees, swales, and sidewalks that are rebuilt or retrofitted with additional controls;

_3% by performance standards on new and expanded developments that would include bioinfiltration, blue and green roofs, subsurface detention/ infiltration;

_3% by existing schools, residences, and other development;

_1% by additional areas in open spaces and waterfront areas.

NEW YORK CITY
CALCULATION METHODOLOGY

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EXCERPT 2: Amended Standard for Stormwater Release Rates
(Chapter 31 of Title 15 of the Rules of the City of New York (RCNY), 2012)

§31-03 Stormwater Performance Standard for Connections to Combined Sewer System

For a New Development:

_Stormwater Release Rate will be greater of 0.25cfs or 10% of the Allowable Flow;

_If Allowable Flow is less than 0.25cfs, the Stormwater Release Rate shall be the Allowable Flow;

_Allowable Flow is the stormwater flow from a development that can be released into existing storm or combined sewer based on drainage plan and built sewers.

For Alterations:

_Stormwater Release Rate for the altered area will be directly proportional to the ratio of the altered area to the total site area and no new points of discharge are permitted;

_Alterations are as defined in the Construction Codes and related requirements for any horizontal building enlargement or any proposed increase in impervious surfaces.

Examples:

_A typical one acre site in Brooklyn will be required to detain and release runoff at a rate of 0.25 cfs under the proposed rule compared to 2.5 cfs under existing standards

_For a half acre site in Brooklyn, the allowable flow would be 1.25 cfs. Since 10% of the allowable flow is 0.125 cfs, the release rate would be 0.25 cfs

_For a 3,000 sq ft site in Brooklyn, the allowable flow would be 0.172 cfs. Since this is less than 0.25 cfs, the release rate would be 0.172 cfs

data source:
NYC Department of Environmental Protection

"

FF Notes:

Excerpt 2 introduces the FF team to the City's amended Stormwater Performance Standard that went into effect on July 4, 2012. The standard outlines an amendment to the existing rules governing site connection to the City's combined sewer system. The new rule language modifies the stormwater release rate, the maximum rate of flow at which stormwater runoff is allowed to enter the sewer system from a site. The rule applies to new and existing developments as well as to alteration of existing buildings that would result in increased building footprint and impervious surfaces.

The intent of the modification is to improve performance and to provide additional capacity to the existing sewer system by requiring greater on-site retention of stormwater runoff. The rule is an integral component of the City's Green Infrastructure Plan as it relates to the application of performance standard on 3% of the GI Plan's 10% goal.

The new standard specifies different release rates to be used depending on the footprint of a new development. It is interpreted and re-written as follows:

_If the site area is more than or equal to 1.0 acre, or 43,560 sq.ft., the release rate shall be 0.0003444 cu.ft/min for every sq.ft of the site;

_If the site area is more than or equal to 0.10 acre (4,356 sq.ft.), and is less than 1.0 acre (43,560 sq.ft.), the release rate from the entirety of the site shall be 0.25 cfs. Thus, the unit release rate shall be 0.25 cfs divided by the total site area.

_If the site area is less than 0.10 acre, or 4656 sq.ft., the release rate shall 10 times that a site bigger than or equal to 0.10 acre, thus 0.003444 cu.ft./min for every sq.ft. of the site.

NEW YORK CITY
CALCULATION METHODOLOGY

EXCERPT 3: Guidelines for the Design and Construction of Stormwater Management Systems *(DEP, 2012)*

2. Sizing Stormwater Management Systems

2.1 Calculating Developed Site Flow and Runoff Coefficients

The developed site flow, or the rate of run-off from the site with a proposed new development or alteration, is calculated using the rational method for the total site area, rainfall intensity, and the site's surface coverage, per DEP's Criteria. Once calculated, the developed flow should then be compared to the required release rate (see Excerpt 2)*, storage volume and storage depth as described below to develop detailed site plans and designs. If the developed flow exceeds the release rate then it must be captured and detained to comply with DEP's storm-water performance standard.*

If the developed site flow is less than the release rate required by DEP's stormwater performance standard, the developer and licensed professional should refer to the drainage plan of record for the site's allowable flow to the sewer system.

The overall developed site flow can be reduced by minimizing impervious surfaces, maximizing pervious areas, and implementing green infrastructure source controls as part of the proposed development.

Onsite surface coverage is represented in the weighted runoff coefficient, C_w*, as follows:*

$$C_w = (1/A)\sum_{k=0}^{n}(A_k C_k)$$

- **A** = *the total site area (acres)*
- **k** = *the index for each onsite surface coverage type*
- **A_k** = *the area of each surface coverage type (acres)*
- **C_k** = *the runoff coefficient associated with each surface coverage type*

The C-values above reflect annual average runoff rates. Any request for variances from the above coefficients should be submitted to DEP for review and approval with appropriate supporting documents such as boring and permeability test results, manufacturer-specified values, and design details.

$$Q_{dev} = C_w \cdot A_s / 7,320$$

- **Q_{dev}** = *the developed flow (cfs)*
- **C_w** = *the weighted runoff coefficient*
- **A_s** = *the total site area (ft^2)*
- **7,320** = *43,560ft^2/ac divided by the rainfall intensity of 5.95 in/hr for the event with a 5 year return period and a 6 minute time of concentration*

Calculating the developed site flow during site planning and building design allows the developer and licensed professional to consider different combinations of surface coverage types with various runoff coefficients (C-values), and the effect of these combinations on developed site flow.

data source:
NYC Department of Environmental Protection

FF Notes:

Excerpt 3 summarizes New York City's approach to sizing stormwater management systems on existing or new development sites. This particular section of the manual provides a glimpse into the City's calculation methodology and its standards, outlined as follows:

_When calculating the developed runoff on a site, the City uses the weighted runoff coefficient, C_w, to determine the average runoff rate for the entire site, as opposed to calculating the developed flow for each type of pervious / impervious surface separately;

_The weighed coefficient is then plugged into the equation used to determine the developed flow, a rate at which the runoff accumulates on an entire site. The resulting flow rate is then compared against the required release rate, governed by the City;

_The City considers the extreme precipitation data of the 5yr-6minute storm as a standard in calculating the volume of water accumulated on site over time, per unit area.

GERMAN CALCULATION METHODOLOGY

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Summarized notes from consultant Mete Demiriz, Ph.D.

Roof and ground drainage calculation according to European Standard DIN EN 12506 [1] DIN EN 752 [2] and the German extension as a national standard DIN 1986-100 [3], are given. In addition, the calculation of the volume of retention tanks and design of emergency roof drainage systems are shown.

Introduction:

Flooding can happen in some areas of a given site within a few minutes. It depends on the flow rate and duration of the rainfall. For the calculation, a dataset for the extreme precipitation intensity is needed.

[1] DIN EN 12056-3, Gravity drainage systems inside buildings, Beuth, Berlin 1.2001
[2] DIN EN 752, Drain and sewer systems outside buildings, Beuth, Berlin, 04.2008
[3] DIN 1986-100, Drainage systems on private ground, Beuth, Berlin, 05.2008

Flowrate calculation for roof and plot drainage in case of normal rainfall

Equation 1

$$Q = r_{(D,T)} \cdot C \cdot A \cdot {}^{1}/_{10000}$$

Q	*flow rate of rainwater, (l/s)*
$r_{(D,T)}$	*rainfall intensity, (l/(s·ha))*
D	*duration of rainfall in minutes*
T	*occurance of rainfall , in every T yr*
C	*runoff coefficient**
A	*effective area, (m²)*

To calculate the sizing of a roof drainage system, the rainfall intensity for duration D of 5 minutes is used to determine the design flowrate.

For the occurrence of rainfall T on a lot area without any designed retention tank, $T = 2$. For the roof area, $T = 5$ The rainfall occurrence T depends on the usage of the property and shall be determined. Calculating this way, for normal rainfall, no safety factor has to be taken into consideration.

TABLE 1 - Rainfall intensity for Berlin, Germany

	ROOF SURFACE		*PLOT AREA (pervious)*					
Rainfall Duration	D = 5 min.		D = 5 min.		D = 10 min.		D = 15 min.	
use	calculation	emergency drainage	calculation	emergency drainage	calculation	emergency drainage	calculation	emergency drainage
rainfall intensity	$r_{(5,5)}$	$r_{(5,100)}$	$r_{(5,2)}$	$r_{(5,30)}$	$r_{(10,2)}$	$r_{(10,30)}$	$r_{(15,2)}$	$r_{(15,30)}$
l / (s*ha)	371	668	281	549	210	391	170	314

Example rainfall intensity $r_{(D,T)}$, data for Berlin, Germany. The data is calculated from the database KOSTRA-DWD 2000 from the German Weather Service.

TABLE 2 - Runoff coefficient C for calculation of the rainwater flow rate

SURFACE TYPE	**C**	*EXAMPLE SURFACES*
impervious surface	**1.0**	roof surface
	0.9	
	0.8	
	0.7	pavers on sand
	0.6	synthetic lawn pavers with more than 15% pervious area
	0.5	gravel roof green roof - extensive assembly (<10cm depth) water connected surface
	0.4	tennis surface
	0.3	green roof - intensive assembly green roof - extensive assembly (>10cm depth) lawn
	0.2	
	0.1	
pervious surface	**0.0**	vegetation surface, park grounds gravel and slag surface

"

FF Notes:

The German methodology for the quantification of stormwater runoff, as outlined by the FF consultant Mete Demiriz, gives insight to an alternative method and standard considered in relation to the New York City calculation methodology.

TABLE 1 summarizes the rainfall-intensity value, $r_{(D,T)}$, used to calculate adequate sizing for the drainage system within a site for various rainfall scenarios. Unlike the NYC standard which factors in the weighted runoff coefficient, C_w, and the rainfall-intensity of the 6-minute/5-year storm, $r_{(6,5)}$, for calculating the average rate of runoff from the entirity of a given site, the German standard distinguishes each surface type and assigns different rainfall-intensity values, $r_{(D,T)}$, to be used for each. It is also noted that different $r_{(D,T)}$ values are taken for sizing of the "everyday" drainage pipe and for the emergency drainage system in case of an exterme storm event.

GERMAN CALCULATION METHODOLOGY

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Flowrate calculation for emergency drainage system

The limits of the calculation process in various cases such as normal rainwater drainage, retention systems, and emergency drainage systems are shown in figure 1.

The calculation of the rainwater flowrate in case of emergency drainage is given by equation 2 and is described in figure 2. For the safety of the building extraordinary attention is mandated by EN 12056-3 so that the emergency system be able to drain the 100-yr storm.

