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Groundwater Remedial Action Work Plan Garfield Avenue Group Sites

Final

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PPG
Hudson County Chromate Sites
Jersey City, New Jersey

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List of Definitions

Chromate Chemical Production Waste (CCPW): A by-product generated from the production of sodium bichromate, including chromite ore processing residue, green-gray mud, and fill mixed with chromite ore processing residue or green-gray mud.

Chromite Ore Processing Residue (COPR): A specific type of CCPW generally characterized as a reddish brown, coarse to fine, gravel with varying amounts of sand and silt particles. The gravel portion of the matrix is typically defined as nodules from the chromate manufacturing process that range in size from ⅛- to ¾-inch in diameter. However, nodules have been infrequently detected at diameters of greater than an inch. Different sized nodules may be found cemented together to form larger clusters. The matrix of these clusters may consist of cement-like silt. These nodules can be disintegrated easily with a hammer. Occasionally when detected in the saturated zone, COPR nodules may appear as a fine-grained material that has weathered. The permeability of this material is variable. The inner matrix of COPR nodules typically contains higher concentrations of hexavalent chromium than the surface of the nodules but lower concentrations than green-gray mud.

Chromium: An element found in nature that is commonly used in manufacturing activities. Chromium may be present in soil or water as trivalent and hexavalent chromium. Trivalent chromium is an essential nutrient at trace concentrations and is generally found is groundwater systems in solid form (i.e., as precipitates with other minerals). Hexavalent chromium can be present in many forms, some of which are carcinogenic at high concentrations. Hexavalent chromium is typically present in the aqueous phase and is more mobile than the trivalent form. Total chromium, as measured in soil or groundwater, is the sum of trivalent and hexavalent chromium.

Green-Gray Mud (GGM): Generally, lime green dense silt, with minor amounts of fine sand and clay. When found in the saturated zone, the grain size of this material may have been affected further due to weathering processes. This can give the material a wet, clayey silt or silty clay appearance with little or no physical or structural integrity. This material has a low permeability. The pH of this material is generally 11 to 12 standard units.

List of Acronyms

µg/L	micrograms per liter
ACO	Administrative Consent Order
A-DGA	amended dense-graded aggregate
AOC	area of concern
ASM	Al Smith Moving & Furniture Company, Inc. property
bgs	below ground surface
CaSx	calcium polysulfide
CCPW	Chromate Chemical Production Waste
CEA	Classification Exception Area
cells/mL	cells per milliliter
CID	Case Inventory Document
COCs	contaminants of concern
COPR	chromite ore processing residue
Cr	chromium
Cr^{+3}	trivalent chromium
Cr^{+6}	hexavalent chromium
CSM	conceptual site model
DGA	dense-graded aggregate
DGW	discharge to groundwater
DIGWSSL	Default Impact to Groundwater Soil Screening Levels
DNAPL	dense non-aqueous phase liquid
EC	engineering control
EDD	electronic data deliverable
El.	elevation
EVO	emulsified vegetable oil
FA	Financial Assurance
FeS	ferrous sulfide
Fishbein	Former Fishbein Property
FSPM	Field Sampling Procedures Manual
FSP/QAPP	Field Sampling Plan-Quality Assurance Project Plan
ft	feet
GA	Garfield Avenue
GGM	green-gray mud
gpm	gallons per minute
GWMP	Groundwater Monitoring Plan
GWQS	Groundwater Quality Standards
GWTP	groundwater treatment plant
Halsted	Former Halsted Corporation Property
Hampshire	Hampshire Urban Redevelopment Renewal, LLC
HASP	Health and Safety Plan

HBLR	Hudson-Bergen Light Rail
HCC	Hudson County Chromate
HDPE	high-density polyethylene
HPT	hydraulic profiling tool
IRB/SRB	iron- and sulfate-reducing bacteria
IRM	interim remedial measure
IRZ	*in situ* reaction zone
ISAB	*in situ* bioprecipitation
ISCR	*in situ* chemical reduction
JCMUA	Jersey City Municipal Utilities Authority
JCO	Judicial Consent Order
JCRA	Jersey City Redevelopment Agency
lbs	pounds
LTM	long-term monitoring
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MGP	manufactured gas plant
MIU	mobile injection units
mm	millimeter
MNA	monitored natural attenuation
MSDS	Material Safety Data Sheet
mV	millivolts
NAVD88	North American Vertical Datum of 1988
Ni	Nickel
NILODN	Notice in Lieu of Deed Notice
NJ	New Jersey
N.J.A.C.	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJPDES	New Jersey Pollutant Discharge Elimination System
OGS	open grade stone
ORP	oxidation-reduction potential
PAH	polycyclic aromatic hydrocarbons
PBR	permit-by-rule
PCE	tetrachloroethene
ppm	parts per million
PSEG	Public Service Electric & Gas Company
PVSC	Passaic Valley Sewerage Commission
RA	remedial action
RAP	Remedial Action Permit
RAPR	Remedial Action Progress Report
RAR	Remedial Action Report
RAWP	Remedial Action Work Plan

RI	remedial investigation
RIR	Remedial Investigation Report
RIWP	Remedial Investigation Work Plan
ROW	right-of-way
s.u.	standard units
Sb	antimony
SRP	Site Remediation Program
SVOC	semi-volatile organic compound
TAL	Target Analyte List
TAP	temporary access permit
TCE	trichloroethylene
Tl	thallium
TOC	total organic carbon
TRSR	Technical Requirements for Site Remediation
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
V	vanadium
VOC	volatile organic compound
WRA	Well Restriction Area
wt.	weight

Executive Summary

AECOM has prepared this Remedial Action Work Plan (RAWP) on behalf of PPG, to present the groundwater remediation strategy at the Garfield Avenue (GA) Group Sites (Project Area), part of the Hudson County Chromate (HCC) Sites in Jersey City, New Jersey. Groundwater within the Project Area is subject to the New Jersey Department of Environmental Protection (NJDEP) Class-IIA Groundwater Quality Standards (GWQS), and is impacted by Chromate Chemical Production Waste (CCPW) metals, primarily total chromium (Cr) and hexavalent chromium (Cr^{+6}), and other non-CCPW contaminants, including select volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and non-CCPW metals.

Groundwater remedial investigation (RI) activities in the shallow, intermediate, and deep water-bearing zones across the Project Area have been completed and documented in the August 31, 2021 *Groundwater Remedial Investigation Report, Final* (AECOM, 2021e) ("Groundwater RIR"), and a limited investigation of the bedrock water-bearing zone on Site 114 is anticipated to be completed later. If warranted, an addendum to this RAWP will be prepared for the bedrock water-bearing zone. The findings from the RI were used to develop a conceptual site model (CSM) that is the basis for a comprehensive remediation strategy for the Project Area and is described in this RAWP. As discussed in the Groundwater RIR, groundwater in this part of Jersey City is classified as Class II-A (potable ground water with conventional treatment at current water quality); however, the groundwater is slightly brackish and is not used for potable, industrial, commercial, or private use.

The groundwater remediation goal for the Project Area is to protect human health and the environment through the attainment of the NJDEP Class II-A GWQS for the contaminants of concern (COCs). The remediation strategy to achieve the remediation goal includes a combination of active remedial actions to treat the saturated zones, where practicable and where Cr^{+6} in groundwater is greater than 1,000 micrograms per liter (µg/L), followed by monitored natural attenuation (MNA) once a stable or immobilized plume is demonstrated, monitoring and maintaining existing groundwater engineering controls, and maintaining institutional controls.

Excavation of the source material across the Project Area, followed by backfilling with clean backfill (amended with FerroBlack®-H reductant, or unamended) has considerably improved groundwater quality with respect to the COCs within the shallow water-bearing zone. To remediate areas of elevated (i.e., greater than 1,000 µg/L) Cr^{+6} in the intermediate and deep water-bearing zones, and localized areas in the shallow water-bearing zone within Site 114 (i.e., the location of the former chromite ore processing plant), three phases of interim remedial measures (IRMs) have been implemented or are currently underway (Phase I, Phase II and Phase III). The IRMs use a combination of *in situ* remediation technologies (injection of reagents and/or establishment of reactive zones) to establish and maintain reactive zones to achieve contaminant concentration reductions. Following active *in situ* treatment, the injected reagent(s) will maintain a geochemically reducing environment for an extended period (enhanced attenuation period), that will further attenuate COC concentrations during the active remedy phase, prior to a transition to an MNA remedy phase.

A request for an Active Category Groundwater Remedial Action Permit (RAP) will be submitted to the NJDEP for review and approval as soon as the requirements for the Active Category Groundwater RAP outlined in NJDEP's *Ground Water Remedial Action Permit Guidance* (https://nj.gov/dep/srp/guidance/srra/rem_action_permit_guidance_gw.pdf) have been met. It is expected that these requirements will be met upon completion of the treatment monitoring programs for the three IRM phases, and at a minimum after four quarters of post-treatment monitoring data are available for the Phase III IRM. The data from these robust area-wide groundwater monitoring required under the NJDEP Discharge to Groundwater Permit-By-Rules (PBRs) for the three IRM Phases are expected to support that the active system remedy is effective. A groundwater monitoring plan, consisting of performance monitoring wells (e.g., upgradient, source area, plume longitudinal, transverse, and fringe) and sentinel wells, will be used to monitor treatment performance, groundwater quality with respect to Cr and Cr^{+6} concentrations, and subsurface geochemistry during and after active treatment to evaluate the effectiveness of the active remedy, following which, transition to an MNA remedy with long-term monitoring will commence. The transition to MNA will be guided by a comprehensive performance data collection program anticipated to span a period of eight to ten years, consistent with the lines-of-evidence approach for metals outlined in the NJDEP's March 2012 *Monitored Natural Attenuation Technical Guidance* (NJDEP, 2012a).

The proposed groundwater engineering controls (FerroBlack®-H amended backfill, competent meadow mat, sheet pile, and capillary break) are intended to prevent or reduce the risk of exposure to contaminated groundwater present within the confines of the Project Area, to prevent mass discharge from the Project Area onto surrounding roadways and properties, and to protect remediated areas from recontamination. Long-term groundwater monitoring and maintenance will be performed to monitor the effectiveness of these engineering controls and aid in the continued protection of public health and the environment. In addition, the existing Classification Exception Area (CEA)/Well Restriction Area (WRA) for the Project Area, originally established in June 2018, will be updated and maintained until the groundwater remediation goal of achieving the NJ Class-IIA GWQS for the COCs has been met.

As discussed in the CSM, overburden materials in the Project Area were deposited in glaciofluvial and glaciolacustrine environments, resulting in a complex and heterogeneous matrix of soils consisting of sands, silty sands, silts, clays, and gravels of varying permeability. Given this composition of the overburden and the presence of source materials (e.g., green-gray mud) remaining beneath the light rail on Site 199, attainment of NJDEP Class II-A GWQS is not practicable in the short term in all portions of the Project Area. Therefore, a long-term remediation strategy that includes active groundwater treatment, MNA, groundwater monitoring, engineering controls, and institutional controls will be established to manage the mass discharge of COCs off site and risk to human health and future receptors. Details about each of these components of the groundwater remediation strategy are provided in this RAWP.

1 Introduction and Background

AECOM has prepared this Remedial Action Work Plan (RAWP) on behalf of PPG to present the remedial action (RA) approach for groundwater at the Garfield Avenue (GA) Group part of the Hudson County Chromate (HCC) Sites in Jersey City, Hudson County, New Jersey. The GA Group Sites include: Sites 114, 132, 133, 135, 137, and 143, the Roadways (Carteret Avenue, Forrest Street, Garfield Avenue, Halladay Street North, Halladay Street South, Caven Point Avenue, and Pacific Avenue), and the Off-Site Properties (Al Smith Moving, Halsted Corporation, Fishbein, Forrest Street Properties, and Ten West Apparel). This RAWP also provides the groundwater RA approach for HCC Site 199. Hereinafter these areas are referred to collectively as “the Project Area” (**Figure 1-1** and **Figure 1-2**).

Groundwater remedial investigation (RI) activities have been completed at the Project Area to delineate the horizontal and vertical extents of groundwater impacts related to Chromate Chemical Production Waste (CCPW), non-CCPW Target Analyte List (TAL) metals, volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs) contamination in the shallow, intermediate, and deep water-bearing zones, and are described in detail in the August 2021 Groundwater RI Report (Groundwater RIR) (AECOM, 2021e). Focused investigations in the bedrock water-bearing zone were also conducted during the groundwater RI. CCPW-related contamination in the bedrock has not been fully delineated and will be completed at a later date and presented in a subsequent report.

In November 2010, PPG prepared a Conceptual Plan for remediation of CCPW in soil and groundwater at the GA Group Sites (AECOM, 2010b). Between November 2010 and March 2020, PPG completed soil remediation activities that have removed a substantial portion of the CCPW-impacted fill and shallow soils. Additional soil remediation activities are ongoing. During this period, PPG performed bench- and pilot-scale tests to evaluate several remediation technologies and selected and began implementing groundwater Interim Remedial Measures (IRMs) in the shallow, intermediate, and deep water-bearing zones of Site 114. Based on the effectiveness of source area soil excavation and the groundwater IRMs, PPG developed a conceptual groundwater remediation strategy and shared this strategy with the New Jersey Department of Environmental Protection (NJDEP) in August 2020 via the Technical Memorandum (GW-093) titled *Remediation Strategy for CCPW in Groundwater for the PPG GA Group, HCC Sites, in Jersey City, New Jersey* (AECOM, 2020a).

Following the submittal of this Technical Memorandum (GW-093), and in order to facilitate NJDEP’s review of the draft groundwater RAWP for the Project Area, PPG provided sections of the draft RAWP ahead of submittal of the draft RAWP via the Technical Memorandum (GW-095) *Remediation Goals / Objectives and Remedial Action Selection for the Groundwater Remedial Action Work Plan for the PPG GA Group, HCC Sites, Jersey City, New Jersey* (AECOM, 2020c). Specifically, PPG provided the sections of the draft RAWP relevant to groundwater remediation goals and objectives and selection of the groundwater remedial action to the NJDEP.

