Climate Resilience Roadmap

Metropolitan Transportation Authority

April 2024

Contents

Cover image: MTA New York City Transit crews cover sidewalk vents at Borough Hall on the 4 5 Lines in January 2024, in advance of heavy rains.

Letter from the President

This Climate Resilience Roadmap is our response to the growing recognition that climate change poses an existential threat to the future of our transit system and our city. It is the first report by the MTA's new climate planning division, formed last year to coordinate our response to the climate crisis.

Through their work, we are embracing our leadership role in this fight. Last Earth Day, we announced the MTA's commitment to achieve an 85% reduction in our own greenhouse gas emissions by 2040. That effort will build on our legacy of running one of the largest sustainable transportation networks in the world – every year, MTA transit helps New Yorkers save 20 million metric tons of carbon emissions by giving them ways to travel without a private car.

But despite these efforts, the New York region is already experiencing the impact of climate change. That includes worsening storms, increased flooding, and rising temperatures. The MTA's historic infrastructure, much of it built more than a century ago, was not designed to withstand these climate conditions.

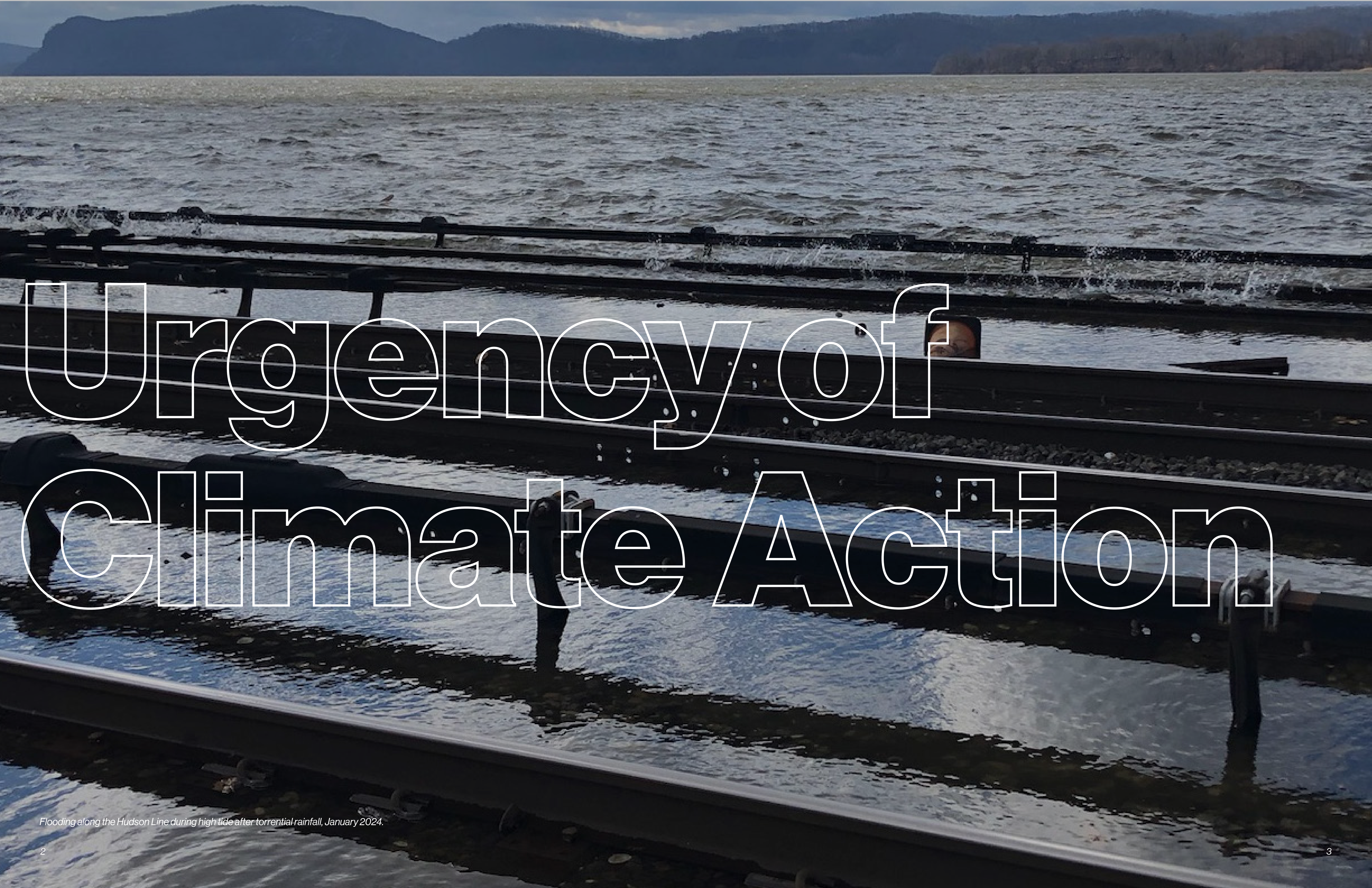
It's a daunting problem. Already, we are taking action wherever we can. Since Superstorm Sandy, we've invested $7.6 billion in repairs and coastal surge protections, including elevating critical infrastructure and securing subway entrances. We've also overhauled the way we prepare for storms, including installing protections at 28 subway stations, sealing more than 8,200 leaks, cleaning and repairing the entire system of subway drain lines, clearing debris from more than 40,000 street grates, and increasing staff to keep the system ready. We've also strengthened our coordination with partners like the New York City Department of Environmental Protection to ensure that we are aligned on necessary preparations, like keeping catch basins clear, when a storm is on the way.

But despite the progress we've made, we must move faster. This report represents a deep dive into understanding our remaining vulnerabilities — not just to one climate hazard but to all of them. It also offers a detailed plan on how we must respond, outlining actions to protect our subways, maintenance yards, bus depots and commuter rail lines from floods, shield our bridges from the impact of high winds, and mitigate the dangers of extreme heat on our infrastructure. We anticipate these projects costing approximately $6 billion over the next 10 years.

Most significantly, it reconceives climate resilience as integral to everything we do. This report charts a path toward integrating climate resilience into the foundation of our work moving forward, enabling us to upgrade and improve our system, while preparing for the weather conditions we know are coming. This is a profound and necessary shift, and it has been made possible thanks to an extraordinary effort across the MTA, spanning virtually every department. By collectively confronting this challenge, and making the necessary investments now, we can ensure that our system continues to thrive and serve New Yorkers into the next century.

Jamie Torres-Springer,
President,
MTA Construction & Development

Urgency of Climate Action



Flooding along the Hudson Line during high tide after torrential rainfall, January 2024.

Climate change is underway

Record-smashing torrential rains disrupt transit service

Light rain began pattering across the New York region at 2 a.m. on September 1, 2021. By morning rush hour, the remnants of Post-Tropical Storm Ida were lashing the region. By the time the storm was over, Ida brought more than 7 inches of total rain, smashed the record for the most single-hour rainfall ever to hit our region, caused $128 million of damage to MTA systems, and took the lives of at least 43 people across the region. Throughout the day, subway pumps removed 4 million gallons of water out of the subway system, above the typical 10 million gallons per day. At the storm's peak, 228,000 gallons of water per hour were pumped out of the subway system.

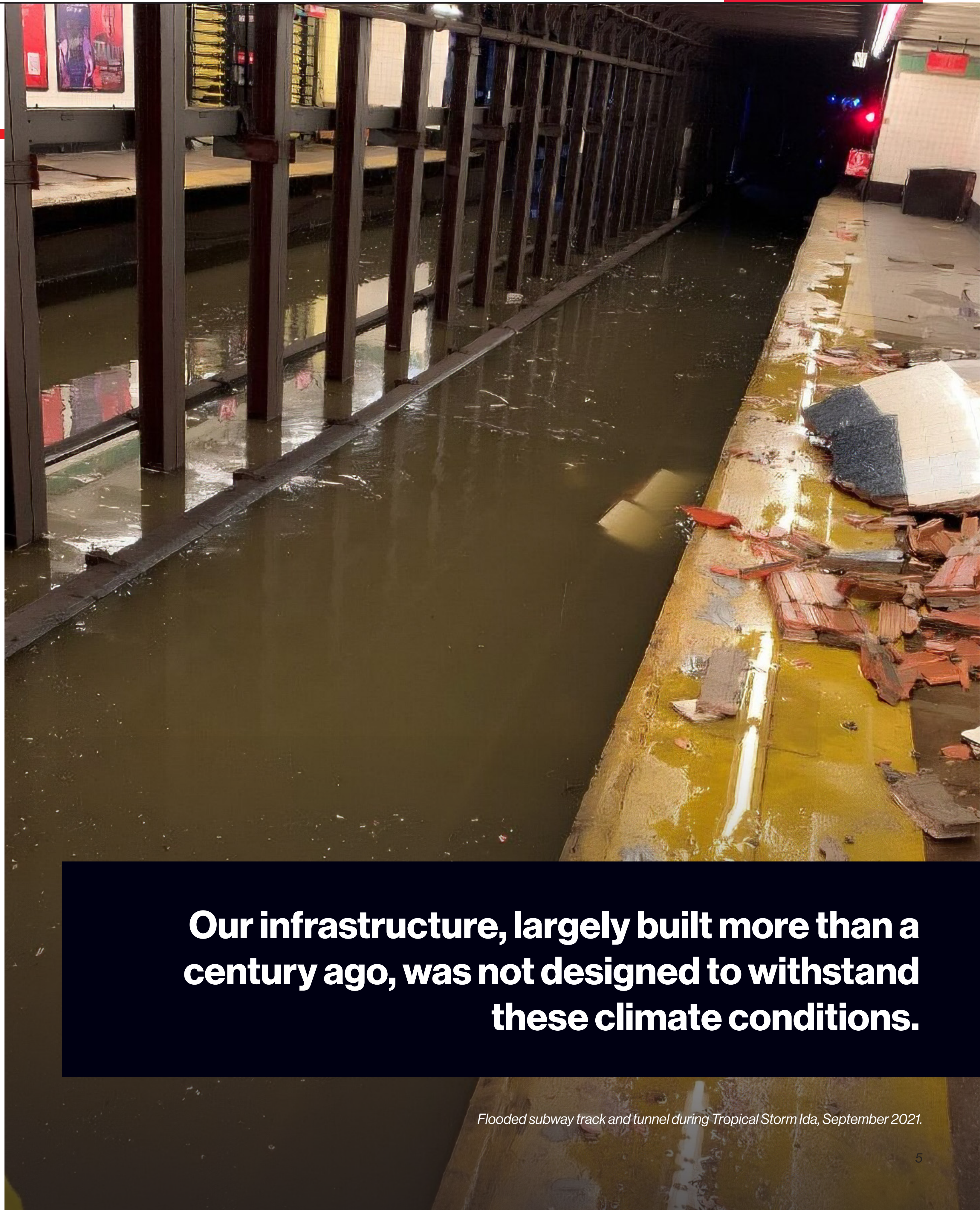
Most storm infrastructure in the city is designed to handle 1.75 inches of rain per hour. Ida easily overwhelmed this threshold. At its peak, the storm dumped 3.45 inches in a single hour, breaking the previous rainfall intensity record of 2.35 inches per hour set in 2006. While Ida was record-setting, it was not an isolated event. Over the past 20 years, there have been 39 debilitating torrential rainfall events that exceeded the capacity of the city's storm sewers. Rainfall of this intensity overwhelms infrastructure and significantly increases the risk of disrupting the weekday commutes of New York's 4.5 million daily subway riders and 440,000 regional railroad riders.

Successful adaptation demands immediate action

Our region needs a functioning transportation network to succeed — for people to reach jobs, go to school, visit family, explore the city, and safely return home. But our infrastructure, largely built more than a century ago, was not designed to withstand these climate conditions.

This is just the beginning. Over the next two decades, climate change projections based on a high-emissions scenario indicate that the New York region will experience more frequent and intense coastal storms, twice the current number of torrential rainfall events, and triple the current number of extreme heat days over 90 degrees. Meanwhile, sea levels are projected to rise approximately 2.5 feet by the 2050s and almost 5 feet by the 2080s.

Without proactive action, our system will struggle to withstand the extreme weather that is coming, resulting in more service delays, prolonged recovery times, and potentially catastrophic damage. MTA infrastructure is particularly important to safeguard because of the vulnerable populations it serves and the low emissions transportation services it provides. Public transportation is one of our best weapons in the fight against climate change — every year, MTA transit avoids at least 20 million metric tons of carbon emissions that would occur if New Yorkers drove their own cars. But some impacts of climate change are already irreversible, and we need to be ready.



Our infrastructure, largely built more than a century ago, was not designed to withstand these climate conditions.

Flooded subway track and tunnel during Tropical Storm Ida, September 2021.

Identifying future risks

The first step is getting smarter. We must target our resources where they are needed most and develop interventions that will have the maximum impact. That is why in 2023, we conducted a systemwide multihazard Climate Vulnerability Assessment to understand the magnitude and timing of climate change impacts on our infrastructure.

The assessment drew on multiple data sets to forecast rising climate threats in the New York City region, including coastal surge, sea level rise, torrential rain, and extreme heat, and then applied that knowledge to identify evolving vulnerabilities across the MTA network through 2080 (see Appendix C for detail).

In addition to tracking climate risks and system assets, the Climate Vulnerability Assessment considers the thousands of climate resilience measures already deployed to protect MTA infrastructure from extreme weather events. These protections include the vast improvements made after Superstorm Sandy and many others installed to protect from torrential rain and extreme heat. Among the primary goals of the Climate Vulnerability Assessment is to identify assets in locations that may still require protections.

Combined with other data, the Climate Vulnerability Assessment will enable us to prioritize the most urgent climate resilience needs and integrate climate impacts into our planning and design for the next Capital Plan and beyond. **Based on the assessment, we have a clearer picture of the climate threats facing MTA systems through 2080.**

The four main climate threats facing the MTA service area are coastal surge, sea level rise, torrential rain, and extreme heat.

Coastal surge

Torrential rain

Sea level rise

Extreme heat

COASTAL SURGE

What it is

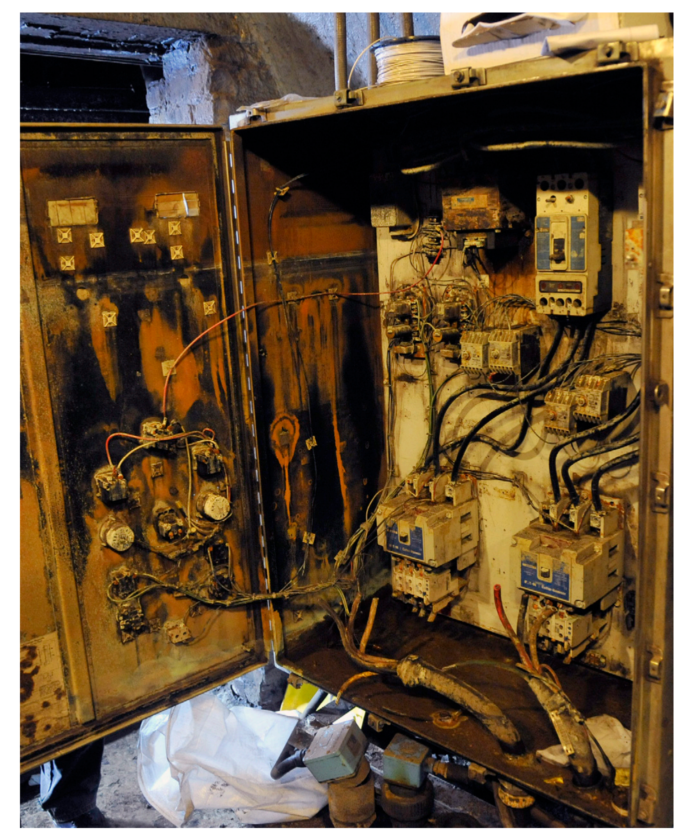
Coastal surge floods occur when hurricane-force winds push ocean water onto land with destructive force and corrosive saltwater.

What's coming

The probability of a severe coastal flood is projected to triple by the 2050s. As sea levels rise, coastal floods will reach further inland compared to historic storm events, putting more areas at risk.

Why it matters

As experienced during Superstorm Sandy, coastal surge floods can inflict devastating, widespread damage with prolonged recovery times. Unlike flooding from torrential rain, flooding from coastal surge is highly corrosive and damaging, and destroys critical equipment and infrastructure, like electrical equipment and track. The effects of saltwater intrusion into facilities and systems can require lengthy and costly repairs, even after service is restored following a coastal storm.



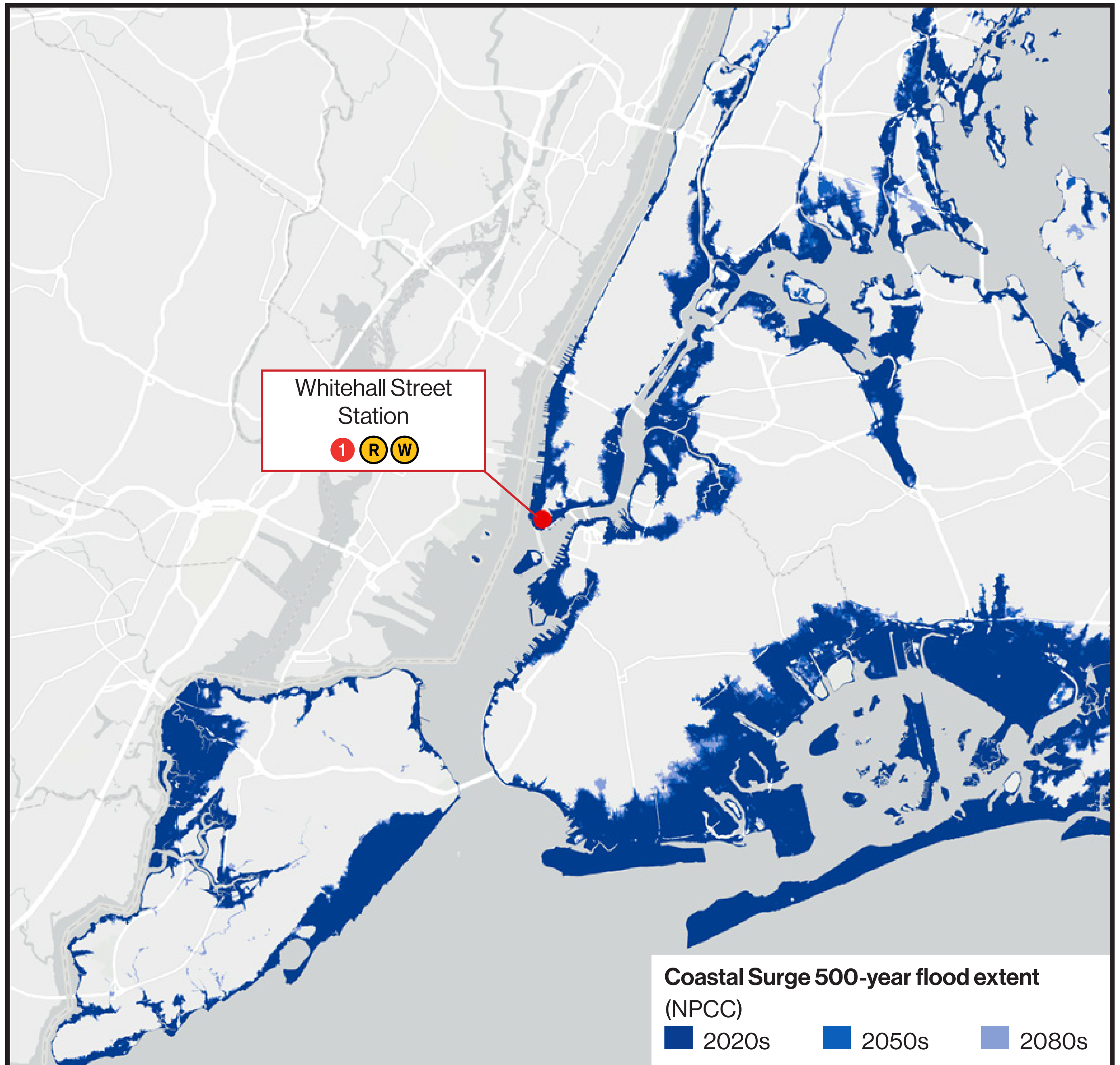
Corroded and damaged electrical circuits following Superstorm Sandy, 2012.

Washout, corrosion, and damage on the Rockaway Line A S, following Superstorm Sandy, 2012.

COASTAL SURGE

Coastal surge flood extents in New York City

Depending on the trajectory and strength of a storm, coastal surge can **impact large portions of low-lying neighborhoods in all five boroughs**. The projected extent of **impacted areas grows over time** due to sea level rise and the increased intensity anticipated from future coastal storms.



Coastal surge flood depths at Whitehall Street Station

As experienced during Superstorm Sandy in October 2012, coastal surge can cause catastrophic damage. Since then, the MTA has installed numerous coastal surge protections. These protections were designed to withstand future coastal surge depths that are increasing due to sea level rise.

SEA LEVEL RISE

What it is

Rising sea levels are caused by the melting of polar and glacial ice, thermal expansion of ocean waters, and vertical land movement. Sea level rise is impacting coastal communities throughout the world, even highly built-up urban areas. New York City is no exception.

What's coming

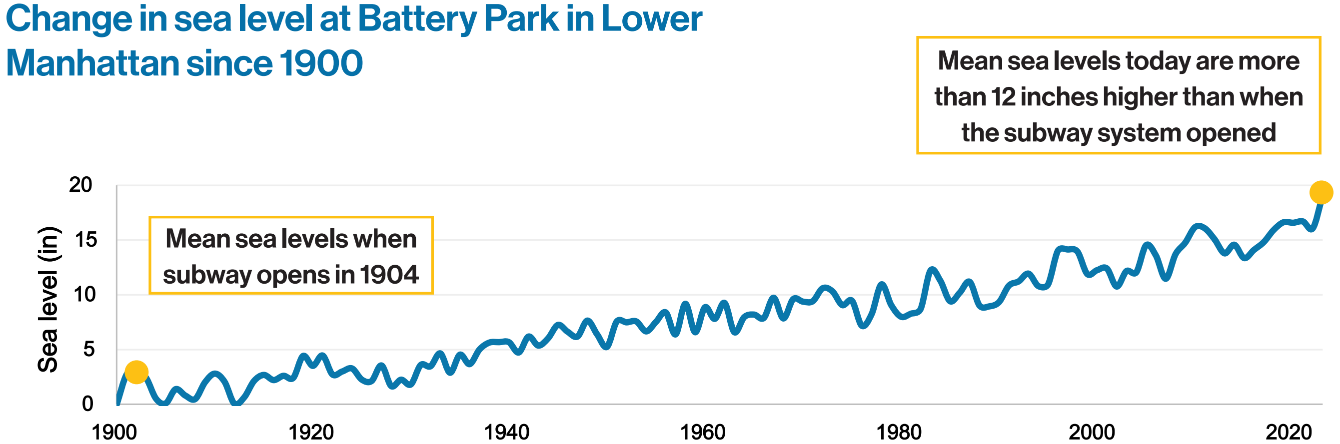
Mean sea levels around the New York City region are projected to rise up to 30 inches by 2050. Rising seas will erode shorelines and cause chronic tidal floods in coastal locations throughout the region, corresponding to monthly lunar high tide cycles. Low-lying coastal areas will experience saltwater inundation more frequently, transitioning from monthly high tide flooding, to daily tidal flooding, to some locations facing permanent inundation.

Why it matters

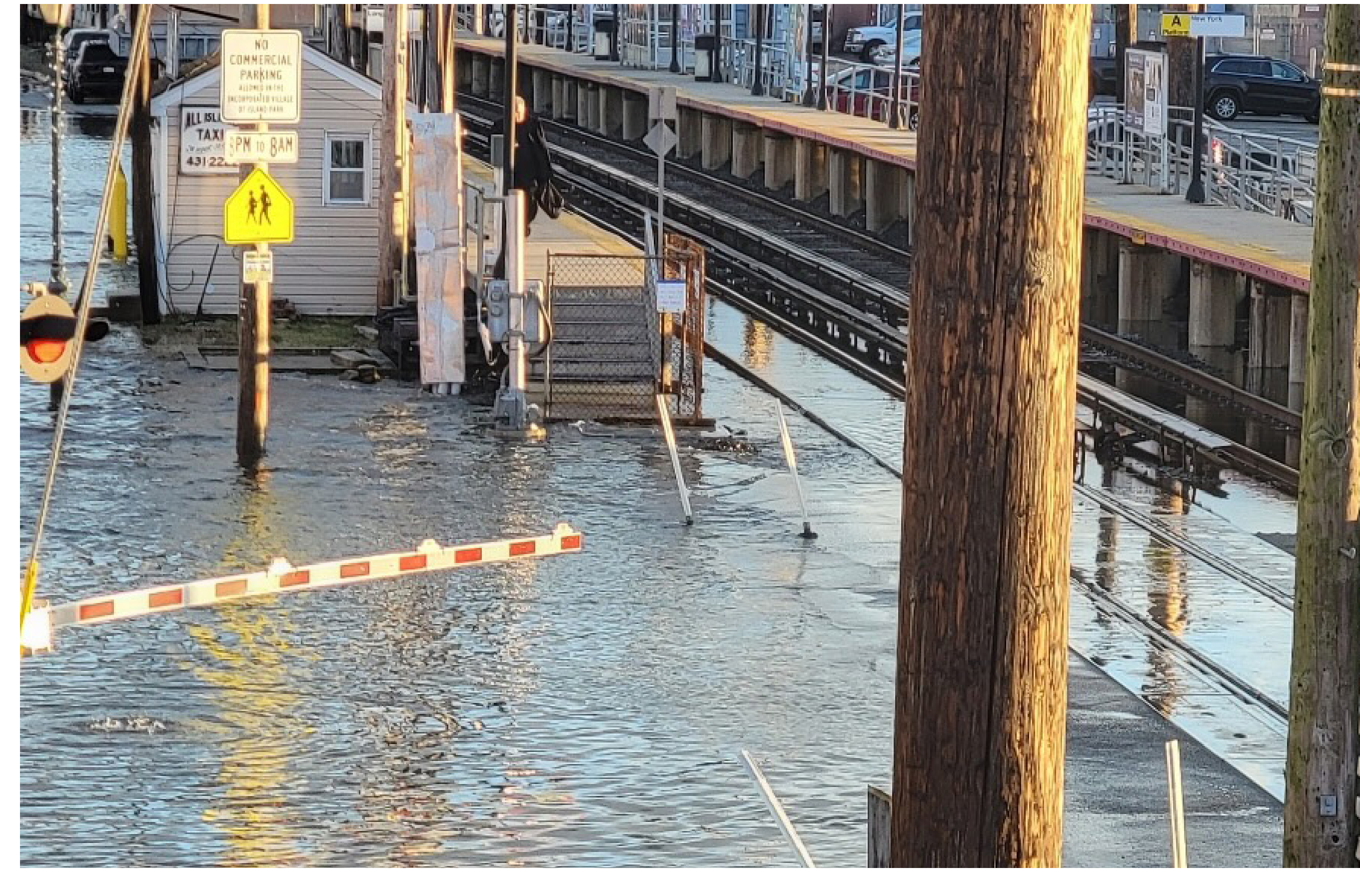
Tidal floods consist of saltwater, which will corrode vulnerable MTA infrastructure with repeated exposure. In addition to coastal areas along the Atlantic Ocean, the East River and New York City Harbor, sea level rise impacts much of the Hudson River because it is a tidal estuary. Therefore, MTA assets adjacent to the Hudson River, including approximately one-sixth of Metro-North's Hudson Line tracks, will be exposed to regular inundation by the 2050s.

Rising sea levels will also raise coastal water tables which will reduce the capacity of local drainage systems during rainstorms, compounding flood challenges.

Change in sea level at Battery Park in Lower Manhattan since 1900



Source: Adapted from New York City Panel on Climate Change, 2015



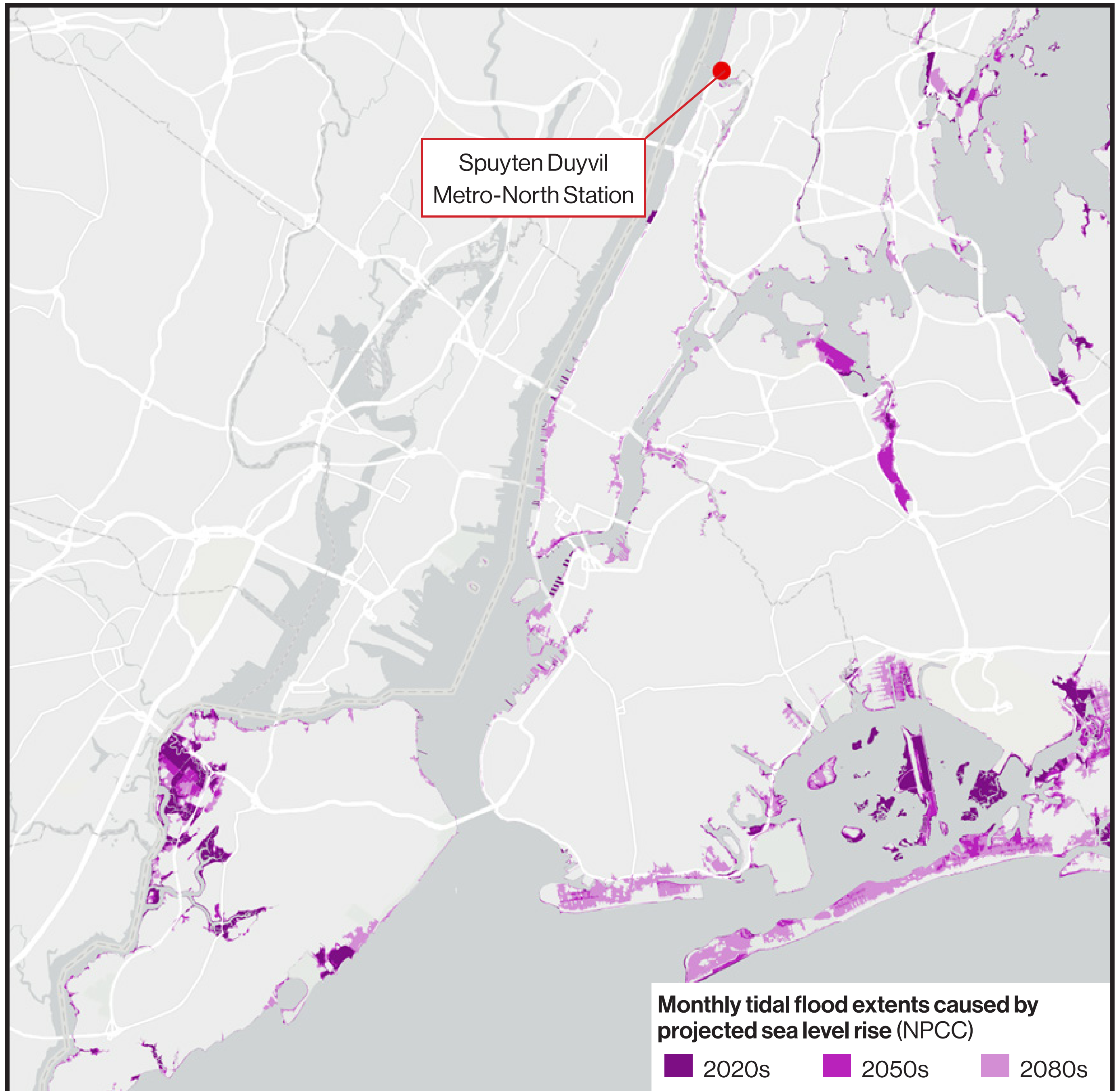
Flooding at Island Park Station on the Long Island Rail Road Long Beach Branch during high tide after a storm, January 2024.

Flooding along the Metro-North Railroad Hudson Line near Garrison Station during high tide after a storm, January 2024.

SEA LEVEL RISE

Tidal flood extents in New York City

As sea level rise continues through the end of the century, **average monthly high tides encroach further into land**, impacting lower elevations first. Monthly tidal floods will impact coastal locations across all five boroughs, extending further inland in locations with filled wetlands.



Sea level rise impacts at Spuyten Duyvil Station

Illustrative rendering showing monthly high tide in the 2030s at Spuyten Duyvil Station with projected 12 inches of sea level rise

Illustrative rendering showing monthly high tide in the 2050s at Spuyten Duyvil Station with projected 30 inches of sea level rise

TORRENTIAL RAIN

What it is

Torrential rainfall events, also known as "cloudbursts," are sudden, heavy downpours where a lot of rain falls in a short amount of time. These events can cause flooding, damage infrastructure, and disrupt transit service.

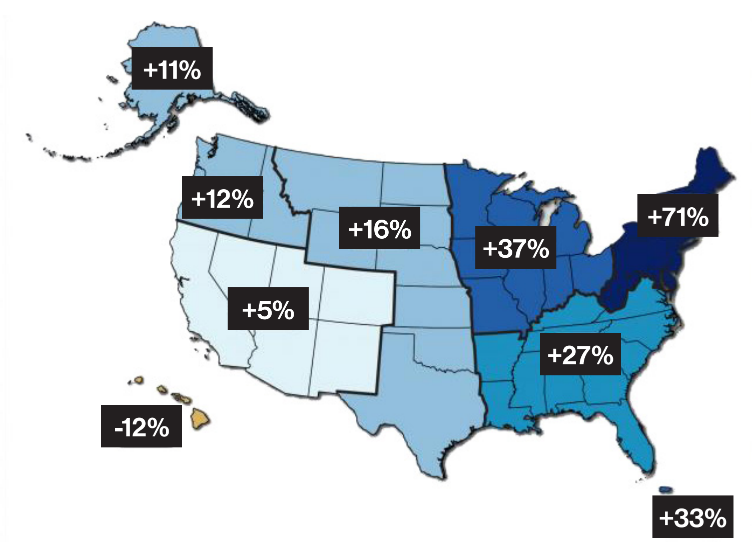
What's coming

By 2050, **the likelihood of torrential rainfall events of 2 inches or greater of total rain accumulation is projected to almost double.**

Why it matters

Unlike coastal surge, floods from torrential rainfall impact inland areas and can be more unpredictable, giving responders less time to prepare. Torrential rain floods generally do not cause the same catastrophic damage to MTA infrastructure as coastal surge floods, but they can still cause prolonged service delays.