Equation 2

$$Q_{emerg} = (r_{(5.100)} - (r_{(D,T)} \cdot C)) \cdot A/_{10,000}$$

- Q_{emerg} — minimum flowrate capacity for the emergency system, (l/s)
- $r_{(5,100)}$ — 5-minute rainfall intensity over 100 year storm, (l/(s·ha))
- $r_{(D,T)}$ — rainfall intensity, normally (5,5), (l/(s·ha))
- D — duration of rainfall in minutes
- T — occurrence of rainfall
- C — runoff coefficient*
- A — effective roof area, (m2)

FIGURE 1 - Limits of calculation processes

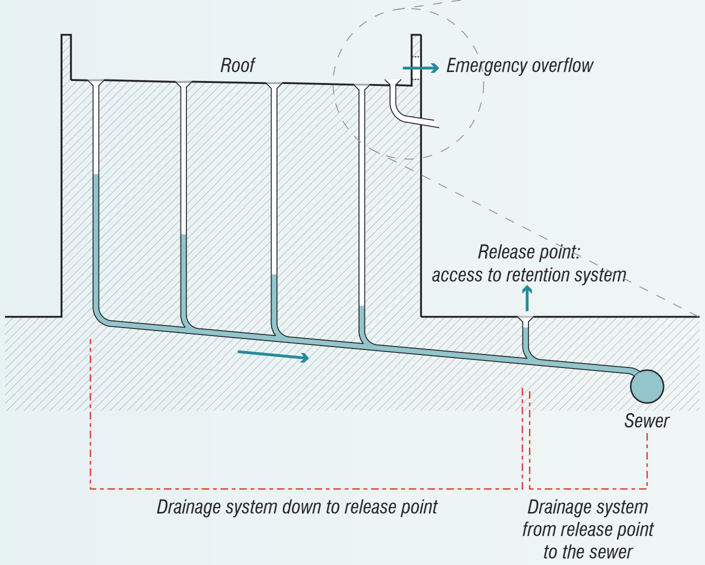
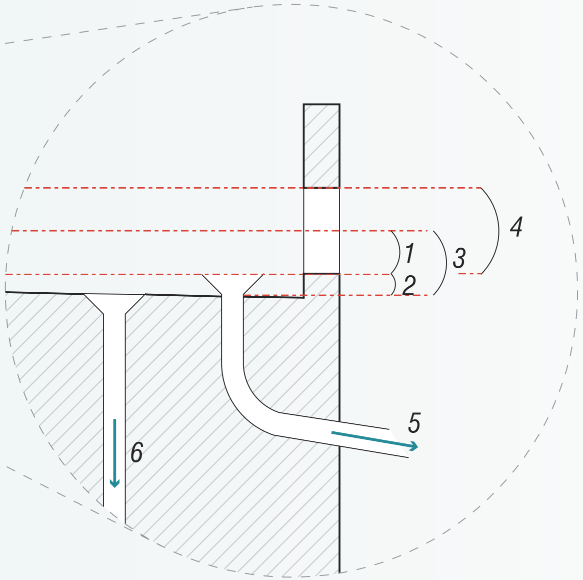


FIGURE 2 - Determining flooding heights in case of flooding on flat roofs



1 - Necessary pressure height (h_1) at emergency outlet
2 - Necessary pressure height (h_2) at roof drainage
3 - Maximum flooding height by flooding
4 - Emergency outlet at the parapet above the pressure height of roof drainage
5 - Free emergency outlet through the front wall, $r_{(5,100)} - r_{(5,5)}$
6 - $r_{(5,5)}$

"

FF Notes:

This particular section lays out the equation used to calculate the sizing of an emergency outlet to divert the overflow of stormwater which could accumulate on a flat roof during an extreme rainfall event. The standard requires the emergency system be sized adequately to drain the rainfall volume of the 100-year storm. The equation takes into account the capacity of drainage pipes into the sewer which, as mentioned in the excerpt, is normally designed to take the 5-minute/5-year storm, $r_{(5,5)}$.

GERMAN CALCULATION METHODOLOGY

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Determining the volume of retention tanks and flooding areas

For the calculation of the retention volume, there are three methods:

Method 1:

At least T of 30 years should be inserted in equation 3 for this method. If a higher flooding security is necessary, a higher value of T should be taken into consideration.

Equation 3

$$V_{ret} = (r_{(D,30)} \cdot A_{tot} - (r_{(D,2)} \cdot A_{rf} \cdot C_{rf} + r_{(D,2)} \cdot A_{nopo} \cdot C_{nopo})) \cdot {}^{(D \cdot 60)}/_{(10{,}000 \cdot 1{,}000)}$$

Method 2:

If the maximum flow rate capacity of the drainage system to the sewer is known, equation 4 can be applied. The calculation should be repeated with D=5, 10 and 15 minutes. The greatest value for V_{ret} should be taken.

Equation 4

$$V_{ret} = (r_{(D,30)} \cdot A_{tot} / 10{,}000 - Q_{max}) \cdot {}^{D \cdot 60}/_{1{,}000}$$

Method 3:

In case of a limited flow rate to the sewer, equation 5 has to be used.

Equation 5

$$V_{ret} = (r_{(D,30)} \cdot A_{tot} / 10{,}000 - Q_{red}) \cdot D \cdot f_r \cdot 0.06$$

V_{ret}	*the amount of rain water to be retained, m^3*
$r_{(D,T)}$	*D-minute rainfall intensity, occurring every T years, (l/(s·ha))*
$r_{(D,30)}$	*D-minute rainfall intensity, occurring every 30 years, (l/(s·ha))*
$r_{(D,2)}$	*D-minute rainfall intensity, occurring every 2 years, (l/(s·ha))*
Q_{max}	*maximum flow rate capacity to the sewer, (l/s)*
Q_{red}	*limited flow rate to the sewer, (l/s)*
D	*duration of rainfall, in minutes, D=5,10,15 (the greatest value for V_{ret} should be taken for calculation)*
f_r	*risk value with a supplementary factor, f_r =1.15*
A_{tot}	*total impervious area, m^2*
A_{rf}	*effective roof area, m^2*
A_{nopo}	*impervious area outside of a building, m^2*
0.06	*unit conversion factor, from l/s to m^3/min*

"

FF Notes:

For the sizing of retention tanks, the German standard provides three different equations that can be used depending on available datasets and variables.

Equation 3 takes into consideration the runoff coefficient of each type of surface in a given site. The equation does not account for the release rate of the runoff into the sewer system. Thus, the volume to retain, V_{ret}, in this case is calculated by subtracting the infiltration volume from the volume of rain that falls on site.

Equation 4 and Equation 5 take into consideration the release rate of runoff into the sewer system - Q_{red} and Q_{max}. However the surface runoff coefficient is not factored in, meaning that the volume of water infiltrated into the ground is disregarded.

The 30-year storm is used in all three methods.

COMPARATIVE ANALYSIS/ FF METHODOLOGY

NYC vs. German Methodology

Excerpt 3 of the New York City Calculation Methodology is directly comparable to the German Methodology. Both outline the equations and standards considered in determining the flow and volume of precipitation, and in the sizing of stormwater management systems.

Both employ the same basic equation, *(flow) = (area) x (rate of precipitation) x (runoff coefficient)*, and thus the same calculation concept. However, the standards used in each methodology vary:

_Different rainfall intensities r(D,T) are used by each method. New York City uses r(6,5) which is the rainfall intensity for the event with a 5 year return period and the 6 minute time of concentration used to calculate the rate of rainfall that accumulates on site. The German methodology, however, uses different r(D,T) values for different scenarios as summarized in 'Table 1 - Rainfall Intensity for Berlin, Germany'.

In contrast to New York City, the German standard employs the 30-year design storm data for sizing of stormwater management systems in anticipation of greater extreme precipitation.

_The use of runoff coefficients varies. The New York City methodology employs weighted coefficients averaged for the entire site, while the German method accounts for each type of surface of a given site, and factors in the runoff coefficient for each surface separately as outlined in *Equation 3*.

FF Methodology

The team developed a unique approach to quantifying the problem, in other words, to calculating the volume of overflow that would accumulate or otherwise outfall into the surrounding water bodies. While still applying the same basic equation *(flow) = (area) x (rate of precipitation) x (runoff coefficient)* as a primary calculation concept, the team modified Equation 4 of the German Methodology to arrive at the FF calculation method. Through a simple and rational process, the team formulated an equation which subtracts the volume of infiltration and the volume of release into the sewer from the volume of total rainfall, leaving the volume of overflow that remains on site to be managed.

In calculating the rainfall rate, the team decided upon using a greater extreme precipitation value as a standard in order to reflect the ever increasing rain event and intensity that the New York Region has been experiencing (as reflected by GRAPH 1 and GRAPH 2 of pg. 68). Instead of using the 30-year storm as employed by the German Methodology, the team determined the 50-year design storm as the most feasible and practical to address the need for extreme stormwater management balanced by economic efficiencies. The extreme precipitation data for New York City is outlined in TABLE 1, and the rate of rainfall over time plotted in GRAPH 4 and GRAPH 5.

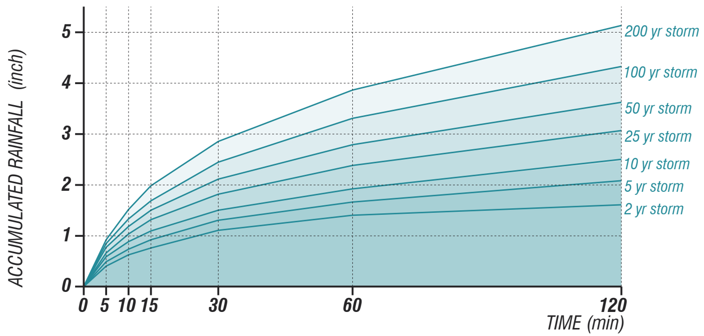
The complete equation and the calculation steps follow.

STORM FREQUENCY	DURATION: 5 min	10 min	15 min	30 min	60 min	120 min
2 yr	0.43	0.66	0.82	1.07	1.34	1.65
5 yr	0.49	0.77	0.96	1.29	1.65	2.07
10 yr	0.55	0.87	1.10	1.49	1.94	2.46
25 yr	0.64	1.02	1.30	1.80	2.40	3.07
50 yr	0.73	1.17	1.50	2.10	2.82	3.64
100 yr	0.83	1.34	1.72	2.44	3.32	4.31
200 yr	0.93	1.52	1.97	2.83	3.90	5.11

(inch)

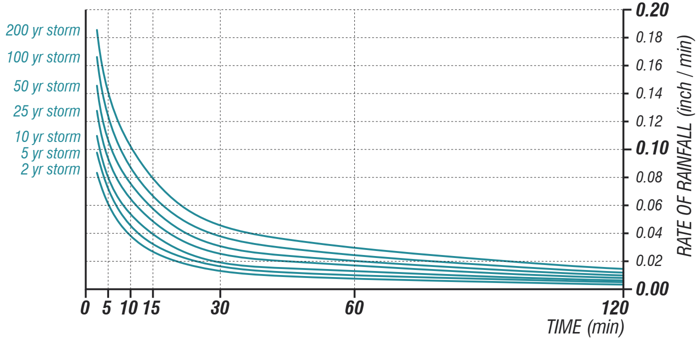
TABLE 1 : Extreme precipitation estimate table for New York City (75.006˚ W 40.713˚N)

Each numeric value in the table signifies the level of precipitation accumulated (in inch) over its corresponding duration, at any given geographic point in the sewershed



GRAPH 4 : Extreme precipitation volume accumulated over time

The graph charted from the data table above better visualizes the accumulated rain volume over time. The changing slope of the graph signifies changes in the rate of rainfall.



GRAPH 5 : Rate of extreme precipitation over time

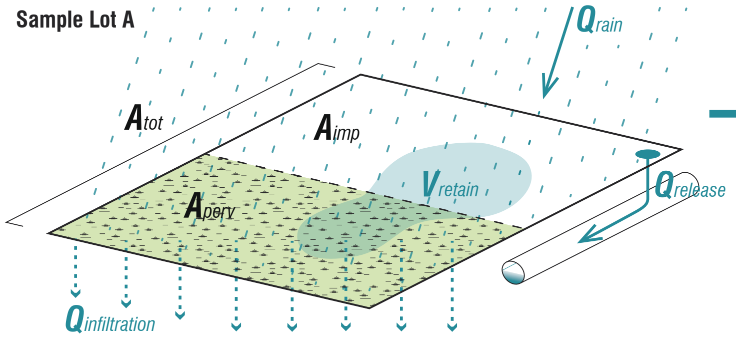
The graph reveals that the most intense rate of rainfall during an extreme storm event occurs during the first 5 minutes of the event. The rate of rainfall dissipates greatly afterward over time.