These August and September 2020 Technical Memoranda (GW-093 and GW-095) were prepared to guide discussions with the NJDEP and stakeholders regarding the remediation strategy. Based on the discussions between September 2020 and February 2021 resulting from these submittals, PPG has further developed the concepts presented in the Memoranda, and this draft RAWP formally documents the groundwater remediation strategy for the Project Area, including groundwater remediation goals and objectives, selection and description of the groundwater remedial action, implementation of the remedial action, remedy transition and monitoring plans, schedule, and reporting.

1.1 Regulatory History

Investigation and remediation activities in the Project Area are regulated by the NJDEP but are administered by the Superior Court of New Jersey under an Administrative Consent Order (ACO) (NJDEP, 1990) and a Partial Judicial Consent Order Concerning the PPG Sites (JCO) (Superior Court of New Jersey Law Division – Hudson County, 2009).

PPG and the NJDEP entered into an ACO in 1990 requiring the investigation and remediation of locations where CCPW or CCPW-impacted materials related to former PPG operations may be present. On June 26, 2009, NJDEP, PPG, and the City of Jersey City entered into a JCO with the purpose of assessing and remediating sources of contamination in impacted soil and groundwater at the Project Area. In accordance with the JCO, PPG is responsible for remediating CCPW, CCPW-impacted materials, and other contaminants of concern (COCs), which are on or have emanated from Site 114 onto adjacent properties and road rights-of-way (ROWs).

The Public Service Electric & Gas Company (PSEG) is responsible for investigating and remediating impacts related to the operation of the former manufactured gas plant (MGP) located within the Project Area (PSEG, 2007; PSEG, 2009; PSEG, 2014a). Soil remediation by PSEG has been completed on the former MGP location within Site 114. A groundwater Classification Exception Area (CEA) was proposed by PSEG primarily for MGP-related constituents within the area impacted by the former MGP operations (PSEG, 2014b). The NJDEP approved PSEG’s CEA proposal and established the CEA for MGP-related constituents on July 25, 2014.

1.2 Project Area Location and Description

1.2.1 Site 114

Site 114 is vacant land located in a commercial and residential area on Garfield Avenue in Jersey City, Hudson County, New Jersey. Site 114 is described in the ACO as Block 2026.A, Lots 1 and 3A and Block 2026.1, Lots 2A, 3B and 4A (current Block 21501, Lots 16, 17, 18, 19, and 20). Site 114 is bordered to the west by Garfield Avenue, to the south by Carteret Avenue and HCC Sites 132, 135, 137, and 143, to the east by Halladay Street, and to the north by Forrest Street and Site 199, part of which includes an active railroad operated by New Jersey (NJ) Transit (referred to as NJ Transit Light Rail).

The total area encompassed by Site 114 is 16.6 acres. Site 114 is the former location of a chromite ore processing facility and a former MGP. The Morris Canal was a man-made surface water body trending northeast/southwest, that formerly bisected the GA Group Sites. The MGP facility operated on the portion of Site 114 located east of the former Morris Canal from about 1886 to the mid-1930s. The western half of Site 114 was the location of the former chromite ore processing facility that operated from about 1911 to 1963. The chromite ore processing operation included a large stockpile of CCPW, primarily consisting of chromite ore processing residue (COPR), extending from the eastern portion of Site 114 southward onto Site 137. The locations of the former ore processing facility and the CCPW storage pile were identified using historical aerial photographs, which were provided in the March 2011 Remedial Investigation Work Plan (March 2011 RIWP) (AECOM, 2011).

Following demolition of above-grade structures associated with the chromite ore processing facility and the MGP facility, the remaining foundations were buried, raising the ground surface elevation (El.) by several feet. Three warehouse structures were later constructed on the property during the late 1960s. These warehouses were demolished down to the concrete floor slabs between August and December 2002.

The areas adjacent to and across the surrounding streets from Site 114 are characterized as commercial and light industrial. An office furniture manufacturer/warehouse and an auto repair shop are located west of Site 114 across Garfield Avenue. Residential areas are present further to the west. A former auto body shop/used car dealer (Site 143), a former abandoned warehouse now a vacant lot (Site 132), and former light industrial machinery/box manufacturer/warehouses/packing and recycling (Site 137) are present to the south of Site 114. Other properties further to the south/southeast include three vacant lots formerly occupied by warehouses (Site 133, Site 135, and Al Smith Moving and Storage). East of the Site 114 across Halladay Street, a former bag manufacturer/warehouse (the former Halsted Corporation) and a former auto/truck repair shop were present. Commercial, light industrial, railroad ROW, and material recycling facilities are located further to the east and southeast. The NJ Transit Light Rail ROW (Site 199) is located along the northern Site 114 boundary. A Light Rail Transit Station is present to the west-northwest of Site 114. Warehouse and light industrial buildings are present toward the northeast and across Forrest Street. Berry Lane Park and several commercial, light-industrial, and residential properties are located to the north and beyond the Light Rail ROW.

The residential areas north and west of Site 114 have been identified as part of the Jersey City Redevelopment Agency (JCRA)-approved Canal Crossing Redevelopment Plan (City of Jersey City, Division of City Planning, 2020).

Prior to the soil remedial action at Site 114, there were approximately 4.0 acres of paved areas (roadways and parking), including Dakota Street, which bisected Site 114 in an east-west direction starting at Garfield Avenue. Dakota Street was not an active public ROW and it is currently enclosed within the fenced area of Site 114. Prior to soil remediation activities, approximately 1.8 acres of Site 114 consisted of landscaped and open areas surrounding the concrete slabs of the warehouses. The landscaped areas consisted primarily of long and narrow vegetated strips along the edges of the concrete slabs. There was a 4.0-acre area on Site 114 that was capped with stone overlying a polyethylene liner, which was constructed by PPG in 1992 as an IRM (i.e., IRM #1).

Site 114 is currently vacant land owned by the JCRA and 900 Garfield Ave, % Ryann LLC (900 Garfield Avenue, LLC). At the present, Site 114 remains completely enclosed by a barrier fence for security purposes.

1.2.2 Site Location and Description of Remaining Garfield Avenue Group Sites

The remaining five sites (Sites 132, 133, 135, 137, and 143) that comprise the GA Group are proximate to each other on abutting parcels, collectively bordered to the west by Garfield Avenue, to the south by Caven Point Avenue, to the east by Pacific Avenue, and to the north by Carteret Avenue (**Figure 1-2**). The total area encompassed by the five sites is 11.3 acres.

1.2.2.1 Site 132 – Former Town and Country

Site 132 is bordered to the west by Garfield Avenue; to the south by vacant land (816 Garfield Avenue [a.k.a. the Former Fishbein Property]), to the east by Site 137, and to the north by Site 143 and Carteret Avenue. Site 114 is located directly north across Carteret Avenue.

The total area encompassed by Site 132 is 3.16 acres. A vacant warehouse, constructed circa 1971, was demolished and the grassy and paved areas were removed in July 2013, and the building slab was subsequently removed. The warehouse was previously occupied by Town and Country Linen.

1.2.2.2 Site 133 – Former Ross Wax

The western parcel of Site 133 (Site 133W) is bordered to the west and to the south by 800 Garfield Avenue (a.k.a. Ten West Apparel), to the east by Halladay Street, and to the north by Site 137. The eastern parcel of Site 133 (Site 133E) is bordered to the west by Halladay Street, to the south by Caven Point Avenue, to the east by commercial property (Al Smith Moving) and Site 135, and to the north by Carteret Avenue.

The total area encompassed by Site 133 is 2.41 acres. Several contiguous warehouses were located on Site 133E, covering an area of approximately 1.7 acres. The warehouses were demolished from September through October 2014. Previous site uses included varnish and paint manufacturing.

1.2.2.3 Site 135 – Former Vitarroz/Narula

Site 135 is bordered to the west by Site 133E, to the south by commercial property (Al Smith Moving), to the east by Pacific Avenue, and to the north by Carteret Avenue.

The total area encompassed by Site 135 is approximately 1.5 acres. Several contiguous warehouses were formerly located on the property, covering an area of approximately 1.2 of the 1.5 acres. These structures were demolished in January and February of 2016 prior to the initiation of soil remediation at Site 135. Previous site uses included general grocery warehousing, operations by the Clorox Chemical Co., and other manufacturing operations.

1.2.2.4 Site 137 – Former Rudolf Bass & Former TSI City Carriers

Site 137 is bordered to the west by Site 132, 816 Garfield Avenue (the Former Fishbein Property), and 800 Garfield Avenue (Ten West Apparel), to the south by Site 133W, to the east by Halladay Street, and to the north by Carteret Avenue. Site 114 is located immediately north of Carteret Avenue.

The total area encompassed by Site 137 is approximately 3.24 acres. Two warehouses and paved areas were formerly located on the property. The larger of these two warehouses located at 45 Halladay Street was owned and operated by Rudolf Bass and was utilized for the storage of used industrial machinery for resale and various businesses including but not limited to woodworking and storage. The smaller warehouse located at 25 Halladay Street was occupied by TSI City Carriers.

Prior to the construction of these warehouses, Site 137 was used to stockpile CCPW generated at the former PPG chromite ore processing facility. The CCPW was stockpiled at Site 137 until about 1958, when the property was cleared and leveled. The 45 Halladay Street building was demolished in March 2014 and the building at 25 Halladay Street was demolished from late August through early September 2013.

1.2.2.5 Site 143 – Former F. Talarico Auto

Site 143 is bordered to the west by Garfield Avenue, to the south and east by Site 132, and to the north by Carteret Avenue. Residential properties are located west of Garfield Avenue. Site 114 is located immediately north of Carteret Avenue.

The total area encompassed by Site 143 is approximately 0.72 acres. A building constructed between 1963 and 1966 and paved areas were present on the property. The property operated as Talarico Auto and was used for auto repair and sales. Previous site uses included vacant land, auto salvage, and residential. The building was demolished in July 2013 and the building slab was subsequently removed in preparation for soil remediation.

1.2.2.6 Site 199

Site 199 is designated by the NJDEP as an orphan sewer site where hexavalent chromium (Cr^{+6})-impacted backfill may have been used. It is located along the NJ Transit Hudson-Bergen Light Rail (HBLR) tracks between Garfield Avenue and Halladay Street. Site 199 covers approximately 2.4 acres (approximately 1,040 feet long by 100 feet wide) and is mostly owned by the Jersey City Municipal Utilities Authority (JCMUA), with smaller portions owned by the City of Jersey City and the JCRA. NJ Transit maintains a ROW extending approximately 50 feet on both sides of the light rail tracks, for operation of the light rail system. In accordance with the Consent Judgment between the NJDEP et al. and Honeywell International, Inc. et al., dated September 7, 2011, Honeywell and PPG share responsibility for addressing chromium-related impacts at this Site.

1.2.3 Roadways and Off-Site Properties

1.2.3.1 Roadways

The Roadways that abut the GA Group Sites include Carteret Avenue, Caven Point Avenue and Pacific Avenue, Forrest Street, Garfield Avenue, Halladay Street North, and Halladay Street South (**Figure 1-2**).

<u>Carteret Avenue</u>

Carteret Avenue is bordered to the south by Site 143, Site 132, Site 137 North, Site 133 East, Site 135, and Halladay Street South (the portion of Halladay Street located between Carteret Avenue and Caven Point Avenue). Carteret Avenue is bordered to the north by Site 114, Halladay Street North (the portion of Halladay Street located between Forrest Street and Carteret Avenue), and the Former Halsted Corporation property.

The total area encompassed by Carteret Avenue Roadway is approximately 1.4 acres. Carteret Avenue Roadway is currently vacant land owned by the City of Jersey City. Prior to soil remediation activities, the property consisted of a two-lane asphalted roadway underlain by underground water, combined sewer, and gas utility lines.

<u>Caven Point Avenue and Pacific Avenue Roadways</u>

Caven Point Avenue and Pacific Avenue Roadways border the GA Group Sites located to the north, including (from west to east): Ten West Apparel (800 Garfield Avenue), Halladay Street South, Site 133 East, the Al Smith Moving property, and Site 135.

The total area encompassed by the Site is approximately 2.4 acres. Caven Point Avenue and Pacific Avenue are active, two-lane, asphalt, municipal roadways underlain by underground water, combined sewer, and gas utility lines, owned by the City of Jersey City.

Forrest Street Roadway

The Forrest Street Roadway is bordered to the south and west by Site 114, to the north by Forrest Street Properties, and to the northeast by a Halladay Street residential property.

The total area encompassed by Forrest Street Roadway is approximately 0.45 acres. Forrest Street Roadway is an active, two-lane asphalt roadway underlain by underground water, combined sewer, and gas utility lines.

Garfield Avenue Roadway

Garfield Avenue Roadway is bordered to the east by Site 114 and to the west by Frenchpark Warehouse Co., Jersey Auto Repair, and vacant land. The Garfield Avenue Roadway extends from Carteret Avenue to the New Jersey Transit Hudson-Bergen Light Rail.

The total area encompassed by Garfield Avenue Roadway is approximately 0.9 acres. Garfield Avenue Roadway is a heavily traveled urban roadway that runs approximately north-south. Concrete sidewalks are present on both the east and west sides of the roadway.

Halladay Street North

The Halladay Street North property is located on Halladay Street between Forrest Street to the northeast and Carteret Avenue to the southwest. Halladay Street North is bordered to the northwest by Site 114 and to the southeast by the Former Halsted Corporation Property (Halsted). The total area encompassed by Halladay Street North is approximately 1.2 acres.

Halladay Street South

Halladay Street South is located on Halladay Street between Carteret Avenue to the north and Caven Point Avenue to the south. The southernmost portion of Halladay Street South, immediately adjacent to Caven Point Avenue, is considered part of Phase 3B South and will be addressed in a separate submission from Halladay Street South. Halladay Street South is bordered to the west by Site 137A, Site 137B, and Site 133 West, and to the east by Site 133 East. Site 114 is located to the northwest across Carteret Avenue from Halladay Street South. The total area encompassed by Halladay Street South is approximately 0.8 acres.

1.2.3.2 Off-Site Properties

The Off-Site Properties that abut the GA Group Sites include Al Smith Moving, Halsted Corporation, Fishbein, Forrest Street Properties, and Ten West Apparel (**Figure 1-2**).

Al Smith Moving & Furniture Company, Inc.

The Al Smith Moving & Furniture Company, Inc. property (ASM) is located at 33 Pacific Avenue, Jersey City, and is bordered to the northwest by Site 133 East, to the northeast by Site 135, to the southeast by Pacific Avenue, and to the southwest by Caven Point Avenue.