Observed change in very heavy precipitation



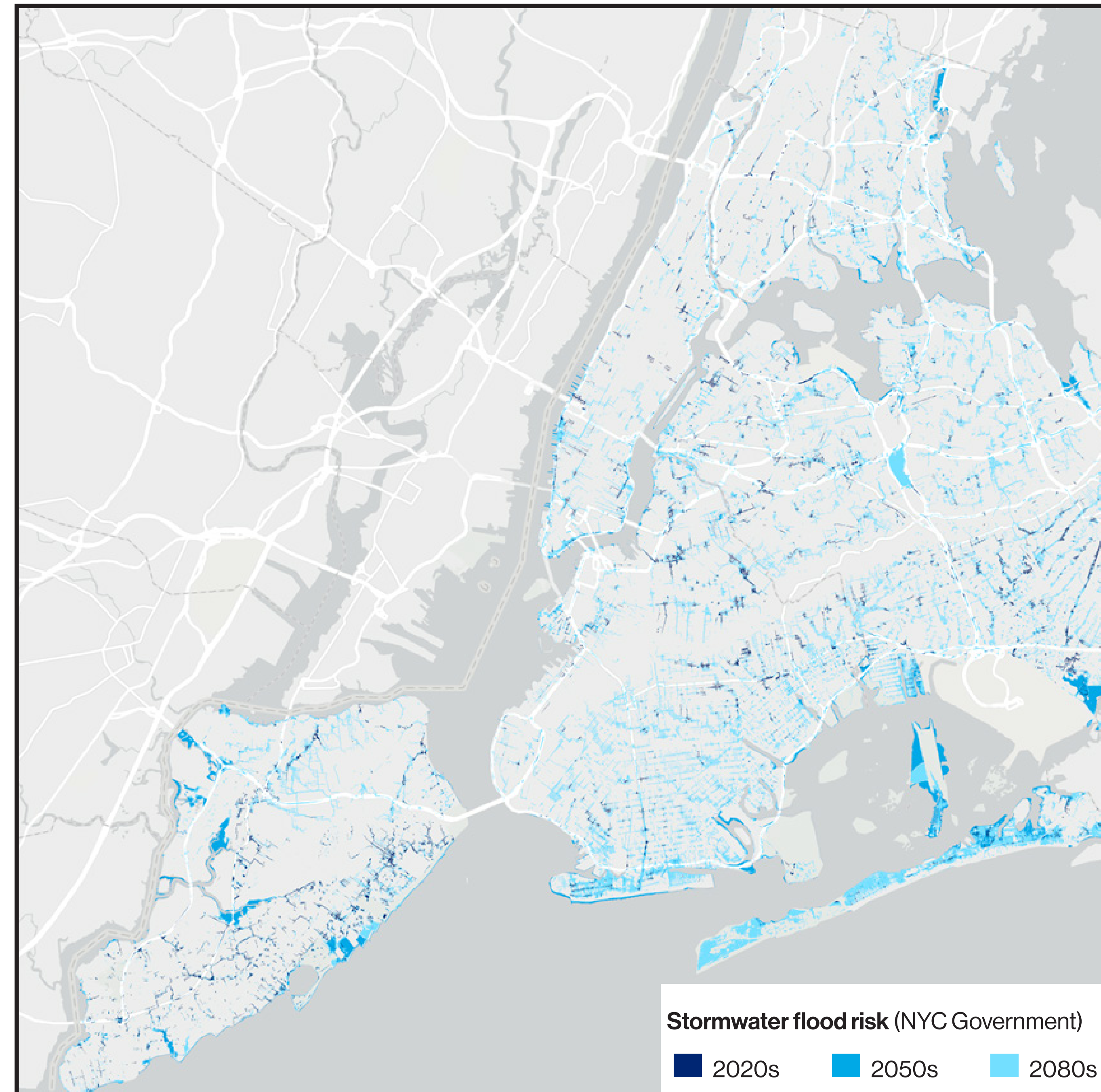
Very heavy precipitation in the Northeast United States has increased 71% between 1958 and 2012.

Source: U.S. Climate Resilience Toolkit, 2015

Torrential rain has increased significantly since the subway first opened in 1904.

Stormwater flood extents in New York City

New York City infrastructure was designed to manage moderate rainfall events that were the norm at the beginning of the 20th century. Extraordinary torrential rainfall events, exacerbated by warmer air and oceans caused by climate change can flood inland and coastal areas by overwhelming streets, sidewalks, and sewers. **Without other places to flow, rapidly increasing stormwater intrudes underground locations**, like the subway and building basements.



EXTREME HEAT

What it is

Heat waves are defined by three or more consecutive days with temperatures above 90 degrees F. Today, the New York City region experiences an average of two heat waves and about 18 total days that exceed 90 degrees F per year.

What's coming

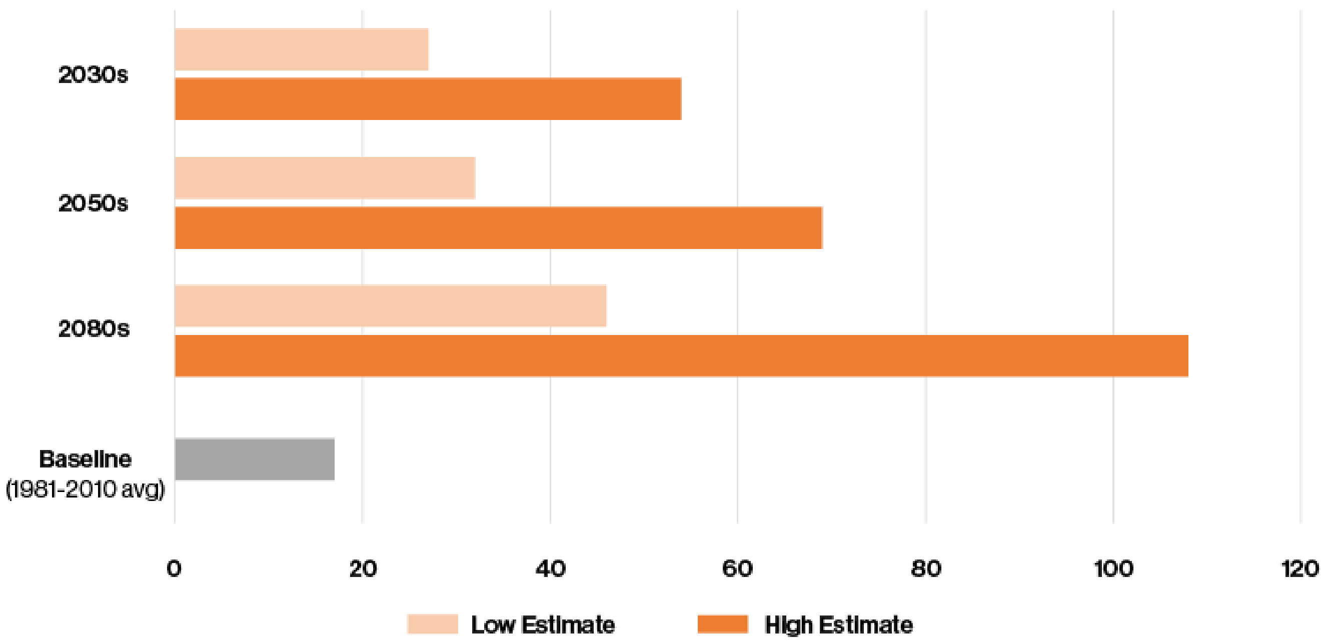
By 2050, heat waves are anticipated to **increase from two events to seven events per year and the number of days with temperatures above 90 degrees F is projected to triple.**

Why it matters

Prolonged exposure to extreme heat can damage equipment and infrastructure, cause service delays, and pose health risks to customers and MTA workers.

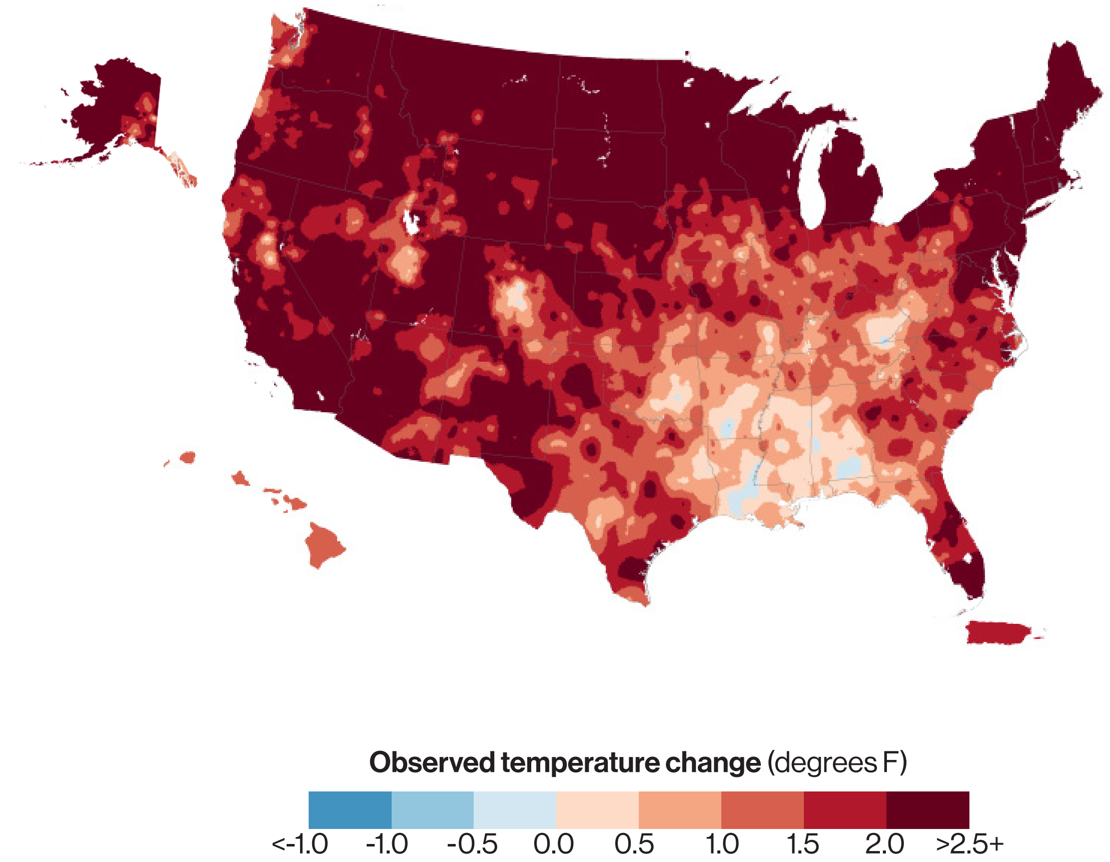
Projected days per year above 90 degrees F in New York City (NPCC)

By the 2050s, we can expect between 30-70 high heat days each year, from the current 18 days



Observed change in annual temperature

Annual average temperatures in the Northeast increased by more than 2 degrees F between 1901-1960 and 2002-2021. The warming trend is projected to continue.



Source: U.S. Global Change Research Program, 2023

The New York City region was reclassified as a humid subtropical climate zone by the National Climate Assessment. This means our climate will be more like Birmingham, Alabama by the year 2050.

Adapting MTA systems to climate change

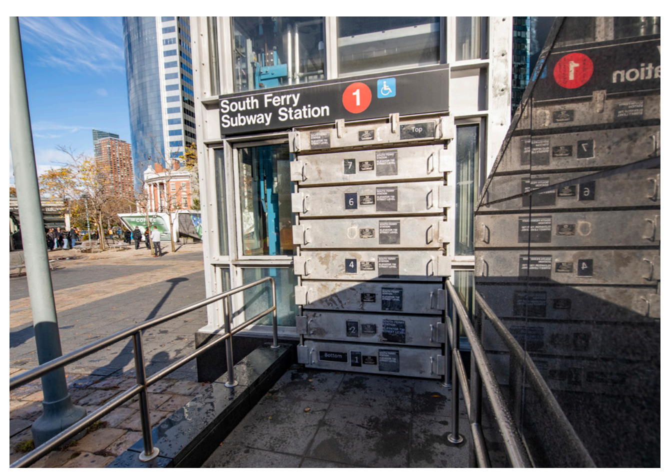
Superstorm Sandy arrived in New York at high tide on October 29, 2012, bringing a 14-foot storm surge. While MTA's operating agencies prepared for the storm, including fully terminating subway passenger service, Sandy's surge was more severe than expected and caused widespread damage across the region. After the storm passed and inspections could begin, the damage to MTA infrastructure became apparent – nine under-river tunnels and multiple yards were inundated, tracks were washed out, and corrosive saltwater had come in contact with sensitive electrical equipment. While service was able to resume quickly – within five days, 80% of service had resumed – the corrosive saltwater caused significant long-term damage. In total, the MTA sustained $5 billion in damage.

Superstorm Sandy impacts within New York City covered 17% (51 square miles) of the city's total land mass, and effects were felt within and outside of the flood zone due to the impacts to critical transportation, electrical, and water infrastructure.

In the years since Sandy, the MTA's resilience efforts have been focused on preventing this much damage and disruption in the event of another storm surge event. Systematic surveys of where water could enter the subway system, raising critical infrastructure, and extensive preparedness efforts ensure that we will be much more prepared for a storm even stronger than Sandy.

Underground stations were particularly impacted by coastal surge during Superstorm Sandy, and in response, the MTA installed state-of-the-art surge protections at over 130 flood-vulnerable station entrances--stairs, escalators, elevators--across 31 underground stations to reduce risk. The MTA also invested in protections for storm surge-vulnerable line equipment and traction power assets across the subway system, such as pump rooms, fan plants, substations, and circuit breaker houses. Additionally, Coney Island Yard and 207 Street Yard received significant damage during Sandy and have since been the focus of extensive investments in coastal surge protections.

Elevating cables and sensitive equipment above the coastal surge floodplain, Coney Island Yard, October 2019.



Testing of coastal surge flood logs installed post-Sandy at the South Ferry Station 1 elevator.

Over the past several years, the MTA has installed entirely new classes of infrastructure to protect its systems from extreme weather caused by climate change. The most significant of these investments have occurred under the Fix and Fortify program. Under this program, **the MTA installed nearly 4,000 coastal surge protections under a systemwide $7.6B program for repair and resilience** of assets that were damaged during Superstorm Sandy, including:

- Entrances protected at underground subway stations
- Subway tunnel portals outfitted with flood logs
- Bus depots protected with flood logs
- Subway yards with perimeter flood protection or external wall hardening
- Railroad substations elevated above the coastal surge floodplain
- Elevated platforms to protect critical railroad signals and communications equipment
- Massive marine doors for the Hugh L. Carey and Queens Midtown tunnels

*In December 2022, the MTA unveiled its **new, storm-resilient Clifton Car Maintenance Shop on Staten Island.** Clifton was rebuilt post-Sandy to sustain SLOSH Category 2 hurricane water and wind pressures, plus an additional three feet surge elevation, and prevent water intrusion.*

Preparing for multiple climate risks

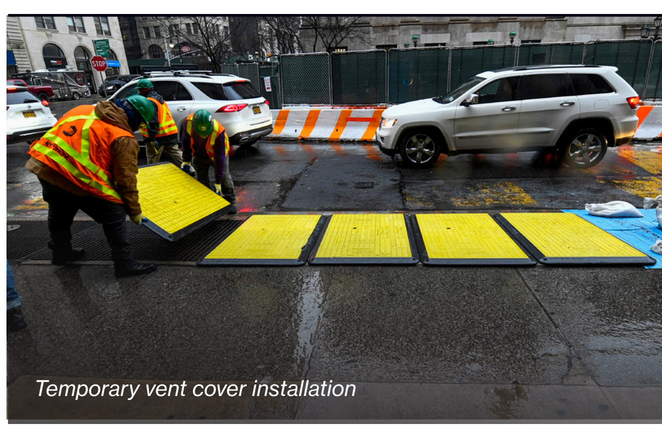
In addition to the coastal surge protections installed after Superstorm Sandy, we are preparing for other risks like torrential rain. By the time Tropical Storm Ophelia's torrential rain hit the region on September 29, 2023, releasing up to 3 inches per hour in some parts of the region, 45% of subway trips still ran on time — and service was fully restored by the next day. That's because over the past 15 years, we've overhauled our approach to torrential rainfall preparation:

Elevated subway vent

Since 2007, we have invested $87.7 million in subway capital projects, including elevated vents that keep stormwater runoff from entering the subway.

NYCDEP catch basin cleaning

We have increased our coordination with the New York City Department of Environmental Protection (NYCDEP), prioritizing tactical actions such as cleaning catch basins and sewer siphons before storms so they can function during storms.



Temporary vent cover installation

We have updated emergency management protocols for torrential rain, including installing temporary vent covers and completing drain cleaning (for more details on the MTA's operational response to extreme weather events, see Appendix B).

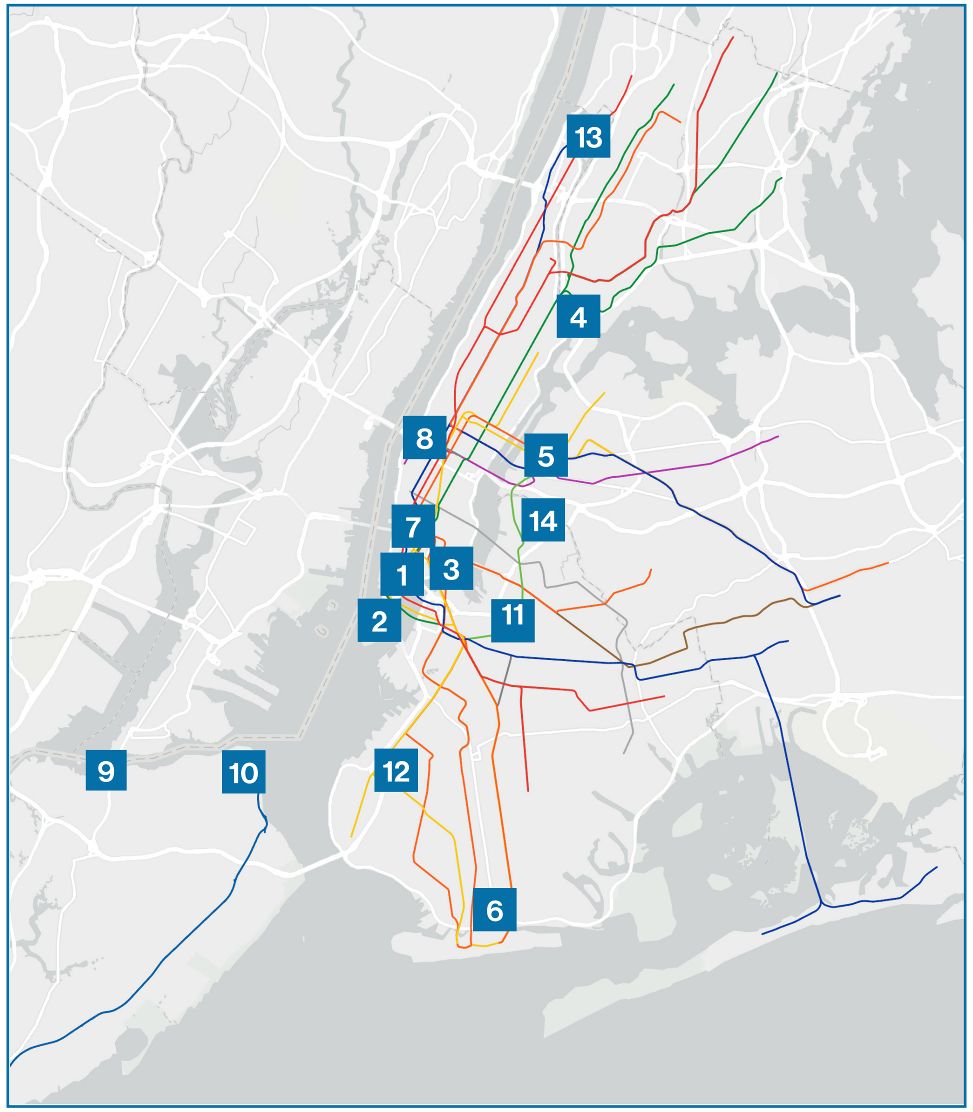
Building on our progress

Going forward, we will remain focused on addressing the multiple climate risks that will become more intense and frequent in the future. We will protect the system to minimize service impacts caused by extreme weather and to speed recovery when extreme events occur.

The following pages contain examples of the thousands of climate resilience measures already installed throughout the MTA system. Even with this new infrastructure, the magnitude of risks posed by climate change means that we must continue preparing for the future.

Coastal surge	Torrential rain
Sea level rise	Extreme heat
Wind	Winter weather

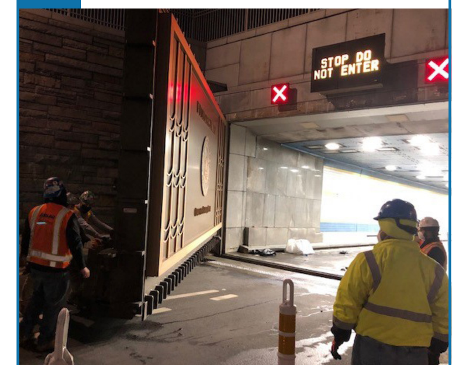
Examples of existing climate resilience infrastructure across subways, bus depots and tunnels



1 Flood Door

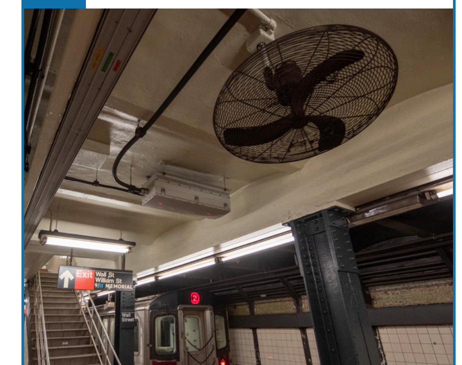
South Ferry 1 Station

2 Flood Door



Hugh L. Carey Tunnel

3 Platform Fan



Wall St 2 3 Station

4 Deployable Vent Mechanical Closure Device

138 St Grand Concourse 4 5 Station

5 Flex-Gate

Vernon-Jackson 7 Station

6 Perimeter Flood Wall

Coney Island Yard

7 Raised Vent

Chambers St 1 2 3 Station

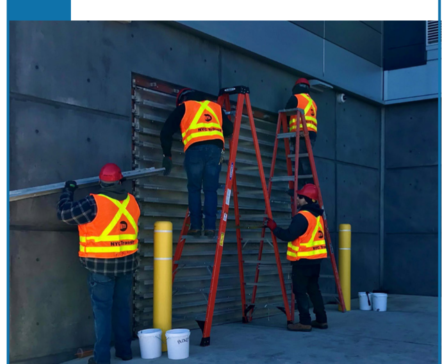
8 Wind and Debris Screen

Michael J. Quill Bus Depot

9 Elevated Electrical Equipment

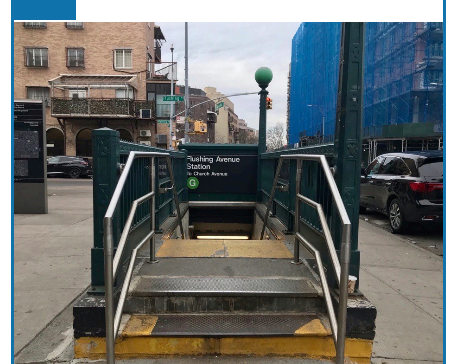
Castleton Bus Depot

10 Flood Log Barrier



Clifton Shop

11 Elevated Top Step



Flushing Av G Station

12 Switch Heater

38 St Yard

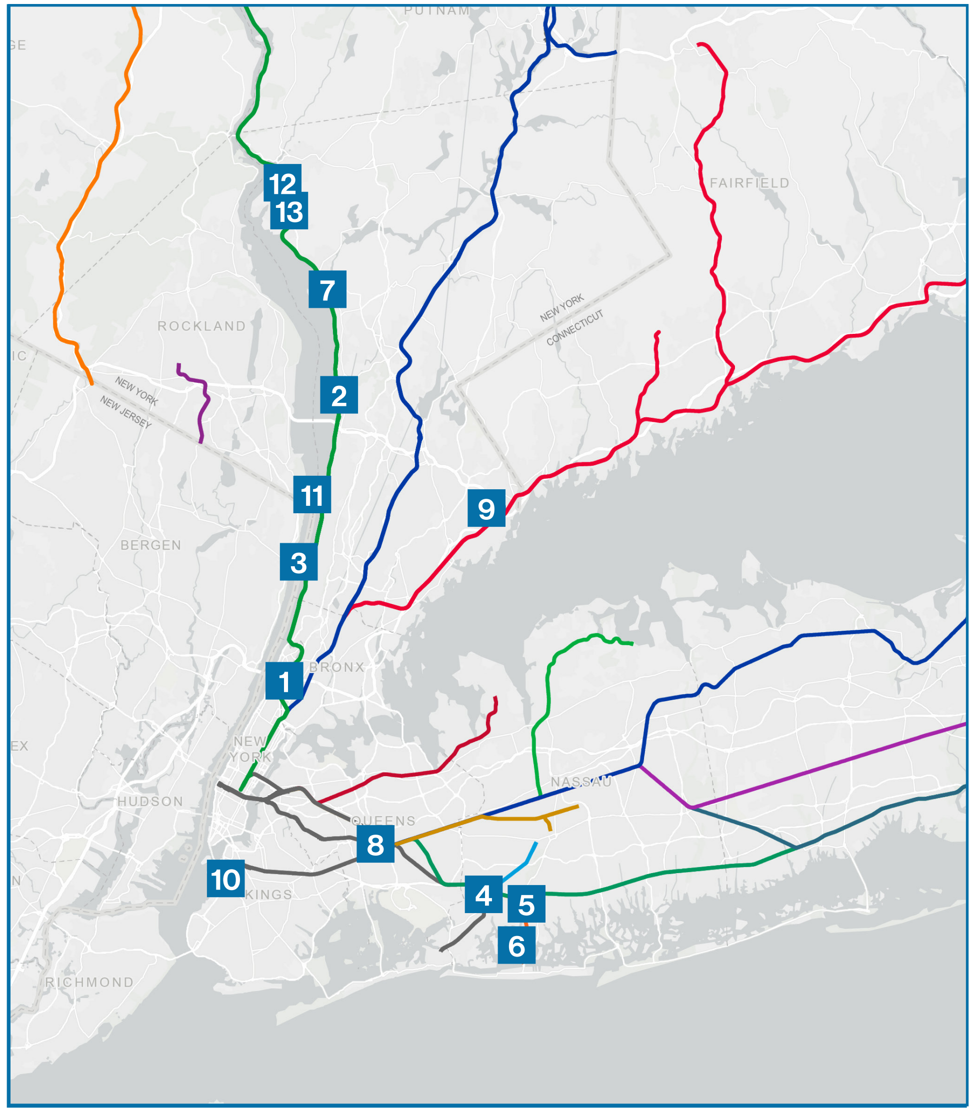
13 Perimeter Flood Wall

207 St Yard

14 Watertight Structure and Marine Doors

North 7 St Fan Plant

Examples of existing climate resilience infrastructure on Long Island Rail Road and Metro-North Railroad



1 Elevated Circuit Breaker House

Harlem Lift Bridge

2 Elevated Substation

Tarrytown

3 Elevated Equipment and Platform

Hudson Line

4 Elevated Equipment

Island Park Station

5 Elevated Substation

Long Beach Branch

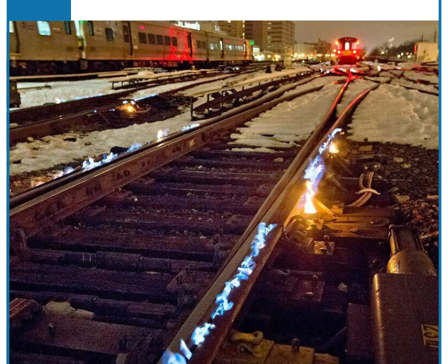
6 Cable Hardening

Long Beach Branch

7 Cable Hardening

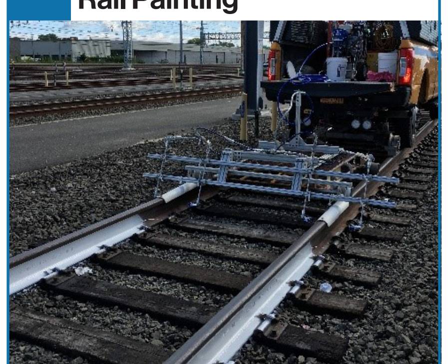
Hudson Line

8 Switch Heater



Jamaica

9 Heat Reflective Rail Painting

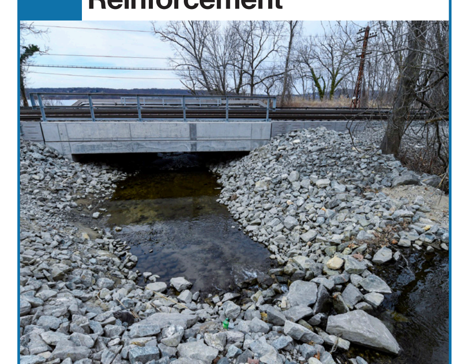


Rye

10 Raised Street-Level Air Grate

Atlantic Avenue Tunnel

11 Culvert Structural Reinforcement



Dobbs Ferry

12 Retaining Wall

Hudson Line

13 Seawall

Hudson Line

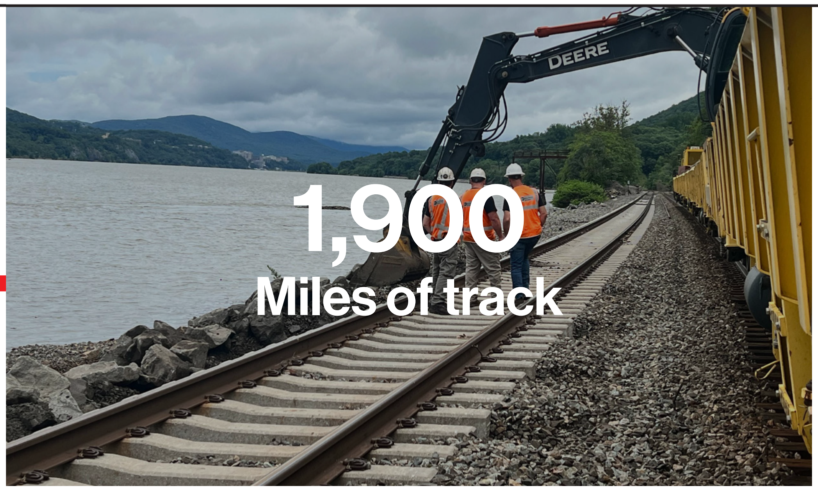
Setting goals to boost climate resilience across our vast system

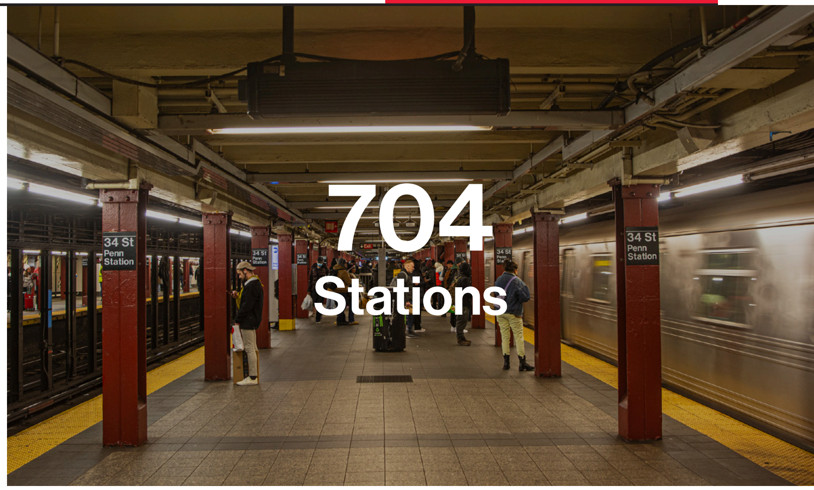
Based on the Climate Vulnerability Assessment and other on-the-ground data, we are proposing 10 climate resilience goals to continue reducing climate risk exposure across the MTA system. In advancing these goals, we intend to maintain the reliability of transit services in the face of extreme weather through actions that mitigate damage and disruption, and allow us to recover quickly after consequential events.

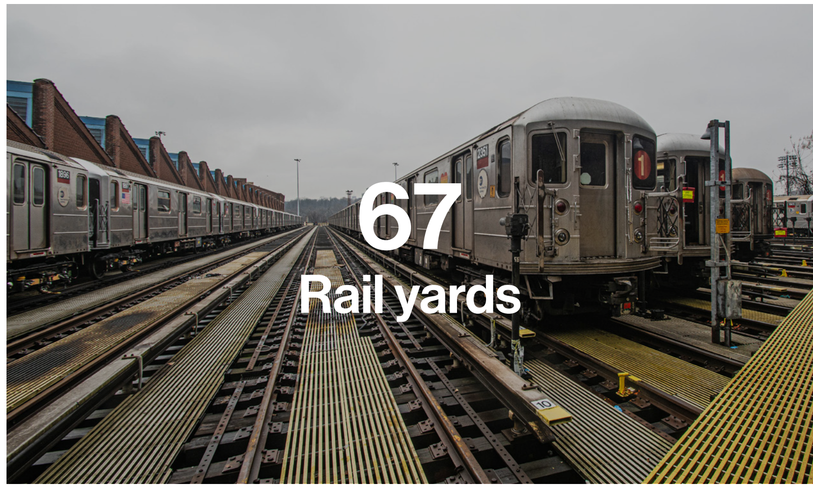
Each goal addresses a specific asset group and the climate vulnerabilities assets face now or in the future. Along with descriptions of specific strategies and actions we plan to undertake, each goal includes an estimated cost range (<$50 million, $50-$250 million, $250-500 million, $500 million-$1 billion, or >$1 billion). Estimates are informed by recent and historical costs for similar projects, including mitigations installed after Superstorm Sandy and other extreme weather events.

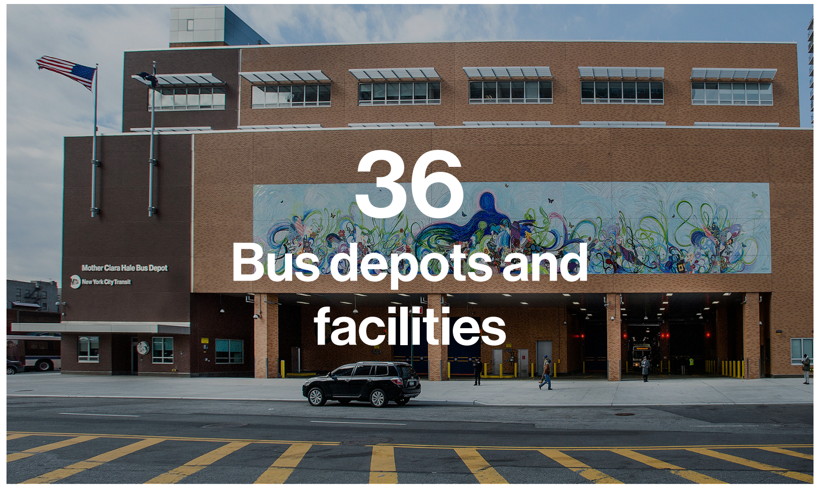
The estimated total cost of all 10 climate resilience goals is approximately $6 billion over the coming 10 years. This estimate will vary depending on design alternatives, project timing, efficiencies with other work, and continually evolving climate hazard projections. Design and implementation of the actions will depend on funding received from the next 5-Year Capital Plan (2025-2029).