Climate data source:
Northeast Regional Climate Center

FF CALCULATION FLOWCHART

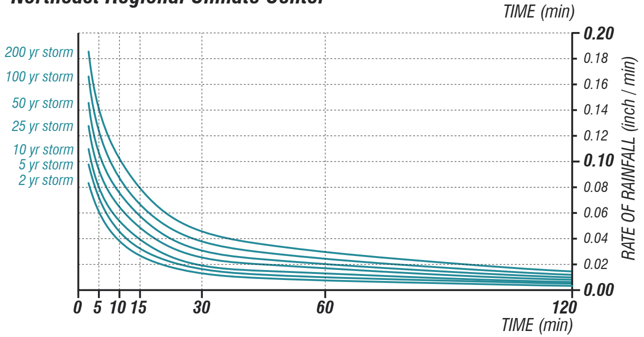
SOURCES

Sample Lot A



Rate of extreme precipitation over time for New York City (40.713˚N,74.006˚W)

Northeast Regional Climate Center



VARIABLES

Total Area: A_{tot}

Impervious Area: A_{imp}

Pervious Area: A_{perv}
(ft²)

Volumes of water to retain: V_{ret}

Find

$r_{(D,50)}$

$r_{(5,2)}$

: the intensity of rainfall for the 50 and 2-year storm event in a given duration of ***D***. According to the German standards, ***D*** of 5,10,and 15 min. should be selected. *(ft³/(min·ft²))*

D_{rain}
(min)

CALCULATION

Calculate the total rate of precipitation that falls on the entire site, A_{tot}

$$Q_{rain} = r_{(D,50)} \cdot A_{tot}$$
(ft³/min)

Calculate the rate of infiltratration through the pervious area, A_{perv}

$$Q_{infiltrations} = (1\text{-}C_{perv}) \cdot r_{(D,2)} \cdot A_{perv}$$
(ft³/min)

Calculate the rate of release through the sewer connection

$$Q_{release} = r_{release} \cdot A_{tot}$$
(ft³/min)

Allowable Release Rate Standard for NYC

§ 31 - 03 Stormwater performance standard for connections to combined sewer system

- Stormwater release rate will be the greater of 0.25cfs or 10% of the Allowable Flow

- If Allowable Flow is less than 0.25 cfs, the Stormwater Release Rate shall be the Allowable Flow

- Allowable Flow is the stormwater flow from a development that can be released into existing storm or combined sewer based on drainage plan and built sewers

Runoff Coefficient

SURFACE TYPE	C	EXAMPLE SURFACES
impervious surface	1.0	roof surface
	0.9	
	0.8	
	0.7	pavers on sand
	0.6	synthetic lawn pavers with more than 15% pervious area
	0.5	gravel roof green roof - extensive assembly (<10cm depth) water connected surface
	0.4	tennis surface
	0.3	green roof - intensive assembly green roof - extensive assembly (>10cm depth) lawn
	0.2	
	0.1	
pervious surface	0.0	vegetation surface, park grounds gravel and slag surface

Calculate the release rate standard of NYC for a given site A:

If $A_{tot} \geq 1.0$ acre (43,560 sq.ft.),
$r_{release} = 0.0003444\ ft^3/min/ft^2$

If $A_{tot} \geq 0.10$ acre (4,356 sq.ft.) and $A_{tot} < 1.0$ acre,
$r_{release} = (15.0\ ft^3/min)/A_{tot}$

If $A_{tot} < 0.10$ acre,
$r_{release} = 0.003444\ ft^3/min/ft^2$

Find runoff coefficient for the pervious surface type:
C_{perv}

$$V_{ret} = ((r_{(D,50)} \cdot A_{tot}) - ((1-C_{perv}) \cdot r_{(D,2)} \cdot A_{perv}) - (r_{release}/A_{tot}) \cdot D_{rain}$$

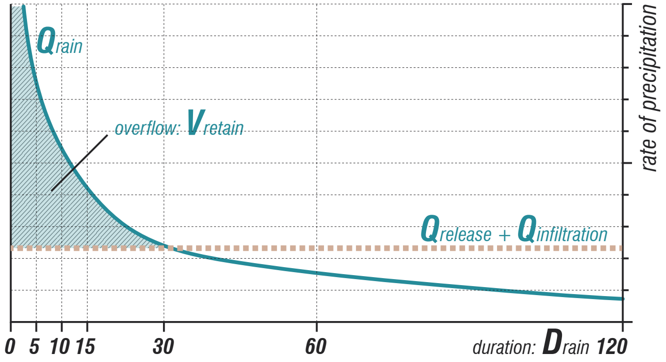
$$V_{ret} = (Q_{rain} - Q_{infiltration} - Q_{release}) \cdot D_{rain}$$

(ft^3)

$$V_{ret} = V_{rain} - V_{infiltration} - V_{release}$$

The volume of overflow that accumulates over the duration, D, is equal to the total volume of precipitation, V_{rain}, subtracted by the volume of infiltration into the ground, $V_{infiltration}$, and by the volume of release into the sewer, $V_{release}$.

Rate of precipitation vs Duration Graph



The graph above represents the calculation equation. The area under the rate of precipitation graph, Q_{rain}, indicates the volume of water accumulated over time. The area between the precipitation, Q_{rain}, and the release/infiltration graph, $Q_{release}+Q_{infiltration}$, signifies the total volume of overflow that needs to be retained, V_{ret}. The integral of the above graph yields the volume of overflow ,V_{ret}, accumulated on site A over time. $(V_{ret} = \int(Q_{rain} - Q_{release} - Q_{infiltration}))$

APPLICATION OF FF METHODOLOGY

The FF team developed a unique approach to stormwater calculations, influenced by both German and New York City standards. The team set out to apply this methodology to the Red Hook Sewershed as a case study.

Comprehensive mapping of the sewershed revealed a framework for this case study analysis. A framework with a scale bounded by the total sewershed area at the upper limit and the single building at the lower. Within this scale, the team discovered unique characteristics of the Red Hook Sewershed. More specifically, the research reveals that within the combined sewered area, the townhouse block constitutes 40% of the land.

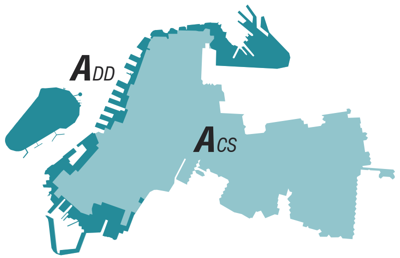
What would it look like to isolate the stormwater management contribution of the townhouse typology? What can a uniform typology representing 40% of the sewershed do to mitigate CSO's? By applying the FF stormwater calculation methodology to; the entire sewershed, the townhouse blocks in aggregate, the single block and finally the individual townhouse the numbers reveal the potential of the townhouse typology as a tremendous aggregator of stormwater management.

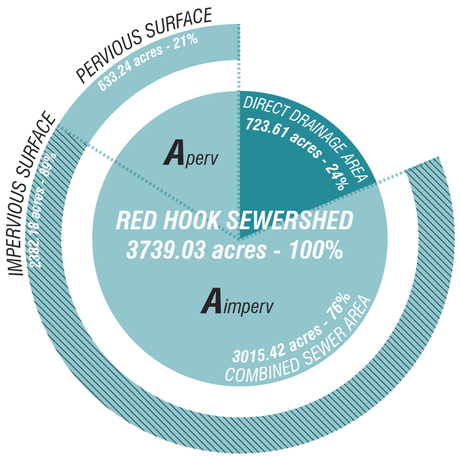
The following pages apply the FF stormwater calculation methodology and walk through, at the aforementioned scales, the volumes of rainwater received from extreme precipitation and the necessary volumes to be retained in order to mitigate CSO's.

STORMWATER CALCULATION FOR RED HOOK SEWERSHED

SOURCES

Red Hook Sewershed Areas





VARIABLES

Area

Total Area of RH Sewershed:

$A_{RH} = 3{,}739.03$ ac

Direct Drainage Area:

$A_{DD} = 723.61$ ac

Combined Sewer Area

$A_{CS} = 3{,}015.42$ ac
$= 131{,}334{,}704$ ft^2

Pervious Area

$A_{perv} = 633.24$ ac
$= 27{,}583{,}934$ ft^2

Impervious Area

$A_{imperv} = 2{,}382.16$ ac

Area of New Development
(5.0% of A_{CS}) :*

$A_{new} = 150.77$ ac
$= 6{,}567{,}684$ ft^2

Area of Existing Development
(95.0% of A_{CS})

$A_{exist} = 2{,}854.65$ ac
$= 124{,}348{,}510$ ft^2

*
Area of "new development and redevelopment" accounts for 5.0% of the combined sewershed area.
(NYC Green Infrastructure Plan, Table 1, pg. 5)

CALCULATION

Precipitation

$Q_{rain} = r_{(5,50)} \cdot A_{CS}$

$Q_{rain} = (0.01216 \text{ ft}^3/\text{min/ft}^2) \cdot (131{,}334{,}704 \text{ ft}^2)$

$Q_{rain} = 1{,}597{,}030 \text{ ft}^3/\text{min}$

Release Rate - New Development

$Q_{release\text{-}new} = r_{new} \cdot A_{new}$

$Q_{release\text{-}new} = (0.0003444 \text{ ft}^3/\text{min/ft}^2) \cdot (6{,}567{,}584 \text{ ft}^2)$

$Q_{release\text{-}new} = 2{,}261 \text{ ft}^3/\text{min}$

Release Rate - Existing Development

$Q_{release\text{-}exist} = r_{exist} \cdot A_{exist}$

$Q_{release\text{-}exist} = (0.003444 \text{ ft}^3/\text{min/ft}^2) \cdot (124{,}348{,}510 \text{ ft}^2)$

$Q_{release\text{-}new} = 428{,}256 \text{ ft}^3/\text{min}$

Release Rate - Total

$Q_{release} = Q_{release\text{-}new} + Q_{release\text{-}exist}$

$Q_{release} = 430{,}517 \text{ ft}^3/\text{min}$

Extreme Precipitation Table for for New York City (40.713˚N,74.006˚W)

Northeast Regional Climate Center

STORM FREQUENCY	DURATION 5 min	10 min	15 min	30 min	60 min	120 min
2 yr	0.43	0.66	0.82	1.07	1.34	1.65
5 yr	0.49	0.77	0.96	1.29	1.65	2.07
10 yr	0.55	0.87	1.10	1.49	1.94	2.46
25 yr	0.64	1.02	1.30	1.80	2.40	3.07
50 yr	0.73	1.17	1.50	2.10	2.82	3.64
100 yr	0.83	1.34	1.72	2.44	3.32	4.31
200 yr	0.93	1.52	1.97	2.83	3.90	5.11

(inch)

Allowable Release Rate Standard for NYC

For new developments and redevelopment:

If $A_{tot} \geq$ 1.0 acre (43,560 sq.ft.), $r_{release} = 0.0003444\ ft^3/min/ft^2$

If $A_{tot} \geq$ 0.10 acre (4,356 sq.ft.) and $A_{tot} <$ 1.0 acre (43,560 sq.ft.), $r_{release} = (15.0\ ft^3/min)/A_{tot}$

If $A_{tot} <$ 0.10 acre (4,356 sq. ft.), $r_{release} = 0.003444\ ft^3/min/ft^2$

For existing developments:

$r_{release} = 0.003444\ ft^3/min/ft^2$

Precipitation Rate

When the duration of precipitation,

$D_{rain} = 5min,$

then the rate of precipitation:

$$r_{(5,50)} = (0.73\ in)\cdot\left(\frac{1\ ft}{12\ in}\right)\cdot\left(\frac{ft^2}{ft^2}\right)\cdot\left(\frac{1}{5min}\right)$$

$$r_{(5,50)} = 0.01216\ ft^3/min/ft^2$$

$$r_{(5,2)} = (0.43\ in)\cdot\left(\frac{1\ ft}{12\ in}\right)\cdot\left(\frac{ft^2}{ft^2}\right)\cdot\left(\frac{1}{5min}\right)$$

$$r_{(5,2)} = 0.00716\ ft^3/min/ft^2$$

Release Rate

$A_{new} = 150.77\ ac > 1.0\ acre,$ *therefore,*

Release Rate for New Development Area:

$$r_{new} = 0.0003444\ ft^3/min/ft^2$$

Release Rate for Existing Development:

$$r_{exist} = 0.003444\ ft^3/min/ft^2$$

Runoff Coefficient

Assumed coefficient (lawn type) for the pervious area:

$$C_{perv} = 0.3$$

Infiltration

$$Q_{infiltration} = (1-C_{perv})\cdot r_{(5,2)}\cdot A_{perv}$$

$$Q_{infiltration} = (1 - 0.3)\cdot(0.00716\ ft^3/min/ft^2)\cdot(27{,}583{,}934\ ft^2)$$

$$Q_{infiltration} = 138{,}251\ ft^3/min$$

Volume to be Managed:

$$V_{ret} = (Q_{rain} - Q_{infiltration} - Q_{release}) \cdot D_{rain}$$

$$V_{ret} = (1{,}597{,}030\ ft^3/min - 138{,}251\ ft^3/min - 430{,}517\ ft^3/min) \cdot 5\ min$$

$$V_{ret} = 5{,}144{,}084\ ft^3 = 38.5\ \text{million gallons}$$

Repeat the above calculation for $D = 10min$, and $D = 15min$, using $r_{(10,50)}$ and $r_{(5,50)}$ respectively, then choose the greatest value of V_{ret} to determine the maximum volume to be managed.