The total area encompassed by ASM is approximately 0.5 acres. ASM is currently vacant land owned by GND PACIFIC HOLDINGS, LLC. Prior to remediation, the property was almost completely occupied by a commercial warehouse building operated by the Al Smith Moving & Furniture Company, Inc. The building was demolished as part of the RA at the Site in 2017.

<u>Halsted</u>

The Former Halsted Corporation Property (Halsted) is approximately 1 acre and occupies Lots 12 through 17 on Block 21502. The property was historically used in bag fabrication operations circa 1927-1928, and as a warehouse. According to the August 2014 *Preliminary Assessment Report, Halsted Corporation Facility, 78 Halladay Street, Jersey City, New Jersey* (AECOM, 2014), historical operations have included sewing and printing of bags used for containing manure, sand, fertilizer, animal feed, and similar purposes. The property is currently vacant and owned by PPG.

<u>Former Fishbein Property</u>

The area identified as the Former Fishbein Property (Fishbein) is located at 816 Garfield Avenue. This property is bordered to the north by Site 132; to the south by Ten West Apparel (800 Garfield Avenue); to the east by Site 137, and to the west by Garfield Avenue.

The total area encompassed by Fishbein is approximately 0.26 acres. PPG purchased the property on December 9, 2013; at that time, it was a vacant, partially paved lot, and is currently in that condition. Historically, the property was used as an automobile scrap yard and a parking area.

<u>Forrest Street Properties</u>

Forrest Street Properties is comprised of the properties located at 84, 86-90, 98-100, and 108 Forrest Street. Forrest Street Properties is bordered to the west by Site 114, to the south by Site 114 and Forrest Street, to the east by the Halladay Street residential properties, and to the north by Site 199 and the NJ Transit Light Rail Line.

The total area encompassed by Forrest Street Properties is approximately 1.38 acres. Forrest Street Properties contains vacant, industrial, and/or commercial land owned by 90 Forrest Associates, LLC (Block 21501, Lots 11 and 12), and 100 Forrest Associates, LLC (Block 21501, Lots 14 and 15). Block 21501, Lot 15 is currently vacant land used for access to 100 Forrest Street. Prior to remediation, the Block 21501, Lot 15 property was vacant and undeveloped.

1.3 NJDEP Forms and Regulatory Cross Reference Guide

New Jersey Administrative Code (N.J.A.C.) 7:26E-5.5 provides the requirements for a RAWP. **Table 1-1** provides a cross reference table of the requirements and their location within this RAWP.

Per N.J.A.C. 7:26E-1.6, the following regulatory forms are included with this submission:

- Cover Certification Form;
- Public Notification Form; and
- Case Inventory Document (CID).

An updated receptor evaluation was submitted as part of the Groundwater RIR (AECOM, 2021e), and is summarized in Section 2.2.

2 Summary of Groundwater Remedial Investigation

The Groundwater RIR (AECOM, 2021e) presents the results, findings, conclusions, and recommendations from the groundwater RI for the Project Area. A Conceptual Site Model (CSM) was prepared and updated during implementation of the groundwater RI to provide the current understanding of Project Area setting and conditions and is included in the groundwater RI report, which is included in **Appendix A.1** of this RAWP. Key findings from the RI relevant to the remediation strategy are summarized below.

2.1 Conceptual Site Model

The information presented in the CSM was prepared in accordance with the NJDEP guidance and is an iterative tool that is updated and refined as additional information becomes available.

2.1.1 Physical and Environmental Setting

The Project Area is located in an urban area in Jersey City, Hudson County, NJ (**Figure 1-2**). The Project Area consists of former industrial and commercial properties and businesses located within the Canal Crossing Redevelopment Area, which encompasses 111 acres of planned redevelopment space in the southeastern section of Jersey City, NJ (City of Jersey City, 2020). The area sits on top of a variety of fill material that was historically used to reclaim land in estuarine areas for industrial development. Many parcels within the Project Area changed ownership several times over the years and each owner used the land for different industrial purposes. For more information about the parcels in the Project Area, see Section 1.2 of this report and/or the Groundwater RIR (AECOM, 2021e) in **Appendix A.1**.

2.1.1.1 Topography

The Project Area has little topographic relief, with ground surface elevations ranging from El. 9 to 16 feet (ft) relative to the North American Vertical Datum of 1988 (NAVD88). However, just to the west of Garfield Avenue the topography rises approximately 30 to 40 ft in elevation within several hundred yards of the Project Area. The topography east of the Project Area is flat, extending to the Hudson River and Upper New York Bay.

2.1.1.2 Surface Water

The only surface water source in the vicinity of the Project Area is the Upper New York Bay, which is located approximately 3,800 ft to the southeast. Precipitation infiltrates into Project Area fill materials, and excess surface water runoff is directed into the City-owned combined sewer system.

2.1.1.3 Wetlands

There are no mapped wetlands on or adjacent to the Project Area.

2.1.1.4 Former Morris Canal

The former Morris Canal bisects the Project Area and extends northeast and southwest beyond the GA Group Sites (**Figure 1-2**). Historical records indicate that the former canal was up to 40 feet wide and 25 feet deep. The canal was decommissioned in the 1920s and was subsequently backfilled by 1951 with a variety of non-native materials, including CCPW.

2.1.2 Geology

A description of the Regional and Project Area geology is presented below.

2.1.2.1 Regional Surficial Geology

The United States Geological Survey (USGS) describes the regional surficial geology as unconsolidated sediments of Recent and Pleistocene age (Stone, et.al, 2002). These include alluvial, estuarine, eolian (windblown), and glacial lacustrine deposits, and glacial till of late Wisconsin age. The native regional surficial units include (Stanford, 1995):

1. **Estuarine and salt-marsh deposits**: Black, dark brown, and dark-gray organic silt and clay, and salt-marsh peat, with some sand; contains shells; that is generally less than 20 ft thick but can be up to 40 ft thick in some portions of the Project Area.

2. **Lake bottom deposits**: Gray to reddish-brown silt, clay, and fine sand; thinly layered to varved; well-sorted and stratified; up to 150 ft thick.

3. **Rahway Till**: Reddish-brown to reddish-yellow silty sand to sandy silt, containing subrounded and subangular pebbles and cobbles and few subrounded boulders; poorly sorted, non-stratified, generally compact below the soil zone; up to 50 ft thick. The Rahway Till forms a nearly continuous blanket on the bedrock surface, except on the steep eastern slope of the Palisades Ridge (Stanford, 1995).

Artificial fill consisting of a variety of debris and materials overlies the native unconsolidated materials in areas where fill was used to reclaim the shoreline from the Upper New York Bay or to fill marshlands and estuarine areas.

2.1.2.2 Project Area Surficial Geology

The Project Area is located on miscellaneous fill material that was used to reclaim the salt marsh for construction of this portion of Jersey City. Native materials beneath the fill include an organic meadow mat layer and unconsolidated deposits of glacial origin. Unconsolidated native surficial deposits pinch out against the rising bedrock surface west of the Project Area, in the vicinity of Garfield Avenue where outcrops of the Diabase are mapped (Volkert, 2016).

The primary surficial geologic units within the Project Area, from top to bottom, include:

- Fill (**the shallow zone**), consisting of:
    - Non-native fill materials in areas where soil remediation is not needed or has not yet been implemented, and
    - Clean fill (unamended or amended with the FerroBlack®-H reductant) where the previously existing non-native fill materials and subsurface structures were excavated to remove sources of chromium (Cr).
- Underlying the fill, a discontinuous layer of estuarine organic-rich deposits (meadow mat);

- Underlying the meadow mat, or directly below the fill where the meadow mat is absent, native soils consisting of sands, silty sands, silts, and clays (**the intermediate zone**) generally separated from the underlying deep zone by a layer of interbedded lower permeability silts, clayey silts, silty sands, and clays (**the transition zone, part of the intermediate zone**); and
- Underlying the intermediate zone, sands with lenses of silt, clay, and gravel underlain by the basal facies of the Rahway Till (**the deep zone, includes the basal till and overlying sands**).

2.1.2.3 Regional Bedrock Geology

Jersey City is located within the upper portion of the drainage basin for Newark Bay and lies within a glaciated section of the northeast-southwest trending Newark Basin. The bedrock is principally composed of Upper Triassic to Lower Jurassic age sedimentary rocks, known collectively as the Newark Supergroup (Drake, Jr. et al., 1997). In New Jersey, the sedimentary rocks of the Newark Supergroup are composed of reddish-brown arkosic sandstone, mudstone, siltstone, conglomerate, and dark gray argillite (Volkert, 2016). The Newark Supergroup is divided into three formations based on lithology, including:

- A lower unit identified as the Stockton Formation,
- A middle unit identified as the Lockatong Formation, and
- An upper unit identified as the Passaic Formation.

These sedimentary units have been intruded by igneous rock, principally diabase, in the form of sills and dikes, with the intrusions now generally forming ridges such as the Palisades and the Heights in Jersey City. More detailed descriptions of each of these bedrock units are provided in USGS Open File Map OFM-110 (Volkert, 2016).

2.1.2.4 Project Area Bedrock Geology

Consistent with the regional bedrock units, bedrock within the Project Area includes the Stockton Formation in the eastern portion of the area, the Lockatong Formation in the central portion of the area, and the diabase along the western margin of the area. The bedrock surface in the Project Area was shaped by various factors, including weathering, erosion, and glacial activity. Depth to bedrock ranges from 6 ft below ground surface (bgs) to the northwest (west of Garfield Avenue) to 119.5 ft bgs in the southeastern portion of Site 114.

Within the Project Area, the bedrock surface is characterized by two bedrock valleys (or channels) with a bedrock high separating these features in the central portion of Site 114. The bedrock surface rises to the north, east, and west of these features, resulting in a northwest-southeast trending trough with its highest elevations in the northwestern portion of the Project Area and its lowest elevations in the southeastern portion of the Project Area.

2.1.3 Hydrogeology

2.1.3.1 Regional Groundwater Flow

Groundwater occurs regionally in the following geologic formations: the fill, the unconsolidated overburden soils/meadow mat, and the bedrock. A summary of groundwater flow in these formations is provided below:

- **Fill**: Groundwater in the fill is unconfined and is typically encountered within 10 ft bgs. In general, the shallow zone groundwater flow patterns represent a subdued version of land surface topography although variations in these flow patterns can be attributed to heterogeneities in the fill.

- **Native Unconsolidated Overburden and Meadow Mat**: Groundwater flow in overburden materials is controlled by permeability or flow through the connected pore spaces in the soil matrix. Groundwater is mostly unconfined but may be semi-confined to confined in areas with complex stratigraphy consisting of alternating layers of less and more permeable materials. The meadow mat is a dense matrix of organic material and fine-grained soils, and this layer generally exhibits permeability that is three or more orders-of-magnitude less than surrounding materials.
- **Bedrock:** Groundwater within bedrock is stored and transmitted along fractures, bedding planes, and interconnected cracks or voids in the rock. The diabase has no matrix permeability and although fractured, serves as a no-flow boundary in the Project Area. Groundwater flow in the Lockatong and Stockton formations occurs primarily along bedding plane strike, with secondary flow along fractures parallel to bedding and along steeply dipping fractures.

2.1.3.2 Project Area Groundwater Flow

Similar to the regional hydrogeology, groundwater in the Project Area occurs within distinct hydrostratigraphic water-bearing zones (units), as follows:

- **Shallow Water-Bearing Zone**: includes groundwater present in the fill from the water table to the top of the meadow mat. Where the fill was excavated during soil remediation, the backfill is a more uniform dense-graded aggregate (DGA) material or DGA amended with FerroBlack®-H. In the northeastern corner of Site 114, beyond Forrest Street, a native sandy unit underlies the fill above the intermediate water-bearing zone deposits.
- **Intermediate Water-Bearing Zone**: includes groundwater present in the meadow mat, the underlying sand unit, and the transition zone. Where present, the meadow mat is the transition zone between the shallow and intermediate water-bearing zones and generally limits vertical groundwater movement between these zones. Where meadow mat is absent, the shallow and intermediate water-bearing zones are in direct contact. Where present, the transition zone behaves like an aquitard due to its lower permeability. The intermediate water-bearing zone pinches out against the rising bedrock surface west of the Project Area (beyond Garfield Avenue).
- **Deep Water-Bearing Zone**: north of Carteret Avenue, the deep zone consists primarily of sand and gravel with lenses of clay or silt underlain by basal till. South of Carteret Avenue, the deep zone becomes more difficult to differentiate from the intermediate zone as both zones grade into thicker sequences of lower conductivity materials such as silts, clays, and fine sands with silt and clay. The deep water-bearing zone pinches out against the rising bedrock surface on the western margin of the Project Area near Garfield Avenue.
- **Bedrock Water-Bearing Zone**: consists primarily of the Lockatong Formation, with the Palisades Sill (diabase) along the western edge of the Project Area and a section of the Stockton Formation in the eastern portion of Site 114. Groundwater flow within the bedrock occurs only within interconnected bedrock fractures, bedding planes, cracks, and voids. Yields from bedrock wells in the Project Area are low (0.02 to 0.05 gallons per minute [gpm]). Groundwater flow in bedrock is a small fraction of the total groundwater flux through the Project Area.

2.1.4 CCPW Source Areas

The sources of CCPW-related impacts to groundwater in the shallow water-bearing zone in the Project Area include:

- The former chromite ore processing facility on Site 114;
- The former stockpiles of CCPW, which consisted of:
    - A stockpile of COPR extending from the eastern portion of Site 114 southward onto Site 137 (north and south of Carteret Avenue); and
    - A stockpile of green-gray mud (GGM) immediately south of the processing facility;
- Fill materials impacted with CCPW; and
- Fill materials, which included CCPW, used to abandon the former Morris Canal (includes GGM remaining under the light rail on Site 199).