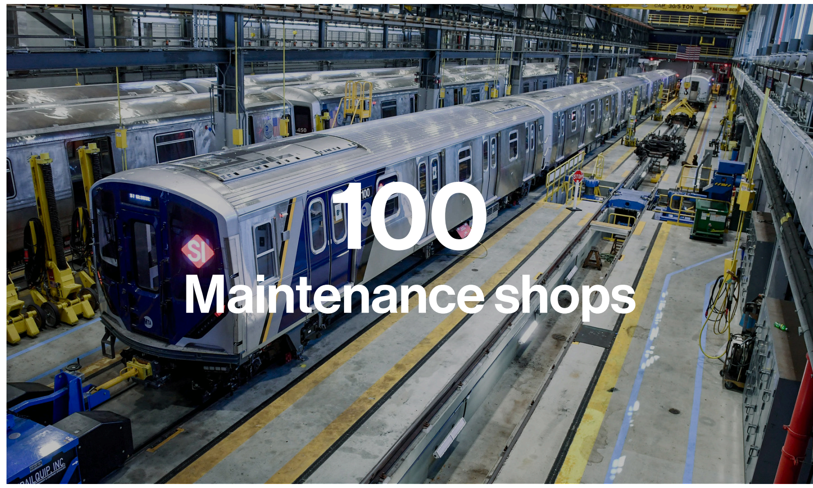
1. **Shield subway stations and tunnels from stormwater**
2. **Protect subway yards from flooding**
3. **Protect open subway infrastructure from flooding**
4. **Safeguard bus depots from flooding**
5. **Manage floods on city streets**
6. **Mitigate Long Island Rail Road flooding**
7. **Reduce Metro-North Railroad flooding**
8. **Expand underground air circulation and cooling**
9. **Protect outdoor infrastructure from heat**
10. **Address heat and wind impacts on bridges**

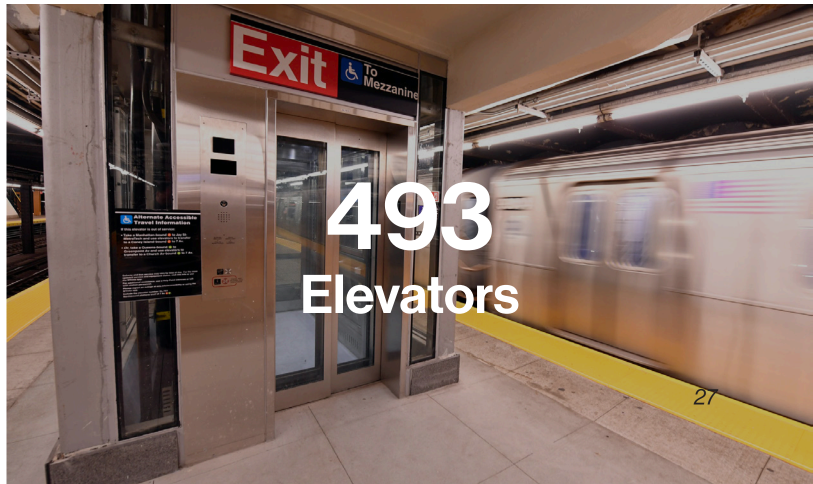












The Plan

Goal 1: Shield subway stations and tunnels from stormwater

Challenges

At its inception, the subway system was designed to be permeable and move water, whether groundwater or rainfall, through stations and tunnels via a vast network of pumping infrastructure and drains that discharge to New York City's sewer system. But it was only designed to handle up to 1.75 inches per hour, an amount appropriate for the time and equivalent to the city's sewer system capacity.

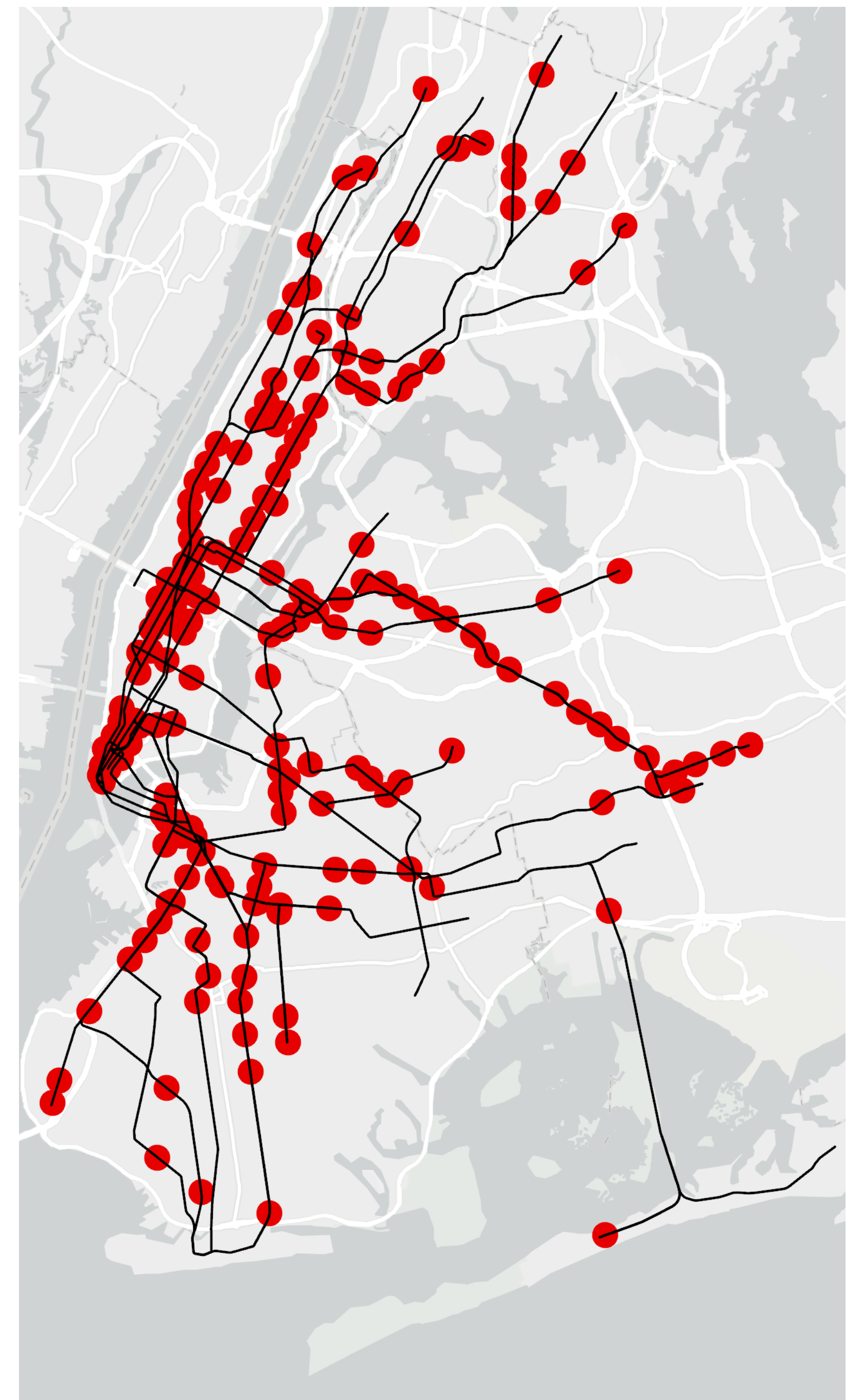
In the last two decades, storms have been exceeding that threshold, with some years experiencing multiple torrential rainfall events. During Tropical Storm Ida in 2021, rain fell at almost twice this rate: 3.45 inches per hour at its peak.

Underground stations and tunnels are particularly vulnerable to this increase: During torrential rain events, excessive stormwater can overtop from the street onto sidewalks, down subway station stairs, and through subway vents onto station platforms and into tunnels. Stormwater runoff is especially problematic where sidewalk curbs are less than the standard 7 inches in height set by the NYC Department of Transportation. Additionally, unlike coastal storms which have a longer period of warning and impact more predicable locations along coasts, torrential rain can occur with very little warning at any location across the city. This makes deployable stormwater protections impractical.

These conditions – system permeability, sewer constraints, low curbs and limited sidewalk space, system ventilation and customer access needs, and unpredictability of torrential rain – make shielding the subway from stormwater flooding challenging.

Since 2007, at least 200 subway stations have been impacted by one or more torrential rain events. Impacts range in severity, from small puddles of water on station platforms to flooding conditions on tracks and in tunnels.

Subway pumping infrastructure can keep up with some torrential rain. But during some events it can become constrained. This is especially true when overburdened city sewers backup. Backups occur when more water than the sewer system can handle gushes through manholes. This backup water can enter tunnels and tracks, further exacerbating flooding.



Subway station impacted by torrential rain since 2007

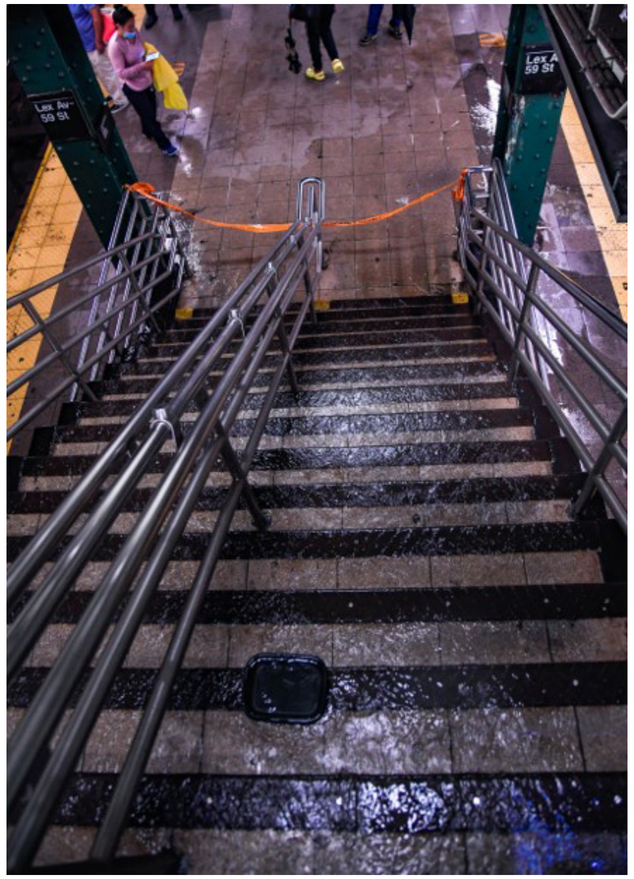
Subway service line

Over the past 20 years, there have been 34 individual torrential rainfall events that have exceeded 1.75 inches per hour in intensity.

Since 2007, at least 200 stations have been impacted by one or more of these torrential rain events.

Excessive stormwater that collects on the street and sidewalks can flow into subway street stairs and vents. During particularly torrential events, this can cause mezzanine, platform, and even track flooding.

Stormwater falling through street vents in the Canal St Station on the R W Lines during Tropical Strom Ophelia, September 2023.



Stormwater flows down stairs in the Lexington Av-59 St Station on the N R W Lines during Tropical Storm Ida, September 2021.

Unlike coastal storms like Superstorm Sandy, torrential rainfall events are not predicted far in advance and their impacts are highly localized, which limits the opportunity for pre-event preparation. That means temporary solutions like deployable flood doors and vent mechanical closure devices are not as effective as structural redesigns that prevent stormwater runoff from entering subway station stairs, vents, and other openings whenever storms come.

Flooding in tunnels during Tropical Storm Ophelia, September 2023.

Subway service delays occur when stormwater floods the track area and rises to a "top of rail" level that causes dangerous electrical safety conditions. Subway service is shut down until the water is removed.

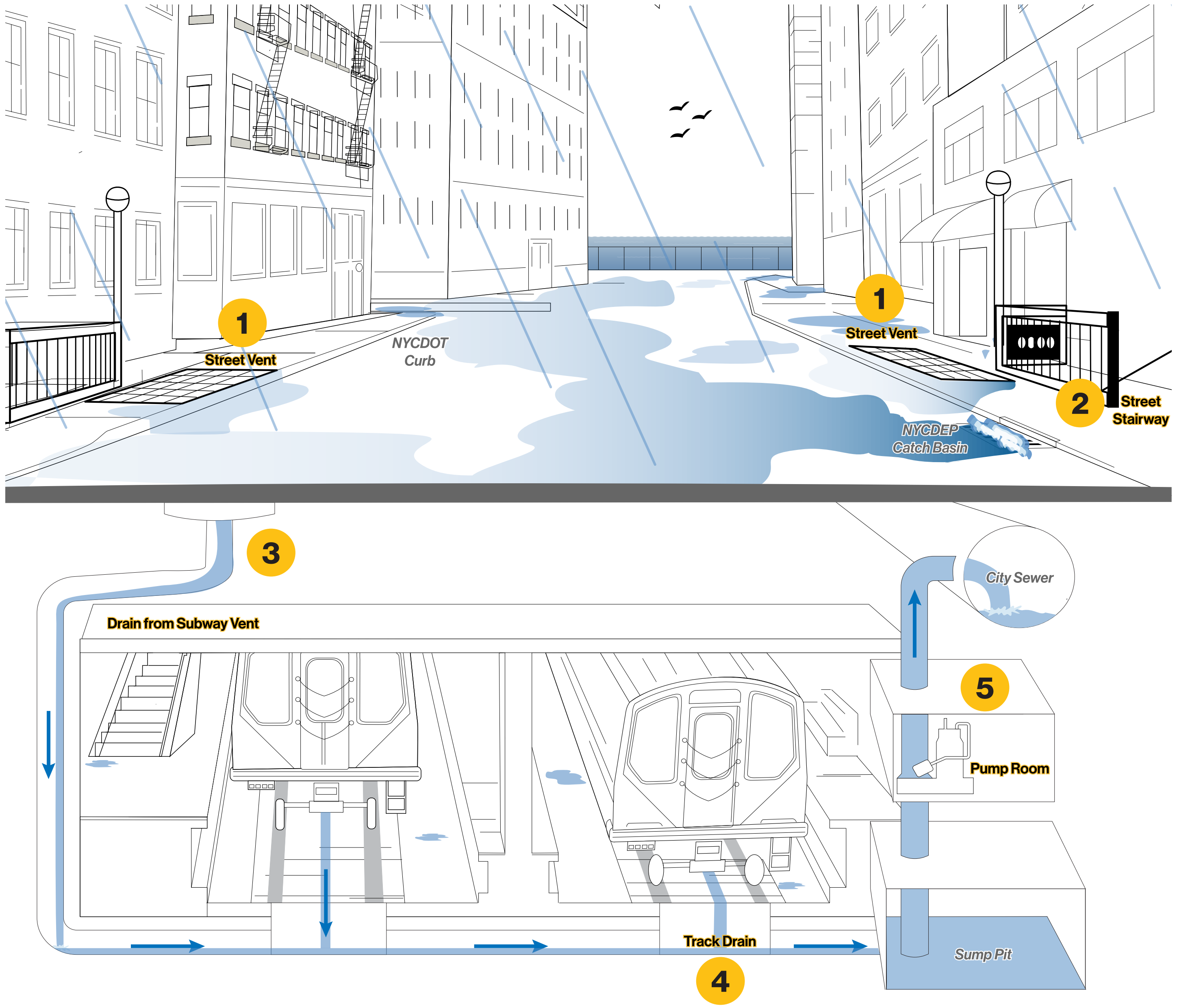
In addition to the major inconvenience caused for millions of customers, **flooding from torrential rain can result in costly operational repairs and infrastructure replacements** from damage to track and electrical equipment. Stormwater floods in tunnels can also cause electrical failures that create unsafe conditions for employees and customers.

Flooded and obstructed track on the Crosstown G Line during Tropical Storm Ophelia, September 2023.

The following pages illustrate how subway drainage works, why torrential rain is impactful, and how MTA's street-level protections help.

Subway drainage during normal rainfall

An extensive drainage system is in place to manage normal rainfall that enters the subway system though openings like **street vents (1)** and **street stairways (2)**.

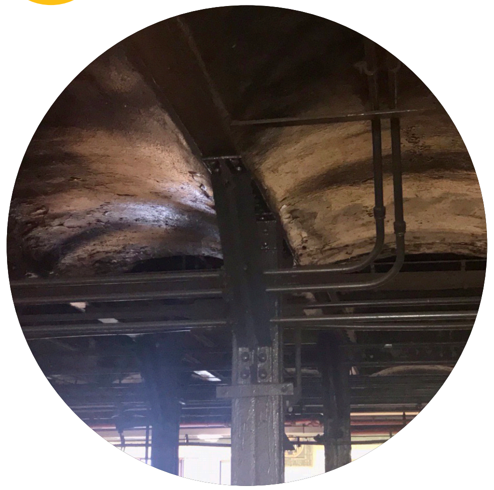


This system includes drain lines, **vent drains (3)**, **track drains (4)**, sump pits, and **pump rooms (5)**. It removes stormwater that enters by discharging to the city's sewer system. Stormwater then travels to a nearby wastewater resource recovery facility.

1 Street vents

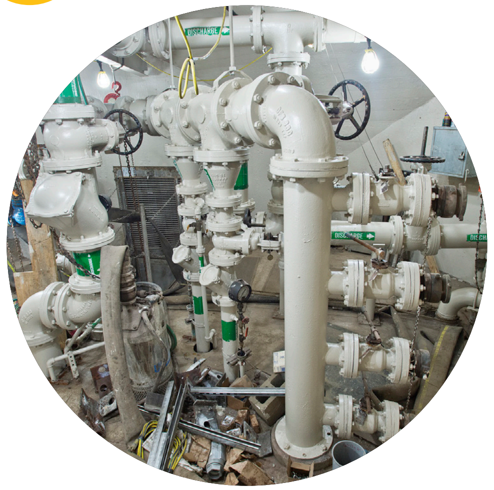
2 Street stairway

3 Vent drain



4 Track drain

5 Pump room

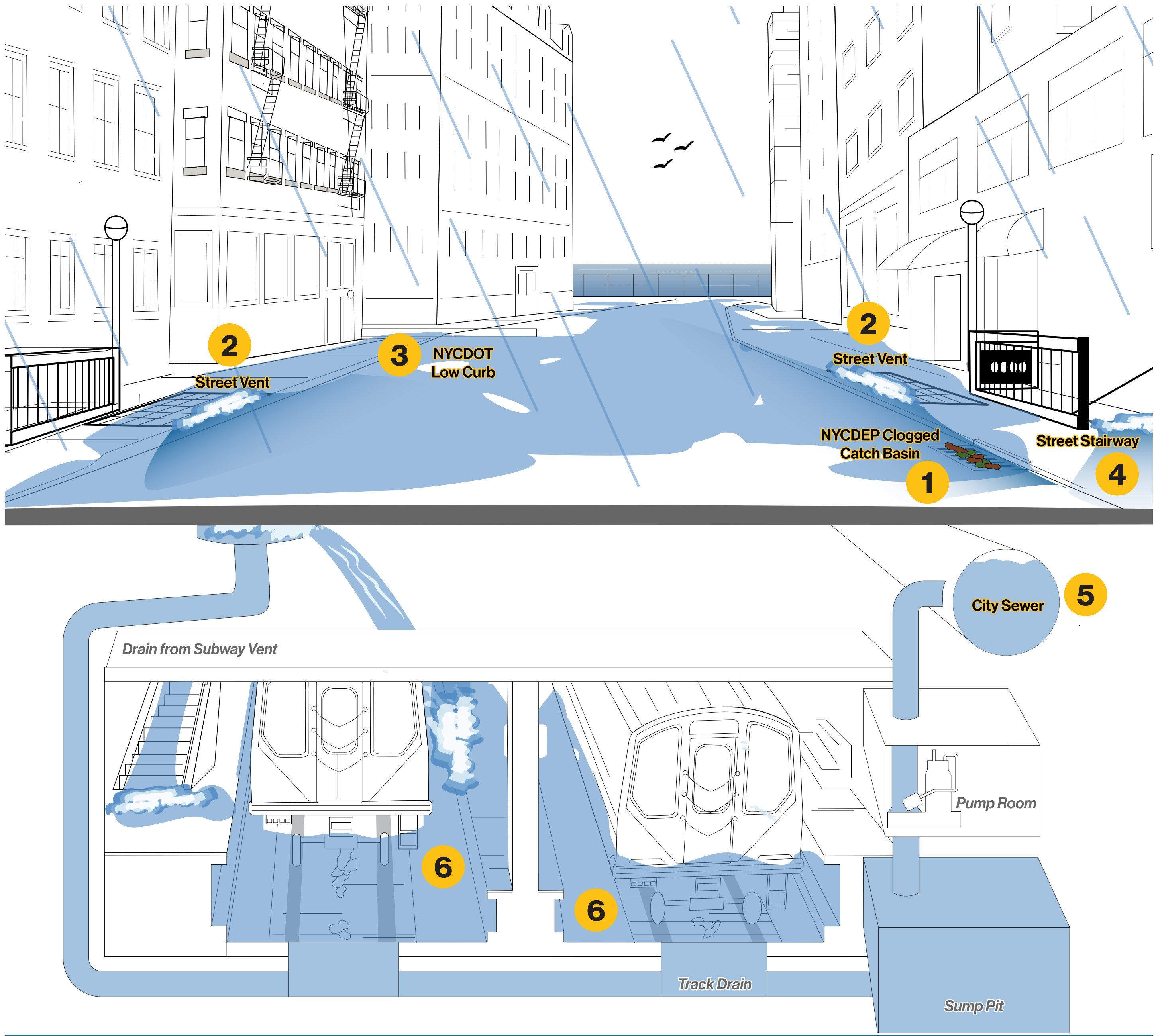


Drainage Deep Dive

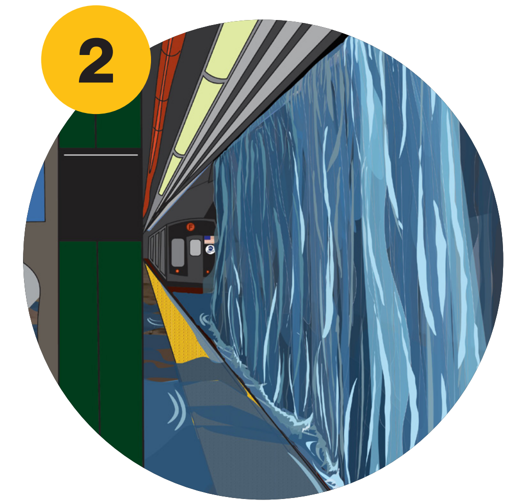
In some locations, such as along the Brooklyn-Queens Crosstown G Line, the subway system pumps out water though complementary infrastructure called deep wells. Deep wells are located where the water table is above the subway's tracks, requiring constant 24/7 pumping to keep groundwater out of the underground system. Today, there are 254 pump rooms and 23 deep wells across the subway system that pump out roughly 10 million gallons of primarily groundwater each day on days without any precipitation.

How torrential rainfall can impact the subway

During torrential rainfall, infrastructure at the street level, like **catch basins (1)** and **curbs (3)**, can help cause huge volumes of stormwater to collect in the street, and enter the subway system though **street vents (2)** and **street stairways (4)**.



When large volumes of stormwater enter through vents and down street stairs, and when **city sewers (5)** are full and backup into stations, the underground drainage system becomes taxed. Stormwater can build up in mezzanines and on stairways and platforms, impacting customer experience. Subway service delays occur when **stormwater floods tunnels and tracks (6)**. Subway service is shut down until the water is removed.



*Trash and debris can **clog catch basins,** causing stormwater to pool on the street and cascade through nearby subway street vents onto the track.*

***Low curb heights** near subway entrances can't hold back stormwater from flowing over streets and sidewalks and down subway street stairways, to the mezzanine.*

Sewer backup at 28 St Station on the 1 Line during Tropical Storm Ida.

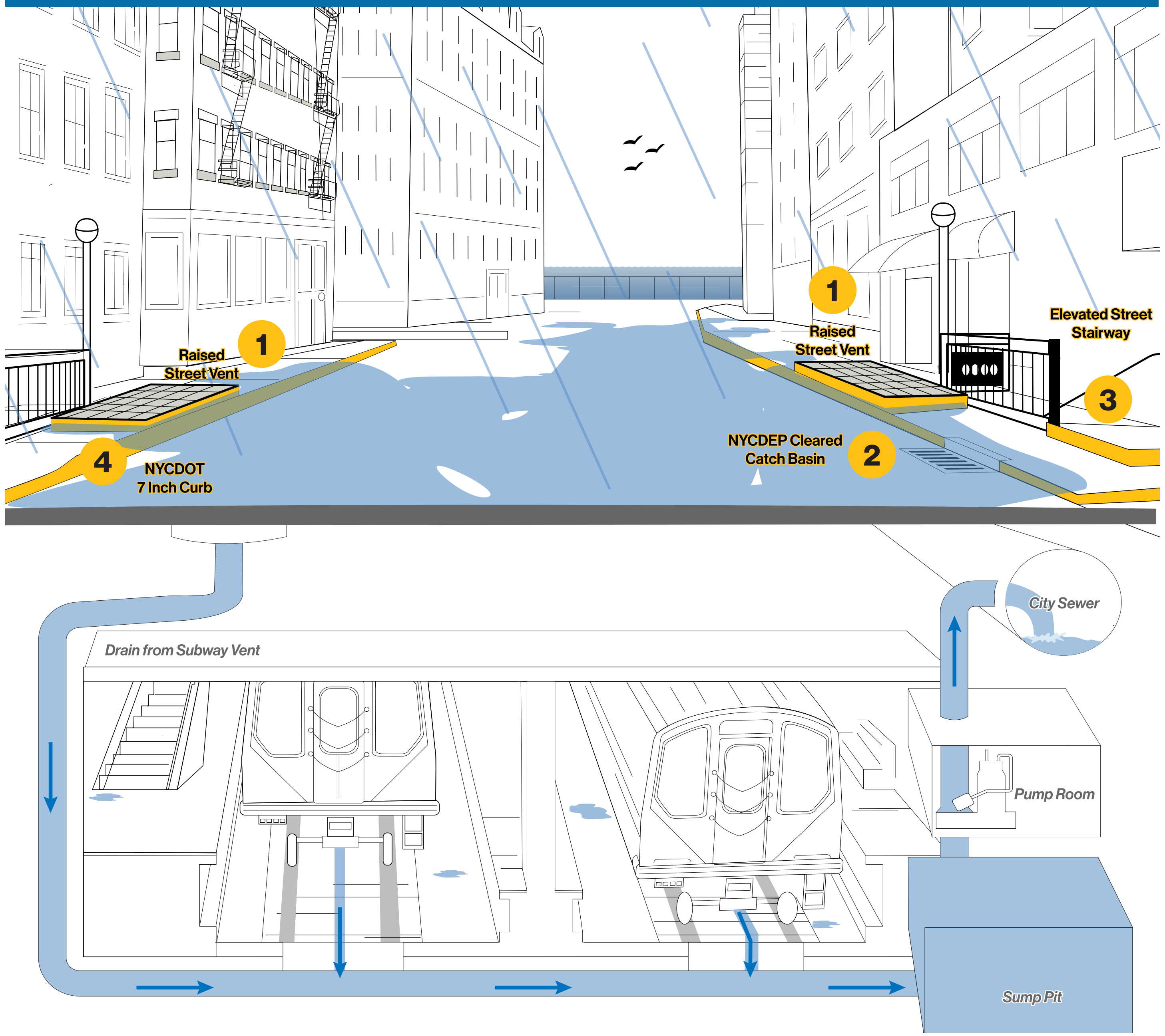
Credit: Steven James

L to R: Tunnel and track flooding during Tropical Storm Ophelia and Tropical Storm Ida.

How mitigations help protect the subway during torrential rainfall

The MTA continues to install stormwater mitigation strategies to keep our trains running during torrential rain. Strategies include **raising vents (1)** to reduce stormwater that enters through vents. We also **elevate street stairs (3)** to reduce stormwater flows from streets and sidewalks down stairways and into mezzanines.

NYCDEP's pre-storm **catch basin cleaning (2)** near MTA infrastructure and NYCDOT's **7-inch curb height standard (4)** also help reduce cascading stormwater into our underground system.



Raised vents

Clear catch basin near MTA vents

Elevated street stairs

7-inch curb near station entrance

Our mitigation strategies, coupled with best practices by our partners, will help protect our underground system during torrential rainfall events and reduce service disruptions for our customers.

Progress to date

The MTA has undertaken several recent initiatives to protect the subway system from stormwater floods resulting from torrential rain. These include:

1. **Installing stormwater mitigations at 28 stations** that were flooded during a torrential rainfall event in August 2007. Protections include installing raised vents, closing sidewalk vents, regrading street vents, and other mitigations.
2. **Executing a system-wide cleaning and repair program,** including sealing more than 8,200 leaks, cleaning and repairing the entire system of subway drain lines, adding five new staff teams, doubling heavy cleaning equipment for maintaining drains, and clearing debris from the entire system of over 40,000 street grates as part of the *Subway Action Plan*[1] enacted between 2017 and 2019.
3. **Identifying vulnerable vents across the system** and developing an action plan to protect them as part of the the Vent Stormwater Mitigation capital project. This includes recommendations to protect 1,719 vent bays based on a detailed survey of each location.
4. **Allocating $102.4 million to upgrade key infrastructure,** including pump rooms, and back-flushing deep wells as part of the *2020-2024 Capital Program.*[2]
5. **Implementing sidewalk-level stormwater mitigations, redesigning street stairs, and improving drainage** across about 70 stations, as part of multiple 2020-2024 Capital Program packages. These packages include the 2020-2024 Street Stair Component Program, Stormwater Mitigation: Street Stairs packages 1 and 2, Stormwater Mitigation Vents: Various Locations package, and Stormwater Mitigation – 81 St and Broadway Sewer Connection project.

1 Subway Action Plan Final After Action Report
2 MTA 2020-2024 Capital Plan

Interagency Stormwater Task Force

Following a series of major storms that disrupted service in the summer of 2021, the MTA and City of New York initiated an Interagency Stormwater Task Force to investigate over 150 MTA locations with elevated flood risks or historical flooding significance, study their root causes of flooding, and propose solutions.

The task force included representatives from the MTA, the NYC Department of Environmental Protection, Department of Transportation, Office of Emergency Management, and the Mayor's Office of Climate and Environmental Justice, and identified recommendations in 2022 to keep stormwater out of MTA facilities.

Based on these recommendations, the MTA has initiated capital investments in the 2020-2024 Capital Program, such as raised street stairs. Other recommendations are operational and are being implemented jointly by the MTA and relevant City agencies. These include integrating MTA priority locations into NYC's Flash Flood Emergency Protocol for pre-storm catch basin cleaning, street resurfacing, and sewer cleaning.

Actions

Goal 1: Shield subway stations and tunnels from stormwater

Estimated Cost: **$500M - $1B**

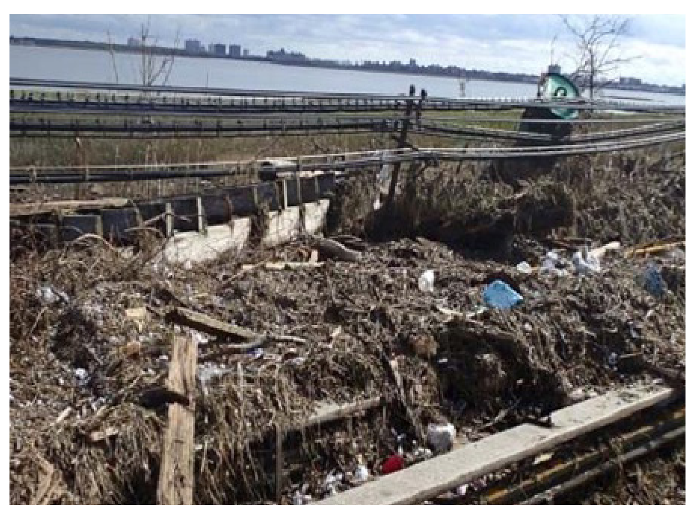
Strategy	Short Term (≤5 Years)
Keep stormwater out **Boost collaboration with City agencies**	» Deploy proactive stormwater management tactics with NYCDEP and NYCEM as part of the Flash Flood Emergency Plan, including cleaning priority catch basins before predicted torrential rainfall events. » Work with NYCDEP to resolve city sewer bottlenecks including catch basins and siphons that require cleaning to prevent runoff or backups into the subway system. Ensure that sewer connections near subway infrastructure, including siphons and tide gates, are operating at full design capacity. » Support NYCDEP initiatives to improve stormwater drainage infrastructure in chronically impacted neighborhoods, including parts of the southern Bronx, northern Brooklyn, and central Queens. » Engage NYCDOT on street resurfacing projects to minimize stormwater runoff into subway vents and station entrances.
	Long Term (>5 Years)
	» Continue proactive stormwater management tactics executed by NYCEM and NYCDEP before predicted torrential rainfall as part of the Flash Flood Emergency Plan. » Collaborate with NYCDEP on implementing a pipeline of capital improvements to expand stormwater capacity adjacent to chronically impacted subway locations, prioritizing locations where connecting city drainage infrastructure is constrained. Partner with NYCDEP to advance design and construction of stormwater drainage capacity expansions in prioritized locations. » Partner with NYCDOT to ensure that all sidewalk curbs adjacent to subway infrastructure are sufficiently sized to prevent stormwater runoff into subway vents and station entrances.
Keep stormwater out **Protect subway tunnel walls from leaks**	**Short Term** (≤5 Years)
	» Subway tunnels were designed with waterproofing membranes to prevent groundwater infiltration. Continue to inspect tunnels regularly to identify leaks and apply grout to address them as they occur.
	Long Term (>5 Years)
	» Continue vigilant tunnel grouting program and monitor the impacts of groundwater table rise on tunnel leaks. Adjust cadence of grouting program as necessary.

Strategy	Short Term (≤5 Years)	Long Term (>5 Years)
Keep stormwater out **Install sidewalk-level protections**	» Advance site-specific sidewalk-level protections at priority stations that have experienced stormwater impacts during one or more recent torrential rain events. » Advance scoping at additional priority stations that have experienced stormwater impacts during one or more recent torrential rainfall events to determine feasible stormwater mitigation interventions, which may include sidewalk-level protections.	» Install site-specific sidewalk-level protections at additional priority stations, where feasible, based on scoping and feasibility study. » Install site-specific sidewalk-level protections at other stations likely to become vulnerable to torrential rainfall in the future, in coordination with other capital projects. » Monitor existing mitigations and identify new locations experiencing stormwater runoff impacts within or between stations.
Keep stormwater out **Develop new technologies to prevent stormwater overtopping into sidewalk vents**	» Explore new protections for vent batteries exposed to flood risks from both coastal surge and torrential rain. New protections may include alternative types of vent mechanical closure devices (MCDs).	» Develop a hybrid passive MCD that could protect vents in areas with future (2050s and beyond) combined coastal surge and torrential rain flood risks. » Implement hybrid passive MCDs at appropriate locations, where feasible, to prevent stormwater runoff and storm surge into vulnerable subway vents.
Remove stormwater that enters **Upgrade subway drainage system equipment**	» Replace or rehabilitate priority pump rooms, where feasible, including replacing old and undersized pumps, adding additional pumps, and improving drain lines in chronically impacted locations that may exacerbate service delays during torrential rain events. Prioritize subway drainage system equipment listed in poor or marginal condition that serve locations impacted by recent torrential rain. » Identify locations that could benefit from expanded pumping capacity (e.g., new pump rooms) across the subway system.	» Construct new pump rooms in locations with currently constrained capacity or that are likely to become constrained due to increased stormwater infiltration into the system, where feasible. » Expand drainage capacity in locations likely vulnerable to groundwater table rise, including adding new deep wells to provide continuous pumping, where feasible. » Ensure subway drainage system equipment operates at full capacity to remove stormwater that enters the subway system even after deploying sidewalk-level protections, like top steps and raised vents.
Remove stormwater that enters **Reduce subway drainage system constraints**	» Remove track drain direct connections and vent drain direct connections between the subway and the city sewer system to reduce service impacts during torrential rainfall events. » Where feasible, expand capacity of constrained vent drains to move larger volumes of stormwater. » Continue regular inspections and periodic overhauls of check valves across the subway tunnel drainage system to help prevent city sewer backups into the subway system.	» Continue reducing direct sewer connections across the system, prioritizing those that backup during torrential rain events. » Continue periodic overhauls of check valves in tunnel drains to help prevent city sewer backups into the subway system.
Remove stormwater that enters **Continue proactive track drain cleaning programs**	» Continue the existing proactive track drain inspection and cleaning program, particularly before the rainy season (spring and summer). » Continue pre-storm drain inspections and cleaning to ensure drains are not blocked by litter ahead of storms. » Bundle drain cleaning and inspections with construction-related shutdowns, like CBTC, to optimize resources.	» Consider expanding proactive track drain cleaning programs to reduce time between maintenance. » Deploy measures to identify blocked drains so cleaning resources can be effectively targeted before a forecasted torrential rainfall event.
Remove stormwater that enters **Retain stormwater until the city sewer capacity recovers**	» Implement a stormwater retention and detention strategy and increase existing track pumping capacity at 3 Av/138 St Station 6 in the Bronx to expand the capacity of the subway right-of-way to hold stormwater from torrential rainfall until it can be safely discharged into the city sewer system. » Leverage construction opportunities at stations to implement stormwater management improvements where additional stormwater detention is needed during torrential rainfall events.	» Expand stormwater detention capacity across the subway system, where feasible, to mitigate the constraints of city sewer infrastructure.