When $D = 10\ min$, $r_{(10,50)} = 0.00975\ ft^3/min/ft^2$

$$V_{ret} = 7{,}114{,}250\ ft^3 = 53.2\ \text{million gallons}$$

When $D = 15\ min$, $r_{(15,50)} = 0.0083\ ft^3/min/ft^2$

$$V_{ret} = 7{,}819{,}650\ ft^3 = 58.5\ \text{million gallons}$$ (greatest)

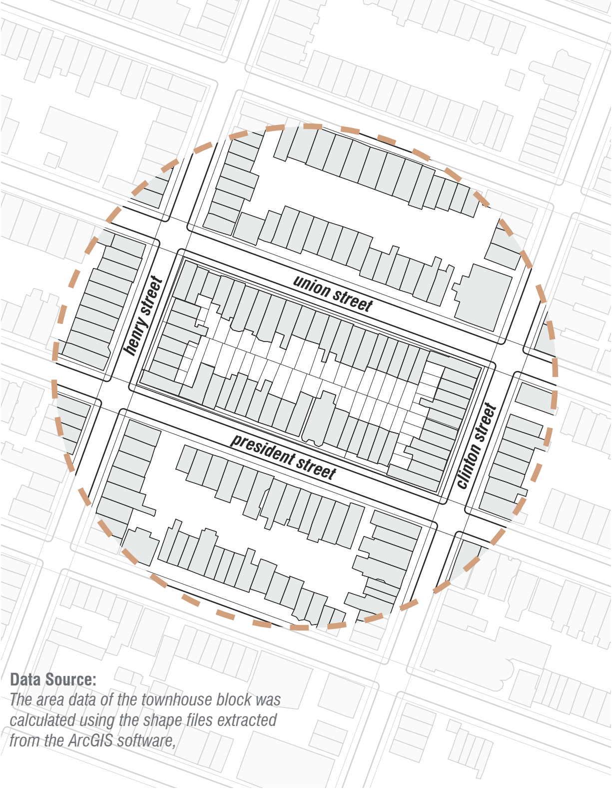
Volume to be Managed:

The total volume of 58.5 million gallons of rain would accumulate in the entire Red Hook Sewershed after the initial 15 min of precipitation during the 50-year storm. The value indicates the overflow volume to be managed by the entire Red Hook Sewershed.

STORMWATER CALCULATION FOR A TOWNHOUSE BLOCK

SOURCES

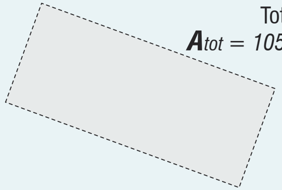
Brooklyn Townhouse Block Sample



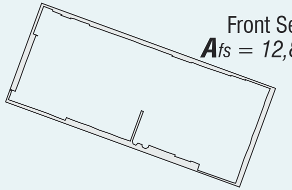
Data Source:
The area data of the townhouse block was calculated using the shape files extracted from the ArcGIS software.

VARIABLES

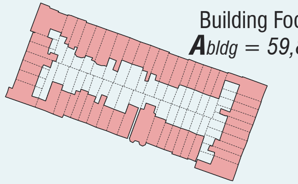
Area



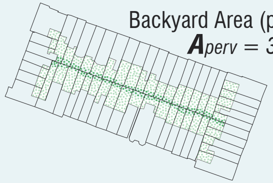
Total Area:
$A_{tot} = 105{,}373\ ft^2$



Front Setback:
$A_{fs} = 12{,}806\ ft^2$



Building Footprint:
$A_{bldg} = 59{,}836\ ft^2$



Backyard Area (pervious):
$A_{perv} = 32{,}723\ ft^2$

CALCULATION

Precipitation

$$Q_{rain} = r_{(5,50)} \cdot A_{tot}$$

$$Q_{rain} = (0.01216\ ft^3/min/ft^2) \cdot (105{,}373\ ft^2)$$

$$Q_{rain} = 1{,}281\ ft^3/min$$

Release Rate

$$Q_{release} = r_{release} \cdot A_{tot}$$

$$Q_{release} = (0.003444\ ft^3/min/ft^2) \cdot (105{,}373\ ft^2)$$

$$Q_{release} = 363\ ft^3/min$$

Infiltration

$$Q_{infiltration} = (1 - C_{perv}) \cdot r_{(5,2)} \cdot A_{perv}$$

$$Q_{infiltration} = (1 - 0.3) \cdot (0.00716\ ft^3/min/ft^2) \cdot (32{,}723\ ft^2)$$

$$Q_{infiltration} = 164\ ft^3/min$$

Extreme Precipitation Table for
for New York City (40.713˚N,74.006˚W)

Northeast Regional Climate Center

DURATION; STORM FREQUENCY (inch)

	5 min	10 min	15 min	30 min	60 min	120 min
2 yr	0.43	0.66	0.82	1.07	1.34	1.65
5 yr	0.49	0.77	0.96	1.29	1.65	2.07
10 yr	0.55	0.87	1.10	1.49	1.94	2.46
25 yr	0.64	1.02	1.30	1.80	2.40	3.07
50 yr	0.73	1.17	1.50	2.10	2.82	3.64
100 yr	0.83	1.34	1.72	2.44	3.32	4.31
200 yr	0.93	1.52	1.97	2.83	3.90	5.11

Allowable Release Rate Standard for NYC

For new developments and redevelopment:

If $A_{tot} \geq$ 1.0 acre (43,560 sq.ft.), $r_{release} = 0.0003444\ ft^3/min/ft^2$

If $A_{tot} \geq$ 0.10 acre (4,356 sq.ft.) and $A_{tot} <$ 1.0 acre (43,560 sq.ft.),
$r_{release} = (15.0\ ft^3/min)/A_{tot}$

If $A_{tot} <$ 0.10 acre (4,356 sq. ft.), $r_{release} = 0.003444\ ft^3/min/ft^2$

For existing developments:

$r_{release} = 0.003444\ ft^3/min/ft^2$

Precipitation Rate

When the duration of precipitation,
$D_{rain} = 5min,$
then the rate of precipitation:

$$r_{(5,50)} = (0.73\ in)\cdot\left(\frac{1\ ft}{12\ in}\right)\cdot\left(\frac{ft^2}{ft^2}\right)\cdot\left(\frac{1}{5min}\right)$$

$$r_{(5,50)} = 0.01216\ ft^3/min/ft^2$$

$$r_{(5,2)} = (0.43\ in)\cdot\left(\frac{1\ ft}{12\ in}\right)\cdot\left(\frac{ft^2}{ft^2}\right)\cdot\left(\frac{1}{5min}\right)$$

$$r_{(5,2)} = 0.00716\ ft^3/min/ft^2$$

Release Rate

Since each lot within the townhouse block is smaller than 0.10 acre, even with any possible new development, the release rate average for the whole townhouse block is not affected by the amendment. Therefore,

$$r_{release} = 0.003444\ ft^3/min/ft^2$$

Runoff Coefficient

Assumed coefficient (lawn type) for the pervious area:

$$C_{perv} = 0.3$$

Volume to be Managed:

$$V_{ret} = (Q_{rain} - Q_{infiltration} - Q_{release}) \cdot D_{rain}$$

$$V_{ret} = (1{,}281\ ft^3/min - 363\ ft^3/min - 164\ ft^3/min) \cdot 5\ min$$

$$V_{ret} = 3{,}770\ ft^3 = 28.2\ \text{thousand gallons}$$

Repeat the above calculation for $D = 10min$, and $D = 15min$, using $r_{(10,50)}$ and $r_{(5,50)}$ respectively, then choose the greatest value of V_{ret} to determine the maximum volume to be managed.

When $D = 10\ min$, $r_{(10,50)} = 0.00975\ ft^3/min/ft^2$
$V_{ret} = 5{,}005\ ft^3 = 37.4$ **thousand gallons**

When $D = 15\ min$, $r_{(15,50)} = 0.0083\ ft^3/min/ft^2$
$V_{ret} = 5{,}215\ ft^3 = 39.0$ **thousand gallons** (greatest)

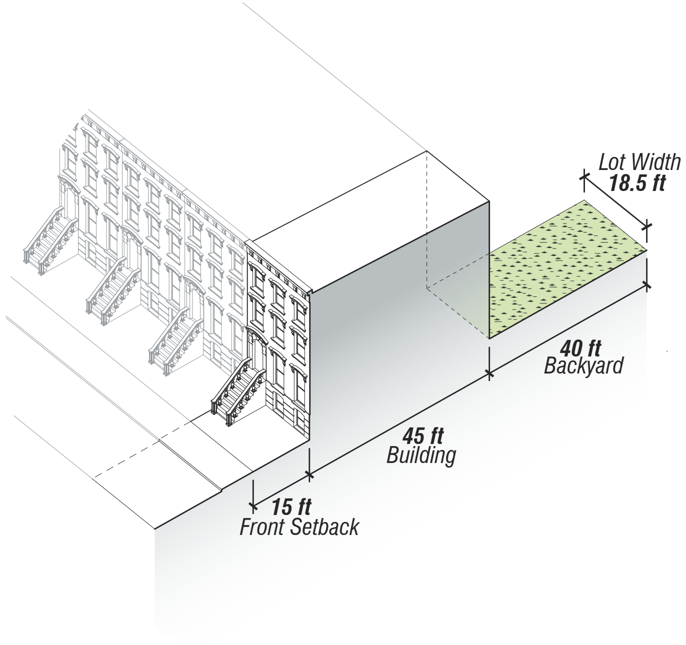
Volume to be Managed:

Approximately 39.0 thousand gallons of rain would accumulate in a typical townhouse block after the initial 15 min of precipitation during the 50-year storm. It indicates the volume of water to be managed on a typical townhouse block as a whole.

STORMWATER CALCULATION FOR A TYPICAL TOWNHOUSE

SOURCES

Typical Brooklyn Townhouse



VARIABLES

Area

Total Lot Area:

A_{tot} = 100 ft x 18.5 ft = 1,850 ft²

Backyard Area (pervious)

A_{perv} = 40 ft x 18.5 ft = 740 ft²

Front Setback Area (impervious)

A_{fs} = 15 ft x 18.5 ft = 277.5 ft²

Building Footprint (impervious)

A_{bldg} = 45 ft x 18.5 ft = 832.5 ft²

CALCULATION

Precipitation

$$Q_{rain} = r_{(5,50)} \cdot A_{tot}$$

$$Q_{rain} = (0.01216\ ft^3/min/ft^2) \cdot (1{,}850\ ft^2)$$

$$Q_{rain} = 22.50\ ft^3/min$$

Release Rate

$$Q_{release} = r_{release} \cdot A_{tot}$$

$$Q_{release} = (0.003444\ ft^3/min/ft^2) \cdot (1{,}850\ ft^2)$$

$$Q_{release} = 6.37\ ft^3/min$$

Infiltration

$$Q_{infiltration} = (1 - C_{perv}) \cdot r_{(5,2)} \cdot A_{perv}$$

$$Q_{infiltration} = (1 - 0.3) \cdot (0.00716\ ft^3/min/ft^2) \cdot (740\ ft^2)$$

$$Q_{infiltration} = 3.71\ ft^3/min$$

Extreme Precipitation Table for
for New York City (40.713˚N,74.006˚W)

Northeast Regional Climate Center

STORM FREQUENCY	DURATION 5 min	10 min	15 min	30 min	60 min	120 min
2 yr	0.43	0.66	0.82	1.07	1.34	1.65
5 yr	0.49	0.77	0.96	1.29	1.65	2.07
10 yr	0.55	0.87	1.10	1.49	1.94	2.46
25 yr	0.64	1.02	1.30	1.80	2.40	3.07
50 yr	0.73	1.17	1.50	2.10	2.82	3.64
100 yr	0.83	1.34	1.72	2.44	3.32	4.31
200 yr	0.93	1.52	1.97	2.83	3.90	5.11