2.1.5 CCPW Groundwater Impacts

Groundwater analytical results were compared to the NJDEP Class-IIA Groundwater Quality Standards (GWQS) in accordance with N.J.A.C. 7:9C (NJDEP, 2020a) to delineate the horizontal and vertical extent of Cr-related impacts to groundwater within the Project Area. Currently there is no GWQS for Cr^{+6}; therefore, Cr-related impacts are evaluated using the GWQS for Cr of 70 micrograms per liter (µg/L). The current understanding of the distribution of Cr in groundwater is presented in plan-view and on cross-sections in the Groundwater RIR figures included in **Appendix A.1:**

- Horizontal delineation was achieved for the shallow, intermediate, and deep water-bearing zones in accordance with the NJDEP's Technical Requirements for Site Remediation (TRSR) (NJDEP, 2012b).
- Horizontal delineation within bedrock was achieved on the eastern and northern portions of Site 114. Additional delineation is required to the south and west of Site 114, within a limited area in the southwestern portion of Site 114 and northern portions of Sites 143 and 132.
- Vertical delineation within the overburden was achieved in several parts of the Project Area. However, additional vertical delineation is required in bedrock in the southwestern portion of Site 114 and northern portions of Site 143 and Site 132.

2.1.6 Fate and Transport of Chromium in Groundwater

In general, Cr leached from source areas, infiltrated into the subsurface and migrated downward through the unsaturated zone. Once within the saturated zone, migration occurs horizontally or vertically along the prevailing direction of groundwater flow via advection or diffusion based on soil type. When low-permeability soils are encountered, Cr-impacted groundwater may spread laterally along the permeability contrast where low permeability soil is encountered or diffuse into the low permeability soils. Back-diffusion of Cr from these lower-permeability soils into surrounding higher-permeability soils may occur over time, depending on concentration gradients or hydraulic conditions.

A more detailed discussion of the fate and transport of Cr-related impacts to groundwater for each of the water-bearing zones within the Project Area is presented in the Groundwater RIR (AECOM, 2021e). Key elements from the Groundwater RIR are summarized below:

- The Cr groundwater plume in the Project Area does not extend very far from the former source areas, even where preferential pathways exist, such as utilities or other anthropogenic features.
- No liquid wastes were generated from operations at the former chromite ore processing facility. Therefore, density-driven flow is not a likely contaminant transport mechanism in the Project Area.
- Shallow water-bearing zone:
    - Prior to source removal, shallow fill materials and CCPW-impacted soils above the meadow mat were sources of Cr impacts to the shallow water-bearing zone groundwater.
    - The shallow sources of Cr to groundwater are being eliminated as impacted shallow soils are removed and clean/amended fill is placed.
    - Soil remedial actions completed to date have significantly reduced Cr concentrations in the shallow water-bearing zone, with only a few localized areas remaining that exhibit Cr concentrations greater than the NJDEP GWQS.
- Intermediate water-bearing zone:
    - The primary source of Cr-impacts to the intermediate water-bearing zone is the overlying shallow water-bearing zone. Materials used to fill the former Morris Canal also serve as sources of impacts to the intermediate water-bearing zone.
    - Cr migration occurs both horizontally and vertically, depending on hydraulic conditions.
    - Fine-grained, low-permeability, soils in the intermediate zone may be sequestering Cr within the soil matrix. While groundwater flux and Cr mass transport within low-permeability soils is low, these materials may retain diffused Cr with the potential to slowly back-diffuse Cr into surrounding higher permeability soils.
    - In portions of the Project Area north of Carteret Avenue, the intermediate zone is more heterogeneous than south of Carteret Avenue, with layers of permeable sands and gravels interbedded with lower permeability layers of finer-grained materials.
    - The intermediate zone thickens in the southeastern corner of Site 114 as the bedrock surface deepens. Overburden deposits become more homogeneous, with permeability increasing, and sands and gravels prevail.
    - South of Carteret Avenue and east of the former Morris Canal, the intermediate zone is characterized by thicker and more continuous sequences of silts and clays.
    - Where present, the interbedded silts and clays of the transition zone limit vertical migration of Cr-impacted groundwater into underlying soils.
    - Placement of the sheet pile and sealing of the sheet pile joints has significantly reduced horizontal migration of Cr-impacted groundwater off Site 114 within the intermediate water-bearing zone.
    - Current monitoring data indicate that groundwater within the intermediate water-bearing zone is impacted by levels of Cr greater than the NJDEP GWQS, both within the GA Group Sites and in off-site areas.

- Deep water-bearing zone:
  - The source of Cr impacts to the deep water-bearing zone is the overlying intermediate water-bearing zone.
  - Migration of groundwater impacts from the intermediate water-bearing zone into the deep water-bearing zone occurs primarily along downward vertical hydraulic gradients within portions of the former Morris Canal.
  - The deep water-bearing zone north of Carteret Avenue is less homogeneous than it is south of Carteret Avenue, with layers of permeable sands and gravels interbedded with layers of finer-grained material of lower permeability overlying the basal till.
  - The deep zone thickens in the southeastern corner of Site 114 as the elevation of the bedrock surface lowers, with deposits grading into less permeable silts and clays underlain by basal till.
  - Where present, the lower-permeability transition zone separating the intermediate and deep water-bearing zones attenuates the groundwater flux and Cr mass transport into the deep zone.
  - The bottom of the deep water-bearing zone consists of a layer of basal till sitting atop bedrock. The basal till is continuous across the Project Area and limits vertical migration of Cr-impacted groundwater into the underlying bedrock. Discontinuous sand stringers or sand lenses of limited extent within the basal till may serve as preferential migration pathways for Cr-impacted groundwater. However, these more permeable zones within the basal till comprise a very small portion of the overall thickness of the basal till.
  - Groundwater flow within the deep water-bearing zone is influenced by the shape of the underlying bedrock surface. The bedrock high in the middle of Site 114 disrupts flow in the deep water-bearing zone effectively creating two migration pathways in the deep overburden around this bedrock high.
  - Groundwater conditions in the basal till are influenced by the shape of the bedrock surface. Based on the extensive monitoring well and remediation well network on Site 114 in the intermediate and deep water-bearing zones, and the 19 monitoring wells installed as part of the groundwater RI, , basal till underlying the northwestern and eastern portions of Site 114 that contain elevated concentrations of Cr in groundwater does not exhibit Cr concentrations greater than the GWQS, demonstrating vertical attenuation of Cr as the overburden geology transitions into the basal till. The basal till in the central portion of Site 114 is encountered at shallower depths due to the bedrock high situated in this area, and is adjacent to higher-permeability deep-zone deposits with elevated concentrations of Cr. Migration of Cr-impacted groundwater into the basal till in these areas occurred to a limited extent horizontally via discontinuous sand stringers and vertically via diffusion.
  - In the southwestern portion of Site 114 (west of the bedrock high), a localized bedrock valley creates a restricted flow regime in the deep water-bearing zone, with groundwater flowing into the valley from upgradient areas to the north and discharging from the valley to the southeast over a rise in the bedrock surface. The southern limit of the valley coincides with the location of the former CCPW stockpile identified as the Light Toned Pile (refer to Figure 2-1 in the Groundwater RIR [**Appendix A.1**]). The restricted groundwater flow regime in this area allowed for vertical migration of Cr-impacted groundwater into the basal till/weathered bedrock.

  - Chromium concentrations in the deep water-bearing zone in the southeastern portion of Site 114 located east of the bedrock high attenuate quickly as the deep zone deposits become lower in elevation and fall below the areas of impacted groundwater.
- Bedrock water-bearing zone:
  - Based on data collected to date, the only portion of bedrock groundwater within the Project Area which exhibits CCPW-related impacts is situated in the southwestern quadrant of Site 114.
  - The source of bedrock groundwater impacts in the southwestern portion of Site 114 is the overlying overburden, with migration from overburden soils into the bedrock along downward vertical hydraulic gradients. Chromium-impacted groundwater may also enter the bedrock horizontally in areas where the elevation of the bedrock fluctuates significantly, thereby placing bedrock in lateral contact with adjacent overburden soils.
  - Migration of Cr-impacted groundwater within weathered bedrock is similar to porous media due to the high degree of interconnectivity between the weathered bedrock elements. Zones of highly-weathered bedrock where the rock occurs within a clay matrix exhibit lower permeability with reduced potential for contaminant migration.
  - Within competent bedrock, migration occurs along bedding planes and interconnected fractures, cracks, or voids in the rock.

2.2 Receptor Evaluation

An updated receptor evaluation was prepared for the Project Area and included with the Groundwater RIR (AECOM, 2021e). Conclusions from the receptor evaluation are summarized below:

- Groundwater beneath the Project Area is not used as a source of potable water, as the area is served by the municipal water supply system.
- Land use surrounding the Project Area includes predominantly commercial and industrial properties (e.g., warehouses, garages, etc.).
- Residential properties are located to the west of the Project Area, between Garfield Avenue and Randolph Avenue (upgradient of the groundwater plume).
- No schools or childcare centers are present within 200 feet of the Project Area.
- No sensitive receptors are present within 200 ft downgradient of the 70 µg/L Cr isopleth in the shallow, intermediate, or deep water-bearing zones. In addition, the results of the well search included in the updated receptor evaluation show that no irrigation or domestic supply wells are located within a half-mile of the Project Area.

2.3 Classification Exception Areas

Three CEAs were proposed or established for the Project Area to serve as institutional controls and provide notification to the public that COC concentrations remain at concentrations greater than the GWQS. These CEAs are discussed below.

2.3.1 CEA for Project Area Groundwater

A CEA for the Project Area was established by the NJDEP on June 7, 2018 (NJDEP, 2018a) and an updated CEA/Well Restriction Area (WRA) Form was submitted with the Groundwater RIR (AECOM, 2021e) to propose a revision to the CEA. The proposed updated CEA encompasses an area of approximately 35 acres and extends vertically to a depth of approximately 114 ft bgs. The CEA includes the shallow, intermediate and deep water-bearing zones, and a portion of the bedrock water bearing zone where Cr-related contamination was observed during the recently completed RI. The vertical extent of the CEA within the bedrock will be updated in the future, if additional information becomes available indicating that an update to the CEA is necessary. The CEA serves as an institutional control and provides notification to the public that COC concentrations remain at concentrations greater than the GWQS within the areas encompassed by the CEA.

2.3.2 CEA for Historic Fill-related COCs

The Project Area is located within an area of New Jersey where historic fill was widely used to raise the topographic elevation (NJDEP, 2013a). Historic fill refers to non-indigenous material, which was contaminated prior to emplacement and which includes construction and demolition debris, dredge spoils, incinerator residue, fly ash, and other non-hazardous solid wastes.

Prior to filling and land reclamation activities, which began in the late 1800s, the shoreline near the Project Area was located slightly east of Garfield Avenue. The low-lying marshy areas were filled over time using a variety of fill materials transported from various source areas. Research indicates that fill included construction spoils, silts and sands, demolition debris, garbage from New York City, incinerator ash, coal ash, ship ballast, industrial waste, and other miscellaneous materials. Historical maps indicate that the majority of filling activities occurred between 1905 and 1947 (AECOM, 2012a). As most of the Project Area was underlain by non-native historic fill from the ground surface to the meadow mat prior to implementation of any soil remedial actions, it is expected that some of the non-CCPW related impacts to groundwater are attributable to historic fill.

As described in the February 2012 *Remedial Investigation Report – Soil* (2012 Soil RIR) (AECOM, 2012a), several non-CCPW-related COCs were found in soil samples at concentrations greater than their applicable regulatory criteria:

- TAL metals such as aluminum, mercury, cadmium, zinc, etc. were detected in soil samples at concentrations greater than their respective Default Impact to Groundwater Soil Screening Levels (DIGWSSLs), and the distribution of these metals was coincident with the historic fill material found throughout this section of Jersey City.
- SVOCs, including compounds typically associated with historic fill (e.g., polycyclic aromatic hydrocarbons [PAHs]), were identified in soil in the western portion of Site 114 and were coincident with the historic fill material found throughout this section of Jersey City. The concentrations of these SVOCs fall within the range of historic fill and the soil boring logs support the designation of historic fill.

Additionally, historical boring logs advanced during various soil RI programs show a variety of fill types and fill layers across the Project Area.

Several historic fill-related contaminants have been detected at concentrations greater than their respective GWQS in Project Area groundwater. The distribution of historic fill-related compounds in the Project Area groundwater was evaluated in PPG's Technical Memorandum *GW-072A, Constituents of Concern Emanating from Site 114 – Groundwater* (Emanating from Groundwater

Technical Memorandum), included in Appendix A to the Groundwater RIR (AECOM, 2021e), and in PSEG's 2014 Groundwater RIR (PSEG, 2014a). These documents identified the constitutes in groundwater associated with historic fill. NJDEP has concurred with this assessment, in an email dated February 24, 2021 (NJDEP, 2021b).

A CEA/WRA Fact Sheet Form for historic fill-related impacts to groundwater was submitted with the Groundwater RIR (AECOM, 2021e) to propose establishment of a virtual CEA. The following historic-fill related COCs were included in the Historic Fill virtual CEA application:

- Beryllium
- Cadmium
- Cobalt
- Mercury
- Selenium
- Silver
- Zinc
- 3+4-Methylphenol

2.3.3 CEA for MGP-related Impacts

As stated in Section 1, PSEG is responsible for remediating impacts related to the operation of the former MGP on Site 114. Several MGP-related COCs remain in groundwater at concentrations greater than their respective NJ GWQS. The COCs related to the former MGP are summarized in the Emanating from Groundwater Technical Memorandum*,* included in Appendix A of the Groundwater RIR (AECOM, 2021e).

On June 6, 2014, PSEG submitted a proposal for the establishment of a CEA for groundwater contamination relating to the operation of the former MGP on Site 114 (Block 21501, Lots 16, 17, 18 and 19) (PSEG, 2014b), which was approved by the NJDEP on July 25, 2014. The CEA associated with the former MGP remediation encompasses an area of approximately 76 acres and extends vertically to a depth of 100 ft bgs.

3 Summary of Completed and Ongoing Remedial Actions

This section summarizes the completed and ongoing remedial actions at the Project Area. Soil remedial activities completed over the past decade have removed a substantial portion of CCPW-impacted fill and shallow soils, and additional soil remedial activities are ongoing. These soil remedial activities have resulted in a considerable and extensive improvement of groundwater quality within the shallow water-bearing zone. During soil remediation and restoration activities, groundwater engineering controls were established, which include a capillary break, amended backfill, and steel sheet pile. In addition, competent low-permeability meadow mat, a naturally occurring feature, is present across large portions of the Project Area. The meadow mat has limited vertical migration of Cr-impacted groundwater and promotes reducing conditions where Cr^{+6} is reduced to trivalent chromium (Cr^{+3}) in this saturated zone area.