Goal 2: Protect subway yards from flooding

Challenges

There are 24 yards across the subway system that provide a critical support network for the repair, maintenance, cleaning, and storage of more than 6,500 subway cars. Many yards were constructed in former low-lying wetland areas adjacent to water bodies and are therefore vulnerable to coastal surge flooding, sea level rise, tidal flooding, and flooding from torrential rain.



Damaged tracks near Rockaway Park Yard after Superstorm Sandy, October 2012.

Flooding in yards can cause service disruptions that extend throughout the system by preventing MTA personnel from completing repairs or inspections. Flooding can also damage critical equipment. This could include signal systems that allow trains to be directed in and out of the facilities and circuit breaker houses, which provide third rail power—the electricity needed to operate railcars—and control to tracks. In short, the New York City subway system cannot function without yards.

The threats posed by each kind of flooding are different.

Coastal surge and sea level rise

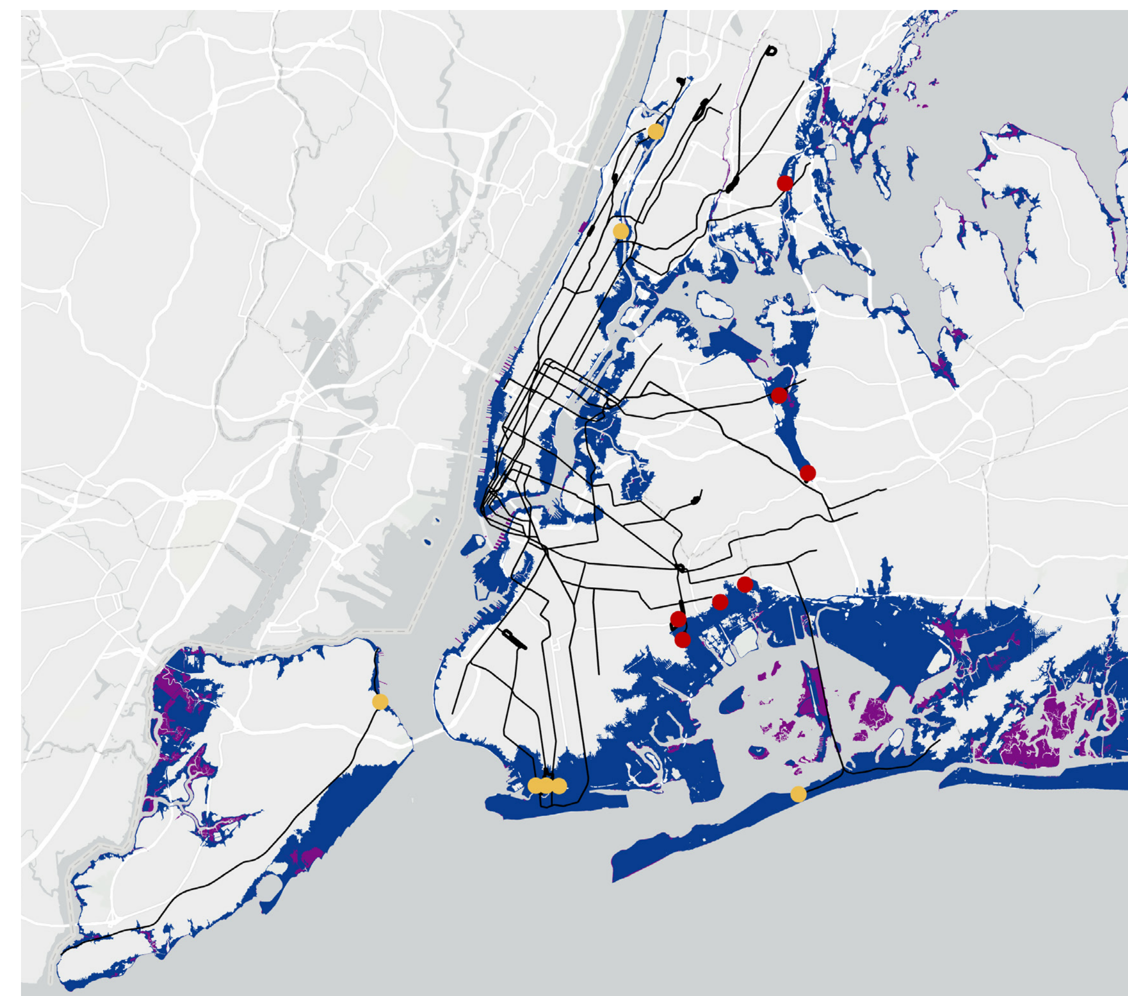
Unlike torrential rains, saltwater floods from coastal surge, sea level rise, and tidal flooding are corrosive and run the risk of long-term damage. In 2012, during Superstorm Sandy, tidal surge inundated yards, including Coney Island and 207 Street, damaging power and communication systems, switches, signals, and track. In some cases, the saltwater breached the perimeter of yards and flowed into tunnels, further damaging assets throughout the system. Not accounting for completed coastal surge protections at six yards, subway yard exposure is as follows:

Coastal surge exposure

	2020s	2050s	2080s
Subway yards (24 yards total)	13	13	14

Sea level rise/tidal flood exposure

	2020s	2050s	2080s
Subway yards (24 yards total)	5	6	8



Subway yard potentially vulnerable to coastal surge or sea level rise (2020s)
Subway yard/SIR shop with coastal surge protections installed
2020s Coastal surge 500-year flood extent (NPCC)
2020s Projected monthly tidal flooding with sea level rise (NPCC)

Torrential rain

Stormwater flooding in yards, although not corrosive, also disrupts service when trains requiring repairs or inspections are unable to enter or exit. System-wide maintenance and construction activities are also disrupted when work trains are unable exit. Flooding from torrential rainfall also increases the chance of train derailment within the yard, as debris can foul the tracks without the operators' awareness, and muddy conditions damage and weaken railroad ties. Torrential rain during Tropical Storm Ida in September 2021 impacted eight yards and eight yards were also impacted during Tropical Storm Ophelia in September 2023, resulting in equipment damage and service disruptions.

Flooding conditions at Lenox Terminal Yard in Manhattan from torrential rainfall during Hurricane Irene, August 2011.

Westchester Yard flood control

Westchester Yard in the Bronx is a critical facility that keeps the subway system in service. The approximately 30-acre complex includes seven miles of track, 224 switches, 84 signals, car wash facilities, an inspection barn, and multiple storage areas for rail materials. 6 trains are stored and maintained at Westchester Yard, plus one-third of all work trains that service the entire subway system.

Like many of the other 23 yards serving the subway system, Westchester Yard was built in the early 20th century. Notably, it was also constructed in a former wetland area adjacent to Westchester Creek. While the location was not originally prone to chronic floods, climate change is increasing the impacts of torrential rainfall events, the risks of storm surge, and even the potential for tidal floods caused by sea level rise. For example, flooding and service impacts were reported during Superstorm Sandy in 2012, Tropical Storm Ida in 2021, and Tropical Storm Ophelia in 2023.

To improve stormwater drainage and pumping capacities at Westchester Yard, a combination of storm sewers, inlets, and a new lift station – a facility that moves wastewater from a lower to higher elevation – to channel water out of the yard during periods of heavy rains is planned.

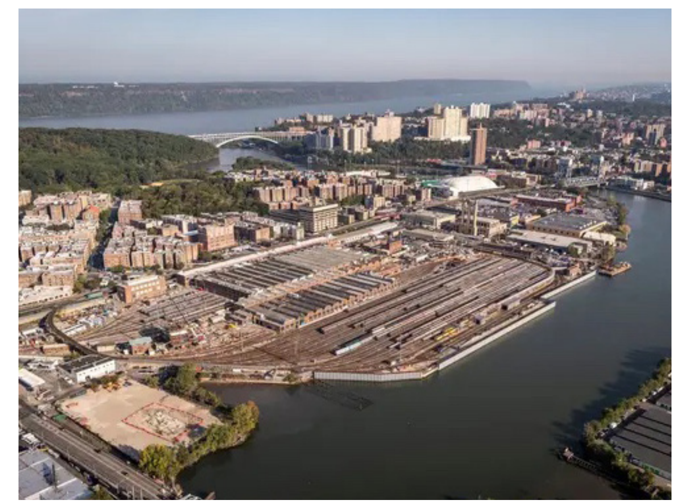
6 trains at Westchester Yard.

Flooding conditions at Westchester Yard from torrential rainfall during Tropical Storm Ophelia, September 2023.

Progress to date

Subway yard protections

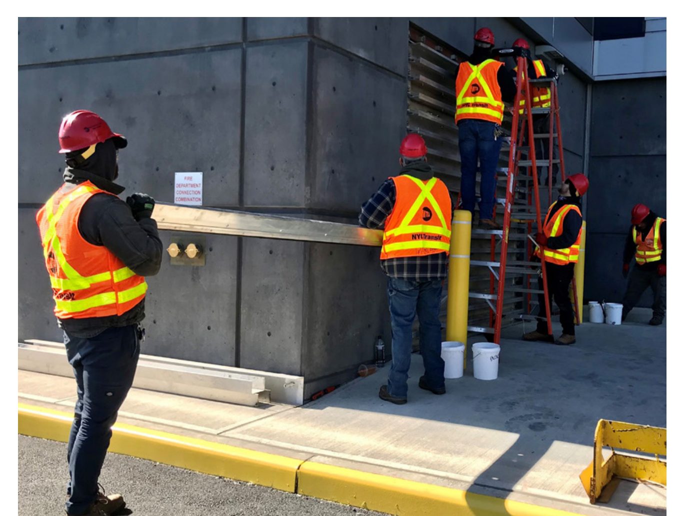
Following Superstorm Sandy, the MTA installed protections at the six most critical yards that flooded during the storm: 148 Street, 207 Street, Coney Island, Culver (Avenue X), Stillwell, and Rockaway Park. Coney Island and 207 Street received perimeter flood wall protection, 148 Street received a heightening of a pre-Sandy flood wall, and Rockaway Park received flood gates. Culver (Avenue X) and Stillwell are located in the same complex as Coney Island and are protected by the perimeter flood protection.



A bird's-eye-view of the perimeter flood wall at 207 St Yard in Inwood, Manhattan.

The Coney Island Yard perimeter flood wall under construction, October 2019. The perimeter flood wall, now complete, spans 12,000 linear feet and is driven approximately 30 feet below ground.

Staten Island Railway (SIR) protections



Deployment testing of flood logs at Clifton Shop, March 2023.

The MTA installed coastal surge protections at St. George Terminal (perimeter floodwalls, flood doors, and flood logs) and Clifton Shop (flood logs), two critical locations that were damaged by Superstorm Sandy surge.

Actions

Goal 2: Protect subway yards from flooding

Estimated Cost: **$500M - $1B**

Strategy	Actions
Upgrade and expand yard drainage systems in anticipation of future coastal surge and torrential rainfall floods	**Short Term** (≤5 Years) » Rebuild/replace priority drainage system assets in yards, like pump rooms, listed in poor or marginal condition. » Scope drainage improvements and coastal surge protections, where feasible, and elevate equipment at priority yards exposed today to coastal surge. » Identify feasible passive mitigation strategies in priority yards that are chronically exposed to combined torrential rainfall flood and tidal flood risks. **Long Term** (>5 Years) » Elevate critical facilities above future coastal surge floodplains, where feasible. » Install additional pumps for problematic hot spots, potentially accompanied by floodproofing or barriers at chronically impacted locations. » Advance stormwater retention systems, where feasible, in appropriate locations. » Install protections at additional yards exposed today to coastal surge.
Install combined coastal surge and torrential rainfall protections under the Westchester Yard Flood Control Project	**Short Term** (≤5 Years) » Install storm sewers, inlets, and a new lift station at Westchester Yard to channel water out of the facility during periods of torrential rain as part of the Westchester Yard Flood Control Project. **Long Term** (>5 Years) » Identify flood mitigation technologies installed at Westchester Yard that could be effective in locations outside of Westchester Yard.
Mitigate flood impacts as yard equipment is replaced	**Short Term** (≤5 Years) » Elevate sensitive equipment as part of any capital project, where feasible, anticipating current and future flood risks. **Long Term** (>5 Years) » Monitor the impacts of sea level rise and tidal flooding risks at coastal subway yards and advance appropriate mitigations. » Replace equipment where feasible, like switch machines, with types that can be submerged.

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Goal 3: Protect open subway infrastructure from flooding

Challenges

While about 63% of the subway system is underground, there are approximately 272 miles of revenue track that run on or above ground. While some above ground and open cut tracks and rights-of-way are vulnerable to infrequent coastal surge, the combination of tidal floods caused by sea level rise and inland flooding from torrential rain presents more frequent challenges.

Coastal surge and sea level rise

Coastal surge is the most consequential, though infrequent, climate risk facing some open track locations due to the destructive force the surge and the corrosive nature of saltwater. This risk will increase over time as sea level rises and storms increase and intensify.

NYCT Subways infrastructure is often elevated in coastal locations, typically much higher than projected coastal surge flood depth. SIR infrastructure varies between being elevated, open-cut, or at-grade and faces increasing flood risk from coastal surge events.

In addition to coastal surge, tidal floods caused by sea level rise pose different types of flooding risks for open subway infrastructure. Vulnerable locations include stations like Howard Beach and Broad Channel on the Rockaway Line, and the southern portion of the SIR line around Tottenville and Richmond Valley. Each of these low lying rights-of-way traverse areas at or near sea level with drainage that is easily impacted by tides and torrential rain flooding. For example, Richmond Valley station is built over federally protected tidal and freshwater wetlands. Flooding here already results in service disruptions several times a year.

Tottenville Station and Yard borders the Arthur Kill tidal strait and faces increased flood and coastal erosion risk from sea level rise.

Coastal surge exposure

	2020s	2050s	2080s
Subway & SIR at grade/ elevated track miles[1]	22%	24%	26%
Subway & SIR at grade/ elevated stations[2]	43	54	59

Sea level rise/tidal flood exposure

	2020s	2050s	2080s
Subway & SIR tracks	<1%	1%	12%
Subway & SIR stations	4	9	24

1. 301 miles of Subway and SIR track are at grade/elevated.
2. 212 Subway and SIR stations are at grade/elevated.

In addition to their impacts on infrastructure, chronic tidal floods will complicate customer access to subway stations. Access will become particularly challenging on rainy days that coincide with high tides when floods fill adjacent streets and sidewalks.

In these locations, including Broad Channel, the MTA will engage in long term conversations with city partners and pursue flexible approaches to climate resilience that preserves transit access for customers traveling to and from these highly vulnerable locations.

Torrential rain

Open cut and at-grade subway infrastructure is also vulnerable to torrential rainfall flooding. Floods at these locations can be the primary drivers of subway service delays during torrential rainfall events. Open cut rights-of-way are where subway infrastructure is below the surrounding streets and are uncovered. During torrential rainstorms, open cut and at-grade track drainage infrastructure may not be able to keep up with water entering the right-of-way from direct rainfall and runoff from surrounding properties, which causes flooding. For example, the open cut section of the Franklin Avenue Shuttle S between the Prospect Park and Park Place stations recently experienced impacts from torrential rain during Tropical Storm Ophelia in September 2023. At-grade stations can also experience impacts from torrential rain. This flooding can also be exacerbated when city stormwater drainage infrastructure is at capacity, and stormwater from subway infrastructure cannot drain to overwhelmed city sewers.

Subway portals, where tracks go from underground to above-ground, are another vulnerable location in the subway system. This is because there is a large opening that stormwater can enter and flow into lower portions of subway tunnels. When rainfall amounts are torrential in portals and surpass the subway's underlying drainage capacity, tracks and tunnels can flood.

Progress to date

Coastal surge and torrential rain

A NYCDEP Mill Creek Bluebelt retention pond south of Richmond Valley Station mitigates tidal flooding that threatens the SIR right-of-way.

For elevated stations, post-Sandy completed initiatives include installing flood mitigation devices at critical rooms within stations, like electrical, communications, and signal rooms, and elevating critical equipment above predicted flood depths. Post-Sandy investments also protect key SIR locations and assets from coastal surge, however some coastal flood risk remains for other areas and assets.

Near SIR Richmond Valley, NYCDEP recently completed two stormwater management installations as part of the Mill Creek Bluebelt. These retention reservoirs mitigate local flooding by expanding stormwater detention capacity. At Richmond Valley, this has reduced flood volumes from high tide flooding and torrential rainfall, however stormwater flood risks persist and will continue to grow with climate change.

Actions

Goal 3: Protect open subway infrastructure from flooding

Estimated Cost: **$250M - $500M**

Strategy	Short Term (≤5 Years) / Long Term (>5 Years)
Design tidal/inland flood and coastal erosion mitigations, including shoreline protections and equipment elevations	**Short Term** (≤5 Years) » Design appropriate flood mitigations at current and future exposed locations, such as Tottenville station, right of way, and terminal. » Advance feasible drainage improvements at vulnerable subway portals systemwide, including increasing pumping capacity, to reduce flooding and service impacts. **Long Term** (>5 Years) » Install feasible mitigations which may include fortified waterfront bulkheads and/or engineered stone revetment to protect waterfront structures from erosion and wave action.
Coordinate with external partners on regional and neighborhood-scale protections that intersect with MTA infrastructure	**Short Term** (≤5 Years) » Specific initiatives include the U.S. Army Corps of Engineers (USACE) NY NJ Harbor and Tributaries Study (HATS) and NYCDEP Bluebelts. **Long Term** (>5 Years) » Provide design feedback and construction access to support stormwater mitigation projects by external partners.

Goal 4: Safeguard bus depots from flooding

Challenges

The MTA's bus system includes extensive support infrastructure beyond the vehicles themselves, including a Bus Command Center, field staffing facilities, radio towers, and 28 depots where buses are fueled, inspected, serviced, and parked when not in use. These depots also contain additional bus stock along with critical communications and dispatch facilities. However, many depots are in low-lying coastal areas making them vulnerable to coastal surge flooding. A functioning bus network is a core part of the region's emergency response to extreme weather events. For example, in the aftermath of Superstorm Sandy, subway tunnels were flooded and buses assumed an immediate role providing post-disaster transportation between Brooklyn and Manhattan. A "Bus Bridge" between Manhattan and Brooklyn carried 3,700 passengers per hour, with three buses loading simultaneously, riding into Manhattan from Brooklyn in dedicated lanes. If one depot is catastrophically impacted during a storm, as Castleton Depot was during Superstorm Sandy, other depots can help mitigate the impacts and enable buses to perform emergency post-disaster operations. If multiple or all depots are catastrophically impacted and equipment is damaged, the ability of buses to support citywide emergency response is limited.

More than 300 special temporary shuttle buses carried subway customers across the East River while train service was being restored following Superstorm Sandy, November 2012.

Coastal surge and sea level rise/tidal flood

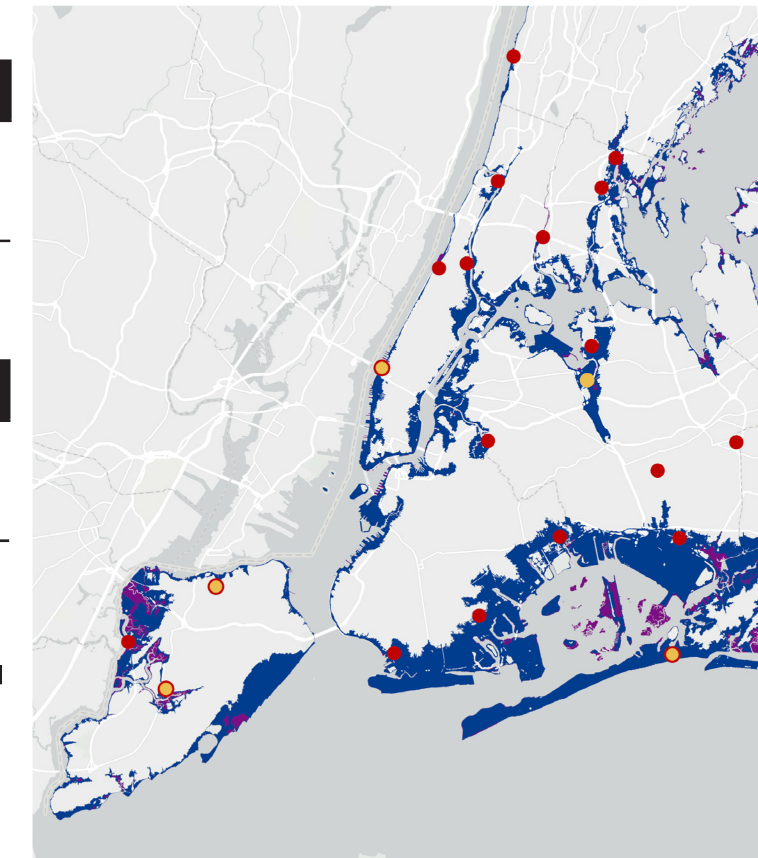
Today, 19 of 28 total bus depots are in a coastal surge floodplain. Five of these depots currently have coastal surge mitigations installed, but 14 remain vulnerable. Seven depots or surrounding MTA property will be exposed to tidal floods by the 2080s. Before accounting for completed protections, bus depot exposure is summarized as follows:

Coastal surge exposure

	2020s	2050s	2080s
Bus depots (28 depots total)	19	19	19

Sea level rise/tidal flood exposure

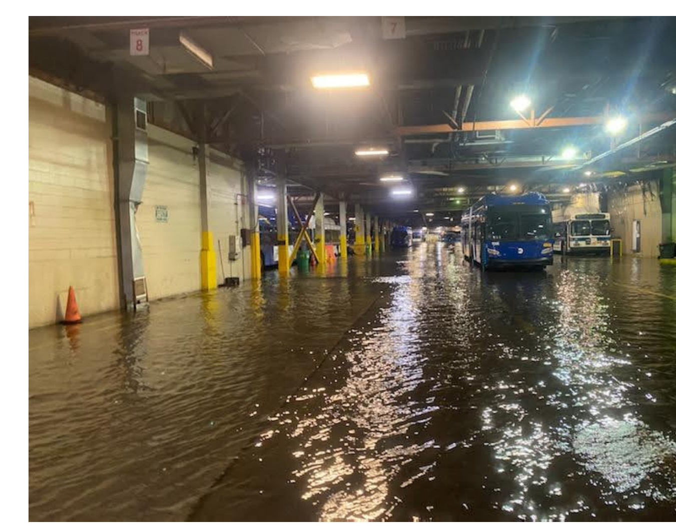
	2020s	2050s	2080s
Bus depots (28 depots total)	2	5	7



- **Bus depot** potentially vulnerable to coastal surge or torrential rain (2020s)
- **Bus depot** with coastal surge protection and potential vulnerability to torrential rain (2020s)
- **Bus depot** with coastal surge protections installed
- 2020s Coastal surge 500-year flood extent (NPCC)
- 2020s Projected monthly tidal flooding with sea level rise (NPCC)

Torrential rain

Several bus depots, both in coastal and in inland areas, are currently vulnerable to flooding from torrential rain. These depots, including Castleton in Staten Island, are in areas where the city's stormwater drainage capacity cannot handle intense torrential rain events greater than 1.75 inches per hour. During Tropical Storm Ida with its peak hourly rain of 3.45 inches per hour, at least four depots were impacted.



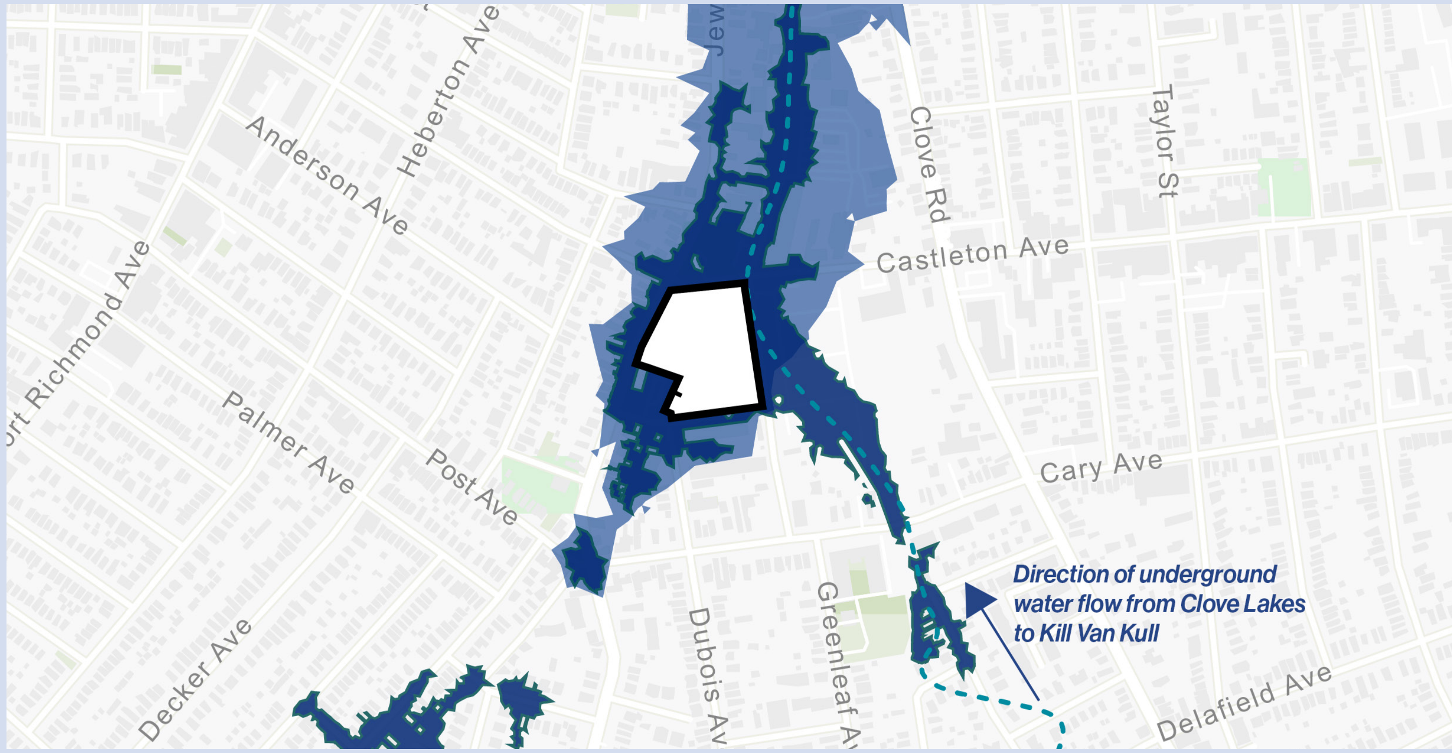
Flooding from torrential rain during Tropical Storm Ida at the Jackie Gleason Depot, Brooklyn, September 2021.

Confronting chronic floods at Castleton Depot, Staten Island

Castleton Bus Depot stores and services about 370 buses. Located on Staten Island's North Shore near the St. George Ferry Terminal and Staten Island Railway, bus routes originating from Castleton serve more than 3.75 million passengers every year.

Castleton Depot and much of the surrounding neighborhood sit above a historic waterway called Bodine Creek. The creek now runs through a large sewer below the bus depot. During torrential rains, stormwater flows from Clove Lakes Park upstream of the bus depot and overwhelms the entire area where Bodine Creek was located. For example, Castleton experienced more than 4 feet of stormwater flooding during Tropical Storm Ida in 2021, causing $8M in damage to 28 buses.

Castleton Depot, Staten Island



Castleton Bus Depot

2020s Stormwater flood risk (NYC Government)

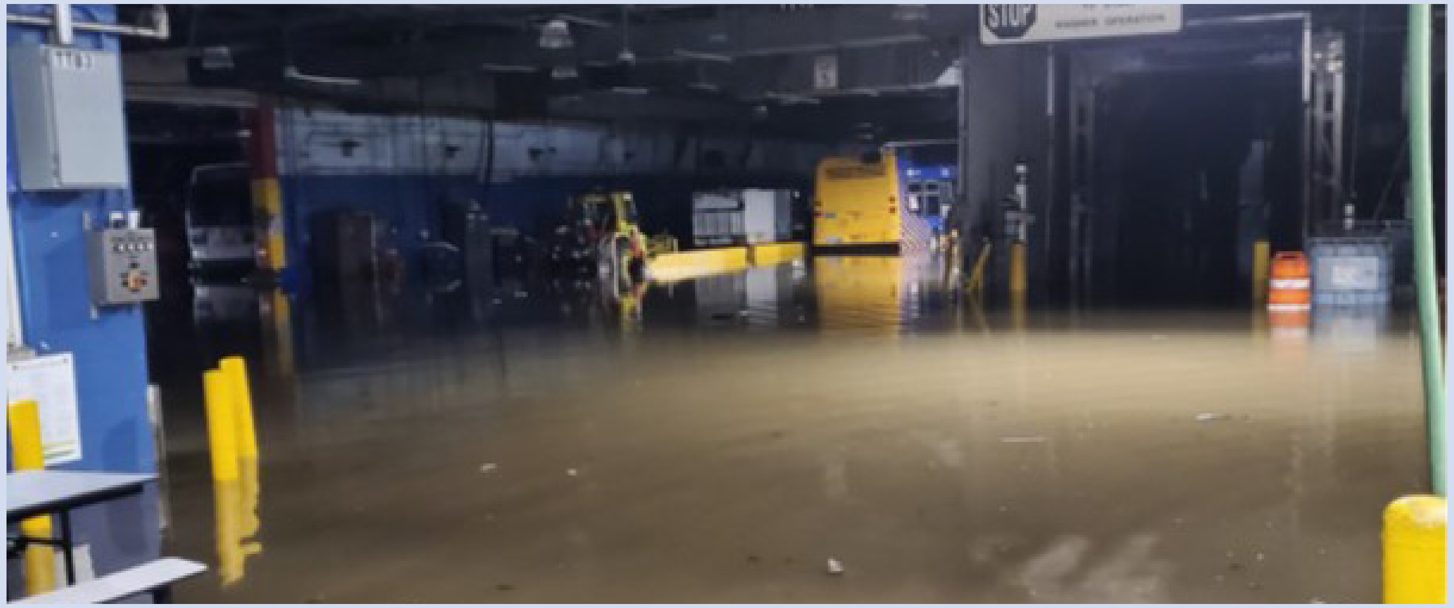
2050s Coastal surge 500-year flood extent (NPCC)

Bodine Creek Historic Path

Elevated electrical equipment inside Castleton Depot. Electrical equipment in Castleton Depot is elevated above flood depth to reduce the likelihood of major damage in the event of future floods.

To reduce the magnitude of neighborhood-scale stormwater flood risks, the NYC Department of Environmental Protection (NYCDEP) is studying the feasibility of a nature-based drainage system called a Bluebelt. If constructed, the Willowbrook/Westerleigh Bluebelt would restore natural drainage corridors and provide stormwater detention in wetlands and ponds. The MTA will coordinate with NYCDEP on stormwater detention opportunities that could benefit Castleton Depot.

While the MTA will continue to evaluate appropriate building-scale torrential rain mitigations, Castleton was prioritized for coastal surge mitigations following Superstorm Sandy. These post-Sandy investments are designed to protect the depot from a 500-year coastal storm. Mitigations include reinforced outside walls, elevated electrical equipment, deployable flood logs at doors and vehicle access points, and pressure-tight manholes in the depot interior to prevent sewer surcharging.



Flooding conditions at Castleton Depot during Tropical Storm Ida, September 2021.

Progress to date

Following Superstorm Sandy, coastal surge mitigations were installed in five depots most impacted by the storm, including Casey Stengel, Castleton, Michael J. Quill, Yukon and Far Rockaway. Examples of mitigations installed at these buildings include:

» Deployable flood panels to protect vulnerable garage doors and equipment.

» Elevated electrical panels above projected flood depth.

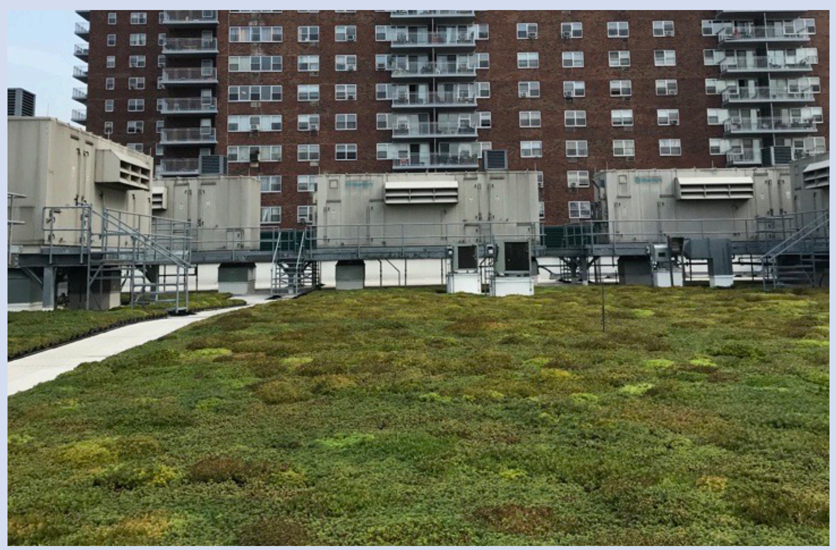
» Watertight exterior flood doors and flood proofing treatments of building facades.

These strategies can be deployed at other depots and locations that are susceptible to coastal surge.

Stormwater management innovations at bus depots

Green roof at Mother Clara Hale Depot, Manhattan

In 2015, the MTA opened Mother Clara Hale Depot, the first bus depot to achieve national building sustainability certifications. A 60,000 square foot green roof on top of the facility uses plants to significantly reduce stormwater runoff and to cool the building's interior. The green roof continues to function as designed almost 10 years since it was installed.