(inch)

Allowable Release Rate Standard for NYC

For new developments and redevelopment:

If $A_{tot} \geq$ 1.0 acre (43,560 sq.ft.), $r_{release} = 0.0003444\ ft^3/min/ft^2$

If $A_{tot} \geq$ 0.10 acre (4,356 sq.ft.) and $A_{tot} <$ 1.0 acre (43,560 sq.ft.), $r_{release} = (15.0\ ft^3/min)/A_{tot}$

If $A_{tot} <$ 0.10 acre (4,356 sq. ft.), $r_{release} = 0.003444\ ft^3/min/ft^2$

For existing developments:

$r_{release} = 0.003444\ ft^3/min/ft^2$

Precipitation Rate

When the duration of precipitation,

$D_{rain} = 5min,$

then the rate of precipitation:

$$r_{(5,50)} = (0.73\ in)\cdot\left(\frac{1\ ft}{12\ in}\right)\cdot\left(\frac{ft^2}{ft^2}\right)\cdot\left(\frac{1}{5min}\right)$$

$$r_{(5,50)} = 0.01216\ ft^3/min/ft^2$$

$$r_{(5,2)} = (0.43\ in)\cdot\left(\frac{1\ ft}{12\ in}\right)\cdot\left(\frac{ft^2}{ft^2}\right)\cdot\left(\frac{1}{5min}\right)$$

$$r_{(5,2)} = 0.00716\ ft^3/min/ft^2$$

Release Rate

Since a typical townhous lot is smaller than 0.10 acre, even with any possible new development, redevelopment or alteration, the release rate for the plot is not affected by the amendment. Therefore,

$r_{release} = 0.003444\ ft^3/min/ft^2$

Runoff Coefficient

Assumed coefficient (lawn type) for the pervious area:

$C_{perv} = 0.3$

Volume to be Managed:

$$V_{ret} = (Q_{rain} - Q_{infiltration} - Q_{release}) \cdot D_{rain}$$

$$V_{ret} = (22.50\ ft^3/min - 6.37\ ft^3/min - 3.71\ ft^3/min) \cdot 5\ min$$

$$V_{ret} = 62.10\ ft^3 = 465\ gallons$$

Repeat the above calculation for $D=10min$, and $D=15min$, using $r_{(10,50)}$ and $r_{(5,50)}$ respectively, then choose the greatest value of V_{ret} to determine the maximum volume to be managed.

When $D=10\ min$, $r_{(10,50)} = 0.00975\ ft^3/min/ft^2$

$V_{ret} = 79.58\ ft^3 = 595\ gallons$ (greatest)

When $D=15\ min$, $r_{(15,50)} = 0.0083\ ft^3/min/ft^2$

$V_{ret} = 79.13\ ft^3 = 592\ gallons$

Volume to be Managed:

The maximum volume of approximately 600 gallons of rain would accumulate in a typical townhouse lot after the initial 10 min of precipitation during the 50-year storm. It indicates the volume to be managed on a single townhouse lot. As an example, a detention tank with a capacity of 600 gallons, or approximately 3ft x 4ft x 5ft in dimension, would provide adaquate stormwater management on a single townhouse lot.

SYNTHESIS OF RED HOOK SEWERSHED CASE STUDY

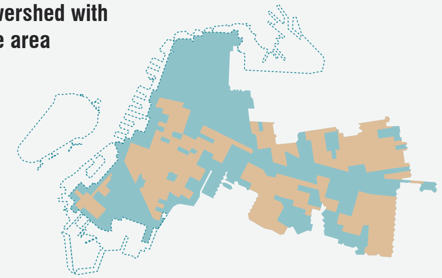
Individually within the scale of the sewershed, the townhouse is small and highly distributed. However, collectively, the townhouse blocks are large and uniform representing 40% of the sewershed. In aggregate, townhouses within the Red Hook Sewershed represent a capture potential which far exceeds the City's GI Plan goal of managing 1 inch of rainfall over 10 % of the impervious surface. This potential highlights and further emphasizes two FF assertions:

_greatly enhanced engagement and GI incentives for private property owners are essential to meeting the long term GI Plan goals.

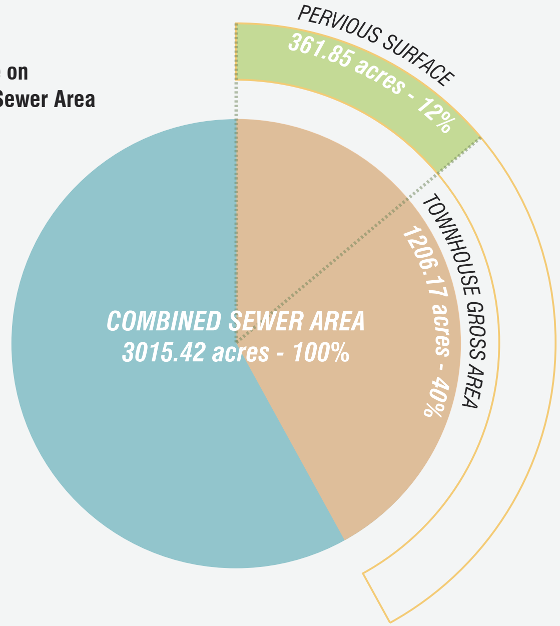
_designing to manage 1 inch of rainfall does not accurately harness the stormwater capture potential of our built environment nor does it reflect regional extreme precipitation.

Data Source:
The area takeoff of the Red Hook Sewershed was calculated using the shape files extracted from the ArcGIS software.

Red Hook Sewershed with the townhouse area highlighted



Area Figure on Combined Sewer Area



ABOVE DRAWING GENERATED BY FLUID FRONTIERS

Townhouse Area

Townhouse area, A_{TH} accounts for 40% of combined sewer area, A_{CS}:

$$A_{TH} = (3{,}015.42\ ac) \cdot (0.40) = 1{,}206.17\ ac = 52{,}540{,}765\ ft^2$$

Stormwater Capture Potential in Townhouse Area

With 39.0 thousand gallons to be managed per 105,373 ft² block, volume to be managed by the entire townhouse area:

$$V_{TH} = (39{,}000\ gallons)/(105{,}373\ ft^2) \cdot (52{,}540{,}765\ ft^2)$$

$$V_{TH} = 19.5\ million\ gallons$$ (per 50-yr storm event)

Volume to be Managed According to the Green Infrastructure Plan

*"Capture the first inch of rainfall on 10% of the impervious areas in combined sewer watersheds"**

$$V_{GI} = (0.10)(A_{imperv}) \cdot (1\ inch)$$

$$V_{GI} = (0.10)(103{,}766{,}889\ ft^2) \cdot (1/12\ ft) = 864{,}724\ ft^3$$

$$V_{GI} = 6.5\ million\ gallons$$

* *Green Infrastructure Plan, 2010, pg 4*

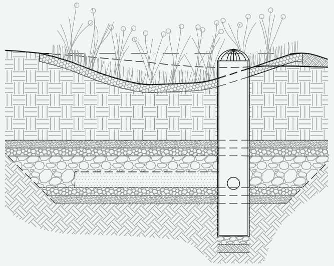
GREEN INFRASTRUCTURE IN A TYPICAL TOWNHOUSE BLOCK

The relative physical uniformity of the townhouse represents a design opportunity capitalizing on this repeating urban form. The shared outdoor spaces, building facades and roofs of townhouse blocks are elements of the built environment for which “ready to implement” strategies exist. As articulated earlier, at the individual townhouse scale, a 600 gallon retention tank can capture the resulting stormwater volume from 15 minutes of extreme precipitation. However, the FF team is not satisfied with grey solutions alone and calls for a balanced mix of blue, green and grey stormwater management solutions. Such a balance would capitalize on the many co-benefits of GI including mitigation of urban heat island, habitat creation, increased property values and reduced heating and cooling costs.

Section Detail dwg Source:
Oregon State University
architectmagazine.com
greenroofplan.com

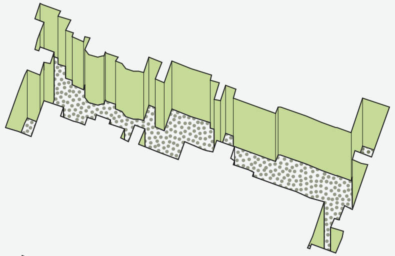
Image Source:
Austin Water
ecobrooklyn.com
Texas A&M Green Roof Project

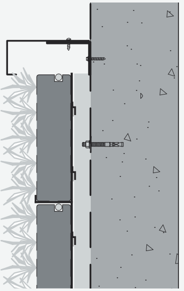
Shared Outdoor Space



Filtration Rain Garden

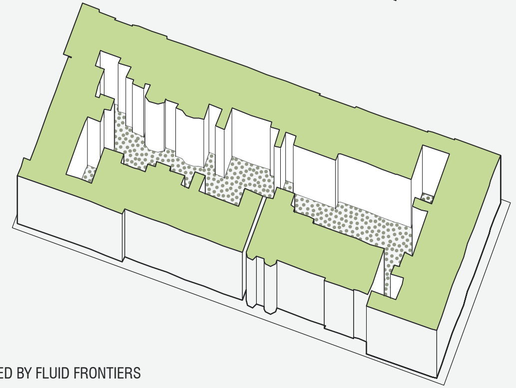
Building Facade

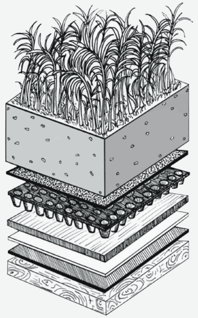




Living Wall

Building Roof





Intensive Green Roof

ABOVE DRAWING GENERATED BY FLUID FRONTIERS

CANNONEER COURT PARKING LOT RETROFIT

Green Infrastructure | Medium Scale

Brooklyn, New York

PRATT INSTITUTE,
GAIA INSTITUTE,
THREAD COLLECTIVE

Pratt Institute is a 25 acre campus in the heart of Clinton Hill Brooklyn. Students and faculty from art, design and urbanism programs as well as neighbors from the surrounding community enjoy the ample grounds and sculpture park. The Institute's commitment and attention to maintaining natural green spaces is evident and the campus serves as a resource for the whole community.

In 2012 Pratt Institute was awarded a grant for the design and construction of two green infrastructure projects on its Brooklyn campus. The projects included a 5600 sq ft green roof and a retrofit of the Cannoneer Court parking lot. The grant, awarded by the New York City Department of Environmental Protection (DEP), is part of the City's ambitious Green Infrastructure Plan, a watershed scale plan with the goal of managing 1 inch of rainfall from 10% of the City's combined sewer area, roughly 21,600 acres citywide.

Pratt's winning proposal totaling $640,000 was a collaborative effort between the School of Architecture's Sustainable Environmental Systems program and the Institute's Facilities department. Faculty, students and staff contributed equally in all aspects of the design, project management and construction. Once complete, students will be an integral part of maintaining and monitoring the projects.

Image credit:
Marcel Negret
Kate Selden

Flooding problem, prior to the intervention

Condition during the construction process

At the southeastern corner of the campus lies Cannoneer Court parking lot, a 50,000 sq ft lot bordered by the Institute's gymnasium, a dormitory, Classon and DeKalb Avenues. The Cannoneer Court site had three challenges which shaped the proposed green infrastructure intervention. Firstly, rain events of one inch or more resulted in ponding water. In 2000 the Institute renovated the parking lot using permeable pavement. The 2000 design had a standard layering of aggregate and geotextile below the permeable pavement. After 10 years the permeability of the pavement failed and rainwater began to pond. In order to bring the parking lot back into use, the Institute pumped the standing water into an adjacent dry well. The second design challenge was the additional runoff from the adjacent gymnasium. The ARC Building, is a 50,000 sq ft building whose rooftop contributes significant stormwater runoff to the parking lot site. Lastly, the existing parking lot could not lose any parking spaces.