Based on bench- and pilot- scale testing conducted between 2011 and 2015, groundwater IRMs have been, are being, or are planned to be conducted in a phased approach to remediate targeted portions of the Project Area. Finally, three CEAs have been proposed or established for the Project Area to serve as institutional controls and provide notification to the public that COCs concentrations remain greater than the GWQS.

Collectively, these soil and groundwater remedial actions are important components of the overall groundwater remediation strategy for the Project Area. The rest of this section is organized as follows:

- Section 3.1 summarizes the soil remedial actions completed and ongoing, and existing groundwater engineering controls;
- Section 3.2 summarizes the bench- and pilot-scale testing that was completed and used to select groundwater remedial alternatives;
- Section 3.3 summarizes groundwater IRMs that have been completed, or are ongoing; and
- Section 3.4 summarizes the institutional controls that have been proposed or established.

3.1 Soil Remediation

3.1.1 Soil Excavation, Backfilling, and Restoration

Between 2010 and 2020, Cr-impacted soil was excavated from HCC Sites 114, 132, 133 East, 135, 137 North, 143, and 186, from adjacent properties (ASM, Forrest Street Properties, and Halsted), and adjacent roadways (Carteret Avenue, Halladay Street, and Forrest Street). As of June 30, 2021, 878,400 tons of hazardous waste material and 213,450 tons of non-hazardous waste material have been excavated from these areas (AECOM, 2021d). Excavated material was disposed of at licensed, off-site locations in accordance with applicable regulations.

Approximately 1,388,000 tons of imported clean fill material was placed in the Project Area through June 30, 2021 (AECOM, 2021d). Clean backfill (DGA) for a portion of these areas was amended with FerroBlack®-H, a chemical reductant designed to remediate heavy metals such as Cr. This water-based suspension of ferrous sulfide solids is used to prevent the amended backfill from being recontaminated by rising Cr-impacted groundwater during periods of precipitation and infiltration, and to support groundwater remediation of Cr.

Placement of FerroBlack®-H-amended backfill has resulted in substantial improvement in groundwater quality within the shallow water-bearing zone, as is evident from the groundwater analytical data collected from shallow-zone monitoring wells in these remediated areas (refer to Figure 5-11 in **Appendix A.1**). Additional excavation and backfilling activities are ongoing at Site 133 West, Site 137 South, and at the adjacent Ten West Apparel and former Fishbein properties. A description of FerroBlack®-H-amended backfill as a groundwater engineering control is discussed in Section 3.1.2.2 and Section 6.4.2.

Soil remedial action reports (RARs) for several HCC Sites, adjacent roadways, and off-site properties were submitted to the project stakeholders and have been approved, or conditionally approved by the NJDEP. The following table summarizes the 19 HCC Sites/roadways/off-site properties where soil remediation was completed, and the 14 RAR Determinations issued as of December 2021[1].

Table 3-1 Soil Remediation Status [1]

Site Name	Excavation Complete	Backfill Complete	Restoration Complete	RAR Determination	Consent Judgement Compliance
Site 114	11/24/2014	1/21/2015	1/31/2018	10/31/2019	6/1/2020
Site 132	9/5/2014	5/15/2015	1/31/2018	6/27/2019	11/1/2019
Site 143	9/5/2014	5/15/2015	1/31/2018	9/30/2019	6/26/2020
Site 137 (North)	5/15/2015	8/3/2015	1/31/2018	9/30/2019	6/26/2020
Halladay Street South (AOC HSS-1A)	10/22/2015	7/29/2016	1/31/2018	5/2/2019	6/30/2020
Site 133 (East) (AOC 133E-1A)	10/22/2015	7/29/2016	1/31/2018	10/11/2019	3/24/20
Site 135 (North)	5/25/2016	7/29/2016	1/31/2018	10/11/2019	1/15/2021
Site 135 (South)	8/23/2016	12/29/2016	1/31/2018	10/11/2019	1/15/2021
108 Forrest Street	7/19/2017	8/9/2017	5/2/2018	10/29/2019	-
Al Smith Moving	1/8/2018	1/26/2018	2/15/2018	5/28/2019	10/11/2020
Forrest Street	8/4/2017	9/1/2017	6/27/2018	10/29/2019	-
Halsted Corporation	8/10/2018	8/24/2018	4/24/2019	-	-
Halladay Street South (AOC HSS-1B)	11/30/21	12/31/21	Anticipated Feb 2022	-	-
Phase 3B-South (Sites 133 West, 137 South, Ten West Apparel, Fishbein, and portions of Halladay Street South)	11/30/21	12/31/21	Anticipated Feb 2022	-	-
84, 86-90, 98-100 Forrest Street	Approved RAWP for Restricted Use Remedy			9/28/2021	
Carteret Avenue	1/15/2020	2/7/2020	12/16/2020	9/28/2021	-
Halladay Street North	4/2/2020	4/10/2020	4/10/2020	12/29/21	-

[1] Based on Master Schedule for the NJ PPG Chrome Remediation Sites, Exhibit 2/3, Revision date July 30, 2021 (Riccio, 2021). RAR Determination for Carteret Avenue, Halladay Street North, and 84, 86-90, 98-100 Forrest Street is also included.

Site Name	Excavation Complete	Backfill Complete	Restoration Complete	RAR Determination	Consent Judgement Compliance
Garfield Avenue	Approved RAWP for Restricted Use Remedy			-	
Pacific Avenue and Caven Point Avenue	Approved RAWP for EC and NILODN			-	

Notes:
AOC = Area of Concern
EC = engineering control
NILODN = Notice in Lieu of Deed Notice

3.1.2 Engineering Controls

The November 16, 2018 memorandum titled *Site 114 – Summary of Proposed Groundwater Engineering Controls* (AECOM, 2018b) introduced the concept of groundwater engineering controls as a component of the overall groundwater remediation strategy for the Project Area. The memorandum identified four features that were either installed during soil remediation, or are naturally occurring within the Project Area, that would serve as engineering controls for contaminated groundwater. The four features are:

1) Capillary break;
2) FerroBlack®-H-amended backfill;
3) Competent meadow mat; and
4) Sheet pile barrier.

Each of these installed or natural features are intended to prevent or reduce the risk of exposure to contaminated groundwater in the Project Area and, also, serve to reduce mass discharge from the Project Area onto surrounding roadways and properties. **Figure 3-1** depicts the as-built conditions of these controls as of August 2021. A brief discussion of these engineering controls is provided below, and Section 6.4 describes how the controls serve the overall groundwater remedial objectives for the Project Area.

3.1.2.1 Capillary Break

Since soil remediation was and will be performed prior to groundwater remediation, a capillary break consisting of an impermeable high-density polyethylene (HDPE) liner or a 6-inch layer of open grade stone (OGS) was required in certain areas to prevent the formation of surficial Cr^{+6} blooms. The criteria for determining the need for a capillary break are described in the approved *Capillary Break Design Final Report (Revision 2)* (AECOM, 2017f). The extents of the installed capillary break are detailed in the approved *Capillary Break Design Final Report* (Revision 2) (AECOM, 2017f) and *Capillary Break Design Final Report (Revision 2) Addendum (Revision 1)* (AECOM, 2021a).

The impermeable HDPE liner capillary break was installed in portions of Site 114 at approximately 1 to 2 ft bgs, in Forrest Street, along Halladay Street (in the vicinity of the 101 Pacific Avenue building), and at Site 199. the capillary break consisting of a 6-inch layer of OGS was installed in portions of Site 114 at elevation 13.2 feet NAVD88 (**Figure 3-1**).

3.1.2.2 FerroBlack®-H-Amended Backfill

Backfill (DGA) amended with FerroBlack®-H at varying dosages (0.7% to 2.8% by weight [wt.]) was placed in various portions of the Project Area, shown on **Figure 3-1**. The required FerroBlack®-H soil dose was determined based on the concentration of Cr^{+6} in groundwater and is summarized in the table below:

Table 3-2 Basis for Use of FerroBlack®-H in Backfill

Cr^{+6} Concentration in Shallow Groundwater	FerroBlack®-H Solution (% by wt.)
Less than 1 part per million (ppm)	0
Greater than 1 ppm but less than 100 ppm	0.7
Greater than 100 ppm	2.0-2.8

Notes:
ppm parts per million
% percentage
wt. weight

The thickness of the amended backfill layer ranges from 5.5 ft to 21.4 ft (AECOM, 2017f; AECOM, 2021a). As of September 30, 2021, approximately 12,200 tons of FerroBlack®-H has been mixed with clean fill to prevent recontamination of shallow soils by rising Cr^{+6}-contaminated groundwater beneath the amended backfill. The FerroBlack®-H also serves as a first step in treating total Cr and Cr^{+6} contamination in groundwater.

According to the approved Discharge to Groundwater (DGW) Permit-By-Rule (PBR) for FerroBlack®-H application at the Project Area (NJDEP, 2012c; NJDEP, 2013c; NJDEP, 2015; NJDEP, 2017a; NJDEP, 2017b), four quarters of groundwater monitoring (following placement of the amended backfill) is required to demonstrate the effectiveness of the FerroBlack®-H in preventing recontamination of groundwater by Cr^{+6} in the shallow water-bearing zone. A discussion of the effectiveness of the backfill amendment is provided in Section 6.4.3. Groundwater monitoring under the PBR was completed for Site 114, Site 132, Site 133 East, Site 135, Site 137 North, Site 143, Halladay Street South, and Forrest Street, Carteret Avenue, and Halladay Street North. As soil remediation is completed in additional project areas (e.g., Site 133 West, former Fishbein property, etc.), four quarters of groundwater monitoring will be conducted, as outlined in the 2017 *Groundwater Monitoring Plan – Final* (AECOM, 2017c) (GWMP) and approved PBR.

3.1.2.3 Competent Meadow Mat

As discussed in Section 2, the meadow mat is a naturally occurring, low-permeability estuarine, organic-rich layer comprised primarily of peat, which is present at depths ranging from 10 to 25 ft bgs (**Figure 3-1**). As an engineering control, competent meadow mat is 1 foot or greater in thickness and, where present, limits vertical flow of impacted groundwater from the intermediate water-bearing zone into the shallow water-bearing zone. In addition, the meadow mat acts as a long-lasting natural source of organic carbon (reductant) that maintains a reducing geochemical environment, which promotes reduction of Cr^{+6} to Cr^{+3}.

3.1.2.4 Sheet Pile

Steel sheet pile was driven into the native soil/fill during soil remedial actions conducted by PPG and PSEG to aid in dewatering activities and to limit off-site mass discharge of groundwater COCs and MGP fluids. In general, the sheet pile begins at the ground surface, intersects the shallow and intermediate water-bearing zones, and terminates in the deep water-bearing zone. Sheet pile is currently present at the perimeter and the interior of Site 114 (bisecting Site 114 into eastern and western portions), and along Carteret Avenue and Sites 143, 132, 137, and 135 (**Figure 3-1**), and will be used as an engineering control in the intermediate water bearing zone and in the portion of the deep water-bearing zone where present. Additional details pertaining to the use of the sheet pile as a groundwater engineering control are provided in Section 6.4.4.

3.2 Groundwater Bench- and Pilot-Scale Tests Supporting Selection of Remedial Action

PPG has conducted a series of bench- and pilot-scale tests to evaluate the effectiveness and implementability of several groundwater remedial technologies to treat groundwater COCs. Key bench- and pilot-scale tests conducted in recent years supporting the groundwater remedial action selection are summarized in **Table 3-3**, and include the following:

- Bucket testing of chemical reagents for soil amendment;
- Pilot testing of FerroBlack®-H as a soil amendment;
- Groundwater in situ pilot testing with biological and chemical reagents; and
- Hydraulic fracturing.

These tests provided valuable design data on the following:

- Cr treatment performance;
- Reagent longevity and use;
- Information on fluid injection flows, pressures, and transport within the shallow and intermediate water-bearing zone.

Findings from these tests were used to select remedial alternatives for this RAWP.

3.3 Groundwater Interim Remedial Measures

Three groundwater IRMs (i.e., Phase I, Phase II, and Phase III) have or are currently being implemented on Site 114 (**Figure 3-2**) to actively treat groundwater impacted with Cr^{+6} in the shallow, intermediate, and deep water-bearing zones. As confirmed during implementation and post-treatment monitoring, the Phase I IRM has reduced Cr^{+6} concentrations within the Site 114 area and is expected to reduce future mass flux from the treated areas in the Project Area and potential mass discharge outside of the Project Area. These IRMs are being implemented under PBR authorizations issued by the NJDEP. Progress reports for the IRMs have been submitted to the NJDEP on a quarterly basis as required by the PBRs and will continue through the completion of the post-treatment performance monitoring period. Copies of PBR authorization requests and approvals for each IRM phase are provided in **Appendix B**.

The three IRMs use a combination of demonstrated active remediation technologies, including *in situ* anaerobic bioprecipitation (ISAB) and *in situ* chemical reduction (ISCR), to achieve the remediation objectives. Post-treatment monitoring data from Phase I IRM show that the IRM decreased groundwater Cr and Cr^{+6} concentrations up three to four orders of magnitude across most of the treatment area, with Cr^{+6} concentrations below the detection limits at most monitoring locations and reductions in the lateral extent of the groundwater plume within the treatment area (Arcadis, 2021). Lessons learned from the Phase I program were adopted as part of the Phase II design, and current treatment monitoring data from the Phase II IRM program indicate the development of a reactive zone and decreases in groundwater Cr and Cr^{+6} concentrations in the treatment areas (AECOM , 2021b).

These results indicate that the extent of treatment achieved during the Phase II program will be consistent with Phase I.

3.3.1 Current Status

The Phase I IRM program was completed during early 2020 and the post-treatment performance monitoring will be performed through early 2022. The Phase II IRM system is installed, and remediation is ongoing and will be followed by an additional two years of post-treatment PBR monitoring. Operation of the Phase III IRM system began in September 2021, and, similar to Phases I and II, active operations will be followed by two years of post-treatment monitoring. The following subsections summarize the work completed in the Phase I and II IRMs, and work planned under the Phase III IRM program. Descriptions of the *in situ* treatment technologies are included in Section 6.1.