Nature-based retention at Spring Creek Depot, Brooklyn

The MTA partnered with NYCDEP in 2011 to install green infrastructure at the Spring Creek Depot in Brooklyn. Stormwater runoff is directed from the depot's parking lot into a vegetated area, as shown in the photo, that can store and treat stormwater. With proper maintenance, the project can capture and treat up to 21,000 gallons of stormwater runoff.

Actions

Goal 4: Safeguard bus depots from flooding

Estimated Cost: **$500M - $1B**

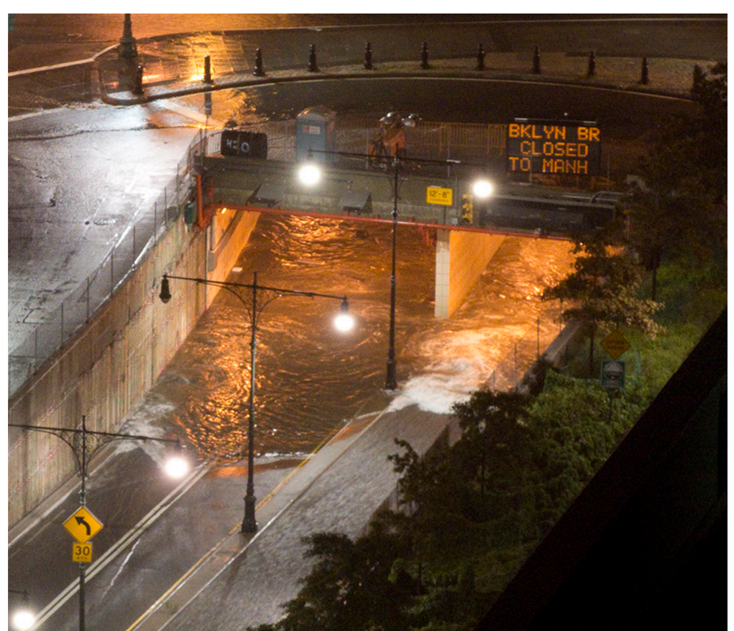
Strategy	**Short Term** (≤5 Years)
Install site-specific stormwater flood mitigation and detention strategies at chronically impacted depots	» Scope stormwater flood mitigations at chronically impacted depots, where feasible, in coordination with Zero Emissions Bus Transition. Depending on site conditions, examples of stormwater flood mitigations may include sewage backwater valves, floodproofing exterior walls of buildings, elevating equipment, and increasing the height of existing flood logs. » Collaborate with partner agencies to explore neighborhood-scale stormwater mitigations that could reduce runoff impacts to depots, particularly at Castleton.
	Long Term (>5 Years)
	» Advance stormwater flood mitigations, where feasible, at chronically effected depots, including depots currently experiencing impacts. » Continue coordinating with NYCDEP on stormwater detention opportunities, particularly the Willowbrook/Westerleigh Bluebelt project, that would benefit Castleton.
	Short Term (≤5 Years)
Implement coastal surge protections at vulnerable depots	» Install coastal surge protections, where feasible, at priority vulnerable depots in coordination with the depot improvements anticipated in the Zero Emissions Bus Transition plan. Depending on site conditions, examples of protections include deployable flood panels and flood logs. » Ensure that sensitive equipment within depots is elevated above the coastal floodplain.
	Long Term (>5 Years)
	» Install appropriate coastal surge protections at remaining vulnerable depots in tandem with improvements that support the Zero Emissions Bus Transition plan.

Goal 5: Manage floods on city streets

Challenges

In 2019, B&T carried more traffic along its seven bridges and two tunnels than any similar authority in the nation—more than 329 million vehicles. But while all of B&T's facilities are in a state-of-good-repair, more than half are over 75 years old, making them more vulnerable to impacts from climate change, particularly flooding from coastal surge and torrential rain. When B&T's bridges and tunnels are closed from street flooding, as the Hugh L. Carey and Queens Midtown Tunnel were following Superstorm Sandy, regional mobility becomes critically curtailed and our customers are inconvenienced.

Additionally, chronic flooding on streets impacts bus operations and can cause service impacts. These vulnerabilities are emerging in locations where bus routes travel on low lying streets that become overwhelmed during combined tidal floods and stormwater floods from torrential rainfall events.



Flooding at the Hugh L. Carey Tunnel during Superstorm Sandy, 2012.

Coastal surge and sea level rise/tidal flood

Both MTA tunnels and the plazas at six bridges are vulnerable to coastal surge flooding. Bridges are also vulnerable to a process called scour, which is the erosion of sand and gravel around bridge abutments and piers. Both of these risks will become more acute due to sea level rise in the 2050s and 2080s. Additionally, 142 bus routes, or more than 40% of all routes, are vulnerable today to sea level rise and tidal flood exposure. This vulnerability increases in the 2050s.

During Superstorm Sandy, both tunnels faced extensive flood damage to roadways and tunnel walls, including saltwater destruction of communications and signal infrastructure. At the Hugh L. Carey Tunnel, both tubes were flooded for more than 6,000 feet, or about two-thirds of the tunnel's total length, with around 60 million gallons of saltwater. Flooding overwhelmed pumping systems, knocked out critical functions, and rendered the tunnel impassable. The Queens Midtown Tunnel was inundated to a length of about 2,500 feet with about 12 million gallons of saltwater. For both tunnels, the saltwater damaged ventilation buildings, electrical systems, communication systems, wall and ceiling finishes, fiber optic cables, traffic control devices, and security and monitoring systems.

Torrential rain

Torrential rain can threaten the operation of B&T facilities and bus operations when the intensity of the storm exceeds the capacity of municipal stormwater drainage systems. This can cause flooding both on and off MTA property, including along the approaches to bridges and tunnels, and on city stress along bus routes. When torrential rainfall occurs during lunar high tides, flood risks increase further — a combination that will become more common over time with sea level rise. In fact, 95% of bus routes traverse at least one street exposed to stormwater floods during torrential rain.

Coastal surge exposure

	2020s	2050s	2080s
Bridges (7 bridges total)	6	6	6
Tunnels (2 tunnels total)	2	2	2

Sea level rise/tidal flood exposure

	2020s	2050s	2080s
Bridges (7 bridges total)	0	2	4
Tunnels (2 tunnels total)	0	0	2

Sea level rise/tidal flood exposure

	2020s	2050s	2080s
Bus Routes (327 total routes)	142	157	210

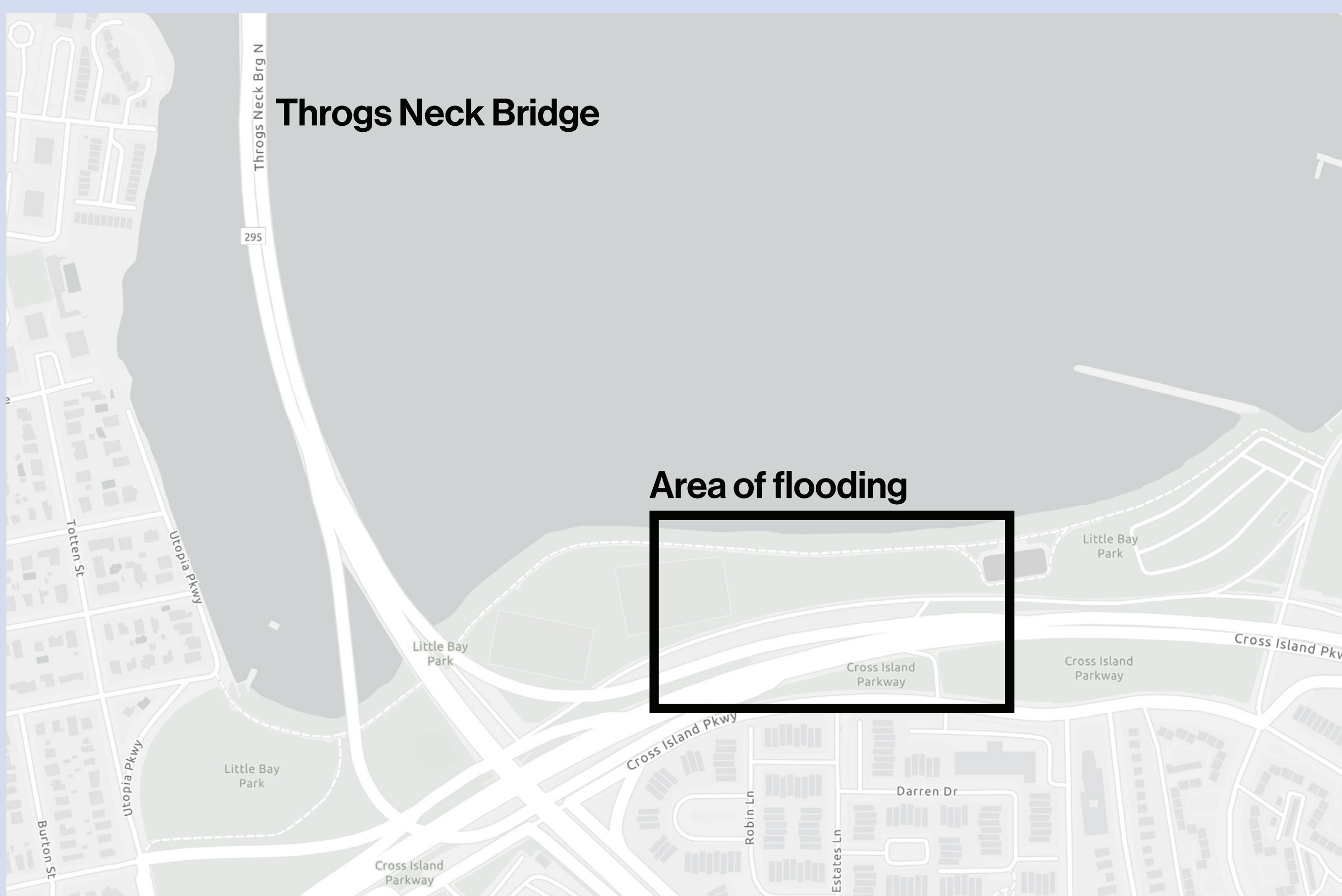
Street flooding during Tropical Storm Ida from a bus passenger video, September 2021. Credit: Joe English.

Torrential rain impacts at the Throgs Neck Bridge approach

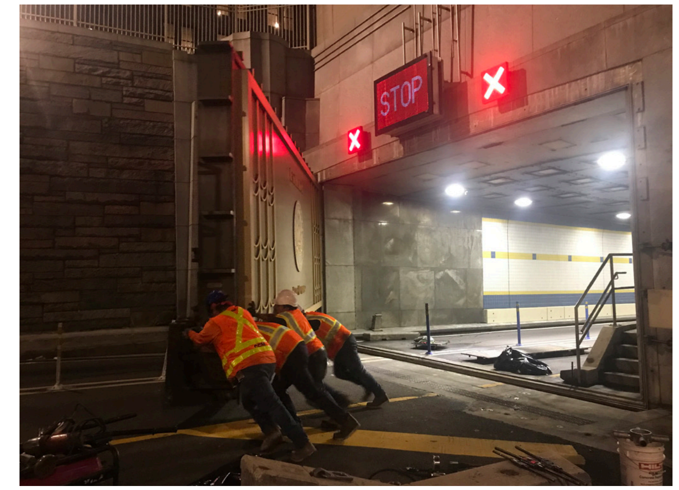
The Throgs Neck Bridge connects the Bronx and Queens and was constructed in 1961 to reduce congestion on the Bronx Whitestone Bridge. One section of the Cross Island Parkway near the Queens side approach of the Throgs Neck Bridge experiences frequent flooding under normal rainfall, forcing B&T to restrict traffic flow on the bridge's on-ramps.

Street flooding at the Throgs Neck Bridge approach during torrential rain, April 2023.

Between July 2021 and September 2022, there were at least eight instances of observed flooding, including September 13, 2022, when flooding was observed in both directions on the Cross Island Parkway, and the Throgs Neck Bridge on-ramps were closed for over two hours. Similarly, torrential rainfall from Tropical Storm Ophelia in September 2023 caused off-property flooding on the Cross Island Parkway, leading to closure of the Queens-bound Cross Island Parkway on-ramp. Chronic flooding of the Cross Island Parkway will continue to impact the Throgs Neck Bridge, leading to service disruptions and financial loss from tolls. To address the flooding issues at the Throgs Neck Bridge approaches, the MTA will coordinate with city and state entities, including NYCDEP.



Progress to date



Testing of the Hugh L. Carey Tunnel flood gates, Manhattan side, May 2023.

Significant work has been completed to protect B&T assets from climate change hazards. After Superstorm Sandy, the MTA addressed coastal surge vulnerabilities to both tunnels by installing new pumping systems, elevating emergency generators and electrical equipment, and adding deployable and permanent flood barriers at tunnel portals and plazas. Existing plaza walls and seawalls were also elevated and reinforced. B&T has also installed measures to prevent scour at the Throgs Neck Bridge, Cross Bay Bridge, and Marine Parkway Bridge.

For torrential rain, B&T is reviewing standards for the design of drainage at facilities, considering the volume of torrential rain projected through the end of the century. Additionally, prior to torrential rainfall, detours are proactively implemented on some bus routes, particularly in areas of known "hot spot" flooding, so that bus operators can avoid flooded streets.

Actions

Goal 5: Work with partners to manage floods on city streets

Estimated Cost: **< $50M**

Strategy	**Short Term** (≤5 Years)
Address chronic flooding at B&T approaches	» Reduce floods at vulnerable MTA bridge and tunnel approaches that result in operational impacts by coordinating with partner agencies , including NYCDEP and NYCDOT.
	Long Term (>5 Years)
	» Ensure that future climate risks are considered in capital improvement projects for impacted B&T approaches with city and state entities.
Prepare for tidal flood impacts on bus operations	**Short Term** (≤5 Years)
	» In locations with chronic tidal floods, deploy alterative bus routes to avoid tidal flooding impacts on customers and buses during emergencies.
	Long Term (>5 Years)
	» Together with NYCEM and NYCDOT, consider route updates and stop relocations in anticipation of current and future tidal floods.

Goal 6: Mitigate Long Island Rail Road flooding

Challenges

The LIRR network traverses a wide array of geographies and topography, including waterfront coastal areas. Much of the system is either at-grade, in a below-grade open cut, or elevated on an embankment or viaduct structure and therefore exposed to the outdoor elements and extreme weather. These characteristics shape how climate risks impact the LIRR system.

Although a relatively small percentage of the overall LIRR system is or will be exposed to coastal flooding and sea level rise, several waterfront branches are extremely vulnerable.

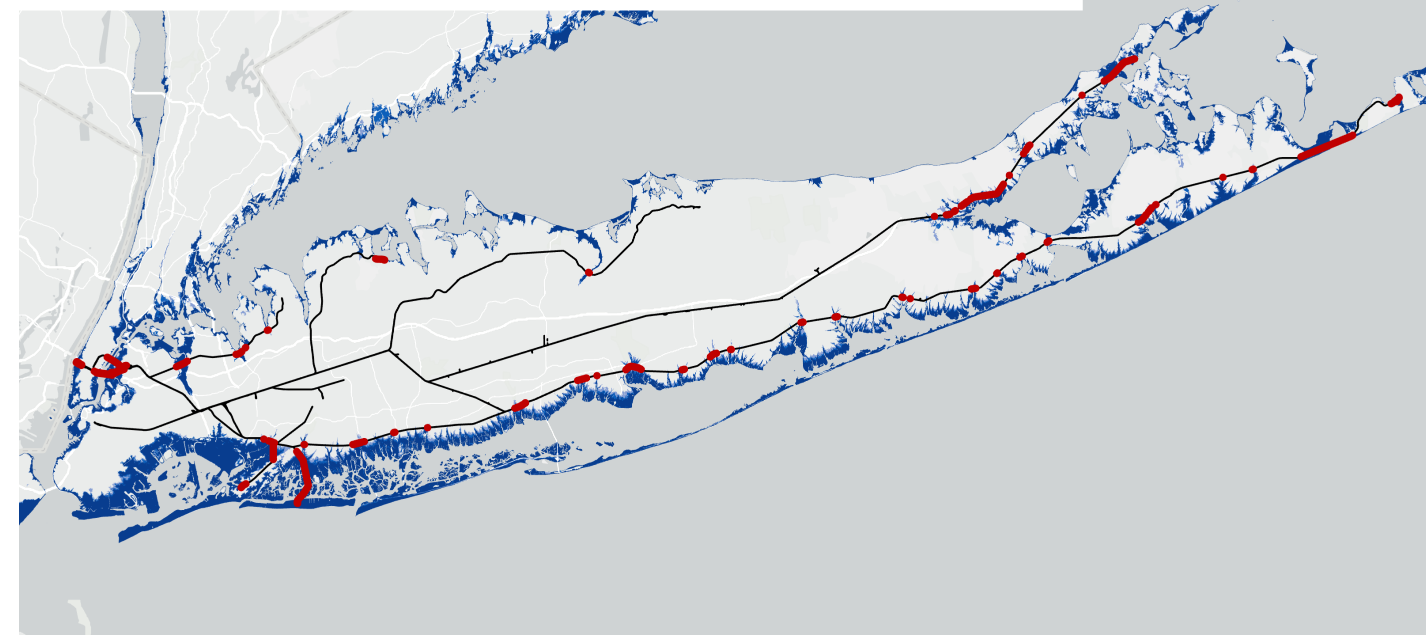
Coastal surge exposure:

	2020s	2050s	2080s
LIRR track miles (percentage of 700 miles total)	11%	12%	17%
LIRR stations (126 stations total)	13	14	21
LIRR yards (32 yards total)	11	14	17

Sea level rise/tidal flood exposure:

	2020s	2050s	2080s
LIRR track miles (percentage of 700 miles total)	1%	2%	5%
LIRR stations (126 stations total)	1	6	12
LIRR yards (32 yards total)	3	6	9

Long Island Rail Road: Coastal surge impacted tracks

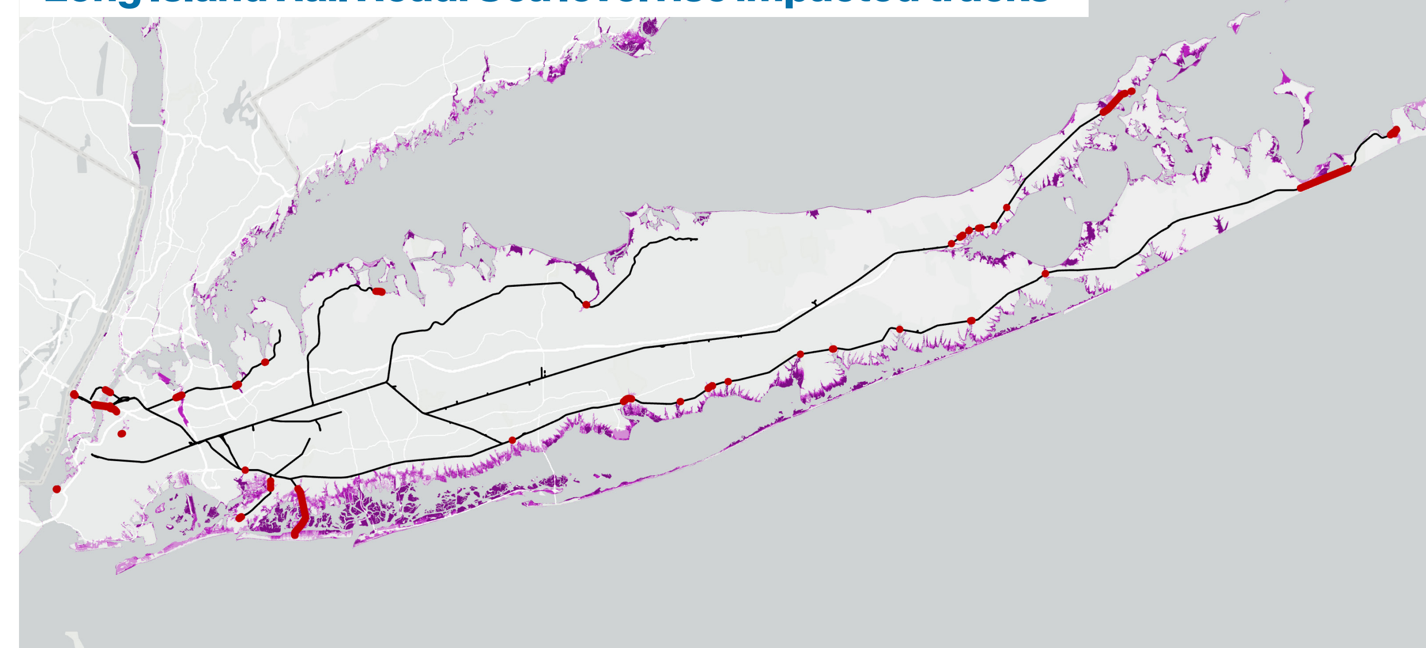


Coastal surge 500-year flood extent (NPCC, NOAA)

2020s 2050s 2080s

Track exposed to coastal surge by the 2080s

Long Island Rail Road: Sea level rise impacted tracks



Projected monthly tidal flooding with sea level rise (NPCC, NOAA)

2020s 2050s 2080s

Track exposed to monthly tidal floods by the 2080s

Coastal surge and sea level rise

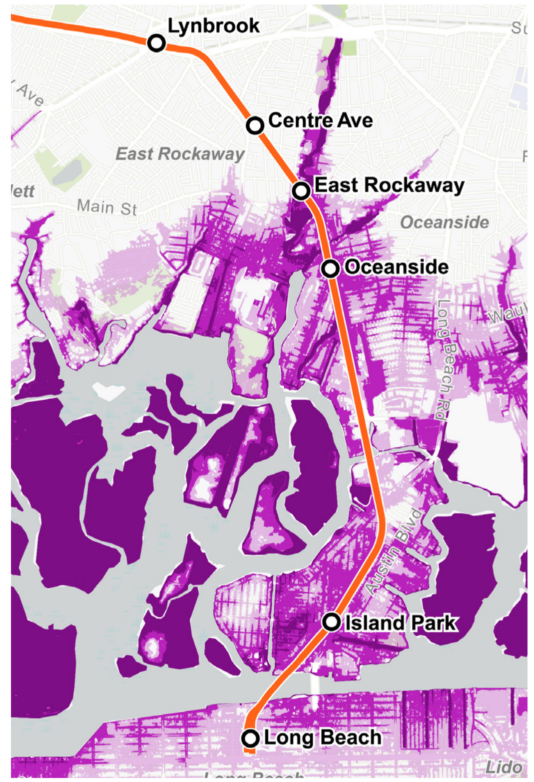
Long Beach Branch: In 2022, the Long Beach Branch served approximately 2.75 million riders, representing a 49% increase over 2021 ridership. The Long Beach Branch is one of the system's most at-risk routes. Approximately 60% of the nearly 8-mile route is in the coastal surge floodplain today. The branch is also currently vulnerable to flooding from torrential rainfall events, which interrupt service and damages assets and infrastructure.

With climate change and sea level rise, incidents of tidal flooding will grow, resulting in disruptions that will impact millions of riders. **By the 2050s, over 42% of the branch may be subject to chronic tidal flooding due to sea level rise.**

Far Rockaway Branch: In 2022, the Far Rockaway Branch served over 4 million riders, representing a 47% increase over 2021 ridership. The over 5-mile route faces a similar combination of flood risks as the Long Beach Branch. Over 23% of the Far Rockaway Branch is in the coastal surge floodplain today. By the 2080s, nearly 7% of the line may be subject to chronic tidal flooding due to sea level rise.

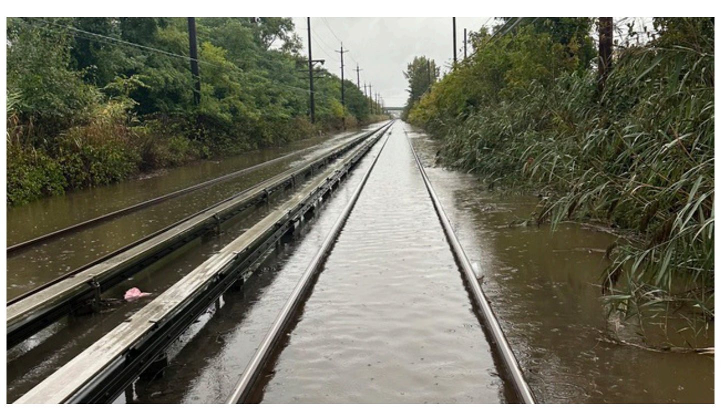
The high water table surrounding both the Long Beach and Far Rockaway branches contributes to present-day vulnerability to flooding during torrential rainfall events, particularly during high tide. This kind of flooding is anticipated to increase as sea levels rise.

Sea level rise impacts along the Long Beach Branch



Projected monthly tidal flooding with sea level rise (NPCC, NOAA)

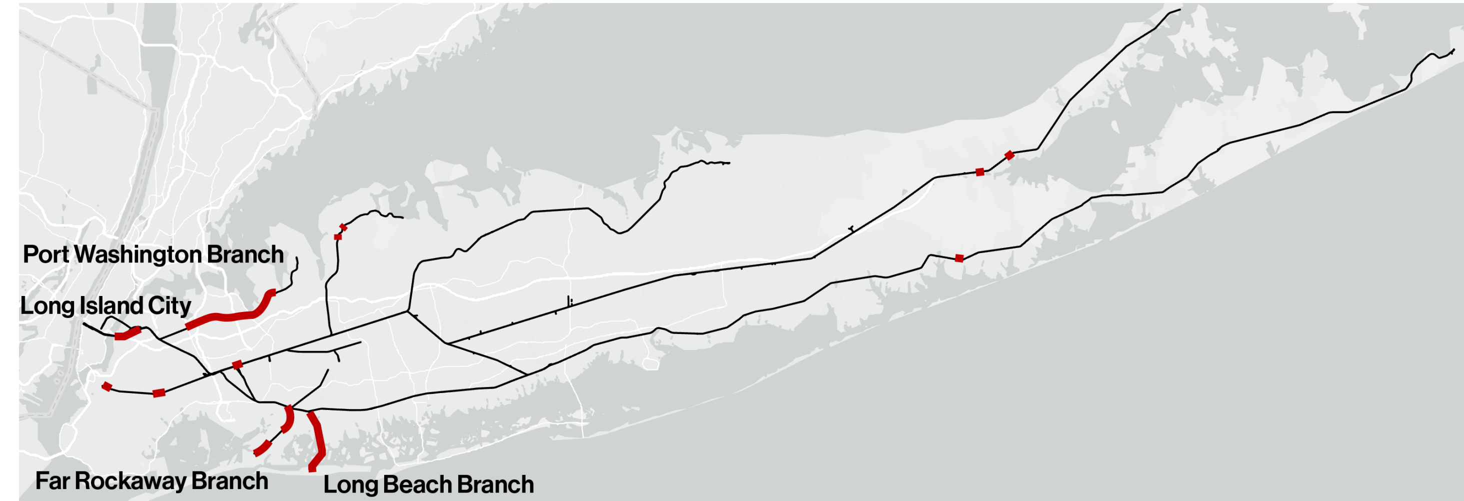
- 2020s
- 2050s
- 2080s



Long Beach Branch flooding from Tropical Storm Ophelia on September 29, 2023.

Far Rockaway Branch flooding from Tropical Storm Ophelia on September 29, 2023.

Long Island Rail Road: Recent stormwater flood impacts



Location with stormwater flood impacts during one or more recent torrential rain events since 2018.

Torrential rain

Port Washington Branch: This 14.6-mile long route runs between Woodside and Port Washington stations and connects with the City Terminal zone to provide service along a densely populated corridor between Midtown Manhattan and communities in Queens and northwestern Nassau County. Despite its relative short distance, in 2022, the branch served 8.3 million riders, accounting for 16% of LIRR riders. The Port Washington Branch is also an important part of the regional transit network since it provides alternative service for subway riders when there are disruptions to the Flushing 7 Line.

Stormwater from torrential rain cascades into Great Neck Station, August 2017. Credit: John Jung.

The Port Washington Branch is vulnerable to torrential rain. **Much of the branch is either at-grade or in a below-grade open cut, meaning that stormwater from nearby streets and properties flows into track and stations if local stormwater drainage infrastructure is overwhelmed or insufficient.** During Tropical Storm Ida, historic amounts of rainfall resulted in considerable disruptions along the Port Washington Branch, with notable flooding at Murray Hill, Bayside, Douglaston, and Great Neck stations. At Great Neck, large volumes of stormwater cascaded from the streets down stairways and into the station and platform. At Douglaston, excessive stormwater flowing towards the tracks caused a washout east of the station. During Hurricane Henri on August 21, 2021, severe flooding in the Great Neck Station resulted in the suspension of service and required the deployment of buses to supplement service between Port Washington and Bayside stations. During a torrential rainfall event on August 8, 2007, stormwater flooding reached the platform edge of the Bayside Station, resulting in the suspension of service.

Washout from torrential rainfall flooding near Bayside on the Port Washington Branch from Tropical Storm Ida, September 2023.

Long Island City area facilities: Yards, shops, and stations in Long Island City, including Hunterspoint Avenue station, Hunterspoint Ave Yard, and Midday Storage Yard are vulnerable to flooding from coastal surge and torrential rainfall. These facilities are in locations with a high water table and in close proximity to the tidally-influenced Newtown Creek and East River; the impacts of this are seen at Hunterspoint Avenue, where the right-of-way south of and leading to the station floods during torrential rainfall events.

During Tropical Storm Ophelia, flooding at Hunterspoint Avenue and Borden Avenue necessitated the de-energization of the third rail and deployment of mobile pumps. These flood risks will grow with sea level rise. For example, the growing extent of tidal flooding may necessitate the regular deployment of coastal surge protections currently under construction at Long Island City Yard.

Portable pumps deployed to mitigate torrential rainfall flooding near Hunterspoint Ave right-of-way during Tropical Storm Ophelia, September 29, 2023.

Progress to date

Coastal surge and sea level rise

Post-Sandy, the MTA reconstructed and raised substations along the Long Beach Branch.

Elevated equipment along the Long Beach Branch at Island Park Station.

Superstorm Sandy demonstrated the devastating impact of coastal surge on LIRR infrastructure. To date, the MTA has made over $240 million in Sandy restoration and resilience investments across LIRR. Over $120 million has been dedicated specifically to the Long Beach Branch, which sustained severe coastal surge flood damage from Superstorm Sandy. The MTA restored and elevated critical signal and communications system components to increase long-term service reliability and mitigate against future storm surge damage. Additional work to rebuild and elevate three Sandy-damaged substations at Oceanside, Oil City, and Long Beach has improved reliability and resilience in the face of future extreme weather events.

The MTA has also completed Post-Sandy restoration and resilience work on the Wreck Lead Bridge systems, the Long Island City Yard substation, power and signals in West Side Yard, and upgraded pumps and infrastructure inside the Atlantic Avenue Tunnels. Work is currently advancing to install flood barriers for Long Island City Yard, West Side Yard, and the East River Tunnels Queens Portals. These investments help protect critical, coastal surge-vulnerable assets and systems.

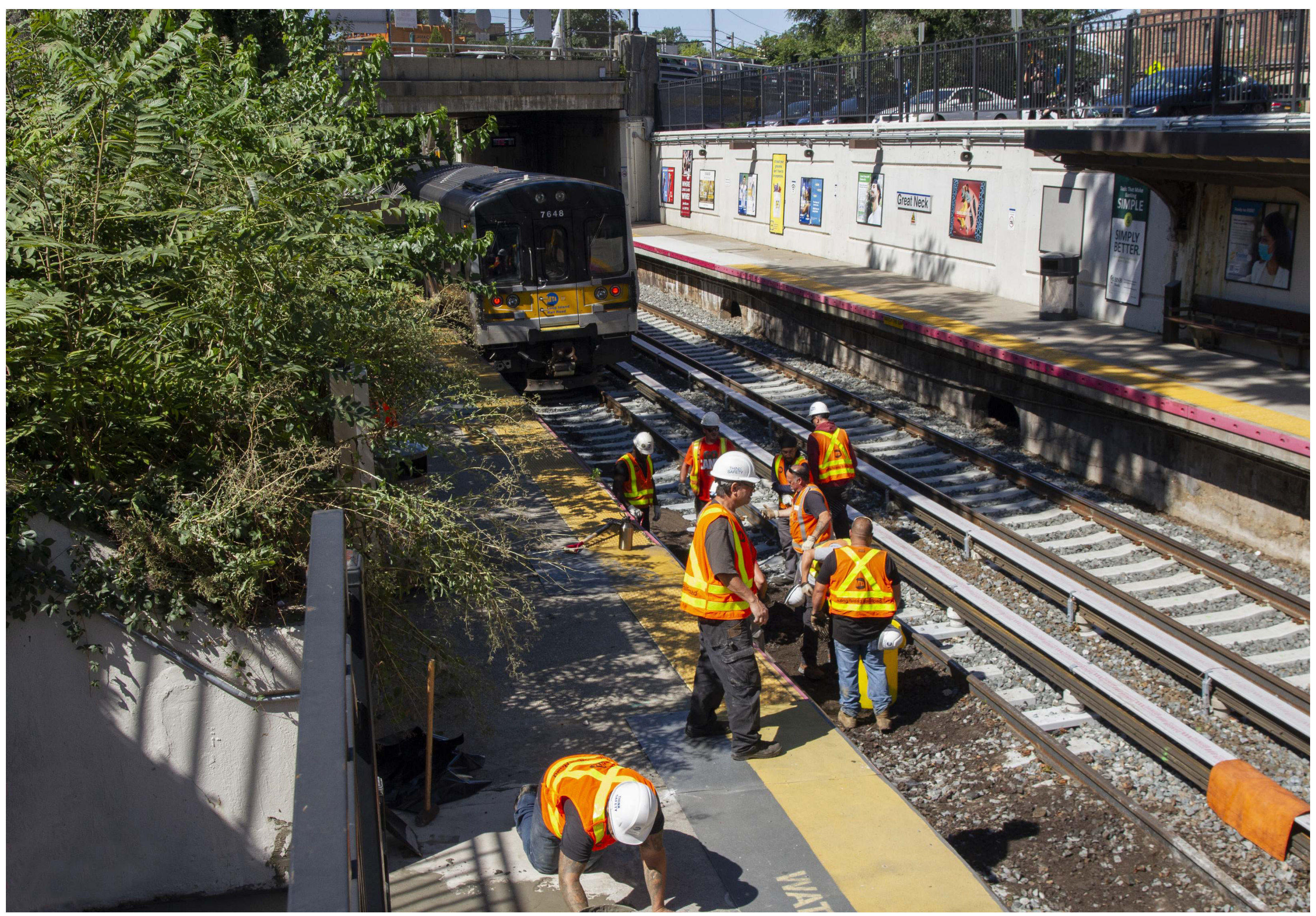
Investments in infrastructure improvements can also have resilience benefits by providing operational flexibility and redundancy during extreme weather events. The modernization of Harold Interlocking in Queens, the busiest rail interlocking in the country which serves the LIRR's Main Line and Port Washington Branch, as well as Amtrak's Northeast Corridor, will reduce congestion, create redundancy to critical tunnels and infrastructure, and provide flexibility during major extreme weather events.

Torrential rain

Sandy investments to elevate critical assets have also reduced the extent of torrential rainfall flooding damage on infrastructure, however much of right-of-way remains vulnerable to rainfall flooding.