The design team led by Sustainable Environmental Systems (SES) Director, Jaime Stein consisted of Professor Paul Mankiewicz (founder and Director of the Gaia Institute) and SES graduate students. The team's intervention was not to repave or regrade the parking lot but to work with the existing pavement and site slopes to develop a series of stormwater conveyance trenches and infiltration zones to manage a 2.5 inch rainfall without losing a single parking space. The concept went through 6 design iterations each created in collaboration with the Institute's facilities team and reviewed by DEP. To begin, the team divided the lot into a grid of drainage sheds. Stormwater calculations were kept simple. Using the runoff coefficients for each material (existing and proposed) we calculated the total stormwater volume for each grid. We then sized the void spaces under each permeable surface to ensure sufficient water capture. Working with the site slopes and overland flow of water the pattern of permeable pavers, bioswales permeable paver trenches began to emerge. The overall design speaks to the selection and strategic placement of infiltration surfaces (permeable pavers) trenches (also made of permeable pavers), bioswales.

The design iterations led to many adaptations on the original design. Two design elements which were deemed too experimental for the grant requirements included the use of recycled glass aggregate to create the subsurface void space and the absence of geotextile below the pavers as well as below the engineered soil of the bioswales. Another requirement of the grant was to have an overflow to the existing sewer system. Experimentation was allowed for this requirement and a raingarden was placed on the western border, positioned between the ARC Building and the lot. This project was successfully built in December of 2015 by Tam Green Materials, the Architect of Record was Gita Nandan of Thread Collective.

Sub-surface section, prior to intervention

Image source: *Pratt Institute*

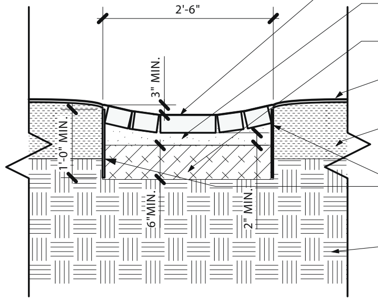
Left: *Construction of the trench drain connection to the rain garden*

Right-Above: *Connection of trench pavers, mini-swales, and permeable pavers*

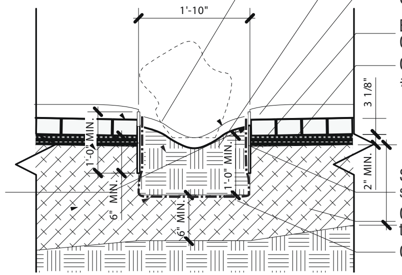
Right-Below: *Construction of bioswales*

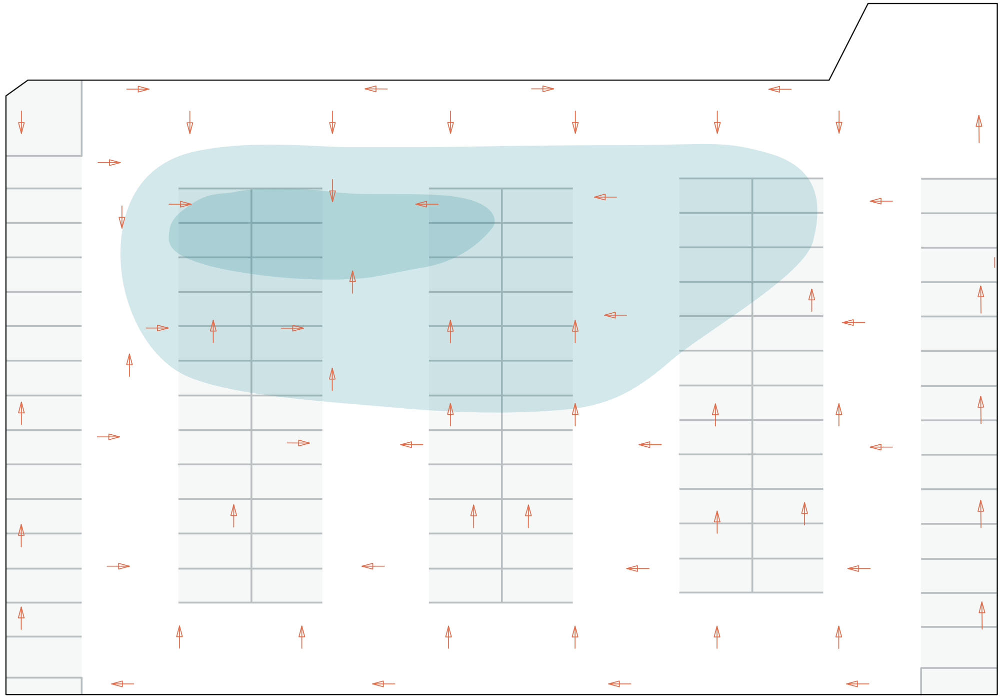
image credit: *Kate Selden*

Trench Drain Section Detail



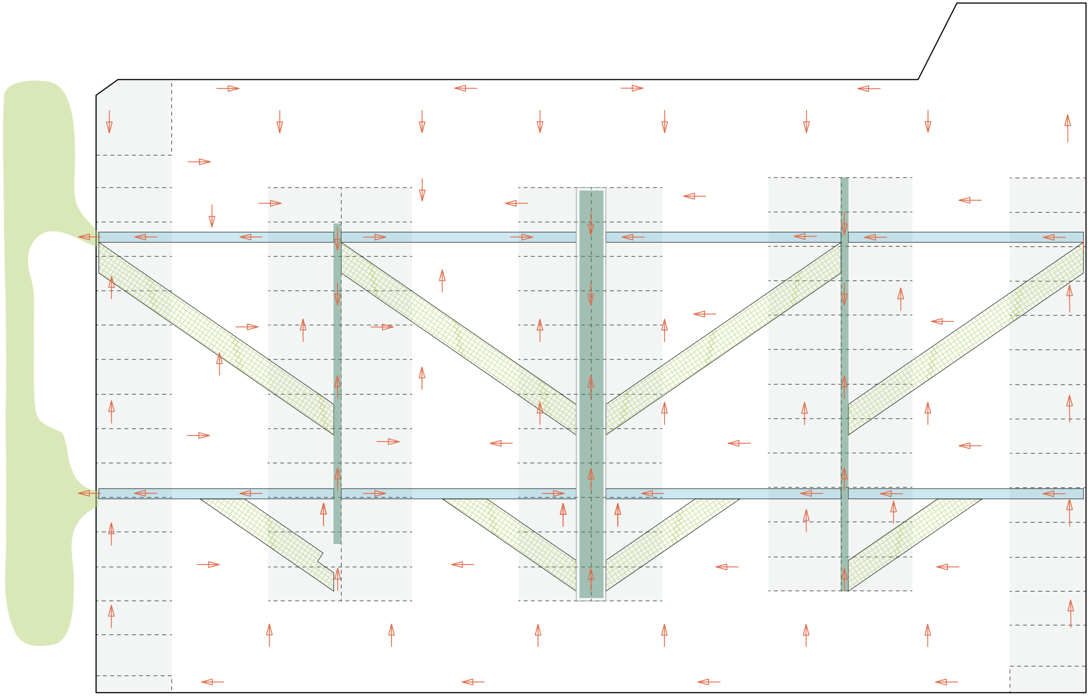
Trench at Mini-Swale Section Detail





Condition prior to the retrofit

- Parking lot boundary
- Parking spaces
- Runoff flow direction
- Flooding zone



Condition after the retrofit

- Trench Pavers
- Miniswales
- Bioswale
- Flat Permeable Pavers
- Rain Garden

Project Water Capture Metrics:

3,031 ft³ of flat permeable pavers:	*22,672 gallons*
968 ft³ of trench pavers:	*7,240 gallons*
1,117 ft³ of bioswales:	*8,355 gallons*
662 ft³ of mini-swales:	*4,952 galllons*
3,347 ft³ of rain gardens:	*25,035 gallons*

WATER SQUARE BENTHEMPLEIN

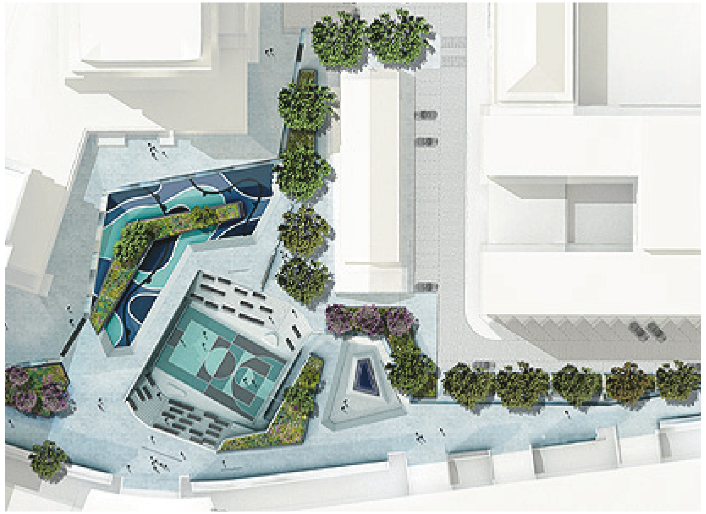
Blue Infrastructure | Medium Scale

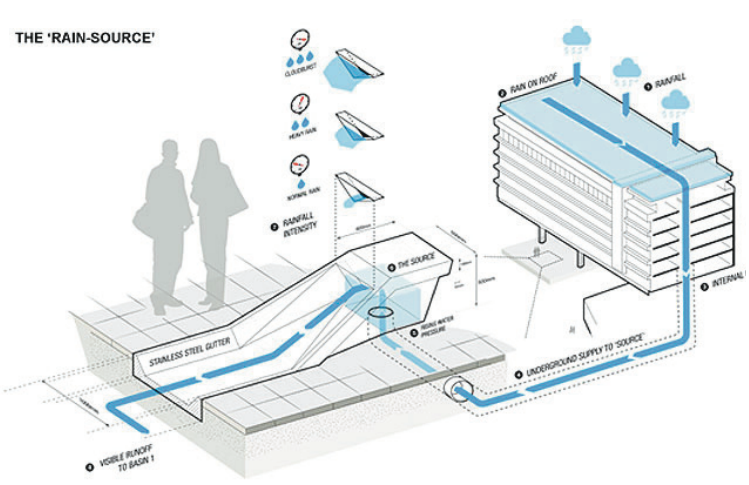
Rotterdam, Netherlands
de URBANISTEN

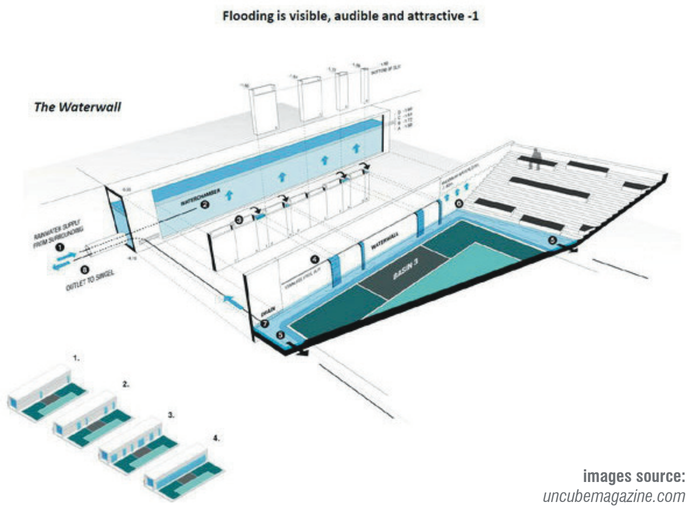
The so called "water square" in Benthemplein at the center of Rotterdam is an intervention on existing urban environment. The water park is entirely fed by stormwater runoff channeled directly from the surrounding buildings and impervious surfaces. Instead of storing the runoff in underground pipes or covert cisterns, the design attempts to celebrate water and its movement as the main attraction for the community: during a storm event water runoff from nearby buildings and sidewalks is channeled through exposed stainless steel gutters into three, tiered basins. The first inch of rain is immediately released into the sewer system as this water is used to flush out the surface from dust and other pollutants. The subsequent rainfall is detained in the exposed pools where the stormwater creates temporary ponds.