3.3.1.1 Phase I IRM

The Phase I IRM was implemented between July 2017 and March 2020. As outlined in the Phase I PBR (Arcadis, 2017b), the objectives of the Phase I IRM program were:

- Achieve reductions of groundwater Cr and Cr^{+6} concentrations on Site 114:
    - In the northern area of Site 114, remove groundwater Cr and Cr^{+6} mass and reduce concentrations in the intermediate and deep water-bearing zones to less than 1,000 milligrams per liter (mg/L) via continuous groundwater extraction to make the area more suitable for ISAB during the Phase II IRM.
    - In the southern area of Site 114, establish an anaerobic reactive zone in the intermediate and deep water-bearing zones to reduce concentrations of Cr and Cr^{+6} via ISAB.
- Achieve the same objectives within a localized area of shallow groundwater in the northern portion of Site 114 via ISAB.
- Document post-treatment groundwater trends showing continuing attenuation/reduction of Cr toward achieving the NJDEP Class II-A GWQS.
- Collect and evaluate site-specific information regarding the remediation system operation to support optimization of subsequent IRM phases.

The Phase I IRM treatment included a combination of groundwater extraction and injection using pulsed organic carbon substrate delivery. The IRM configuration included the following components:

- Groundwater was recovered in the northern portion of Site 114 in areas containing the highest Cr and Cr^{+6} concentrations, and at wells closer to the injection areas, to enhance propagation of the reactive zone for Cr^{+6} ISAB and provide treatment to those areas by removing Cr.
- Recovered groundwater was treated to remove Cr via an on-site groundwater treatment plant (GWTP) and treated groundwater or potable water was used for pulsed organic carbon substrate delivery into the intermediate and deep water-bearing zones in the southern portion of the site.
- Organic carbon was introduced to a small area in the shallow water-bearing zone in the northern portion of Site 114 to treat a localized area of elevated Cr and Cr^{+6}.

The Phase I IRM well network consisted of 68, 4-inch diameter remediation wells (42 intermediate-zone wells and 26 deep-zone wells), 13 2-inch diameter monitoring wells (seven intermediate-zone wells and six deep zone wells), and six pre-existing shallow-zone wells in the former IRM #1 pilot test area (Arcadis, 2018).

Approximately 14 million gallons of groundwater were extracted and treated from the treatment area, and 9.4 million gallons of reagent injection solution (dilute organic carbon and potable water) were injected into the target treatment zones. An estimated 32,427 pounds (lbs) of Cr and 29,544 lbs Cr^{+6} were removed via groundwater extraction and ex situ treatment as a result of Phase I IRM operations (Arcadis, 2021).

Performance monitoring data collected through the third quarter of 2021 demonstrate that considerable concentration reduction of Cr^{+6} was achieved during Phase I operations and has been sustained during the post-treatment monitoring program. In both intermediate and deep water-bearing zones where operations were targeted, Cr^{+6} concentrations are currently below the detection limit. The magnitude of concentration reductions of Cr and Cr^{+6} is approximately three and four orders of magnitude compared to baseline conditions, with limited exceptions. For example, only transient reductions in Cr^{+6} were observed in well cluster 114-P1-MW1I/D and the development of a reactive zone in this area was limited. The 114-P1-MW1I/D well cluster is located within the sheet pile on Site 114, within a static hydraulic zone near two injection wells. The treatment response in the localized area near wells 114-P1-MW-1I and 114-P1-MW-1D was less complete based on competing hydraulic forces between the sheet pile and adjacent operating injections wells (114-P1-MW-1I) and/or due to their construction in lower permeability strata (114-P1-MW-1D). The lower-permeability zones in this area represent the upper portion of the deep water-bearing zone, which can store immobile Cr^{+6}. The localized Cr^{+6} impacts within the sheet pile and the diffused Cr^{+6} within the low permeability zone are considered immobile and not migrating offsite, and therefore do not represent an exposure risk to receptors.

The reactive zone established during Phase I IRM operations continues to be active and robust, as evidenced by sustained total organic carbon (TOC) concentrations that are elevated from the baseline, continued indication of iron sulfide generation, and sustained reducing geochemical conditions (i.e., low dissolved oxygen, low to negative oxidation-reduction potential [ORP], increasing methane concentrations, etc.) (Arcadis, 2021). Continued post-treatment performance monitoring will provide additional data to support the evaluation of reactive zone persistence in the subsurface.

3.3.1.2 Phase II IRM

As outlined in the Phase II PBR (Arcadis, 2019), the objectives of the Phase II IRM program are:

- Establish anaerobic reactive zones to support ISAB and ISCR reduction of Cr and Cr^{+6} within:
    - The northern portion of Site 114 where Phase I groundwater extraction was used to reduce Cr; and
    - The southeastern portion of Site 114.
- Document post-treatment trends showing continuing attenuation/reduction of Cr toward achieving the Class II-A GWQS.
- Collect site-specific information regarding the system operation to support the design of Phase III IRM.

The Phase II IRM design adopted the design learnings from Phase I and resulted in a denser well network. The expectation for the Phase II program is that similar concentration reductions and reactive zone establishment will be achieved through the Phase II area as was achieved in the Phase I area.

Baseline sampling of the Phase II IRM well network was completed in March 2020 and full-scale operation of system began in October 2020. The Phase II IRM includes a combination of groundwater extraction and injection using pulsed reagent delivery and is configured as follows (refer to **Figure 3-2):**

- In the central portion of Site 114, groundwater is being recovered using 15 extraction wells from areas containing elevated Cr and Cr^{+6} concentrations. This extraction layout provides direct treatment of the area by removing Cr, resulting in less overall Cr in the subsurface. This area is also strategically advantageous to hydraulic operation, as the centralized location enhances the subsurface progression of organic carbon and reactive zone distribution from both Phase II (north to south) and Phase I (south to north) IRM operations. Recovered groundwater is ex situ treated to remove Cr mass using an on-site GWTP prior to discharge to the Passaic Valley Sewerage Commission (PVSC), in accordance with the PBR.
- Groundwater extraction is also performed to induce hydraulic gradients across the injection area to support flushing of Cr mass towards the extraction wells and to maintain the hydraulic balance in the treated area within the sheet pile enclosure. In addition, the extraction well locations, in most cases, target areas with the highest Cr and Cr^{+6} concentrations that benefit the removal of Cr mass from Site 114.
- In the northern portion of Site 114, a combination of localized groundwater extraction and reagent injection will provide a degradable source of organic carbon or chemical reductant that will establish a reactive zone for ISAB or ISCR of Cr^{+6} to Cr^{+3} and subsequent precipitation and fixation of Cr within the aquifer matrix.
- In the southeastern corner of Site 114, groundwater may be recovered from non-DNAPL areas or treatment zones to manage groundwater mounding in that area during the injection of substrates to support ISAB in an area not included in the Phase I IRM. The extracted groundwater will be treated and discharged to the PVSC in accordance with the PBR.
- Similar to Phase I IRM operations, the extraction/injection dynamics will help maintain the hydraulic balance inside the sheet pile enclosure around Site 114 and will also support flushing of Cr mass within the pumping wells hydraulic capture radius toward the extraction wells for removal and treatment.
- In Phase II IRM areas where dense non-aqueous phase liquid (DNAPL) associated with the former MGP is present, the DNAPL will be removed from pumping or injection wells, as practical, before extraction or injections commence or during the treatment period. This flexible and adaptive approach will be implemented according to the approved modification of the Groundwater Phase II IRM PBR (NJDEP, 2021a).

The Phase II IRM well network consists of 159 4-inch diameter remediation wells (84 intermediate-zone wells and 75 deep-zone wells) and 24 2-inch diameter monitoring wells (12 intermediate- zone wells and 12 deep-zone wells).

An estimated 117,000 to 138,000 gallons of reagent (organic carbon substrate and chemical reductant) and 11,000,000 to 15,000,000 gallons of potable water will be injected into the treatment zones over a 12-month period, per the PBR authorization.

The following bullets provide the operational summary of the Phase II IRM system, as of September 30, 2021:

Northern Area of Site 114:

- A total of approximately 6.1 million gallons of organic carbon substrate (molasses) and potable water, as well as 4.9 million gallons of the chemical reductant (calcium polysulfide [CaSx]) has been delivered into the target treatment areas to establish reactive zones.
- Approximately 9 million gallons of contaminated groundwater have been extracted from this area, which amounts to the removal of an estimate 9,108 lbs of Cr and 9,061 lbs of Cr^{+6}.

Southeastern Area of Site 114:

- Over 2.2 million galls of organic carbon substrate (molasses) and potable water have been injected into the target treatment areas within the southeastern portion of Site 114 to establish reactive zones.
- Approximately 313,000 gallons of contaminated groundwater have been extracted from this area, which amounts to the removal of an estimated 869 lbs of Cr and 635 lbs of Cr^{+6}.
- To allow extraction to proceed from wells that have contained, or could contain DNAPL in the southeastern area, a separate DNAPL extraction system was constructed in August 2021, and was brought into operation in September 2021.

Operational and treatment monitoring in the northern and southeastern areas of Site 114 are underway. Increased TOC concentrations above baseline conditions (i.e., breakthrough) in portions of the intermediate and deep water-bearing zones and development of the bioprecipitation reactive zone have been observed during monthly treatment monitoring. Similar to the Phase I findings, the presence of TOC has been correlated with decreases in Cr and Cr^{+6} concentrations and continued advancement of the reactive zone is expected as the ISAB and ISCR injection program is completed in the Phase II IRM north area and southeastern areas (AECOM, 2021f).

3.3.1.3 Phase III IRM

The third phase of the groundwater IRMs is underway, and is intended to actively treat Cr^{+6}-contaminated groundwater in the shallow, intermediate, and deep water-bearing zones where Cr is present at concentrations greater than 1,000 µg/L in areas that are not targeted by the Phase I and Phase II IRMs.

The Phase III IRM area (**Figure 3-2**) is comprised of select water-bearing zones within the following areas outside Site 114:

- Carteret Avenue;
- Select areas within HCC Sites 132, 137 and 143;
- Halladay Street North;
- Intersection of Carteret Avenue and Pacific Avenue; in the vicinity of the 101 Pacific Avenue property;
- Forrest Street; and
- Site 199.

The Phase III IRM includes targeted treatment in strategic areas within the lower portion of the deep water-bearing zone within Site 114 below the transition zone and beneath the vertical limits of the Phase I IRM but above the top of the basal till (i.e., the lower portion of the deep water-bearing zone).

This phase of the IRM includes a combination of in situ reagent injections to stimulate biotic or abiotic reduction of Cr^{+6} (ISAB or ISCR) and localized FerroBlack®-H emplacement to form a reactive zone in select areas. A conceptual layout of the Phase III IRM is provided on **Figure 3-2**. Descriptions of how these technologies will be implemented to achieve the groundwater remediation goal are provided in Section 6.1.

In areas planned for in situ treatment via injections using ISAB or ISCR, a degradable source of organic carbon (molasses) or chemical reductant (CaSx) will be delivered using mobile injection units (MIUs) through an injection well network with adequate spatial coverage to establish an in situ reactive zone within each target treatment area, similar to the Phases I and II IRMs. It is anticipated that where well-based delivery is proposed for the Phase III IRM, reagent delivery will be performed using injection methods. Groundwater extraction options to manage groundwater mounding within the treatment areas; if required, will be completed using a temporary well-point dewatering system or localized groundwater extraction using pumps from injection or dedicated extraction wells. The extraction method will depend on the final location of well points and the hydraulic conditions encountered in each of the treatment areas during implementation. The injection approach and extraction option using pumps were effective in the Phase I and the initial stages of Phase II IRMs, and the Phase III design retains the flexibility to optimize the treatment process. Relevant design details of the Phase III IRM system were provided in the PBR application (AECOM, 2021c), included in **Appendix B**.

In areas planned for FerroBlack®-H emplacement, the reagent will be delivered into the target zones via a series of soil borings in a line perpendicular to the direction of groundwater flow. Once emplaced, the FerroBlack®-H will establish a reducing environment within the zone of influence of the injected material. The active mechanism of this reagent is described in further detail in Section 6.4.2.

The Phase III IRM PBR application was submitted to the NJDEP's Bureau of Case Assignment and Initial Notice on April 20, 2021. The Phase III IRM PBR application was approved by NJDEP. The Phase III IRM system began operations, starting with injections of the organic carbon substrate (molasses) and potable water in the Carteret Avenue treatment area in September 2021. Activities to support FerroBlack®-H emplacement in the lower portion of the deep water-bearing zone on Site 114 commenced on September 9, 2021 and are ongoing.

3.4 Groundwater Institutional Controls

As described in Section 2.3, two CEAs have been established for CCPW- and non-CCPW-related groundwater impacts within the Project Area. A proposal to establish a third virtual CEA, for historic fill-related COCs, has been submitted to the NJDEP with the Groundwater RIR (AECOM, 2021e).

4 Groundwater Remediation Goals and Objectives

Investigation and remediation activities at the Project Area are regulated by the NJDEP as administered by the Superior Court of New Jersey under the 1990 ACO and the 2009 Partial Consent JCO Concerning the PPG Sites. In accordance with the 2009 JCO, PPG is responsible for remediating CCPW and CCPW-related constituents in soil and groundwater at the Project Area that are present in exceedance of their respective remediation standards. PPG is also responsible for CCPW and non-CCPW constituents that were determined to be emanating from Site 114 onto adjacent parcels, in accordance with the 1990 ACO.

4.1 Constituents of Concern

4.1.1 CCPW Parameters

Extensive groundwater investigations have occurred since 2005, as documented in the Groundwater RIR (AECOM, 2021e). The primary groundwater COCs that are the target of active treatment include the CCPW metals (antimony [Sb], nickel [Ni], thallium [Tl], vanadium [V], and Cr) and Cr^{+6}. PPG maintains responsibility for CCPW metals-related impacts (i.e., at concentrations greater than the GWQS) to groundwater within and outside Site 114 (as defined by the extent of the 70 µg/L Cr isopleths depicted on **Figures 4-1** through **4-3**).

4.1.2 Non-CCPW Parameters

The secondary groundwater COCs exhibiting concentrations in groundwater above their respective GWQS on Site 114 include VOCs, SVOCs, and TAL metals. An evaluation of these non-CCPW constituents is described in the Emanating From Groundwater Technical Memorandum (AECOM, 2021e). Non-CCPW constituents exceeding their respective GWQS on Site 114 are included in the Project Area CEA.