While flooding incidents can result in temporary service disruptions, since Sandy, the LIRR has also invested $30 million in emergency response and management equipment, including portable pumps, generators, and extreme weather response equipment that are deployed to locations with flooding after the storm abates, enabling LIRR to resume service quickly.

In response to flooding along the Port Washington Branch, the MTA has partnered with NYCDEP to examine existing stormwater drainage and potential mitigation measures at in-city locations such as Murray Hill, Bayside, and Douglaston, which were impacted by flooding during Tropical Storm Ida. The below-grade nature of stations like Murray Hill and Bayside makes these locations particularly vulnerable to deluges of rain that flow towards localized low spots. As a result of this analysis, LIRR has increased pre-storm drain cleaning, monitoring, and inspections, but additional stormwater mitigation actions are needed to address these risks.



Repairs and clean-up of the Port Washington Branch Great Neck Station after Tropical Storm Ida, when torrential rainfall led floodwater and debris to cascade into the open cut right-of-way and station, impacting tracks and service.

Actions

Goal 6: Mitigate Long Island Rail Road flooding

Estimated Cost: **$500M - $1B**

Strategy	**Short Term** (≤5 Years)	**Long Term** (>5 Years)
Install protections from sea level rise and torrential rainfall flood risks along the Long Beach and Far Rockaway Branches	» Coordinate with local communities on community-wide resilience protection plans to mitigate flooding (i.e. City of Long Beach's Critical Infrastructure Flood Protection Project), as the climate risks that threaten LIRR also impact the communities these branches serve. » Identify appropriate floodproofing and/or elevation of vulnerable areas, prioritizing locations susceptible to tidal flooding in the next 20 years, and sized to dovetail with local resilience plans.	» Implement feasible floodproofing measures. » Upgrade undersized drainage infrastructure.
Address torrential rainfall risks along the Port Washington Branch and in the Long Island City area	» Design enhancements of drainage systems at impacted stations and low-lying tracks » Coordinate with NYC DEP to resolve city sewer bottlenecks that require cleaning catch basins and siphons to prevent runoff or backups into the LIRR system.	» Implement feasible drainage improvement measures. » Coordinate with local government and private property owners to reduce runoff into the LIRR Right of Way. This includes examining local street geometries, identifying opportunities to install curbs, and increasing upstream stormwater retention.

Goal 7: Reduce Metro-North Railroad flooding

Challenges

Similar to LIRR, the majority of the Metro-North Railroad (MNR) system runs adjacent to and across bodies of water including the Hudson River, Bronx River, and the Long Island Sound, creating significant vulnerabilities to flooding.

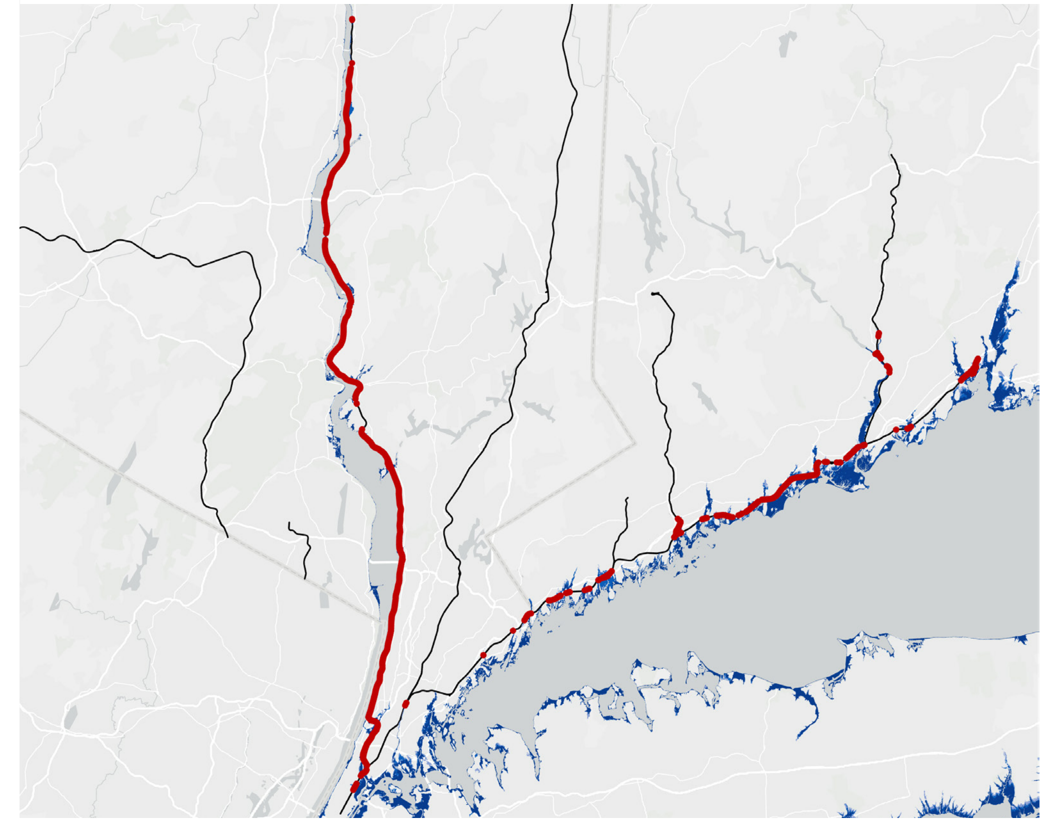
Coastal surge exposure

	2020s	2050s	2080s
MNR track miles (percentage of 900 miles total*)	17%	20%	35%
MNR stations (85 stations total)	31	34	38
MNR yards (19 yards total)	4	5	6

Sea level rise/tidal flood exposure

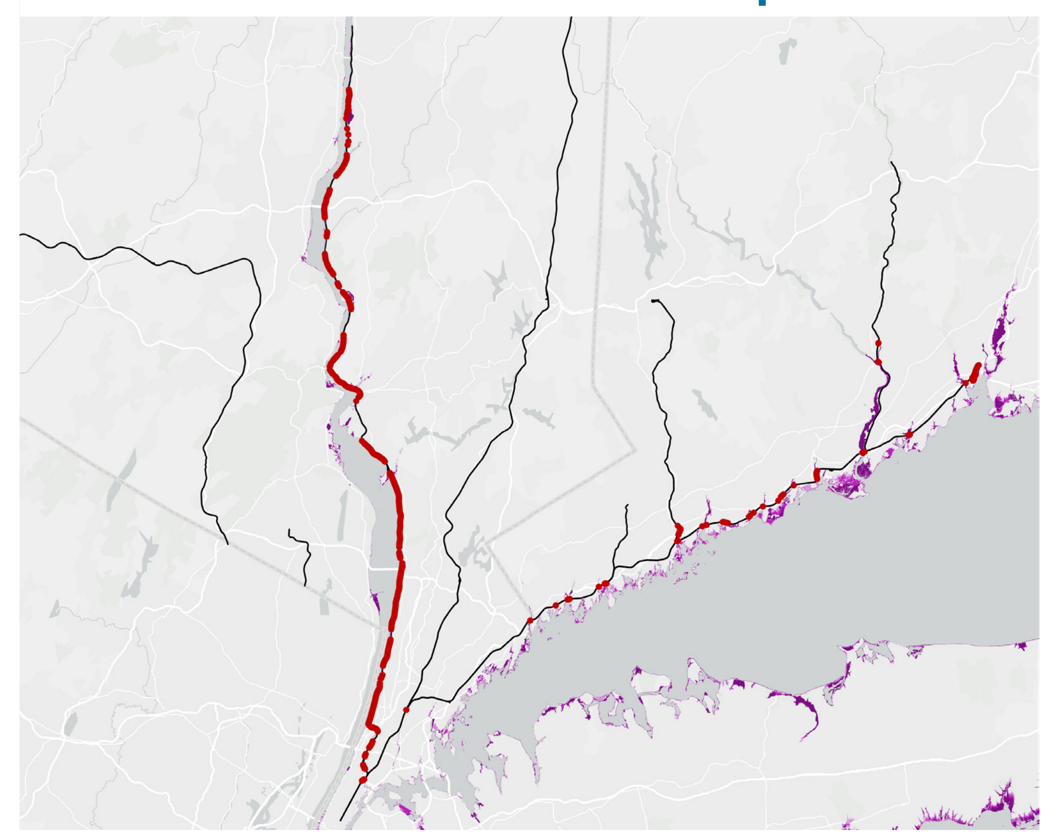
	2020s	2050s	2080s
MNR track miles (percentage of 900 miles total)	1%	5%	15%
MNR stations (85 stations total)	11	14	25
MNR yards (19 yards total)	5	6	6

Metro-North Railroad: Coastal surge impacted tracks



Coastal surge 500-year flood extent (NPCC, NOAA)
- 2020s
- 2050s
- 2080s
- Track exposed to coastal surge by the 2080s

Metro-North Railroad: Sea level rise impacted tracks

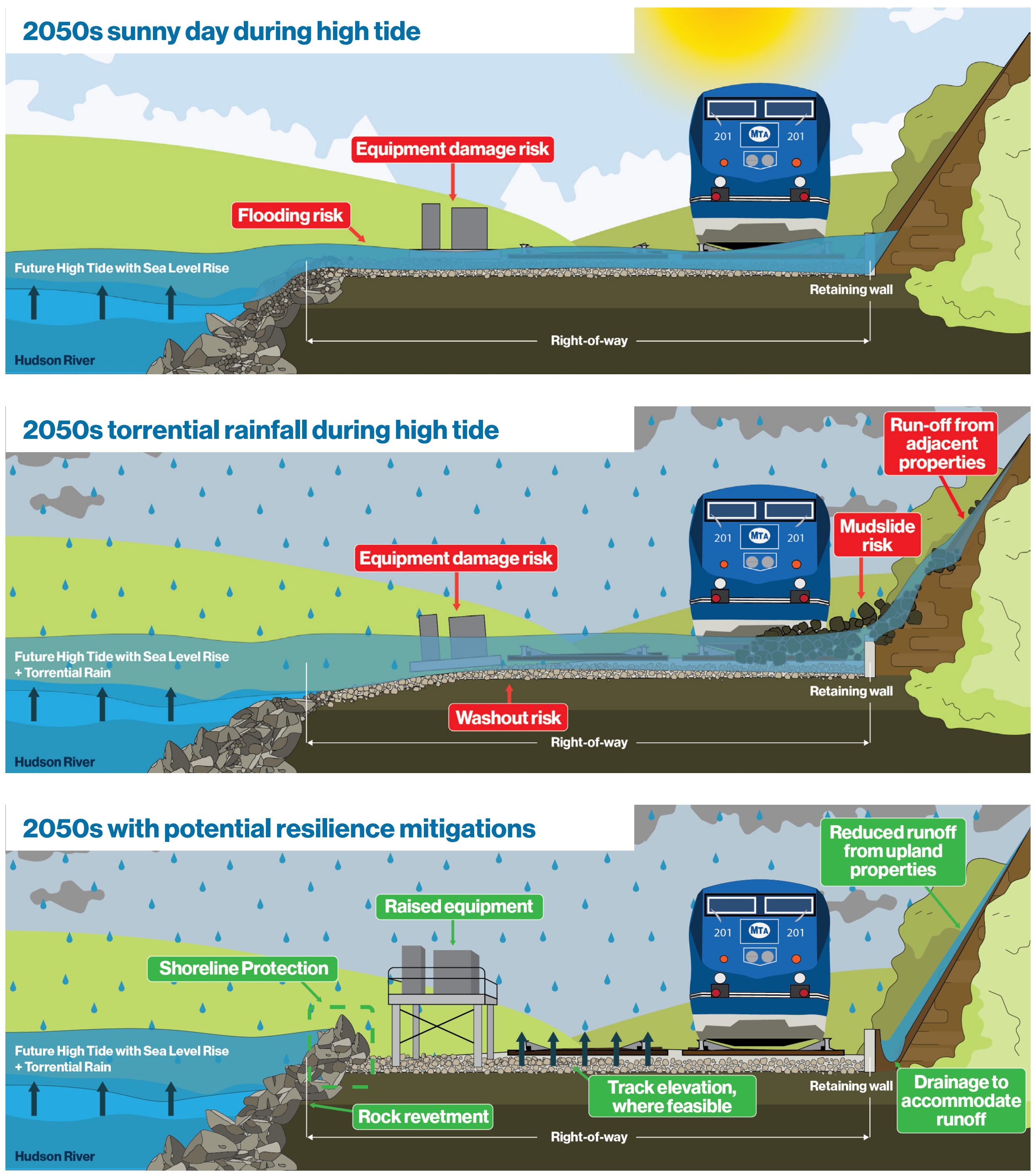


Projected monthly tidal flooding with sea level rise (NPCC, NOAA)
- 2020s
- 2050s
- 2080s
- Track exposed to monthly tidal floods by the 2080s

Coastal surge and sea level rise/tidal flood

Hudson Line: The Hudson Line's proximity to the Hudson River brings increasing flood risk. Over 50% of this approximately 74-mile-long route is currently vulnerable to coastal surge risk during coastal storms like hurricanes. This number will grow to 80% by the 2050s as sea levels rise and coastal storms become more frequent and intense due to climate change.

For 10 million annual Hudson Line riders, that means more risk of service delays as storms and chronic flooding get worse in the coming decades. It will also impact riders on Amtrak and freight deliveries carried by CSX, as both services rely on portions of the Hudson Line.



If we don't take action, sea level rise and torrential rainfall will pose severe threats to the Hudson Line.

Sea level rise will lead to higher tides and chronic tidal flooding along the Hudson Line right-of-way. By the 2050s, nearly one-sixth of all Hudson Line tracks will be subject to monthly high tide flooding. Without proactive mitigations, sea level rise accelerates shoreline erosion and enables smaller, routine storms to result in more extensive flooding. These higher tides can also reduce the functionality of existing gravity-dependent drainage systems, further exacerbating flooding.

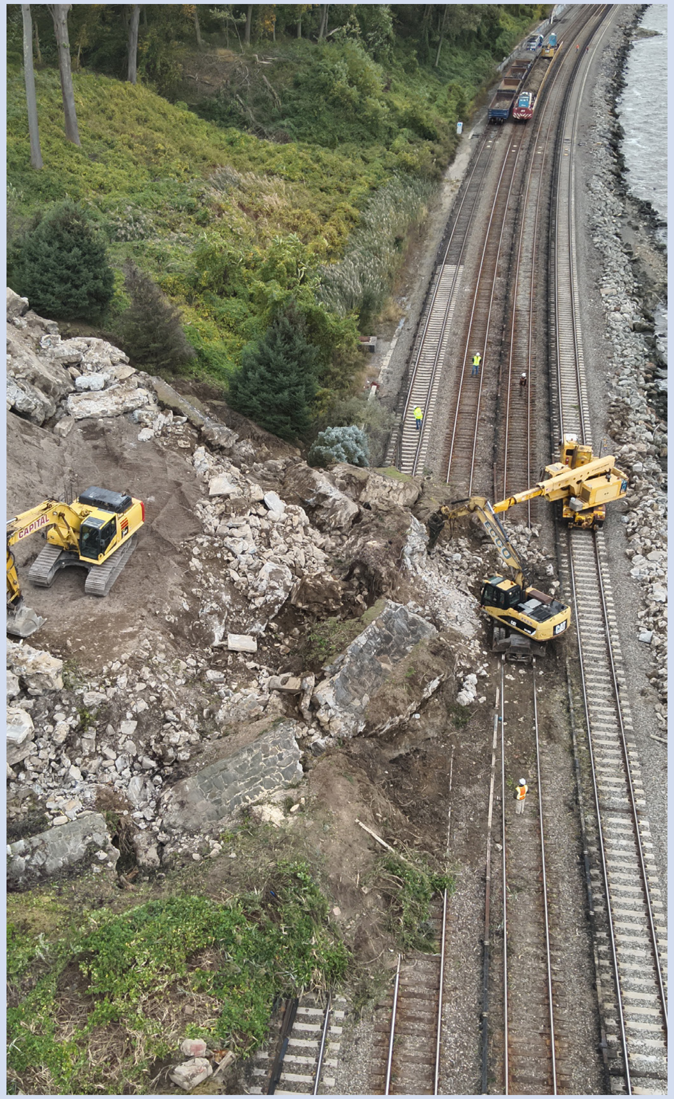
The Hudson Line is also vulnerable to torrential rain flooding in low-lying areas with insufficient drainage or near riverine locations. Such flooding can be difficult to clear depending on available pumps and existing stormwater management infrastructure, which may be undersized for draining torrential rain levels. The volume and force of floodwaters can weaken and damage culverts, embankments, ballast, and wood ties which are critical to track stability, and safe and timely train operations.

Flooding from Tropical Storm Ida washed out a culvert and the ballast supporting tracks at Dobbs Ferry, September 2021.

Torrential rains exacerbate landslide risks

Approximately 41% of MNR's track systemwide is adjacent to steep slopes, making the system vulnerable to landslides during torrential rain events. On October 21, 2023, the failure of a private retaining wall uphill of the Hudson Line brought over 350 cubic yards of soil and plants and 250 cubic yards of rock and cement wall debris tumbling down across all four tracks of the line. With tracks and third rail buried, service was halted on MNR's Hudson Line and Amtrak service to Albany. After the retaining wall collapsed early on Saturday, crews worked around the clock to remove debris from the tracks and restore service by rush hour on Monday morning.

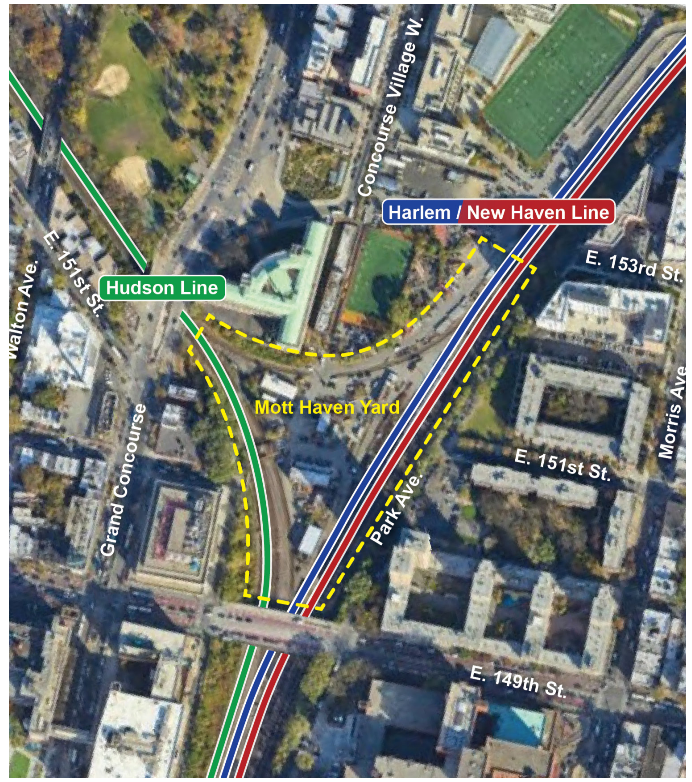
More frequently, rain and wind from storms topples trees and carries debris onto the right-of-way, disrupting service and damaging assets. From 2021 through 2023, MNR reported approximately 480 incidents of downed trees along the right-of-way. Responding to these events requires the deployment of significant resources on short notice, including staffing and funds. These incidents highlight the challenges extreme weather and proximity to steep slopes have on MTA infrastructure and service.

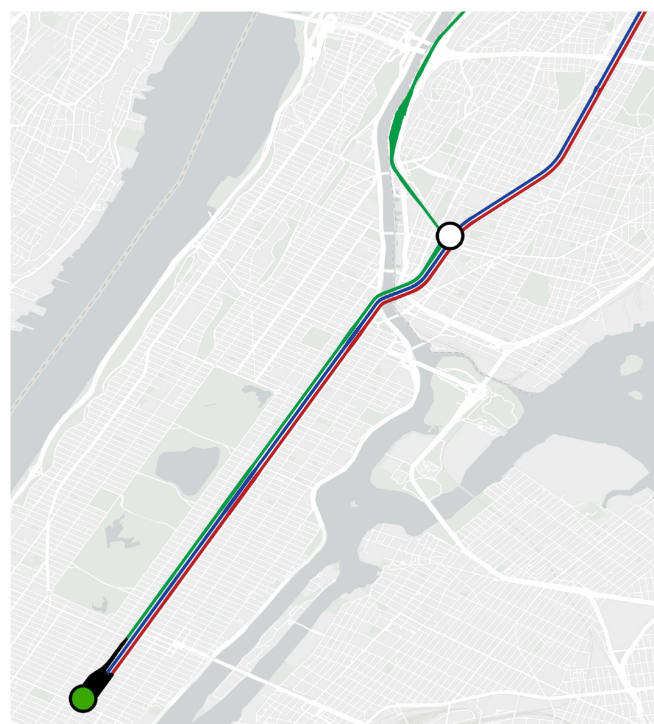


Torrential rain

Mott Haven Yard: Mott Haven Yard is a critical junction for MNR service where the tracks for all three East of Hudson lines (Hudson, Harlem, New Haven) converge to facilitate movement into and out of Grand Central Terminal. **Flooding here can impact all three East of Hudson lines, which carry approximately 98% of all MNR riders.** This nearly nine-acre facility also houses employee facilities, support vehicles, and critical substations.

The yard is prone to severe flooding from torrential rain due to its low-lying topographic nature and location. **The yard flooded at least 13 times between July 2016 and October 2023.** While the level and duration of flooding, service impact, and damage to assets has varied, the frequency of flooding has increased, highlighting the increasingly vulnerable nature of this yard in the face of climate change. In 2023 alone, the yard flooded four times. Impacts varied from slower service due to trains operating with speed restrictions as floodwaters approached the running rail, to the complete suspension of service along all three lines that pass through the yard from Grand Central Terminal to the Bronx. The accumulation of floodwaters also increases the chance of train derailment within the Yard as debris can block the tracks, lead to muddy conditions, or damage and weaken railroad ties. Depending on the severity of the event, full-service restoration can take many hours after flooding has subsided since equipment must be repositioned and signals and other equipment must be inspected to ensure safety.





Hudson Line

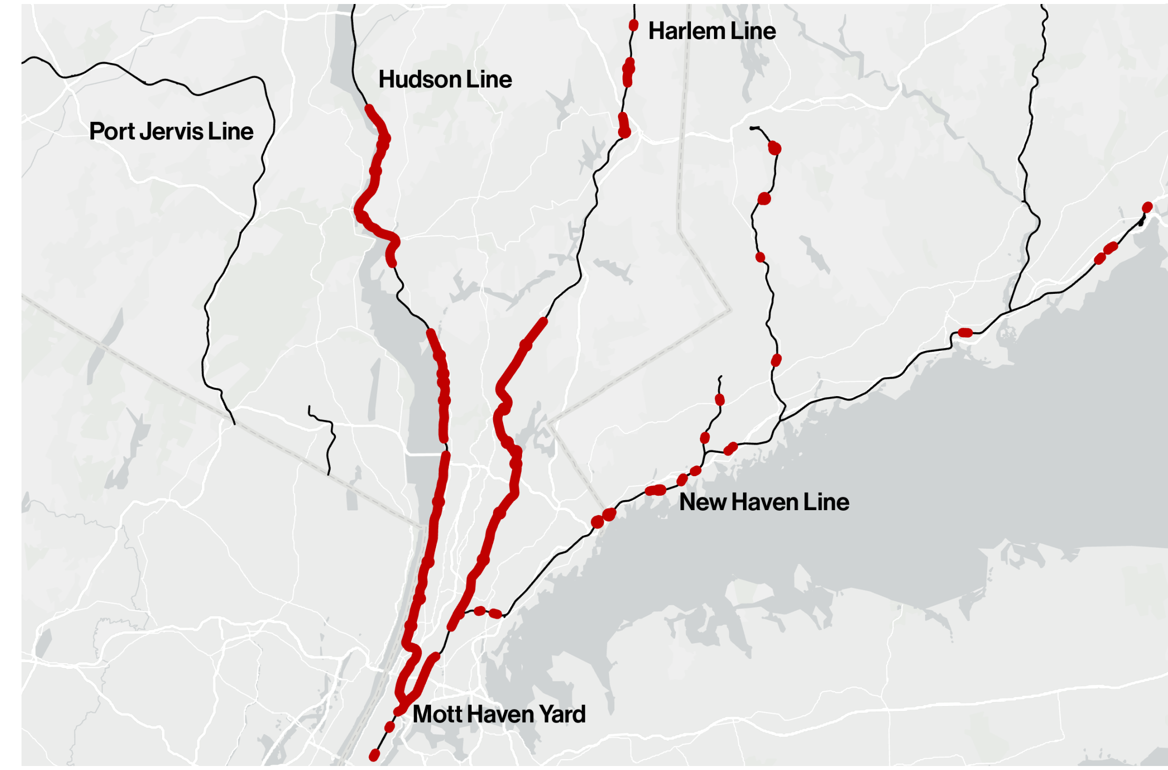
Harlem Line

New Haven Line

Mott Haven Yard

Grand Central Terminal

Metro-North Railroad: Recent stormwater flood impacts



Location with stormwater flood impacts during one or more recent torrential rain events since 2018

Flooding at a critical junction

On September 29, 2023, the remnants of Tropical Storm Ophelia dumped record-breaking rains in the New York City region and resulted in a state of emergency. At Mott Haven Yard, a high-water alarm sounded around 9:00am. **Within 30 minutes, floodwaters had risen approximately two feet**, rendering all tracks impassable. This resulted in the suspension of service from and to Grand Central Terminal on the Hudson, Harlem, and New Haven lines for over seven hours.

Harlem Line: Metro-North's Harlem Line is approximately 82 miles long, with 38 stations extending from Grand Central Terminal in New York City to Wassaic Station in Dutchess County, New York. In 2022, the Harlem Line served nearly 15 million riders, accounting for approximately 30% of all Metro-North ridership. **In addition to flooding challenges of its own, the Harlem Line also serves as the primary alternative route between New York City and Dutchess County when emergencies or other service disruptions occur on the Hudson Line.**

The Harlem Line's topography and low elevation increases its vulnerability to flooding during torrential rain events. Recent storm impacts demonstrate the disruptive and destructive potential of torrential rainfall. Tropical Storm Ophelia on September 29, 2023 resulted in a washout and damages to a signal cabinet, which houses the circuitry that controls signals mostly commonly located at at-grade crossings and interlockings. This resulted in no service north of North White Plains Station until the following morning. Just two months earlier, on July 10, 2023, a rainstorm resulted in scattered flood conditions and a washout between Harlem Valley-Wingdale and Dover Plains stations. Tropical Storm Ida in early September 2021 led to flooding, debris on track, and multiple washouts, including between Goldens Bridge and Purdy's stations, Mount Kisco and Chappaqua stations, and Valhalla and Mount Pleasant stations.

As storms become stronger and more frequent, the Harlem Line's risk will increase. Heavy rains reduce natural stormwater infiltration into the ground, as well as the capacity of existing stormwater drainage infrastructure, leading to more frequent and heavier floods and increasing the risk of mudslides and embankment washouts, which force service shutdowns and damages infrastructure.

Flooding north of Valhalla station during Tropical Storm Ophelia, September 2023.

Track washout south of the Dover Plains Station after heavy rain and flash flooding on July 10, 2023.

New Haven Line: Sea level rise and torrential rain will impact the New Haven Line, which runs close to the Long Island Sound. The average elevation of the New Haven Line, which carried 23 million riders in 2022, is higher than that of the Hudson Line, so the risks are less acute, however tidal flooding will become a growing challenge for the New Haven Line towards the end of the century. Resilience planning for at-risk segments of the New Haven Line in Connecticut will advance in coordination with Connecticut DOT.

Flooding at Pelham Station, July 2022.

West of Hudson lines: Port Jervis and Pascack Valley also face growing risks from torrential rain. Additional localized rainfall flooding data and modeling is required to better understand and map future flooding hotspots, however these lines have already experienced the kind of damage these events can bring. Hurricane Irene in late August 2011 brought high winds and over 10 inches of rainfall that caused major damage to the Port Jervis Line. Torrential rainfall caused the Ramapo River to overflow, washing away ballast and structures supporting MNR tracks near Sloatsburg and Tuxedo, resulting in tracks suspended approximately 7 feet in the air. Bridges and signal systems also sustained damage. Resilience planning efforts for the Port Jervis and Pascack Valley lines will be coordinated with NJ Transit.

Hurricane Irene caused significant damage and washouts along the Port Jervis Line, August 2011.

Progress to date

Coastal surge

Elevated equipment platforms protect critical equipment during flooding from a combination of high tide and storm surge on January 13, 2024.

MNR's Hudson Line sustained significant damage during Superstorm Sandy in 2012; over half of the right-of-way was flooded during the storm, resulting in significant damage to power, communications, and signal systems, amongst other assets. **The MTA has completed over $400 million in coastal surge mitigation investments to date**, targeted towards resilience measures for power, communications, and signals systems along 30-mile electrified portion of the line, from the Bronx to Croton-Harmon. These post-Sandy investments facilitate the ability of critical assets to withstand the impacts of coastal surge and recover more quickly once surge recedes.

Torrential rain

In the aftermath of Hurricane Irene in 2011, the MTA **restored the damaged Port Jervis Line and installed new culverts and retaining walls to improve drainage.** The new drainage structures channel stormwater underneath the tracks, so that stormwater does not flood over the tracks and wash away ballast. This system held up to Superstorm Sandy.

Heavy rain and high winds from Tropical Storm Ida washed out a 110-year-old culvert north of Dobbs Ferry station along the Hudson Line in 2021, disrupting and reducing service until the culvert could be replaced. The MTA built the reconstructed culvert with flood resilience in mind, ensuring that the new structure is wide and high enough to pass water underneath the tracks during major storms. The culvert was completed on budget and ahead of schedule and serves as a potential model for future culvert replacements.

In the aftermath of torrential rainstorms that result in washouts, such as one on July 9, 2023 that impacted the area near Manitou station, also on the Hudson Line, the MTA rapidly dispatched staff and resources to clean up debris, restore track, and replenish shoreline rock revetment to minimize impact to service.

The MTA is advancing flood protections for two critical substations within Mott Haven Yard that provide traction power and signal power by preventing water ingress to the substations via flood barriers and the sealing of wall penetrations.

A rebuilt culvert along the Hudson Line near Dobbs Ferry, March 2022. The area was washed away during Hurricane Ida.

Actions

Goal 7: Reduce Metro-North Railroad flooding

Estimated Cost: **> $1B**

Strategy	Short Term (≤5 Years)	Long Term (>5 Years)
Implement Hudson line resilience measures	» Stabilize steep slopes by analyzing conditions of retaining walls and rock slopes. » Mitigate shoreline erosion by conducting shoreline infrastructure inspections, with a focus on areas exposed to tidal flooding over the next 20 years. » Design and implement expansions of priority undersized culverts susceptible to near-term tidal flooding and torrential rainfall flooding. » Analyze and advance improvements of underperforming or insufficient stormwater drainage locations. » Assess and design floodproofing measures and/or elevation of critical assets and segments of right-of-way. This includes studying the elevation of shoreline structures, track raising, flood wall/flood gate installation and developing an implementation strategy that accounts for projected sea level rise through the end of the century. » Collaborate with local partners to investigate and mitigate flooding along the Hudson line.	» Fortify at-risk structures along steep slopes and the shoreline. » Expand culverts susceptible to torrential rainfall and future tidal flooding. » Implement feasible floodproofing measures.
Advance drainage improvements at vulnerable locations	» Design and implement Mott Haven Yard stormwater mitigation measures. » Design and implement expansions of priority undersized culverts along the Harlem line susceptible to near-term tidal flooding and torrential rainfall flooding. » Analyze and advance improvements of underperforming or insufficient stormwater drainage locations along the Harlem, New Haven, and Port Jervis lines.	» Continue implementing and monitor Mott Haven Yard stormwater mitigation measures. » Expand culverts susceptible to torrential rainfall and future tidal flooding.
Address flooding, runoff, and erosion risks by stabilizing and protecting vulnerable segments of right of way	» Stabilize steep slopes by analyzing conditions of retaining walls and rock slopes along the Harlem Line. » Assess and design floodproofing and/or elevation of critical assets and segments of right-of-way along the Harlem Line. » Collaborate with local partners to investigate and mitigate flooding along the Harlem, New Haven, and Port Jervis lines.	» Stabilize steep slopes by fortifying at-risk Harlem line structures and analyzing conditions of retaining walls and rock slopes along the New Haven and Port Jervis Lines. » Mitigate shoreline erosion by conducting shoreline infrastructure inspections along the New Haven Line. Rehabilitate structures at priority locations. » Implement feasible resilience measures. » Coordinate with regional partners, including the Connecticut Department of Transportation, on long-term New Haven Line sea level rise and stormwater resilience measures.
Expand understanding of how extreme weather impacts infrastructure and service	» Implement real-time extreme weather sensors through tools such as gauges and live video feeds, to expand data collection tools and provide information about flood conditions, triggers, and hotspots of runoff entering MTA rights of way.	» Develop localized future stormwater flooding data through collaborations with New York State, academic institutions, and/or commissioning of MTA-specific modeling and data for the West of Hudson Lines.

Goal 8: Expand underground air circulation and cooling

Challenges

Underground subway areas are often hotter than at the surface because of multiple heat sources resulting from subway operations, including warm air from train car air conditioning units, heat from the friction of train braking actions, and heat generated from communications and electronics equipment and the air conditioning units that keep this equipment cool.

During hot, humid days, all these elements contribute to uncomfortable conditions for customers and MTA employees in underground locations with limited air circulation. **And the number of hot, humid days is increasing: Days above 90 degrees are projected to increase three-fold between now and the 2050s.** Employees and customers with underlying health conditions may be especially impacted by extreme heat conditions in underground stations.

Additionally, chronic exposure to extreme heat can increase the likelihood that aging equipment will fail, resulting in diminished useful life across all asset types. This can also cause subway delays and equipment breakdowns.

Underground assets sensitive to prolonged extreme heat include:

Communications room equipment at 8 St- NYU Station R W

Communications rooms

Each subway station has a communications room with sensitive equipment that controls systems like fare collection and customer communications. Equipment inside communication rooms cannot function when exposed extreme heat for a prolonged time.

Maspeth Substation

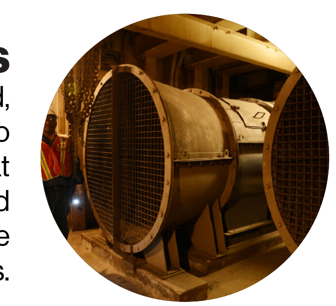
Substations

Substations provide power to the third rail that enables train movement. Extreme heat can reduce the electrical capacity of substations, causing subways to operate at reduced speeds.

Signal at Cortlandt St Station R W

Signals

Signals are electronic devices that control the spacing between subway trains and are vulnerable to voltage fluctuations caused when the electrical grid is stressed during periods of extreme heat.



Fan plants at 54th Ave and Vernon Blvd

Fan plants

Fan plants provide air ventilation across underground tunnels and, in case of fire, serve as smoke ejectors. Prolonged exposure to extreme heat conditions impacts sensitive control equipment that monitors tunnel ventilation. In the most extreme cases, prolonged heat exposure can cause these systems to fail, forcing service disruptions.