The basins, which serve as sunken playgrounds during dry weather, turn into detention tanks during a storm event. With a combined capacity of 450,000 gallons, the basins hold the runoff that would otherwise overload the city's underground infrastructure

images source
urbanisten.nl





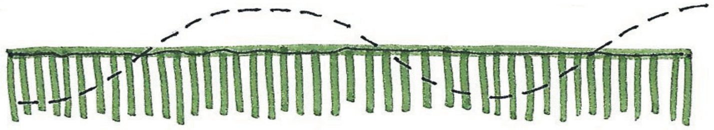


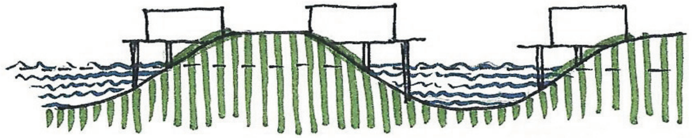
images source:
uncubemagazine.com

PLAN TIDE
Blue Infrastructure | Large Scale

Dordrecht, Netherlands

KLUNDER ARCHITECTEN &
DE STIJLGROEP





The housing project between Biesboch Nature Reserve and the city of Dordrecht was formerly a sports field surrounded by dykes. The vision for intervention of the site involved re-naturalization of the field by returning it to a freshwater tidal landscape.

Through the cut-and-fill strategy, fingerlike peninsulas were created for the housing development. Then, the resulting pier-like landscape was filled with water connected to the nearby canal, allowing tidal currents to rise up close to the houses made accessible by both boat and car.

The natural growth of reeds, tidal plants, scrub bushes and swamp forest, interspersed with open water, achieved a highly desirable relationship between land and water, and introduced an ecosystem. The owners of the 96 homes are responsible for the maintenance and management of their own landscape. Such a landscape-water relationship serves as a focus for social/communal interaction and sustainability.

Plan Tide was awarded the first prize for the competition 'SUBURBIA 2.0', and was recognized for its achievements in creating relationships between water and urban planning as well as for enhancing the real estate value.

Images source
worldlandscapearchitect.com

Before

After

Images source
worldlandscapearchitect.com

FF COMMUNITY ENGAGEMENT

The concept of a unified sewer shed emerges.

Conversations with community boards and the team's GIS analysis revealed the Red Hook Sewershed as a largely "non-unified" geographic area with a great diversity of built environment typologies and active civic organizations lacking a common goal.

The team began by mapping the zip codes, assembly districts, community boards, and neighborhood boundaries in Brooklyn. When zooming into the Red Hook Sewershed, it was striking how fragmented the area is in terms of political and community organizations. The sewershed spans Community Boards 2, 3, 6, 8, and 9. This initial sense of a non-unified sewershed was further corroborated by a conversation with Community Board 3 in Bedford Stuyvesant. Not being aware that they are (1) part of the Red Hook Sewershed, (2) contribute to the one and only wastewater treatment plant with a maximum capacity, and (3) their connection to stormwater management issues in other locations of the sewershed (as they are on elevated terrain), they told the team to contact Community Board 6 in Red Hook when approached for a meeting to introduce the Fluid Frontiers project. Interim presentations of the research were made to the environmental committees of Community Boards 2, 3, 6 and 8.

Fluid Frontiers seeks to help in engaging private property owners in the implementation of stormwater management strategies. The research identified townhomes as the optimal typology to focus on due to their prevalence within the sewershed and as such the townhouse block as an optimal scale to implement stormwater management interventions. With this in mind, the research team embarked on a comprehensive analysis of community and civic organizations within the sewershed whose scale and constituency matched the optimal stormwater management locations identified (the townhouse and townhouse block). The team compiled a comprehensive list of over 100 community groups, civic organizations, and block associations within the Red Hook Sewershed. All of which have been contacted and will be presented with the team's findings.

The project team has formally presented its findings to:

_Community Boards 2, 3, 6, and 8;

_Downtown Brooklyn Partnership;

_Atlantic Avenue Business Improvement District;

_Boerum Hill Block Association;

_Carroll Gardens Block Association;

_Fifth Avenue Committee.

During the community engagement process, the FF team surveyed residents regarding "trouble spots", or areas of persistent local flooding in their neighborhoods. The team explored many ways in which to prioritize stormwater management intervention. Community identified trouble spots are viewed as visual cues representative of upland runoff impacts. It is proposed that applying the FF methodology of determining stormwater flow from topographic and building typology information, one could delineate the "watershed" of these trouble spots and strategically identify stormwater management intervention.

fluid frontiers

PRINCIPALS:
Zehra Kuz
Jaime Stein

Pratt Institute
School of Architecture
Brooklyn, NY
fluidfrontiers@gmail.com

QUESTIONNAIRE

Where in the sewershed do you live?

______________________ (STREET NAME)

between ______________ (STREET NAME) and ______________ (STREET NAME)

Do you own your property?

Yes / No

Do you experience any flooding <u>during a rain event</u> at / near your address?

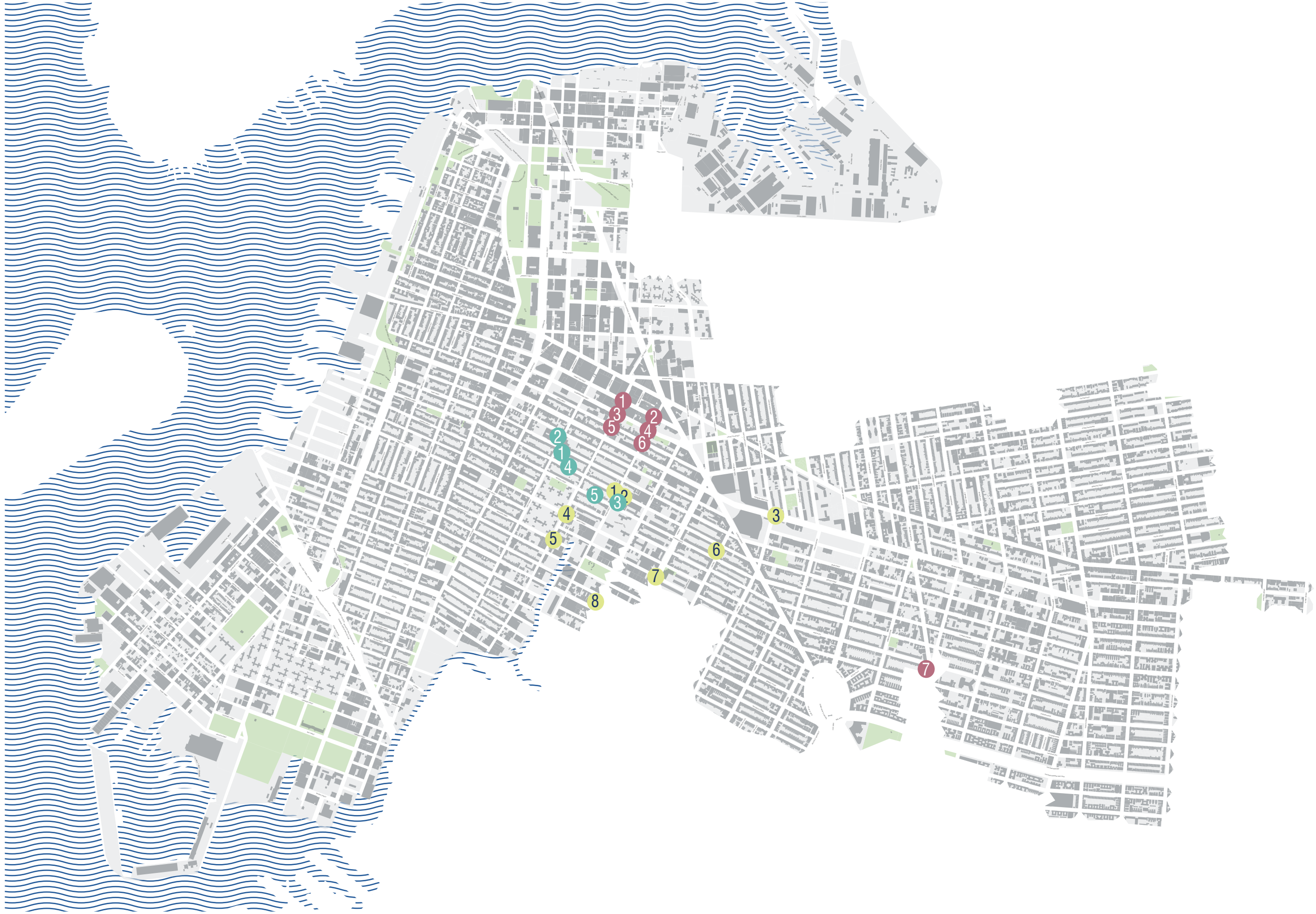
Yes / No

Are you interested in learning about the ways to manage stormwater on your property?

Yes / No

Comments :

10/22/2015
Boerum Hill Association



COMMUNITY IDENTIFIED TROUBLE SPOTS IN RED HOOK SEWERSHED

- Parcels
- Building Footprints
- Parks and Open Space
- Elevation Lines

TROUBLE SPOTS

1 Cross Streets: Bond and Livingston
2 Cross Streets: Nevins and Livingston
3 Cross Streets: Bond and Schermerhorn
4 Cross Streets: Nevins and Schermerhorn
5 Cross Streets: Bond and State
6 Cross Streets: Nevins and State
7 Cross Streets: Washington Av and Park Pl

1 150 Nevins St
2 258 Bergen St
3 212 South Oxford St
4 445 Baltic St
5 190 Butler St
6 76 5th Av
7 336 Butler St
8 273 3rd Av

1 136 Dean St
2 116 Hoyt St
3 256 Bergen St
4 169 Bergen St
5 Wyckoff St between Bond St and Nevins St

DRAWING GENERATED BY FLUID FRONTIERS

FF SYNTHESIS

Status Quo / Existing Condition

New York City is currently in non-attainment of the Clean Water Act and has been since it was signed into law in 1972. Although some of the contributing polluters have been eliminated and pollutants reduced, there is still a long way to go until the goal of fishable and swimmable is met. Part of this challenge is due to increased precipitation due to climate change within the Northeast Region. As a result, stormwater impact in the City is worsening and outpacing the existing water treatment infrastructure. DEP's response lacks the necessary rigor and speed.

Throughout this documentation, the team thoroughly reviewed and referenced the DEP's ongoing efforts and strategies. Understanding DEP's strategies for stormwater management and the existing capacity of the Red Hook sewershed's infrastructure provided the necessary foundation on which to build the research. The team started with the stormwater management goals laid out in the City's 2010 GI Plan.

Getting to 10%

According to DEP representatives in a recent Long Term Control Plan public meeting, 80% of stormwater is currently being captured and treated before it is released to coastal waters citywide.

The DEP's goal, to manage one inch of rainfall over 10% of the combined sewer area is broken down into the following approaches:

_3% impervious area capture by street trees, swales, and sidewalks that are rebuilt or retrofitted with additional controls;

_3% by performance standards on new and expanded developments that would include bioinfiltration, blue and green roofs, subsurface detention/infiltration;

_3% by existing schools, residences, and other development;

_1% by additional areas in open spaces and waterfront areas.

A 1/3rd of these efforts clearly involves engaging the private sector. Without greater engagement of private property owners, DEP will not meet the goals laid out in the GI Plan. To do so requires creative concepts and actionable incentive programs to spark public initiative.

Approach

FF Team was anxious to define the gap that exists between the DEP's projected goals and existing conditions on the ground. FF developed a methodology that can be replicated citywide which prioritizes analysis by sewershed and yields recommendations specific to the unique qualities of each sewershed. The team identified Red Hook as the first location for analysis based on the team's existing relationships with community and civic organizations in the area.

The team was interested in understanding the magnitude of stormwater that is released to the shores untreated after extreme rainfall. The FF team began the investigation from a multi-faceted point of view and used different means to reveal what is specific to the Red Hook Sewershed.

Analysis began by collecting and compiling related information about the geographic area of the Red Hook Sewershed. Analysis was completed in the areas of surface, land use and building type. Composite GIS maps were generated in order to reveal aspects that are otherwise hidden from view. Superimposing several layers of information into a single frame disclosed information that would be only possible by simulation. For example, the topographic information with color coded cardinal orientation, on pages 35 and 52 are good examples of how 3 dimensional information can be collapsed onto a flat surface. The team also isolated different elements to highlight one aspect at a time, to further understand certain relationships or prevailing connectivity among certain building types. In this way, the team examined elevated infrastructure, schools, commercial, residential, and mixed use buildings as well as building size and height. These typologies were further investigated for their ability to mitigate stormwater impact.