With the exception of tetrachloroethene (PCE) in groundwater detected in the shallow water-bearing zone at monitoring well 114-MW41A located on Site 199 (refer to Figure 4-1 in **Appendix A.1**), and 1,4-dioxane detected in the localized area between the southeast corner of Site 114 and four off-site intermediate zone monitoring wells (MW8D, 114-MW19B, 114-MW20B and 114-MW40B), the non-CCPW constituents identified as emanating from Site 114 in groundwater are either MGP-related, or historic fill-related. PSEG maintains responsibility for remediation of MGP-related constituents in groundwater both on- and off-Site 114 pursuant to their Site Remediation Program (SRP) case[2]. Historic fill-related groundwater contamination is documented in the Historic Fill virtual CEA/WRA proposal submitted to NJDEP with the Groundwater RIR (AECOM, 2021e).

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[2] PSEG is responsible for investigating and remediating impacts related to the operation of the former MGP located in the Project Area (PSEG, 2007; PSEG, 2009; PSEG, 2014). MGP-related impacts within the Project Area are being addressed by PSEG under NJDEP Site Remediation Program (SRP), Program Interest Number G000005480, Activity Number LSR120001, per the July 2019 agreement between PPG and PSEG (PPG and PSEG, 2019).

4.2 Remediation Criteria

Per N.J.A.C. 7:9C, remediation standards applicable to the Project Area are the Class II-A Groundwater Quality Standards (NJDEP, 2020a). GWQS have been established for the COCs, in µg/L:

Table 4-1
NJDEP GWQS for Groundwater COCs

Groundwater Constituent of Concern	NJDEP GWQS (µg/L)
CCPW-related COCs	
Chromium (total)	70
Antimony (total)	6
Nickel	100
Thallium	2
Vanadium	60
Non-CCPW-related COCs Emanating from Site 114	
Tetrachloroethene	1
1,4-dioxane	0.4

Table 4-2
NJDEP GWQS for Non-CCPW COCs Included in the Project Area CEA

Groundwater Constituent of Concern	NJDEP GWQS (µg/L)
1,1,2-Trichloroethane	3
1,1-Dichloroethylene	1
1,2-Dichloroethane	2
Aluminum	200
Bis(2-ethylhexyl)phthalate	3
Chloride	250,000
cis-1,2-Dichloroethene	70
Copper	1,300
Iron	300
Manganese	50
Pentachlorophenol	0.3
Sodium	50,000
Styrene (monomer)	100
Sulfate	250,000
Trichloroethylene	1
Vinyl Chloride	1

The NJDEP has established specific remediation requirements for Cr in groundwater within the State of New Jersey via a memorandum dated February 8, 2007 from Lisa Jackson, Commissioner, to Irene Kropp, Assistant Commissioner (NJDEP, 2007). This memorandum provides the following remediation objectives specific to Cr in groundwater at NJDEP SRP sites, inclusive of the Project Area:

- Cr groundwater contamination below a depth of 20 ft bgs should be controlled, contained or treated through the use of conventional or innovative technologies;
- Cr groundwater contamination should be controlled, contained or treated through the use of conventional or innovative technologies;
- A capillary break should be installed to prevent any crystallization of chromate on soil surfaces; and
- A CEA should be established.

The NJDEP has provided clarifying information for groundwater remediation at Site 114 in a letter dated December 22, 2020 from Mark Pedersen, Commissioner (NJDEP, 2020b). This letter states that the NJDEP expects PPG to make every effort to actively treat groundwater contamination before a containment and control strategy will be considered by the NJDEP. The letter provides the NJDEP's opinion that an active remedy is necessary in the lower portion of the deep water-bearing zone on Site 114, where recent groundwater sampling data have shown Cr concentrations greater than 100,000 µg/L that are not currently being targeted by the Phase I and II IRM active treatment systems. The NJDEP acknowledges that this portion of Site 114 underlies an area on Site 114 proposed for the initial phase of Hampshire Urban Redevelopment Renewal, LLC's (Hampshire) proposed redevelopment, and that efficient implementation of an active remedy in this zone should be coordinated such that PPG's selected remediation strategy does not compromise the potential for redevelopment. Finally, the Pederson letter (NJDEP, 2020b) states that PPG's active remediation (via the Phase I and II IRMs) to date appears to be improving the groundwater quality on Site 114. PPG notes that, based on the September 2, 2020 NJDEP Listserv publication for an Active System Ground Water Remedial Action Permit (RAP), in addition to groundwater pump and treat systems, the NJDEP considers remedial injections and reactive barriers to be active remedies.

4.3 Remediation Goals and Objectives

The long-term remediation goals for groundwater in the Project Area is to protect human health and the environment. This goal will be achieved through compliance with the NJDEP Class II-A GWQS (N.J.A.C. 7:9C) using a combination of active treatment, monitored natural attenuation (MNA), and long-term monitoring combined with institutional and engineering controls.

In specific treatment zones (spatial extents) where active treatment is not feasible, technical impracticability will be evaluated and, if appropriate, an application for a Technical Impracticability determination will be submitted to the NJDEP in accordance with the NJDEP's Technical Impracticability – Guidance for Groundwater (NJDEP, 2013b).

Remediation objectives (short-term and long-term) are the strategies that will be implemented to achieve the remediation goal. These strategies include the following milestones:

- Reduce the exposure of current and future receptors to the groundwater COCs, so as to protect the public health, safety, and the environment.

- Achieve compliance with the GWQS through the initial implementation of an active remedy where practicable in areas with groundwater Cr^{+6} concentrations greater than 1,000 µg/L (**Figures 4-1** through **4-3**), implementation of contingency measures as appropriate, and to transition to an MNA remedy combined with long-term monitoring.
- Design and implement the remediation strategy to control the migration of groundwater and minimize the mass discharge or flux leaving the Project Area.
- Until the groundwater remediation goal is achieved, reduce the risk of exposure to groundwater through monitoring and maintenance of engineering controls, including a capillary break and FerroBlack®-H-amended backfill, establish/maintain a CEA as an institutional control, and monitor groundwater to measure the progress of the remedial action toward meeting the remediation goals.
- Apply for and obtain an Active Category Groundwater RAP after monitoring data demonstrate the effectiveness of the active system remedy (as per the requirements for the Active Category Groundwater RAP outlined in NJDEP's Ground Water Remedial Action Permit Guidance). Transition to an MNA Category Groundwater RAP will be considered when monitoring data demonstrate that it is appropriate to do so.

4.4 Remediation Areas

4.4.1 Remediation Target Area

The horizontal extent of the Project Area where CCPW-related COCs are present in groundwater at concentrations greater than the NJDEP GWQS in the shallow, intermediate, and deep water-bearing zones is depicted on **Figures 4-1** through **4-3.** These areas are defined by the extent of Cr in groundwater within each water-bearing zone at concentrations greater than the 70 µg/L NJDEP GWQS. The vertical extent of CCPW-related groundwater contamination is depicted on Figures 5-1 through 5-9 of the Groundwater RIR (**Appendix A.1**). The horizontal and vertical extent of Cr-related impacts to groundwater defines the limits of the overall remediation target area.

The volume of groundwater targeted for remediation resides in the pore spaces of the hydrogeologic units within the shallow, intermediate, and deep water-bearing zones. In general, overburden materials where groundwater flow and transport are dominated by advection are considered permeable and materials where groundwater flow and transport are dominated by diffusion are considered to exhibit low permeability. The concept of low permeability is well documented in the literature and is commonly understood to include soils that are dominated by fine grained or low primary porosity materials such as silts, clays, glacial till, over-bank deposits, and marine deposits (Horst, et. al, 2019).

Based on the evaluation of hydraulic profiling tool (HPT) data conducted during the groundwater RI (AECOM, 2021e), it is estimated that 73% of the intermediate and deep water-bearing zone soils (not inclusive of the basal till) are permeable, are therefore accessible for active *in situ* treatment, and are soils where extensive reduction of Cr^{+6} can be expected. The remaining 27% of soils in the intermediate and deep water-bearing zones are characterized by low permeability and are inaccessible for active *in situ* treatment. Additional detail regarding the occurrence of low-permeability soils at the Site is presented in the technical memorandum included in **Appendix A.2**. Low permeability soils serve to immobilize Cr^{+6} and impacted groundwater residing in these soils does not pose a risk to human and ecological receptors. Furthermore, it is impractical to delineate or access via active treatment the numerous dead-end or highly constrained pore spaces within these low permeability soils. Therefore, low permeability soils are not targeted for active treatment but will be managed under an MNA remedy and via the excess reductive capacity emplaced within adjacent more permeable zones by the active treatment technologies.

It is not possible to estimate the mass of Cr remaining within overburden soils and groundwater because the mass of Cr initially released is unknown. Furthermore, an assessment of the mass of Cr remaining in the subsurface is not necessary for implementation of the Phase I, Phase II, and Phase III IRMs, nor is this information necessary for the overall remediation strategy for the Project Area.

Groundwater flow in competent bedrock occurs only within interconnected fractures, bedding planes, cracks, and voids, and not within the rock matrix itself. Flow in weathered bedrock immediately below overburden materials is similar to porous media flow due to the high degree of interconnectivity between the weathered bedrock elements, except in areas where the weathered rock has higher clay content within fractures, which reduces the permeability of the weathered horizon. Based on borehole geophysical logging measurements and observations during bedrock well development and sampling, yields from bedrock wells in the Project Area are low (AECOM, 2021e). Overall, groundwater flow in bedrock is a small fraction of the total groundwater flux through the Project Area.

4.4.2 Active Remediation Target Area

One of the objectives of the Project Area groundwater remediation strategy is to achieve compliance with the GWQS through the implementation of an active remedy, where practicable, in areas with Cr^{+6} concentrations greater than 1,000 µg/L. Over the course of treatment and when conditions are appropriate, the active component of the remedy will be transitioned to an MNA remedy. The areal extent where Cr^{+6} is present in groundwater at concentrations greater than 1,000 µg/L in each overburden water-bearing zone is depicted on **Figures 4-1** through **4-3**. To define the active remediation target areas, it was assumed that Cr concentrations within the 1,000 µg/L Cr isopleths consist entirely of Cr^{+6}. Active groundwater treatment for a portion of these areas has already been completed or is ongoing via implementation of the Phase I and II IRMs, and treatment for the remaining areas will be accomplished via implementation of the Phase III IRM. The locations of the Phase I, II and III IRM areas are shown on **Figure 3-2**.

The deep water-bearing zone extends to depths greater than the bottom of existing Phase I and II IRM remediation wells in certain portions of Site 114, especially in the southeastern and southwestern portions of Site 114 (refer to Figures 5-1 through 5-9 in **Appendix A.1**). Certain areas of this lower portion of the deep water-bearing zone (the Lower Deep Zone) exhibit Cr^{+6} concentrations greater than 1,000 µg/L. The Lower Deep Zone includes overburden materials situated below the bottom of the transition zone, above the top of the basal till, and below the bottom of Phase I and II IRM remediation wells. The portions of the Lower Deep Zone warranting active remediation are illustrated on **Figure 3-2** and will be targeted during implementation of the Phase III IRM.

4.4.3 Practicality of Active Treatment

The active *in situ* remedies selected for the Project Area (Section 5.3) include the delivery of remediation compounds to the targeted water-bearing zones to establish groundwater conditions that are favorable for the reduction of Cr^{+6} to Cr^{+3}. The efficacy of the delivery of remediation compounds is directly related to the permeability of the targeted materials. In areas where the permeability does not allow remediation compounds to be delivered into the pore spaces of the targeted materials using demonstrated technologies, technical impracticability will be evaluated and, if appropriate, an application for a Technical Impracticability Determination will be submitted to the NJDEP in accordance with the NJDEP's *Technical Impracticability – Guidance for Groundwater* (NJDEP, 2013b).

4.4.3.1 Hydrogeologic Considerations for Selecting Active *In Situ* Treatment Zones

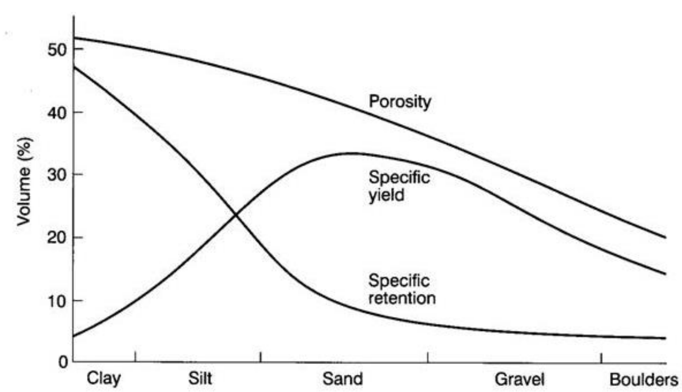
Permeability is the property of a porous material which permits the passage or seepage of water (or other fluids) through its interconnected interstices, voids, or pores. Total porosity is defined as the percentage of the total volume of a rock or soil that is occupied by interstices, voids, or pores (Heath, 1983). Porosity of soils depends on the range in grain size (sorting) and on the shape of the particles that comprise the soil. In general, total porosity increases with increasing sorting and decreases with increasing sphericity. Total porosity decreases with closer packing of the soil particles. Groundwater (or other fluids, e.g., DNAPL) may exist within all available interstices, voids, or pores, but only flows where they are interconnected. The interconnected interstices, voids, or pores that contribute to fluid flow represent the effective porosity of the material. Effective porosity excludes isolated interstices, voids, or pores, and pore volume that is occupied by water (or other fluids, e.g., DNAPL) adsorbed on clay minerals or other grains.

The specific yield of an aquifer, which is also known as effective porosity, is the volume of water that will drain under the influence of gravity. Specific retention of an aquifer is the amount of water retained by capillary forces during gravity drainage. The relationship between total porosity, specific yield, and specific retention can be expressed as follows (Bear, 1979):

$$n = Sy + Sr$$

where n is total porosity [dimensionless],
Sy is specific yield [dimensionless], and
Sr is specific retention [dimensionless].