Switch at 14 St-Union Sq Station 4 5 6

Switches

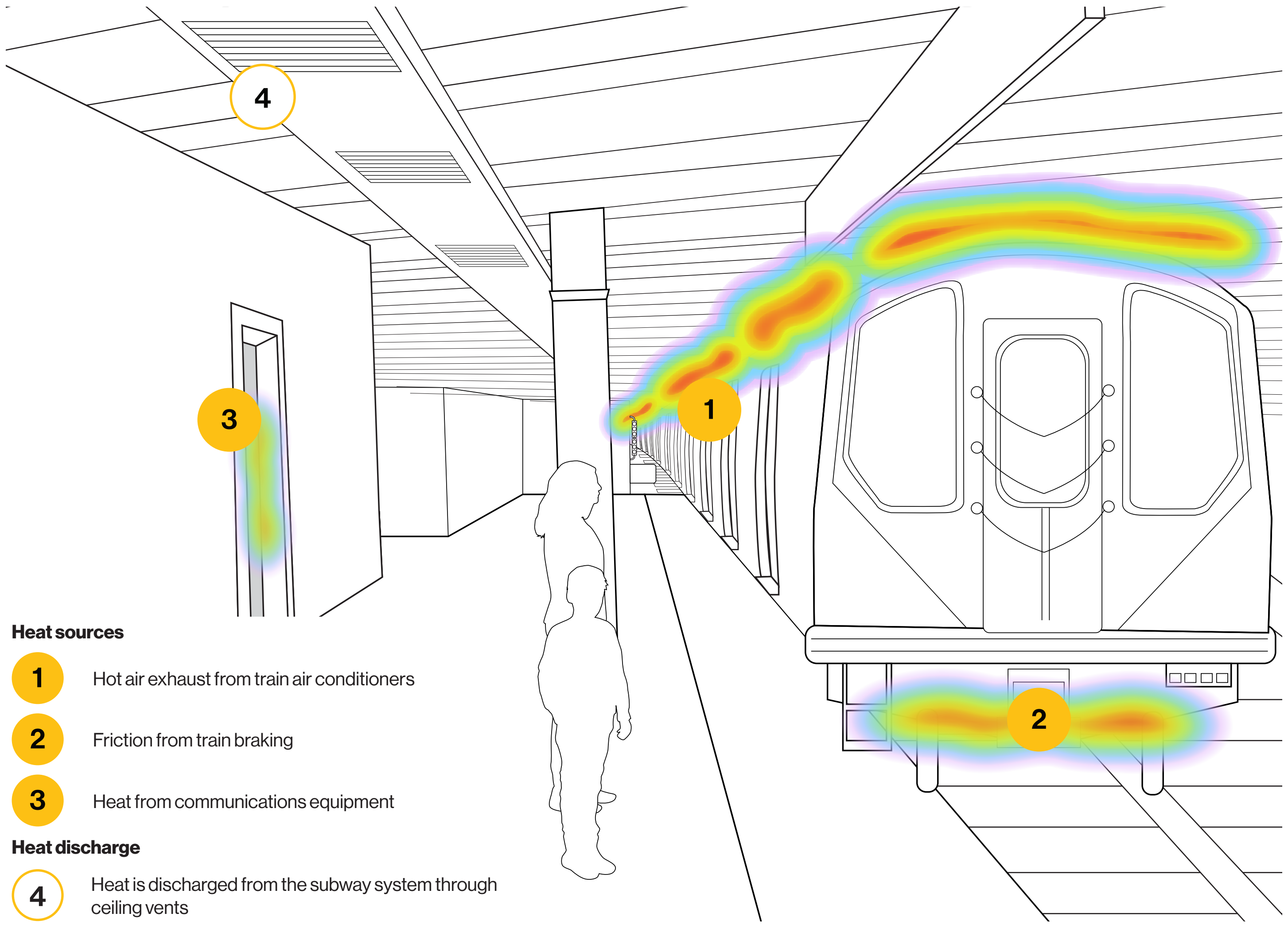
Switches enable movement of trains between tracks. Extreme heat can cause switches to expand and kink, hydraulic fluids to overheat, and increase the risk of failure from over-heated gears.

Platform at Court Sq Station G

Platforms

During the summer, particularly on days where temperatures reach 90 degrees or greater, subway platforms are often significantly hotter than the street level from train braking, train air conditioning units, and limited station ventilation.

Heat in underground subway stations



Heat sources

1 Hot air exhaust from train air conditioners

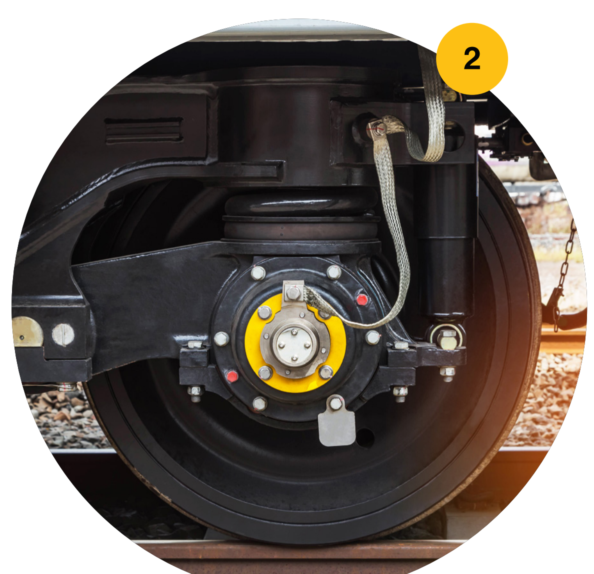
2 Friction from train braking

3 Heat from communications equipment

Heat discharge

4 Heat is discharged from the subway system through ceiling vents

Subway car air conditioning unit



Train brakes

Progress to date

Platform fan at the Wall St Station on the Clark St 2 3 Line.

Installing new cooling and circulation systems on platforms

Newer stations, including 34 St-Hudson Yards 7, those along the Second Avenue Line, and South Ferry Terminal 1, have been designed with integrated cooling technologies. Grand Central-42 St Station 4 5 6 has been retrofitted with air coolers.

Five stations have been retrofitted with fans above passenger platforms to improve air circulation including: Times Square Shuttle S, 14 St-Union Square 4 5 6, Grand Central 7, Wall Street 2 3, and Bowling Green 4 5.

Self-cooling data cabinet in the communications room at the Wall St Station on the Lexington Avenue 4 5 Line.

We have also **installed air conditioning in support locations** inside underground subway stations. These include areas where employees spend a significant amount of time, including staff locker rooms, station agent booths, and control towers, or areas that house temperature-sensitive equipment, including communication rooms and electrical rooms. However, some sensitive underground locations remain exposed.

Additionally, Communications Based Train Control (CBTC) is a new signal system that minimizes frequency of heat-generating accelerating and braking actions, dwell times, and stationary customer platform times. As CBTC is implemented, we can expect reduced heat from reduced braking action.

Exploring new tools to cool subway station platforms

The MTA is exploring ways to cool subway stations, particularly the passenger-occupied zones on platforms. We released a Request for Information (RFI) in September 2023 to solicit innovative and energy efficient approaches from the railway and technology community. Additionally, the MTA is keeping informed on innovations used by other transit organizations. For example, Transport for London (TfL) is piloting platform cooling panels that can be installed above the platform and circulate cold water in pipework within a metal structure, and a heavy-duty fan then circulates chilled air above the platform. The temperature reduction on platforms will vary based on site-specific characteristics, including the number of panels installed and design criteria.

Actions

Goal 8: Expand underground air circulation and cooling

Estimated Cost: **$50M - $250M**

Strategy	**Short Term** (≤5 Years)
Install air circulation equipment to keep hot air moving off plat-forms	» Explore installing platform fans in priority underground stations to improve circulation, where feasible. » Initiate circulation and ventilation study for feasible improvements that could reduce the amount of heat trapped in underground stations and tunnels. » Implement remote heat sensors to detect chronic extreme heat impacts, prioritizing locations like vulnerable underground platforms and systems.
	Long Term (>5 Years)
	» Explore installing platform fans in additional priority underground stations, considering feasibility. » Monitor complementary programs that may reduce heat added in stations and tunnels, including regenerative braking, sliding platform doors, and additional tunnel vents.
Pilot evolving platform cooling strategies	**Short Term** (≤5 Years)
	» Survey innovative approaches to reduce extreme heat impacts on subway station platforms, including results from the September 2023 Request for Information, and by monitoring platform cooling innovations being explored in other public transport systems. » Initiate design of a cooling strategy at a priority location.
	Long Term (>5 Years)
	» Install best and most sustainable approach to station cooling in stations most impacted by extreme heat events based on real-time temperature data collected in stations.

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Goal 9: Protect outdoor infrastructure from heat

Challenges

The Subway, Metro-North Railroad and Long Island Rail Road all have exposed outdoor rail infrastructure that can be damaged by prolonged exposure to extreme heat. Although heat rarely causes catastrophic breakdowns of infrastructure and system asset failures, it can cause safety concerns that result in service delays and shorten the useful life of equipment, potentially requiring more frequent replacements.

Track buckling along the MNR Hudson Line in July 2018

When exposed to extreme heat . . .

Tracks expand, causing buckling and misalignment. These conditions can cause service delays and speed restrictions due to safety concerns for customers and workers on trains running over compromised tracks.

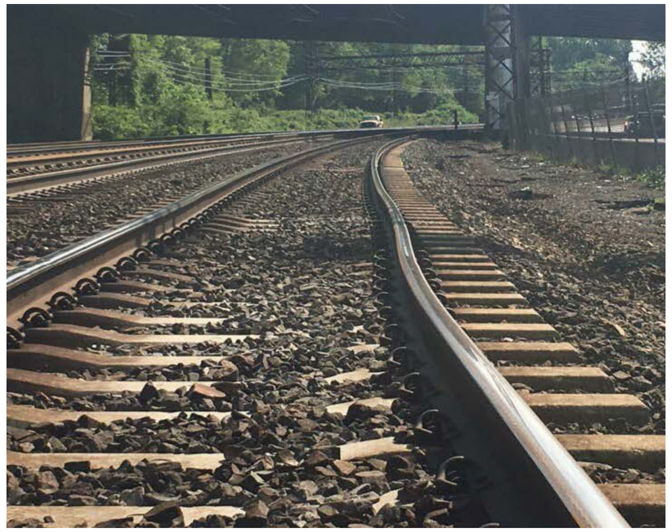
Switches can malfunction as their metallic components expand, potentially compromising the ability of trains to switch tracks safely. Extreme heat exposure could also overheat hydraulic fluids in switches and increase risk of failure from over-heated gears.

Substation power supply can become unstable. Substations regulate the electricity entering the rail system. Extreme heat events impact the electricity grid and could reduce the reliability of trains that depend on stable electricity supply.

Signals can malfunction, limiting the ability to control spacing between trains to prevent them from colliding. Extreme heat can cause the signals' metallic components to expand and overheat hydraulic fluids that enable movement of signal parts, preventing the signal from operating.

Progress to date

Heat patrols



A misaligned track along the MNR New Haven Line near Rye caused by heat conditions on May 18, 2017. This progressed to a heat kink in the rail, which contributed to a derailment.

NYCT Subways, LIRR and MNR deploy heat patrols during unusually hot weather and proactively increase track inspections and stage extra maintainers in key risk areas.

NYCT completes continuous welded rail (CWR) watches during prolonged heat when rail temperatures reach over 100°F to monitor for kinks or other heat impacts in designated areas. NYCT also deploys track geometry cars to identify rail issues.

As a precautionary measure, LIRR and MNR reduce train speeds during prolonged durations of hot weather and closely monitor power systems. MNR also increases patrols of overhead catenary wire on the New Haven Line.

Heat reflective rail paint

Application of heat reflective white paint along a curved section of rail near Rye on the New Haven Line.

In 2018, MNR tested the application of white reflective paint to reduce heat impacts after and a train derailment in Rye, New York the previous year. The paint application successfully reduced rail temperatures by up to 12 degrees and this track segment is now painted yearly.

This approach was expanded to the Walk Bridge in Norwalk, CT, where prolonged heat had caused rails leading to the bridge to expand, preventing the bridge from opening safely to allow for vessel passage. The regular application of white paint at this location successfully mitigates heat-related rail and bridge movement issues at the Walk Bridge.

Mitigating heat impacts on MNR catenary

Trains along the New Haven Line from Pelham to New Haven, and the entirety of the New Canaan Branch are powered through overhead electric wires called catenary. Prolonged heat can cause these wires to expand and sag, leading to service disruptions. The reduction of wire tension requires trains to slow down because of the reduced tension and risk of damage to the wires and pantograph arms, which extend from the top of the train cars to provide a connection to the overhead wires.

Connecticut DOT's upgrade of the catenary system along the New Haven Line to a constant tension system represents one way to manage the impact of extreme heat. The constant tension system incorporates counterweights and pulleys that act as dynamic balancers; this helps make the wires tighter during prolonged heat, or looser during extreme cold. In addition to making operations safer and more reliable, this updated system also reduces wear and tear on catenary infrastructure.

Catenary system counterweights help the system adust to temperature fluctuations.

Actions

Goal 9: Protect outdoor infrastructure from heat

Estimated Cost: **< $50M**

Strategy	
	Short Term (≤5 Years)
Pilot strategies to mitigate extreme heat on vulnerable outdoor track	» Identify and paint outdoor track segments most vulnerable to extreme heat exposure.
	Long Term (>5 Years)
	» Expand white paint treatment and reapplication to outdoor track segments exposed to extreme heat and establish regular rail painting program. » Focus on new heat-resistant materials to incorporate into new capital projects.
	Short Term (≤5 Years)
Improve real-time monitoring of heat conditions	» Install a network of temperature and expansion sensors that detect extreme heat impacts, prioritizing key vulnerable locations.
	Long Term (>5 Years)
	» Focus on emerging technologies and continue to monitor network of sensors.

Goal 10: Address heat and wind impacts on bridges

Challenges

Bridges are designed with temperature changes in mind – they have expansion joints that allow bridge structures to expand in hot weather in a controlled manner. However, during extreme heat events, bridge structures could expand beyond what the joint can absorb. Additionally, asphalt surfaces can melt and deform during extreme heat events. Asphalt and metal components expand during heat waves.

Extreme winds can cause tractor-trailers to tip over while they are crossing the bridge. Winds can increase the risk of bridge instability and lead to damaging conditions, like wind flutter. Wind flutter is when small motions of a bridge deck can extract energy from the wind and produce larger motions, threatening overall bridge safety.

A truck drives over an expansion joint on the upper level of the Verrazano-Narrows Bridge, as crews make repairs in 2015.

Progress to date

Wind fairings on the Bronx Whitestone Bridge.

Wind deflectors at the Verrazano-Narrows Bridge towers.

"Asphalt shoving" (the presence of small mounds or ripples in asphalt) typically increases drastically in periods of prolonged high temperatures. Shoving can weaken pavement and necessitate repairs, impacting customers. B&T uses rubberized asphalt material to reduce the frequency of shoving and mitigate this extreme heat impact.

B&T also has robust and proactive bridge preservation, inspection, and structural health monitoring systems. These are key to ensuring that bridge expansion joints do not buckle or crack from heat stress, particularly with higher average temperatures predicted in the future, which were not accounted for when the bridges were first built.

Additionally, B&T has improved air conditioning in equipment rooms to reduce potential overheating and failure of critical equipment and electrical systems.

B&T has also made significant investments in improving the aerodynamic and wind performance of facilities, including all four suspension bridges. B&T's overall strategy is to upgrade facilities to meet current wind design criteria, with a primary focus on the four suspension bridges where the risk of instability due to high wind events poses the greatest concern.

Actions

Goal 10: Address heat and wind impacts on bridges

Estimated Cost: **< $50M**

Strategy	**Short Term** (≤5 Years)
Reduce the impacts of heat and wind on bridges	» Pilot materials to reduce heat-induced expansion of bridge joints and asphalt pavements, including coatings and additives. » Continue existing temperature and extreme wind monitoring.
	Long Term (>5 Years)
	» Adopt piloted materials as the standard, pending pilot results. » Implement new temperature and wind sensor technologies, as they become available.

Next Steps

Keys to success

The Climate Resilience Roadmap follows on the heels of the 20-Year Needs Assessment and outlines specific capital needs for climate resilience in anticipation of the MTA's 2025-2029 five-year capital plan. **It is essential that we continue to prepare our transit infrastructure for the extreme weather that is already here.** Doing so means that we must transform our legacy transit infrastructure, so that it is resilient to future climate conditions.

Success will depend on resources

Our ability to address the needs identified in the Climate Resilience Roadmap will depend on the resources we have available. These include:

Sufficient funding

The urgency of climate change demands immediate action to keep transit services running into the future. The increasing frequency of disruptive extreme weather events will strain MTA operational resources, workforces, and budgets. **Our ability to act relies on adequate, timely, and sustained funding levels for capital construction and operational response and infrastructure maintenance.** Support from multiple municipal, state, and federal partners is vital to continue to prepare our infrastructure.

Flexibility

Even though the New York region benefits from high-quality risk projections, there are still many uncertainties associated with climate change. Unfortunately, the pace of climate change is occurring quickly and not all climate forecasts are immediately actionable by large infrastructure agencies like the MTA. **Adaptation will require flexibility underpinned by a dynamic and iterative approach.**

Public engagement and support

Reliable transit is an essential service, particularly during periods of extreme weather when customers have extra urgency to get to where they need to be. Acute events will inevitably be disruptive. Our overarching vision in advancing the Climate Resilience Roadmap is to minimize the impacts of extreme weather on transit services and to enable the system to recover as quickly as possible following a disruptive event.

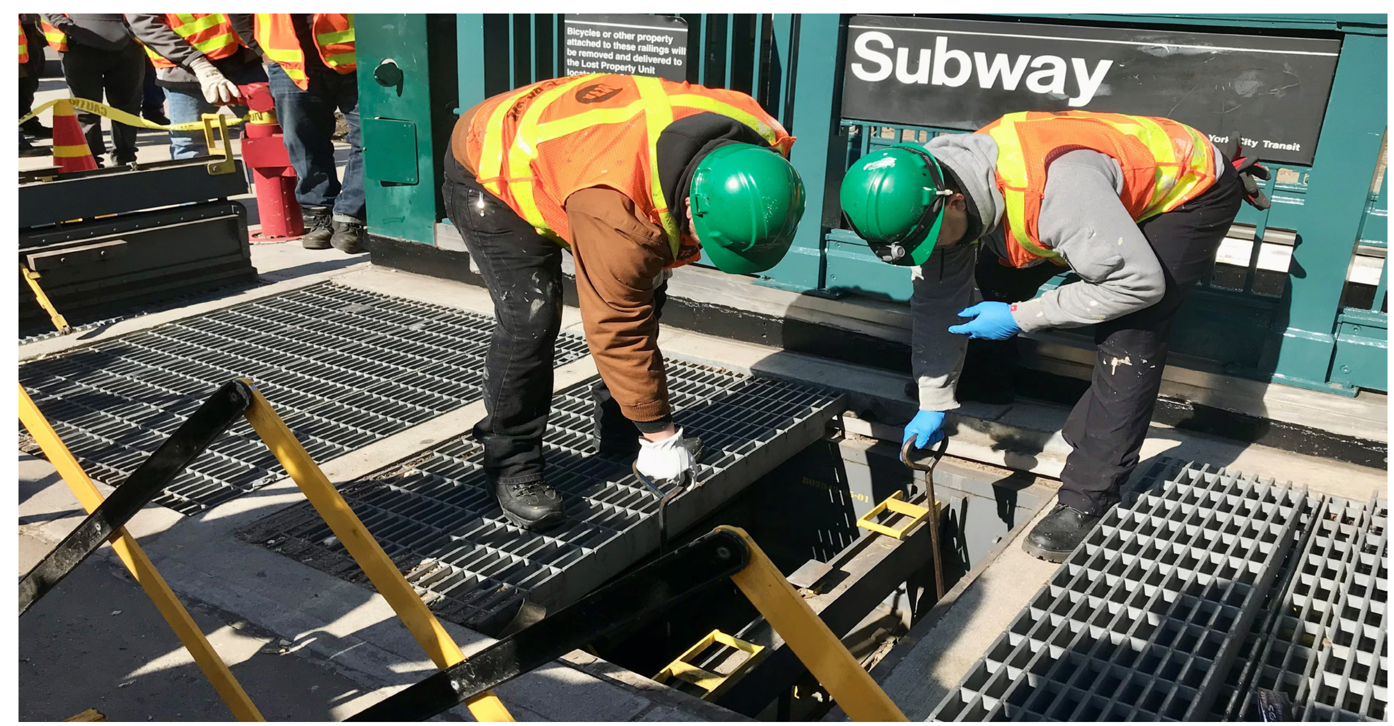
Our customers deserve to know what the MTA is doing to reduce the system's vulnerability to climate change. The Climate Resilience Roadmap is an important milestone in this journey. **Together with our customers, we will ensure that the New York region continues to thrive in the face of climate change.**

Implementation through multiple means

Preparing MTA systems for climate change will require an all-hands-on-deck approach, leveraging the contributions of virtually all parts of the organization. It will involve incremental strategies as we invest in individual pieces of equipment, but also larger protections that are themselves major capital projects. It will be a process that is never fully complete, requiring an ongoing cycle of assessment, preparation, monitoring and coordination across MTA agencies and external partners. The process will require flexibility and an openness to innovation, with solutions based on the best-available science to ensure responsible use of limited funds and human resources.

As the impacts of climate change effect our region into the foreseeable future, the MTA will employ four methods to implement the Climate Resilience Roadmap goals and strategies, including:

- **Capital Plan integration**
- **Resilient design practices**
- **Operating agency actions**
- **Partner agency actions**

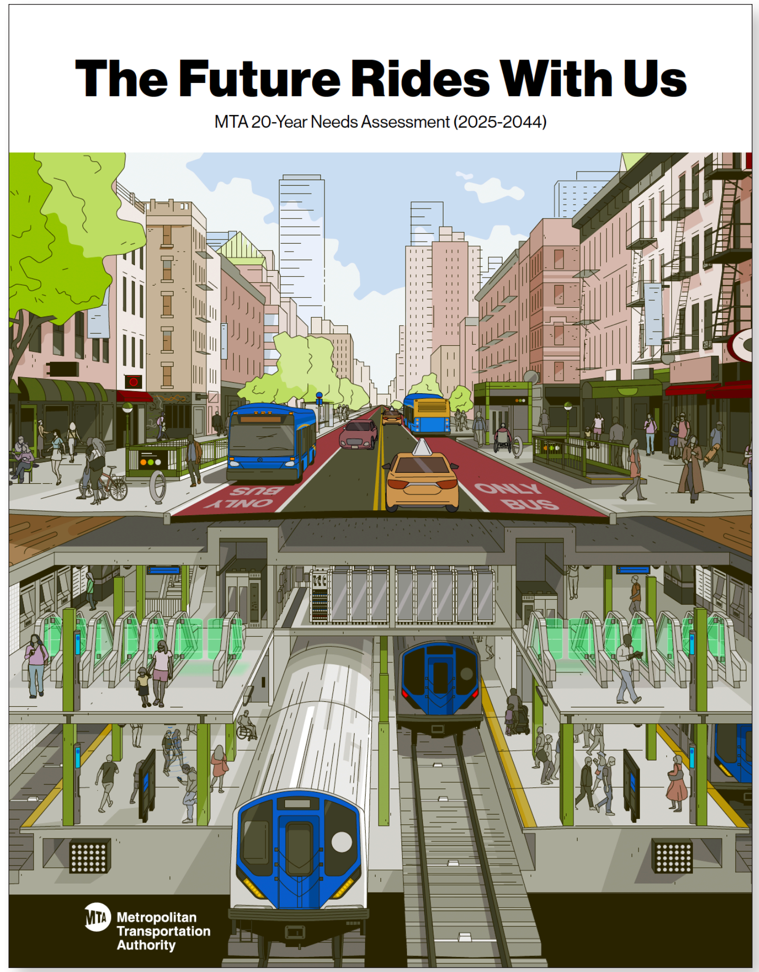


Testing coastal surge vent mechanical closure devices at 138 St-Grand Concourse Station on the 4 5, March 2023.

Capital Plan integration

In October 2023, the MTA released its 20-Year Needs Assessment, an outline of the MTA region's transportation capital needs for the next generation. Released every five years, the 20-Year Needs Assessment provides an extensive, long-term view based upon rigorous data analysis across all the MTA agencies. This most recent iteration highlights the urgency of climate resilience action as a principle to guide the MTA's upcoming capital programs.

The next stage in the MTA's capital planning process is the production of the 5-Year Capital Plan, anticipated to be released in Fall 2024. **As the MTA develops its detailed 5-year capital plans, climate resilience will be incorporated into:**



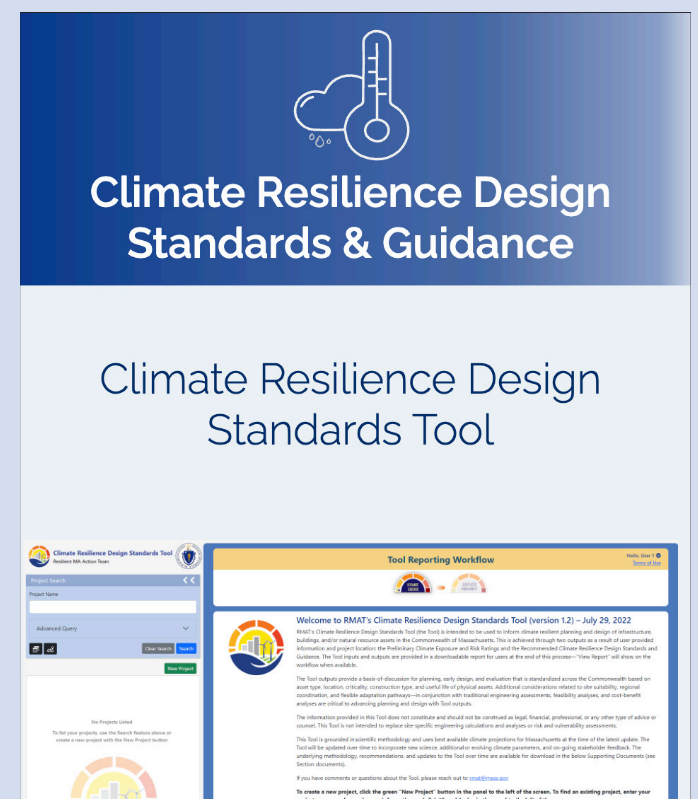
1. **Dedicated projects** to boost climate resilience, such as perimeter flood protection walls that represent a new piece of infrastructure. While these projects are likely to yield cost savings in the long-term by avoiding service impacts or catastrophic damage, they will likely require a capital expenditure which represents new needs for the MTA.

2. **"Integrated" state-of-good-repair upgrades** to thousands of individual assets and facilities that will incorporate climate resilience in the project scoping and design. These improvements may not appear as discrete climate resilience investments in a capital plan since they are necessary for the MTA to continue its normal operations but can achieve important climate resilience benefits with mindful planning. In addition, we will add scope for resilience protections in transit expansion projects to address climate risks to take advantage of construction efficiencies and minimize operational disruption.

Resilient design practices

As the MTA implements its capital projects, there is an opportunity to incorporate future-facing climate information as part of the conception and design. That includes accounting for future hazard exposures likely to occur within the useful life of the asset. Data on future sea level rise, coastal surge elevations, precipitation rates, wind gusts, winter weather snow loads, and temperature extremes will inform design of MTA infrastructure going forward.

Elevated equipment and platforms near MNR Croton-Harmon Yard.



Climate resilience design standards

The MTA is evaluating tools that enable project architects and engineers to incorporate climate change projections into the project design process. For example, Massachusetts has developed an easy-to-use online tool to standardize the use of climate projections for sea level rise/storm surge, extreme precipitation, and extreme heat in projects pertaining to infrastructure, building, and/or natural resource assets.

The tool prompts users to provide the project location, asset type, predicted life, and scope. When combined with geospatial data, the tool provides a preliminary climate exposure and risk screening, recommended climate resilience design standards, and guidance for how to use this information in project planning, design, and evaluation.

Operating agency actions

The MTA's operating agencies (NYCT, LIRR, Metro-North, B&T) are on the front lines of responding to extreme weather interruptions and play a crucial role in adopting and maintaining operating practices that complement the capital investments and actions spotlighted in this Roadmap. The operating agencies oversee much of the regular inspections and maintenance activities that support a safe and resilient infrastructure system, such as drain cleaning, pump maintenance, track inspections, retaining wall and slope assessments, and grouting.

The operating agencies are key to extreme weather preparedness and response. They coordinate in advance of storm events to closely monitor developing conditions and align on public-facing notifications and communications. Operating agencies also pre-position staff and equipment around the system to respond to issues ranging from flooding to downed trees, debris on right of way, and damaged infrastructure such as utility poles and crossing gates. They are the first to arrive at the scene of an extreme weather-related disruption to inspect and recover infrastructure to get service back up and running in a safe manner (Appendix B summarizes existing extreme weather emergency management practices). As such, they are a primary source of information regarding on-the-ground impacts of extreme weather-related service interruptions.

Crews prepare emergency response trucks and pumps in Downtown Brooklyn, September 2023.

Crews clear vegetation along the Sea Beach Line (N), September 2023.

The increasing frequency of impactful extreme weather events caused by climate change puts growing pressure on operating agency budgets as **unpredicted storm damage and response needs strain already limited operating resources.**

Operating agencies also maintain and deploy the MTA's growing suite of flood protection infrastructure, including flood barriers, mechanical closure devices and vent covers. Ensuring that operating agencies have adequate resources to properly test, maintain, and deploy flood protection assets is critical to maintaining a climate resilient system.

Partner agency actions

While MTA is committed to reducing the impacts of climate change on our transportation systems, the system is closely intertwined with the infrastructure, policies, and practices of external partners and utility providers. In many cases, **our infrastructure relies on other agencies' capital investments so that their own infrastructure is fully operational during extreme weather events** – for example, within New York City, we rely on Con Edison to provide electricity, on NYCDEP's sewers to drain water out of underground tunnels, and on NYCDOT to convey stormwater from the streets and sidewalks into catchbasins, rather than into the subway. In partnership with these agencies, we are investigating new operational and capital actions to reduce transit service impacts from extreme weather. For example, with NYCDEP, we are exploring neighborhood-scale drainage solutions in locations where MTA facilities are chronically impacted by stormwater floods from undersized sewers.

Our far-reaching system traverses many jurisdictions and is adjacent to hundreds of private properties. Without sufficient protections, stormwater from adjacent jurisdictions and properties can flow into our low-lying, open-cut rights-of-way, exacerbating the consequential impacts of torrential rain.

Successful climate adaptation will require ongoing engagement with all these entities. Going forward, we will continue existing partnerships with local utilities like NYCDEP. We will also coordinate with adjacent private property owners as they pertain to climate and flood impacts facing our rights-of-way.

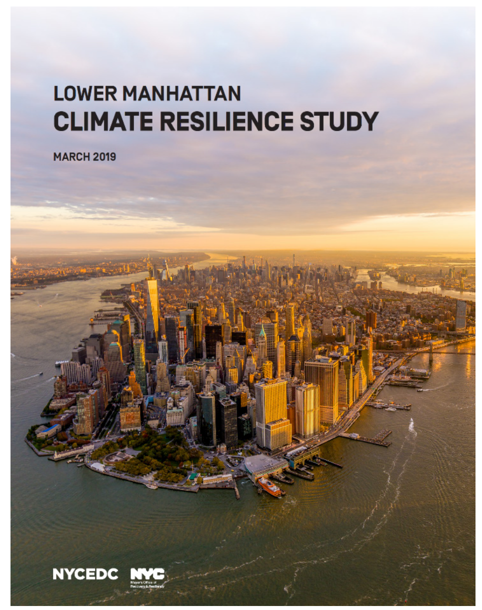
MTA meets with NYCDEP to discuss drainage at Mott Haven Yard, February 2024.

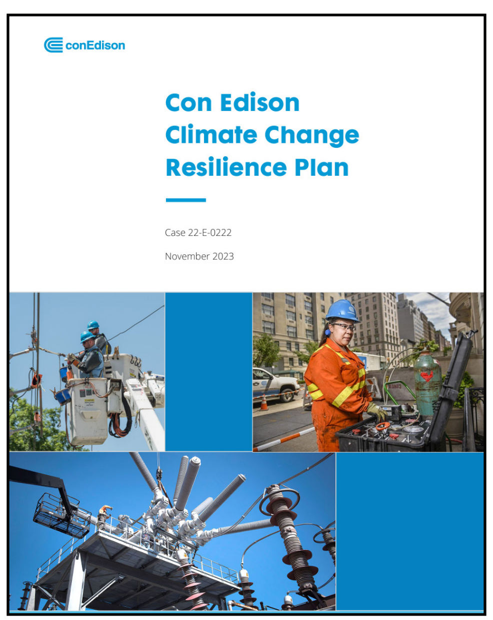
Climate resilience projects across the New York region

Many MTA partners are advancing community-scale resilience initiatives. Close coordination ensures that our climate resilience work is aligned with that of local and regional partners, and builds layers of resilience for the people and communities we serve. Specific examples include:

NYC Economic Development Corporation: Lower Manhattan Coastal Resiliency

Lower Manhattan Coastal Resiliency (LMCR) is a coastal protection initiative to reduce risk from coastal surge and sea level rise in Lower Manhattan. The City, State, and Federal government have committed over $1.7 billion in capital investments for climate adaptation projects spanning the Lower Manhattan coast, while also preserving public access to the waterfront. The MTA is engaged in the LMCR planning process, which would provide neighborhood-scale coastal surge protections and pumping capacity that would benefit MTA assets throughout Lower Manhattan.



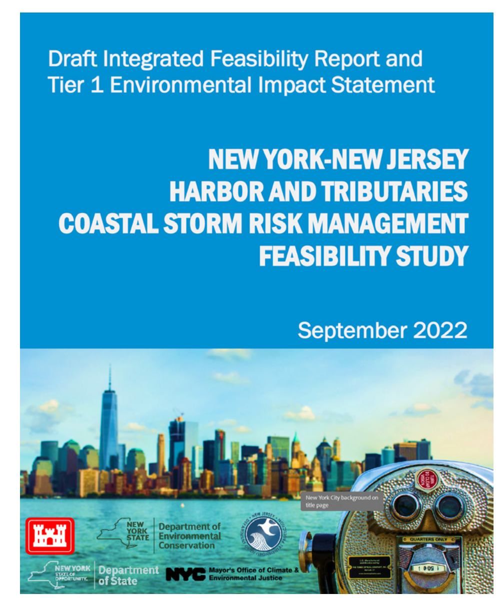


Con Edison: Climate Change Resilience Plan

In November 2023, Con Edison released a Climate Change Resilience Plan that will guide long-term investments to mitigate climate hazards facing the power utility's infrastructure. MTA served on the Climate Resilience Working Group convened by Con Edison and will continue to engage given the reliance of the entire transit system on stable electric power supply, particularly during extreme weather events.

NYC Mayor's Office of Climate & Environmental Justice (MOCEJ): Climate Strong Communities

MOCEJ's Climate Strong Communities initiative will launch "the next generation of equitable, multi-hazard, pro-active resiliency and sustainability projects by maximizing unprecedented infrastructure and climate funding opportunities that are focused on the most at-risk and environmental justice neighborhoods in New York City." The MTA is involved in Climate Strong Communities planning efforts, particularly where neighborhood-scale flood and extreme heat mitigation strategies intersect with MTA assets, workforce and customers.