Additionally, climate data and developing precipitation trends for the Northeast Region were examined. This analysis revealed the frequency of the one-hundred-year storm is increasing while the volume of precipitation of each hundred-year storm is also increasing (see: graph 2, page 63).

After examining New York City and German stormwater calculation standards, the Fluid Frontiers team generated a unique method – FF Methodology - for calculating the volume of stormwater to be managed to shore up the "gap" between the City's limited infrastructure capacity and impacts of extreme regional rainfall. This gap, a volume of stormwater, which cannot be managed by the sewershed's current infrastructure, was found by comparing the maximum stormwater release rate as mandated by the City against projected extreme rainfall data in the Northeast Region.

Coalescing Findings:
Challenges and Opportunities that are Unique to Red Hook Sewershed

Red Hook Sewershed has been identified by the City as a priority area for water management improvement. The FF team identified several target groups found citywide, that can contribute to stormwater management within the sewershed:

_Public Schools are a good example since they cover large impervious surface area;

_Large scale developments or high rise building impact the environment beyond their footprint: Rapid urban transformation and new large-scale developments are happening not only in Downtown Brooklyn but across the sewershed;

_Elevated transportation infrastructure covers more than 700 miles citywide.

While the above elements are found in the Red Hook Sewershed, the target with the largest footprint and the largest capacity for stormwater management unique to Red Hook sewershed is the townhouse block; as revealed by the team's analysis, the townhouse block constitutes more than 40% of the gross sewershed area.

Application of the FF Calculation Methodology to the common townhouse typology indicates that a townhouse lot has a potential to capture, on average, up to 600 gallons of stormwater, and, together, the gross townhouse area within the Red Hook Sewershed has a potential to manage up to 20 million gallons of stormwater on-site.

This townhouse potential under the FF calculation results in almost 3-times the amount the GI Plan's approach (of managing 1" of rainfall on 10% of impervious area) aims to manage specifically in the Red Hook Sewershed (see page 81). By this estimation, engaging private property (townhouse) owners is crucial, and can significantly mitigate the burden posed by stormwater in the Red Hook Sewershed.

The team has compiled an extensive list of exemplary projects, local case studies, and available strategies that can inspire and inform the 'readers' in the Red Hook Sewershed. The list is focused on innovative green and blue strategies that can be implemented in order to mitigate the stormwater management problems similar to the ones experienced in the Red Hook Sewershed. It also includes various strategies that can be implemented through retrofitting an existing urban context or through alteration of site conditions.

However, implementation of green and blue infrastructure on private property is not without challenges. Technical challenges are many, the team has identified the age of buildings, a complicated permitting process and considerable soft costs as some of the greatest for small property owners. A great majority of the building stock was built nearly a hundred years ago and is still standing. Any retrofit or adaptation requires additional scrutiny between the old and the new (structures). The complicated permitting process and the number of professionals (soft costs) required to realize a project in NYC can be overwhelming especially for the small private property owner.

Solutions will require involvement from both the public and private sectors in order to make advancements. The FF team suggests reforming the permitting process and incentive programs for implementation of Green/Blue infrastructure projects by small private property owners. Additional policy reform, such as property easements may contribute to such larger scale group interventions across lot boundaries. It would be collectively beneficial if neighbors sharing the same townhouse block would embark on a green infrastructure project in a townhouse block scale. This way, the project would be efficient, economically manageable and environmentally effective. This brings up the concept for 'portfolio of projects'.

Lastly, the team recommends revising the City's water rate structure. A separate/standalone stormwater bill could be the basis for estimating Green and Blue infrastructure incentives for private property owners. In order to develop an incentive program for the private property owners, DEP needs to know the stormwater impact on the property in question.

Disseminating Project Results and Ensuring On-going Community Engagement

We hope the final aim is achieved, in part, with the culmination of this book. The research team regards this book as a source of information and inspiration for strategies to be implemented by the readers in Red Hook Sewershed.

Fluid Frontiers believes that the City's green infrastructure goals will only be met by engaging private property owners and inspiring public initiatives. Fluid Frontier's intent is to distribute these findings to the comprehensive network of community and civic organizations within the sewershed. However, additional effort is due on the part of the Community Boards - CB 2, 3, 6, 8, and 9 - who are bound by the Red Hook Sewershed borders and have responsibilities to act upon environmental agenda to work collectively TOWARD A UNIFIED RED HOOK SEWERSHED.

The collected and documented work here is solely based on research conducted January 2015 through March 2016 and relies on field observation, GIS and climate data as well as other cited sources. The team's commitment to the agenda is continuing outside of this documentation, in both academic and professional realms.

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FF TEAM

fluid frontiers

Zehra Kuz

Primary Investigator, Editor

Zehra Kuz is a registered architect in New York and Connecticut and Adjunct Professor with CCE at Pratt Institute, School of Architecture, where she has been teaching since 1993. She is the principal of Oasis Design Lab (registered since 2002), a collaborative office for architecture and engineered design. Prior, she worked for Edward Larrabee Barnes - J.M.Y Lee Architects and later for SOM in New York where she was an active member of Professional Development Committee.

Her approach to design is influenced by reciprocal relationships that exist between buildings, their occupants and the surrounding environment. Similar ideas inspired the exhibition "Autochthonous Architecture in Tyrol" accompanied by a catalog and the three-part symposium 'The Organic Approach to Architecture' which she co-authored with Deborah Gans. A Graham Foundation Grant funded the book under the same title.

Jaime Stein

Primary Investigator, Editor

Jaime Stein is an Academic, Sustainability Consultant and Urban Researcher with more than 15 years experience in advocating for sustainable communities through community engagement, sustainability planning and policy analysis.

Currently, Ms. Stein directs the Sustainable Environmental Systems program at Pratt Institute. Her academic research focuses on systems thinking integrated with community self-determination, green infrastructure and community based resilience. She is Co-Director of Pratt Institute's Recovery, Adaptation, Mitigation and Planning (RAMP) Initiative, is a founding member of the Stormwater Infrastructure Matters (SWIM) Coalition as well as the Collective for Community, Culture and the Environment. Jaime also serves on the NYC DEP's Water Infrastructure Steering Committee and is the Mayoral Appointee for the Atlantic Yards Community Development Corporation.

Jessie Braden

Consultant

Jessie Braden has 17 years of professional GIS experience and is the co-founder and Director of Pratt Institute's Spatial Analysis & Visualization Initiative (SAVI). SAVI uses GIS and data visualization to understand urban communities. She also developed and coordinated SAVI's GIS & Design certificate program. Additionally, Jessie is an Adjunct Assistant Professor at Columbia University GSAPP.

Mete Demiriz

Consultant

Mete Demiriz, Prof. Dr. Ing., teaches at Westfälische Hochschule Gelsenkirchen University of Applied Sciences in the Department of Mechanical Engineering and Facilities Management where he has been the Head of the Research and Development Lab of Sanitary Technologies since 1993. He holds a Doctorate from the Ruhr University Bochum, Faculty of Mechanical Engineering, Institute for Thermo- and Fluid Dynamics. He is specialized in water saving and hygiene, water and waste water hydraulics and water supply of special buildings. His work is widely published.

Yubi Park

Research Assistant, Editor, Graphic Designer

Yubi Park is a designer based in Brooklyn, NY. He is a recent graduate of Pratt Institute, and holds a Bachelor in Architecture. He has previously worked at SHoP Architects PC in New York. Prior, he has worked with Ksestudio on various competitions that have been recognized and exhibited in New York and abroad. With a background in the fine arts and an affinity for graphic design, he is currently involved in an interdisciplinary publication project.

Alberto Silva

Research Assistant

Alberto Silva holds a Bachelor of Architecture from Pratt Institute. He has lived in Caracas, Miami, and New York City, which gave him the opportunity to develop his passion for human-center activities, cultural diversity, and architecture. Currently, he is a Junior Architect at SA-DA Architecture in New York.

Korin Tangtrakul

Research Assistant

Korin Tangtrakul is a recent graduate of Pratt Institute's Urban Environmental Systems Management M.S. Program with the class of 2015. At Pratt, she was a Lead Graduate Assistant for SAVI, and GIS Intern for the Pratt Center for Community Development. She was also a coordinator for SWIM Coalition. Her experience includes leading the Grey to Green campaign with Newtown Creek Alliance. Currently, Korin works with the NY Soil & Water Conservation District as a Stormwater Technician, and is the volunteer and outreach coordinator at Sure We Can, a non-profit recycling center.

Artemis Theodorou

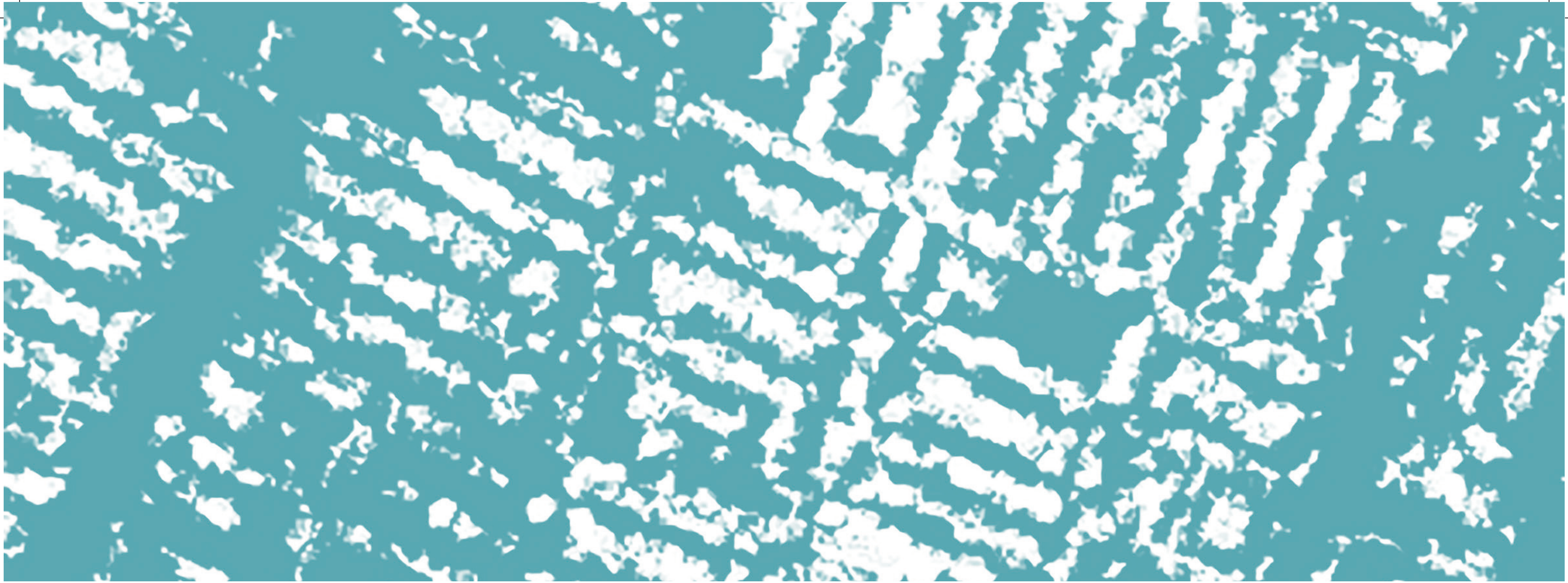
Research Assistant, Graphic Designer

Born and raised in Nicosia, Cyprus, Artemis Theodorou is a designer based in Brooklyn, NY. She holds a Bachelor of Architecture from Pratt Institute. She has worked at Leeser Architects in Brooklyn, NY. Besides architecture, she enjoys cultural theory, photography, cinematography, graphic design and print making.

Meera Vaidya

Research Assistant

Meera Vaidya is a recent graduate from Pratt Institute's M.S. Sustainable Environmental Systems with the class of 2015. Prior, she has complete degrees in Urban Design and Architecture from India and has six years of working experience on wide ranging projects which were certified by LEED India. Currently she is involved in projects with an emphasis on Green Infrastructure and Community Resilience Initiatives.



fluid frontiers

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