U.S. Army Corps of Engineers: New York & New Jersey Harbor & Tributaries Study (HATS)

The US Army Corps of Engineers is investigating measures to manage future coastal surge risk for the New York Harbor. This study identifies and evaluates alternatives consisting of in-water, land-based, and shoreline-based flood mitigation measures, including multiple storm surge barriers, levees, pumps, nonstructural, and natural and nature-based features. The MTA is engaged in the HATS planning processes. The proposed system would provide harbor-wide storm surge protections, potentially reducing the exposure of multiple MTA assets.

Trains laid up at 148 St Yard. Work to mitigate flooding at the 148 St Yard received the Gold Award from the New York chapter of the American Council of Engineering Companies (ACEC) in 2023.

Appendices

Appendix A: History of MTA climate resilience

The MTA and its predecessors have navigated extreme weather challenges since the earliest days of the system. There have been significant innovations over the years, and the future challenges presented by climate change will require even more. The Climate Resilience Roadmap builds on these efforts to highlight the next iteration of climate resilience across the MTA.

- **Events in MTA history**
- **Major weather events**
- **Climate resilience efforts**

1834
Long Island Rail Road is established

1853
New York Central Railroad, a predecessor to Metro-North Railroad, is established

1885
The first elevated transit line opens in Brooklyn

March 1888
Great White Hurricane blankets New York City in 22 inches of snow, paralyzing surface transportation and galvanizing public support for an underground subway system

October 27, 1904
First underground subway service begins

February 9, 1934
Lowest temperature ever recorded in Central Park (-15 degrees F)

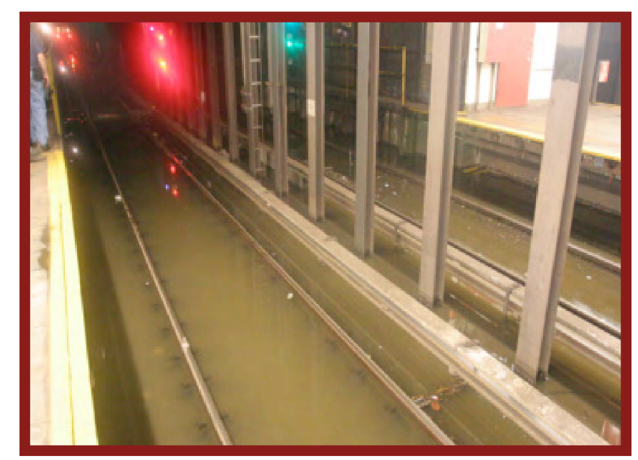
July 9, 1936
Highest temperature ever recorded in Central Park (106 degrees F)

1955
The first air-conditioned subway car is tested

1967
R38 subway cars are delivered with air conditioning

1968
MTA takes control of the subway

August 8, 2007
Torrential rain with up to 4 inches of rain in two hours, during high tide and rush hour, causes major subway delays



2007
First major program of subway stormwater flood protections after August event.

2008

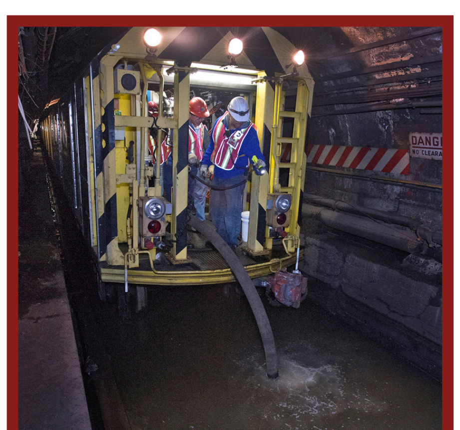
MTA publishes **Greening Mass Transit & Metro Regions: The Final Report of the Blue-Ribbon Commission on Sustainability and the MTA** that underscores the need to adapt infrastructure to climate change impacts

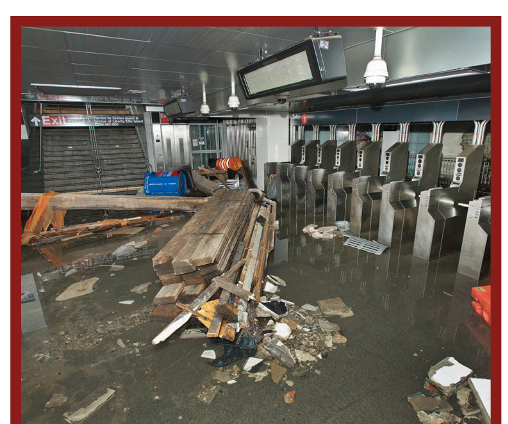
2011

Hurricane Irene halts all MTA transit services and floods portions of New York City, the Hudson Valley and New England

October 2012

Superstorm Sandy hits the New York City region, becoming the region's most consequential natural disaster ever with 53 fatalities and $32.8 billion in damages across New York State





Beginning in 2013

In partnership with the Federal government, MTA begins work on the **Sandy recovery and resiliency program**

2015

New York Transit Museum publishes **Bringing Back The City**, chronicling the role of public transit during crises. *https://bringingbackthecity.com/*

2019

MTA releases *2019 Resiliency Report: Update on agency-wide climate resiliency projects* that described on the wide variety of climate resilience mitigations being installed after Superstorm Sandy.

September 2021

Remnants of **Tropical Storm Ida** cause extensive flash flooding across the New York region and set a record for most rainfall in one hour

2021

MTA Board prepares the **Flash Flood Task Force report** to advance strategies to protect the subway system from urban floods

Remnants of **Tropical Storm Ophelia** cause extensive flash flooding and set a record for most rainfall in one day

September 2023

Appendix B: Preparing for extreme weather emergencies happening today

Even before an extreme weather event occurs, the MTA begins intensive internal coordination and proactive meteorological tracking. Additional coordination protocols are deployed when severe weather approaches, including activation of the MTA's central incident command center.

Coastal surge preparedness

Powerful storms that cause coastal surge are typically forecast in advance of landfall, allowing for a window of time to deploy protections against surge impacts. However, ocean warming due to climate change is causing hurricanes to intensify extraordinarily rapidly. Such rapid onset storms will limit the time for preparation as global warming continues.

The MTA's Hurricane Plan is activated when a declared hurricane is projected to make landfall near the region. The Hurricane Plan details specific steps that must be taken 72, 48, 12 and 8 hours prior to "Zero Hour" of the storm's landfall. Preparedness steps include:

- Inspecting and testing pumps and generators,
- Topping off fuel supplies,
- Clearing culverts and drains,
- Securing station equipment and crossing gate arms,
- Installing deployable flood mitigation measures, and
- Arranging for bus service where needed.

Torrential rainfall preparedness

Unlike coastal storm surge floods, which have a longer period of warning and impact more predicable locations along coasts, torrential rainfall events can occur with very little warning at any coastal or inland location across the region.

The Rain Flood Plan for subways is triggered with forecasts of 0.5 inches of rain per hour for three consecutive hours. Storms forecasted to produce higher rainfall intensities prompt additional preparations. Preparedness activities include:

- Monitoring known flood-prone locations,
- Clearing track drains and drain boxes in pump rooms of any debris,
- Staging debris trains and pump trains, and
- Staging personnel to facilitate response.

Additionally, ahead of torrential rainfall, city agencies clean dozens of catch basins adjacent to subway infrastructure.

With heavy rains in the forecast, MTA New York City Transit's Hydraulics crews prepare emergency response trucks and pumps in Downtown Brooklyn on September 22, 2023.

Extreme heat preparedness

Temperatures exceeding 90 degrees F trigger the Heat Emergency Plan. Subway and railroad maintenance crews perform additional inspections to monitor vulnerable equipment and make repairs before service is interrupted. Subway fan plants push hot and humid air out of tunnels, introducing some air circulation in station areas. Employees are also given additional water breaks to prevent heat-related illness. On regional railroads, tank cars filled with water are staged for deployment in case they are needed to spray down any parts of the right-of-way that may have experienced or are prone to brush fires.

During heat emergencies, the MTA coordinates with Con Edison to reduce the load on the region's power grid, as well as staging generators at key locations in case of localized electrical outages.

Other extreme weather emergencies

The MTA has protocols for other extreme weather emergencies, including winter weather and high winds. For winter weather, emergency plans are triggered by varying amounts of snowfall, freezing rain, sleet, and ice, plus low temperatures. Similarly, high winds trigger emergency protocols for at-grade and above-ground assets, including bridges, elevated stations, and catenary lines. For example, B&T's High Wind Conditions Procedure governs traffic restrictions on bridges, particularly for trucks and other large vehicles.

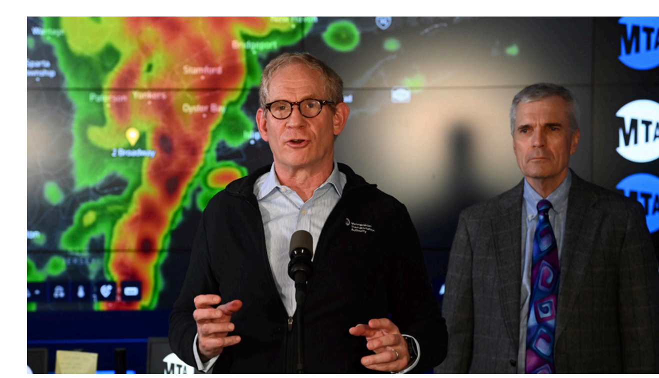
Learning from extreme weather emergencies

Between weather events, the MTA conducts simulated emergency management exercises. These seminars, workshops, and tabletop exercises are training opportunities ahead of real weather emergencies. For example, the MTA conducts simulation exercises for coastal storms and winter weather, where personnel are assigned emergency management roles and gather to respond to the situation.

After an extreme weather event, the MTA's emergency plans are evaluated and updated to improve future responses. **Performance results during an extreme weather event also inform capital priorities for climate resilience.** For example, if a subway station has flooded in multiple recent torrential rain events from street-level runoff, it may point to a capital investment need, like adding a top step.

Technology for climate resilient infrastructure

Weather sensors are an important component of climate-resilient transportation systems. The *Transportation Research Board Special Report on Potential Impacts of Climate Change (2008)* called for the use of sensors as a method to monitor changing climate conditions and to issue advance warning of potential failures when thresholds are exceeded. The MTA intends to broaden deployment of weather sensors across its systems to detect real-time sources of extreme weather impacts across its systems.



MTA Chair & CEO Janno Lieber and Chief Safety & Security Officer Patrick Warren at MTA Headquarters' Situation Room on September 28, 2023, providing an update on storm preparations.

Appendix C: MTA Climate Vulnerability Assessment

Precedents

The Climate Vulnerability Assessment methodology is modeled after national resources and precedents for the transportation sector, including:

» Federal Highway Vulnerability Assessment and Adaptation Framework (2017)

» Federal Highway Administration Vulnerability Assessment Scoring Tool (VAST)[1]

» USDOT Transportation Climate Change Sensitivity Matrix, Federal Transit Administration Asset Management Guide Supplement: Asset Category Overviews and Lifecycle Management (2019)

» Federal Highway Administration Addressing Resilience to Climate Change & Extreme Weather in Transportation Asset Management (2023)

While these resources provided important guidance for the Climate Vulnerability Assessment, modifications were made to develop a methodology that can support the magnitude of MTA assets, the broad geographic area of the MTA system footprint crossing state and municipal boundaries, and unique needs and priorities of this assessment. Given these needs, the approach of the MTA's Climate Vulnerability Assessment also reflects the 2020 National Climate Change Risk Assessment for New Zealand[2] and the 2022 Massachusetts Climate Change Assessment[3].

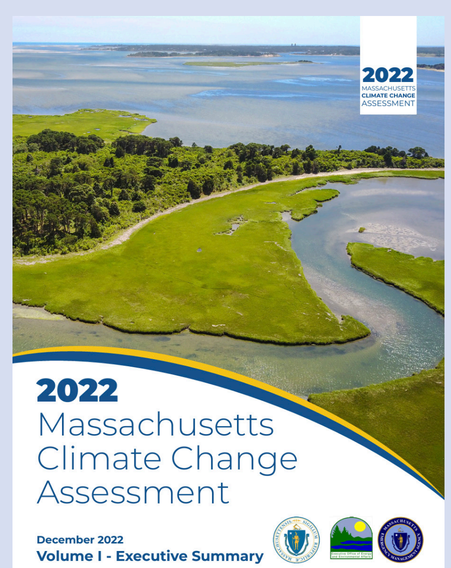
1 https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/scoring_tools_guide/index.cfm
2 https://environment.govt.nz/publications/national-climate-change-risk-assessment-for-new-zealand-main-report/
3 https://www.mass.gov/doc/2022-massachusetts-climate-change-assessment-december-2022-volume-i-executive-summary/download

2022 Massachusetts Climate Change Assessment

The practice of assessing future-facing climate risks is an emerging field, particularly for extensive infrastructure systems like those managed by the MTA. A particularly useful precedent is the Massachusetts Climate Change Assessment, completed in 2022. This document considers three guiding issues in evaluating climate change impacts across the state:

1. **Climate change impacts on people, the environment, and infrastructure**
2. **Disproportionate impacts on environmental justice populations**
3. **Gaps in climate resilience actions already taken across the state**

To address these issues, Massachusetts developed an urgency ranking framework to identify highest priority impacts. Findings of the assessment were incorporated into the Massachusetts State Hazard Mitigation Plan.



Climate Hazard Projections

The Climate Vulnerability Assessment aggregates multiple public climate and environmental hazard data sources to cover the entire MTA service territory. Each source is referenced in the list below. Going forward, MTA will monitor updates in data and scan for sources in emerging areas such as land subsidence and groundwater table rise.

CLIMATE RISK	DATA SOURCE	URL
Sea level rise	New York City Panel on Climate Change (NPCC)	https://climate.cityofnewyork.us/challenges/chronic-tidal-flooding/
	National Oceanic and Atmospheric Administration (NOAA)	https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html
Coastal surge	NYC Mayor's Office of Long-Term Planning and Sustainability (OLTPS) on behalf of CUNY Institute for Sustainable Cities (CISC) and the NPCC	https://data.cityofnewyork.us/Environment/Sea-Level-Rise-Maps-2020s-500-year-Floodplain-/ajyu-7sgg
	New York State Energy Research and Development Authority (NYSERDA)	https://services.nyserda.ny.gov/SLR_Viewer/About
	Connecticut Department of Energy & Environmental Protection (DEEP)	https://ct-deep-gis-open-data-website-ctdeep.hub.arcgis.com/
Torrential rain	New York City Stormwater Resiliency Model	https://experience.arcgis.com/experience/6f4cc60710dc433585790cd2b4b5dd0e
Extreme heat	New York City Council Data Team and the United States Geologic Survey (USGS)	https://council.nyc.gov/data/heat/
	National Weather Service (NWS)	https://www.weather.gov/wrh/Climate?wfo=okx
	Trust for Public Land and the NYC Mayor's Office of Resiliency (MOR)	https://www.arcgis.com/home/item.html?id=1b6cad6dd5854d2aa3d 215a39a4d372d
Wind	American Society of Civil Engineers (ASCE/SEI 7-22)	https://asce7hazardtool.online/
Winter weather	American Society of Civil Engineers Hazard Tool (ASCE/SEI 7-22)	https://ascehazardtool.org/
Steep slope vulnerability	USGS Digital Elevation Model (DEM)	https://apps.nationalmap.gov/lidar-explorer/#/
Wildfire	USDA Wildfire Risk to Communities: Spatial datasets of landscape-wildfire risk components for the United States	https://www.fs.usda.gov/rds/archive/Catalog/RDS2020-0016

New York City Panel on Climate Change (NPCC)

The MTA Climate Vulnerability Assessment relies on climate projections prepared by the New York City Panel on Climate Change (NPCC). The NPCC is a 20-member independent advisory body that synthesizes scientific information on climate changes and the impacts on the New York City region. Members of the NPCC are selected to include a diverse body of expertise, backgrounds, and technical knowledge that spans across multiple disciplines including science, engineering, urban planning, sociology, and architecture.

The NPCC first convened in 2008 with a mandate to provide recommendations on near-, intermediate and long-term quantitative and qualitative climate projections for the New York City region. The panel makes climate projections within one year of the release of an assessment report by the Intergovernmental Panel on Climate Change (IPCC), but not less than once every three years. The previous report, *Special Report: Advancing Tools and Methods for Flexible Adaptation Pathways and Science Policy Integration*, was released in 2019 and the next report will be released in spring 2024.

The MTA's Climate Vulnerability Assessment uses NPCC future climate projections based on a 90th percentile, high emissions global warming model. The high emissions scenario, known as Representative Concentration Pathway 8.5 (RCP8.5), is a future greenhouse gas concentration trajectory used by climate scientists and researchers to model and assess potential climate change impacts. RCP 8.5 is considered a high emission scenario representing a future where greenhouse gas emissions continue to rise throughout the 21st century and beyond.

2019 NPCC report

Assets considered in MTA Climate Vulnerability Assesment

The MTA considered six asset categories across 33 asset subcategories for current and future exposure to climate and environmental hazards. Asset categories and subcategories were identified by staff from each MTA operating agency. Each of these assets were considered in the Climate Vulnerability Assessment.

ASSET	ASSET SUBCATEGORIES	
Stations	» Major Hub (Grand Central, Penn Station)	» Open Cut/Below Grade
	» Underground Station	» Platforms
	» Elevated Stations	» Bus Hubs
	» At-Grade	» Parking Structure
Power Systems	» Substations – Supply	» Transformers
	» Substations – Balancing	» Electrical Distribution Rooms
Right-of-way	» Tunnels & Portals	» Surface Track/Diesel
	» Elevated/Viaduct	» Bridges
	» Surface Track/Heavy Rail (3rd Rail)	» Ramps
	» Surface Track/OCS	
Maintenance & Layover Facilities	» Depots	
	» Shops	
	» Yards	
Ancillary Systems	» Communication Systems & Rooms	» Generators
	» Radio Towers	» Fueling Systems
	» Pump Rooms	» Circuit Breaker Houses
	» Fan Plants	» Signal Bungalows & Node Houses
	» Interlockings	
Support Buildings	» Operations Control Center	
	» Power Control Center	

Appendix D: Climate Resilience Roadmap summary of goals, strategies, and actions

The Climate Resilience Roadmap consists of 10 goals, each with a series of resilience strategies and short- and long-term actions associated with each strategy. Each goal is also accompanied by an estimate of capital costs. These cost estimates consider the funding needs to advance design and construction of actions over the coming 10 year period. Construction costs were calibrated to the year 2027 as an average starting year using standard construction cost adjustment factors. In light of these assumptions, we anticipate total needs of approximately $6 billion to undertake the actions described in the Climate Resilience Roadmap.

Goal 1: Shield subway stations and tunnels from stormwater

Estimated Cost: **$500M - $1B**

Strategy	**Short Term** (≤5 Years)	**Long Term** (>5 Years)
Keep stormwater out **Boost collaboration with City agencies**	» Deploy proactive stormwater management tactics with NYCDEP and NYCEM as part of the Flash Flood Emergency Plan, including cleaning priority catch basins before predicted torrential rainfall events. » Work with NYCDEP to resolve city sewer bottlenecks including catch basins and siphons that require cleaning to prevent runoff or backups into the subway system. Ensure that sewer connections near subway infrastructure, including siphons and tide gates, are operating at full design capacity. » Support NYCDEP initiatives to improve stormwater drainage infrastructure in chronically impacted neighborhoods, including parts of the southern Bronx, northern Brooklyn, and central Queens. » Engage NYCDOT on street resurfacing projects to minimize stormwater runoff into subway vents and station entrances.	» Continue proactive stormwater management tactics executed by NYCEM and NYCDEP before predicted torrential rainfall as part of the Flash Flood Emergency Plan. » Collaborate with NYCDEP on implementing a pipeline of capital improvements to expand stormwater capacity adjacent to chronically impacted subway locations, prioritizing locations where connecting city drainage infrastructure is constrained. Partner with NYCDEP to advance design and construction of stormwater drainage capacity expansions in prioritized locations. » Partner with NYCDOT to ensure that all sidewalk curbs adjacent to subway infrastructure are sufficiently sized to prevent stormwater runoff into subway vents and station entrances
Keep stormwater out **Protect subway tunnel walls from leaks**	» Subway tunnels were designed with waterproofing membranes to prevent groundwater infiltration. Continue to inspect tunnels regularly to identify leaks and apply grout to address them as they occur.	» Continue vigilant tunnel grouting program and monitor the impacts of groundwater table rise on tunnel leaks. Adjust cadence of grouting program as necessary.
Keep stormwater out **Install sidewalk-level protections**	» Advance site-specific sidewalk-level protections at priority stations that have experienced stormwater impacts during one or more recent torrential rain events. » Advance scoping at additional priority stations that have experienced stormwater impacts during one or more recent torrential rain events to determine feasible stormwater mitigations, which may include sidewalk-level protections.	» Install site-specific sidewalk-level protections at additional priority stations, where feasible, based on scoping and feasibility study. » Install site-specific sidewalk-level protections at other stations likely to become vulnerable to torrential rainfall in the future, in coordination with other capital projects. » Monitor existing mitigations and identify new locations experiencing stormwater runoff impacts within or between stations.

Keep stormwater out **Develop new technologies to prevent stormwater overtopping into sidewalk vents**	» Explore new protections for vent batteries exposed to flood risks from both coastal surge and torrential rain. New protections may include alternative types of vent mechanical closure devices (MCDs).	» Develop a hybrid passive MCD that could protect vents in areas with future (2050s and beyond) combined coastal surge and torrential rain flood risks. » Implement hybrid passive MCDs at appropriate locations, where feasible, to prevent stormwater runoff and storm surge into vulnerable subway vents.
Remove stormwater that enters **Upgrade subway drainage system equipment**	» Replace or rehabilitate priority pump rooms, where feasible, including replacing old and undersized pumps, adding additional pumps, and improving drain lines in chronically impacted locations that may exacerbate service delays during torrential rain events. Prioritize subway drainage system equipment listed in poor or marginal condition that serve locations impacted by recent torrential rain. » Identify locations that could benefit from expanded pumping capacity (e.g., new pump rooms) across the subway system.	» Construct new pump rooms in locations with currently constrained capacity or that are likely to become constrained due to increased stormwater infiltration into the system, where feasible. » Expand drainage capacity in locations likely vulnerable to groundwater table rise, including adding new deep wells to provide continuous pumping, where feasible. » Ensure subway drainage system equipment operates at full capacity to remove stormwater that enters the subway system even after deploying sidewalk-level protections, like top steps and raised vents.
Remove stormwater that enters **Reduce subway drainage system constraints**	» Remove track drain direct connections and vent drain direct connections between the subway and the city sewer system to reduce service impacts during torrential rainfall events. » Where feasible, expand capacity of constrained vent drains to move larger volumes of stormwater. » Continue regular inspections and periodic overhauls of check valves across the subway tunnel drainage system to help prevent city sewer backups into the subway system.	» Continue reducing direct sewer connections across the system, prioritizing those that backup during torrential rain events. » Continue periodic overhauls of check valves in tunnel drains to help prevent city sewer backups into the subway system.
Remove stormwater that enters **Continue proactive track drain cleaning programs**	» Continue the existing proactive track drain inspection and cleaning program, particularly before the rainy season (spring and summer). » Continue pre-storm drain inspections and cleaning to ensure drains are not blocked by litter ahead of storms. » Bundle drain cleaning and inspections with construction-related shutdowns, like CBTC, to optimize resources.	» Consider expanding proactive track drain cleaning programs to reduce time between maintenance. » Deploy measures to identify blocked drains so cleaning resources can be effectively targeted before a forecasted torrential rainfall event.
Remove stormwater that enters **Retain stormwater until the city sewer capacity recovers**	» Implement a stormwater retention and detention strategy and increase existing track pumping capacity at 3 Av/138 St Station 6 in the Bronx to expand the capacity of the subway right-of-way to hold stormwater from torrential rainfall until it can be safely discharged into the city sewer system. » Leverage construction opportunities at stations to implement stormwater management improvements where additional stormwater detention is needed during torrential rainfall events.	» Expand stormwater detention capacity across the subway system, where feasible, to mitigate the constraints of city sewer infrastructure.

Goal 2: Protect subway yards from flooding
Estimated Cost: **$500M - $1B**

Strategy	Short Term (≤5 Years)	Long Term (>5 Years)
Upgrade and expand yard drainage systems in anticipation of future coastal surge and torrential rainfall floods	» Rebuild/replace priority drainage system assets in yards, like pump rooms, listed in poor or marginal condition. » Scope drainage improvements and coastal surge protections, where feasible, and elevate equipment at priority yards exposed today to coastal surge. » Identify feasible passive mitigation strategies in priority yards that are chronically exposed to combined torrential rainfall flood and tidal flood risks.	» Elevate critical facilities above future coastal surge floodplains, where feasible. » Install additional pumps for problematic hot spots, potentially accompanied by floodproofing or barriers at chronically impacted locations. » Advance stormwater retention systems, where feasible, in appropriate locations. » Install protections at additional yards exposed today to coastal surge.
Install combined coastal surge and torrential rainfall protections under the Westchester Yard Flood Control Project	» Install storm sewers, inlets, and a new lift station at Westchester Yard to channel water out of the facility during periods of torrential rain as part of the Westchester Yard Flood Control Project.	» Identify flood mitigation technologies installed at Westchester Yard that could be effective in locations outside of Westchester Yard.
Mitigate flood impacts as yard equipment is replaced	» Elevate sensitive equipment as part of any capital project, where feasible, anticipating current and future flood risks.	» Monitor the impacts of sea level rise and tidal flooding risks at coastal subway yards and advance appropriate mitigations. » Replace equipment where feasible, like switch machines, with types that can be submerged.

Goal 3: Protect open subway infrastructure from flooding
Estimated Cost: **$250M - $500M**

Strategy	Short Term (≤5 Years)	Long Term (>5 Years)
Design tidal/inland flood and coastal erosion mitigations, including shoreline protections and equipment elevations	» Design appropriate flood mitigations at current and future exposed locations, such as Tottenville station, right of way, and terminal. » Advance feasible drainage improvements at vulnerable subway portals systemwide, including increasing pumping capacity, to reduce flooding and service impacts.	» Install feasible mitigations which may include fortified waterfront bulkheads and/or engineered stone revetment to protect waterfront structures from erosion and wave action.
Coordinate with external partners on regional and neighborhood-scale protections that intersect with MTA infrastructure	» Specific initiatives include the U.S. Army Corps of Engineers (USACE) NY NJ Harbor and Tributaries Study (HATS) and NYCDEP Bluebelts.	» Provide design feedback and construction access to support stormwater mitigation projects by external partners.

Goal 4: Safeguard bus depots from flooding

Estimated Cost: **$500M - $1B**

Strategy	Short Term (≤5 Years)	Long Term (>5 Years)
Install site-specific stormwater flood mitigation and detention strategies at chronically impacted depots	» Scope stormwater flood mitigations at chronically impacted depots, where feasible, in coordination with Zero Emissions Bus Transition. Depending on site conditions, examples of stormwater flood mitigations may include sewage backwater valves, floodproofing exterior walls of buildings, elevating equipment, and increasing the height of existing flood logs. » Collaborate with partner agencies to explore neighborhood-scale stormwater mitigations that could reduce runoff impacts to depots, particularly at Castleton.	» Advance stormwater flood mitigations, where feasible, at chronically effected depots, including depots currently experiencing impacts. » Continue coordinating with NYCDEP on stormwater detention opportunities, particularly the Willowbrook/Westerleigh Bluebelt project, that would benefit Castleton.
Implement coastal surge protections at vulnerable depots	» Install coastal surge protections, where feasible, at priority vulnerable depots in coordination with the depot improvements anticipated in the Zero Emissions Bus Transition plan. Depending on site conditions, examples of protections include deployable flood panels and flood logs. » Ensure that sensitive equipment within depots is elevated above the coastal floodplain.	» Install appropriate coastal surge protections at remaining vulnerable depots in tandem with improvements that support the Zero Emissions Bus Transition plan.

Goal 5: Work with partners to manage floods on city streets

Estimated Cost: **< $50M**

Strategy	Short Term (≤5 Years)	Long Term (>5 Years)
Address chronic flooding at B&T approaches	» Reduce floods at vulnerable MTA bridge and tunnel approaches that result in operational impacts by coordinating with partner agencies, including NYCDEP and NYCDOT.	» Ensure that future climate risks are considered in capital improvement projects for impacted B&T approaches with city and state entities.
Prepare for tidal flood impacts on bus operations	» In locations with chronic tidal floods, deploy alterative bus routes to avoid tidal flooding impacts on customers and buses during emergencies.	» Together with NYCEM and NYCDOT, consider route updates and stop relocations in anticipation of current and future tidal floods.

Goal 6: Mitigate Long Island Rail Road flooding

Estimated Cost: **$500M - $1B**

Strategy	Short Term (≤5 Years)	Long Term (>5 Years)
Install protections from sea level rise and torrential rainfall flood risks along the Long Beach and Far Rockaway Branches	» Coordinate with local communities on community-wide resilience protection plans to mitigate flooding (i.e. City of Long Beach's Critical Infrastructure Flood Protection Project), as the climate risks that threaten LIRR also impact the communities these branches serve. » Identify appropriate floodproofing and/or elevation of vulnerable areas, prioritizing locations susceptible to tidal flooding in the next 20 years, and sized to dovetail with local resilience plans.	» Implement feasible floodproofing measures. » Upgrade undersized drainage infrastructure.
Address torrential rainfall risks along the Port Washington Branch and in the Long Island City area	» Design enhancements of drainage systems at impacted stations and low-lying tracks » Coordinate with NYC DEP to resolve city sewer bottlenecks that require cleaning catch basins and siphons to prevent runoff or backups into the LIRR system.	» Implement feasible drainage improvement measures. » Coordinate with local government and private property owners to reduce runoff into the LIRR Right of Way. This includes examining local street geometries, identifying opportunities to install curbs, and increasing upstream stormwater retention.

Goal 7: Reduce Metro-North Railroad flooding

Estimated Cost: **> $1B**

Strategy	Short Term (≤5 Years)	Long Term (>5 Years)
Implement Hudson line resilience measures	» Stabilize steep slopes by analyzing conditions of retaining walls and rock slopes. » Mitigate shoreline erosion by conducting shoreline infrastructure inspections, with a focus on areas exposed to tidal flooding over the next 20 years. » Design and implement expansions of priority undersized culverts susceptible to near-term tidal flooding and torrential rainfall flooding. » Analyze and advance improvements of underperforming or insufficient stormwater drainage locations. » Assess and design floodproofing measures and/or elevation of critical assets and segments of right-of-way. This includes studying the elevation of shoreline structures, track raising, flood wall/flood gate installation and developing an implementation strategy that accounts for projected sea level rise through the end of the century. » Collaborate with local partners to investigate and mitigate flooding along the Hudson Line.	» Fortify at-risk structures along steep slopes and the shoreline. » Expand culverts susceptible to torrential rainfall and future tidal flooding. » Implement feasible floodproofing measures.

Advance drainage improvements at vulnerable locations	» Design and implement Mott Haven Yard stormwater mitigation measures. » Design and implement expansions of priority undersized culverts along the Harlem Line susceptible to near-term tidal flooding and torrential rainfall flooding. » Analyze and advance improvements of underperforming or insufficient stormwater drainage locations along the Harlem, New Haven, and Port Jervis lines.	» Continue implementing and monitor Mott Haven Yard stormwater mitigation measures. » Expand culverts susceptible to torrential rainfall and future tidal flooding.
Address flooding, runoff, and erosion risks by stabilizing and protecting vulnerable segments of right of way	» Stabilize steep slopes by analyzing conditions of retaining walls and rock slopes along the Harlem Line. » Assess and design floodproofing and/or elevation of critical assets and segments of right-of-way along the Harlem line. » Collaborate with local partners to investigate and mitigate flooding along the Harlem, New Haven, and Port Jervis lines.	» Stabilize steep slopes by fortifying at-risk Harlem line structures and analyzing conditions of retaining walls and rock slopes along the New Haven and Port Jervis Lines. » Mitigate shoreline erosion by conducting shoreline infrastructure inspections along the New Haven Line. Rehabilitate structures at priority locations. » Implement feasible resilience measures. » Coordinate with regional partners, including the Connecticut Department of Transportation, on long-term New Haven Line sea level rise and stormwater resilience measures.
Expand understanding of how extreme weather impacts infrastructure and service	» Implement real-time extreme weather sensors through tools such as gauges and live video feeds, to expand data collection tools and provide information about flood conditions, triggers, and hotspots of runoff entering MTA rights of way.	» Develop localized future stormwater flooding data through collaborations with New York State, academic institutions, and/or commissioning of MTA-specific modeling and data for the West of Hudson Lines.

Goal 8: Expand underground air circulation and cooling

Estimated Cost: **$50M - $250M**

Strategy	**Short Term** (≤5 Years)	**Long Term** (>5 Years)
Install air circulation equipment to keep hot air moving off platforms	» Explore installing platform fans in priority underground stations to improve circulation, where feasible. » Initiate circulation and ventilation study for feasible improvements that could reduce the amount of heat trapped in underground stations and tunnels. » Implement remote heat sensors to detect chronic extreme heat impacts, prioritizing locations like vulnerable underground platforms and systems.	» Explore installing platform fans in additional priority underground stations, considering operational feasibility. » Monitor complementary programs that may reduce heat added in stations and tunnels, including regenerative braking, sliding platform doors, and additional tunnel vents.
Pilot evolving platform cooling strategies	» Survey innovative approaches to reduce extreme heat impacts on subway station platforms, including results from the September 2023 Request for Information, and by monitoring platform cooling innovations being explored in other public transport systems. » Initiate design of a cooling strategy at a priority location.	» Install best and most sustainable approach to station cooling in stations most impacted by extreme heat events based on real-time temperature data collected in stations.

Goal 9: Protect outdoor infrastructure from heat

Estimated Cost: **< $50M**

Strategy	**Short Term** (≤5 Years)	**Long Term** (>5 Years)
Pilot strategies to mitigate extreme heat on vulnerable outdoor track	» Identify and paint outdoor track segments most vulnerable to extreme heat exposure.	» Expand white paint treatment and reapplication to outdoor track segments exposed to extreme heat and establish regular rail painting program. » Focus on new heat-resistant materials to incorporate into new capital projects.
Improve real-time monitoring of heat conditions	» Install a network of temperature and expansion sensors that detect extreme heat impacts, prioritizing key vulnerable locations.	» Focus on emerging technologies and continue to monitor network of sensors.

Goal 10: Address heat and wind impacts on bridges

Estimated Cost: **< $50M**

Strategy	**Short Term Actions** (≤5 Years)	**Long Term Actions** (>5 Years)
Reduce the impacts of heat and wind on bridges	» Pilot materials to reduce heat-induced expansion of bridge joints and asphalt pavements, including coatings and additives. » Continue existing temperature and extreme wind monitoring.	» Adopt piloted materials as the standard, pending pilot results,. » Implement new temperature and wind sensor technologies, as they become available.

The MTA Climate Resilience Roadmap follows the 20-Year Needs Assessment and outlines specific capital needs for climate resilience in anticipation of the 2025-2029 five-year capital plan.

To learn more about the MTA's climate initatives, please visit **MTA.info/climate**

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