Therefore, specific yield (i.e., effective porosity) is less than the total porosity. The following figure illustrates the relationship between total porosity, specific yield, and specific retention for silts, clays, sands, and gravels (Davis and DeWiest, 1966):



Based on this information, the total porosity of silts and clays is higher than sands and gravels while the effective porosity of sands and gravels is higher than silts and clays. Therefore, silts and clays contain more pore water but do not contribute to advective groundwater flow and mass flux of Cr-impacted groundwater because the pore water in these soils has limited mobility (low effective porosity) relative to sands and gravels. Conversely, due to their higher effective porosity, sands and gravels can more readily accept remediation compounds relative to low permeability soils. This conclusion is supported by findings from the Phase I IRM performance monitoring program which indicate favorable distribution of remediation compounds into more permeable materials.

The basal till at the bottom of the deep water-bearing zone and above bedrock consists of silty clays, sandy silts, and silty sands with subrounded to subangular fine to coarse gravel, cobbles, and occasional interbedded lenses of clay, silt, or fine sand. The thickness of the basal till encountered in soil borings ranges from 1 foot to 30 feet, with the basal till continuous across the Project Area. In general, the basal till consists of a wide range of materials typically exhibiting low permeability and low moisture content (damp to dry) but includes discontinuous stringers or lenses of permeable sands. The observed thickness of sand stringers or lenses within the basal till ranged from 0.2 to 6.5 feet. Of the approximately 390 feet of basal till logged within the Project Area, only 21 feet consisted of sand stringers or lenses, which equates to less than 6% of the basal till (AECOM, 2021e). Therefore, the basal till is unlikely to significantly contribute to advective groundwater flow and mass flux of Cr-impacted groundwater and delivery of remediation compounds into the basal till may not be practicable.

The bedrock water-bearing zone within the Project Area consists primarily of the Lockatong Formation, with the Palisades Sill (diabase) along the western edge of the Project Area and a section of the Stockton Formation in the eastern portion of Site 114. Based on findings from the groundwater RI, yields from bedrock wells are low, ranging from 0.02 to 0.05 gpm (AECOM, 2021e).

4.4.3.2 Integration with CSM for the Project Area

Based on the geology, hydrogeology, and the fate and transport of Cr within the Project Area described in the CSM, it is understood that residual concentrations of Cr^{+6} can be expected to remain in low permeability soils (i.e., silts and clays, highly organic soils, glacial till) after completion of the IRMs and that back-diffusion of Cr^{+6} from these low permeability soils into surrounding higher permeability soils (i.e., sands and gravels) may occur over time. The expected release of Cr^{+6} from low permeability soils via back-diffusion will be highest within the first several years following completion of IRM treatment, after which mass discharge from low to high permeability soils will decline significantly for several years after post-treatment (estimated 5 to 10 years).

Based on hundreds of soil borings completed across the Project Area, correlation of HPT logs with soil boring logs, and four years of IRM operation, maintenance and monitoring, it is evident that soils not suitable for active *in situ* treatment include fine grained and cohesive soils characterized by the following descriptions based on the Unified Soil Classification System (USCS):

- **ML**: Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity.
- **CL**: Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
- **OL**: Organic silts and organic silty clays of low plasticity.
- **MH**: Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
- **CH**: Inorganic clays of high plasticity, fat clays.
- **OH**: Organic clays of medium to high plasticity, organic silts
- **PT:** Peat and other highly organic soils.

Based on the information presented above and lessons learned during groundwater IRM implementation, the following conclusions can be made regarding the practicability of active *in situ* treatment for the water-bearing zones within the Project Area:

- Active *in situ* treatment of permeable soils within the intermediate and deep water-bearing zones is practicable as these soils readily accept remediation compounds. These soils contribute to advective groundwater flow and mass flux of Cr-impacted groundwater.
- Active *in situ* treatment of soils with low permeability within the intermediate and deep water-bearing zones is not possible, as these soils do not readily accept remediation compounds. These soils are unlikely to significantly contribute to advective groundwater flow and mass flux of Cr-impacted groundwater and include the thinly-interbedded fine sands, silts, and clays of the transition zone, any lenses of silts or clays that may be interbedded within the more permeable portions of the intermediate and deep water-bearing zones, and the basal till. Dissolved Cr^{+6} is expected to reside in low permeability soils after cessation of the IRMs with back-diffusion from the low permeability soils to surrounding higher permeability soils, but the excess reductive capacity delivered to the overburden via the IRMs will attenuate back-diffusion of Cr^{+6} from these soils into surrounding higher permeability materials.
- Based on the composition and depositional environment of the basal till and the findings from the groundwater RI (AECOM, 2021e) which indicate that less than 6% of the basal till consists of discontinuous sand stringers or lenses, it is not possible to identify and target sand stringers and lenses within the basal till for active *in situ* remediation.
- Based on the low effective porosity of the bedrock in areas where elevated Cr concentrations have been identified in groundwater samples collected from bedrock monitoring wells (AECOM, 2021e), implementation of active *in situ* remediation is unlikely to be feasible in the bedrock zone.

5 Selection of Groundwater Remedial Action

5.1 Identification of Groundwater Remedial Alternatives

Table 5-1 identifies the groundwater remedial alternatives evaluated for the Project Area. These alternatives were selected based on their performance during pilot testing and implemented IRMs, as described in Section 3.0. Ten remedial alternatives are presented in **Table 5-1** and are briefly described in the subsections below.

5.1.1 No Action Remedy Alternative

A no action alternative is presented in **Table 5-1** for comparison to other alternatives. For this alternative, existing engineering and institutional controls would remain in place, although they would not be monitored or maintained.

5.1.2 Active Remedy Alternatives

According to the September 2, 2020 NJDEP Listserv publication for an Active System Ground Water RAP, active remediation technologies are those that are effectively remediating contamination and are functioning as designed. This includes remedial injections that are performed at an appropriate frequency to demonstrate that they are effectively remediating contamination for a minimum of one year prior to submitting an Active System Groundwater RAP application. Active remedies also include remedial injections and reactive barriers installed for a minimum of one year prior to submittal of an Active System Groundwater RAP application. Therefore, the following eight active remedial action alternatives were evaluated in **Table 5-1** for treating groundwater COCs in the Project Area.

- **Extraction Barrier:** An extraction barrier consists of a row of extraction wells in the target area with radii of influence that form a hydraulic barrier along the target section of the Project Area boundary. Cr- and Cr^{+6}-contaminated groundwater migrating towards the off-site areas would be extracted and treated through an on-site groundwater treatment system and either discharged or reinjected into the subsurface. This alternative manages the mass discharge of Cr and Cr^{+6} that could migrate beyond the Project Area.
- **FerroBlack®-H Emplacement:** This alternative is intended to treat localized areas of contamination by emplacement of a ferrous sulfide based chemical reductant (FerroBlack®-H) into the target zones. The reductant will abiotically reduce Cr^{+6} to the less mobile and less toxic Cr^{+3}, thereby immobilizing it within the aquifer. FerroBlack®-H has proven effective at treating Cr^{+6} based on past bench- and pilot-scale testing and is used as an effective backfill amendment material that has prevented recontamination of the backfilled portions in the Project Area.
- **Pump and Treat**: The pump and treat remedial action alternative removes groundwater from areas containing the highest Cr and Cr^{+6} concentrations in the aquifer within the zone of influence of an extraction well. The technology can be used to spread reagents in the subsurface or maintain hydraulic control within areas surrounded by sheet pile (e.g., Site 114). Extracted water is treated via an ex-situ GWTP prior to discharge or reinjection.
- **ISAB**: The ISAB remedial action alternative remediates Cr and Cr^{+6} concentrations by injecting organic carbon substrates (molasses and emulsified vegetable oil [EVO]) in a target

area to establish a reactive zone and reduce Cr^{+6} to less soluble Cr^{+3} through reactions with biologically-generated reductants or via direct anaerobic respiration with Cr^{+6}. This subsequently precipitates and immobilizes Cr within the zone of influence of the treatment area. The use of organic carbon substrates to stimulate anerobic reduction is an effective remedial approach in the Project Area proven by past pilot testing and ongoing Phase I IRM performance monitoring data.

- **ISCR with CaSx**: The ISCR with CaSx remedial action alternative is implemented by injecting CaSx reagent in a target area to establish a reducing environment and chemically reduce Cr^{+6} to less soluble Cr^{+3}, and subsequently precipitate and immobilize Cr within the zone of influence of the treatment area. Pilot testing has demonstrated the effectiveness of this reagent in reducing Cr^{+6} concentrations.
- **ISCR with FerroBlack®-H**: The ISCR with FerroBlack®-H remedial action alternative is implemented by injecting FerroBlack®-H reagent in a target area to establish a reducing environment and chemically reduce Cr^{+6} to less soluble Cr^{+3}, and subsequently precipitate and immobilize Cr within the zone of influence of the treatment area. FerroBlack®-H has proven effective at treating Cr^{+6} based on bench- and pilot-scale testing.
- **Hydraulic Fracturing for ISCR**: Hydraulic fracturing is a technique used to increase permeability in low permeability zones by creating hydraulic fractures at target depths. A high-pressure water jet is applied at the target depth in a fracture well to perforate the casing at that depth and establish a fracture within the low permeability zone. Reagents can then be emplaced within the established fracture using ISCR to treat Cr and Cr^{+6} in low permeability areas.
- **Enhanced Attenuation**: Enhanced attenuation occurs following a period of active *in situ* treatment during which residual injection reagent, biological processes, or reactive mineral species serve to sustain the continued decrease of contaminant concentrations via interaction with these materials. This alternative is not applicable on its own but follows the injection phase of ISAB or ISCR remedies that serve to establish a geochemically reducing environment and promote expedited rates of attenuation for multiple years beyond active injections (AECOM, 2016).

5.1.3 MNA Remedy Alternative

The MNA remedy alternative uses natural physical, chemical, or biological processes to reduce Cr^{+6} in groundwater to less soluble Cr^{+3}, and subsequently precipitate and immobilize Cr. MNA is typically used after an active remedial action is complete to monitor continued natural reductions in concentrations to target levels. MNA relies on a long-term groundwater monitoring program to demonstrate that favorable natural attenuation processes are ongoing, the contaminant plume is stable and shrinking, risks to receptors are mitigated, and the natural attenuation capacity of the aquifer is not exhausted, as demonstrated by sustained favorable geochemical conditions and decreasing contaminant concentrations.

5.2 Evaluation of Remedial Alternatives

The 10 remedial action alternatives were evaluated and compared, as shown on **Table 5-1** using the following comparative criteria:

- **Overall protection of human health and the environment:** This criterion describes how the alternative protects or continues to protect human health and the environment. Except for the no action alternative, risks to receptors are mitigated through monitoring and maintaining existing engineering and institutional controls.

- **Achievement of remediation goal and objectives:** This criterion describes how successfully each alternative can be used to meet the groundwater remediation goal and objectives.
- **Long-term effectiveness and permanence**: The effectiveness of the remedial alternative to achieve long-term contaminant or mass reduction, and the adequacy and reliability of the alternative to maintain the contaminant or mass reduction are described. The duration of monitoring required is also compared.
- **Short-term effectiveness and compatibility with redevelopment**: This criterion is used to compare the ability of the remedial alternative to be integrated with redevelopment, including the presence and duration of required remediation infrastructure and monitoring requirements.
- **Implementability**: The ability to construct, operate, maintain, and monitor the remedy is considered in the evaluation of implementability of the remedial alternative. This includes the ability to obtain any access or approvals required, and availability of services and materials.
- **Comparative cost**: The comparative cost criterion is used to compare the construction, operating, maintenance, and monitoring costs of the remedial alternatives. Each alternative is assigned a low, medium-low, medium, medium-high, or high comparative cost.
- **Regulatory acceptance**: The anticipated regulatory acceptance of the remedial alternatives, including criteria that need to be demonstrated prior to acceptance, required pairing of remediation technologies that may be required for acceptance, and other considerations are described.

Each alternative is evaluated against the above criteria and assigned a score from 1 to 5 for each criterion, with one being most favorable and 5 being least favorable. The scores for the seven criteria are totaled and the application of the technology is evaluated in the final column of the table based on the comparative score and possible application to the Project Area groundwater.

The results of this evaluation indicate that ISAB and ISCR (combined with either FerroBlack®-H or CaSx) are favorable active remediation alternatives. Enhanced attenuation is also favorable and is coupled with and established by both the ISAB and ISCR active remedies. A permeable reactive or extraction barrier are not suitable alternatives for a Project Area-wide remediation strategy but may be applicable in select areas to control contaminant mass flux, if needed. The FerroBlack®-H reactive zone is a viable alternative for targeted treatment and may also be used to supplement an *in situ* active remedy. MNA is a favorable remediation measure after active treatment is complete. The no action alternative and hydraulic fracturing alternative were eliminated through this analysis.

5.3 Selection of Remediation Alternatives

Based on the remedial action alternatives evaluation summarized in **Table 5-1**, a groundwater remediation strategy was selected for treating CCPW, CCPW-impacted materials, and other groundwater COCs by combining or coupling alternatives proven to be applicable and implementable in the Project Area. The selected groundwater remediation strategy is summarized in **Table 5-2, Figure 5-1,** and **Figure 3-2,** and includes:

- Provide active groundwater treatment where practicable as described in Section 4.4.3 in select areas and water-bearing zones with Cr^{+6} concentrations greater than 1,000 µg/L (Parts 1 and 2 of active treatment remedy as depicted on **Figure 5-1**);
- Provide active treatment (where practicable) of non-Cr COCs within the select areas and water bearing zones where active Cr^{+6} treatment is occurring (Parts 1 and 2 of active treatment remedy as depicted on **Figure 5-1**);
- Long-term monitoring to establish lines of evidence for transition to MNA Remedial Action Permit for metals and non-CCPW COCs (e.g., PCE) in accordance with the NJDEP's MNA Guidance (Part 3 of active treatment remedy as depicted on Figure 5-1);
- Monitor groundwater conditions and engineering controls over the long-term (Parts 1, 2 and 3 of active treatment remedy and MNA treatment remedy as depicted on **Figure 5-1**);
- Maintain engineering controls; and
- Maintain institutional controls (CEA) for COCs that are on or emanating from Site 114.

The components of the remediation strategy are briefly described below and are presented in greater detail in Section 6.

5.3.1 Active Remedy Selection

The selected active remedy uses demonstrated remediation alternatives and includes the following:

- Part 1 of active treatment remedy as depicted on **Figure 5-1**:
  - Injections of electron donors (i.e., organic carbon substrate) to create and support an environment conducive to ISAB, and/or injections of a chemical reductant to support ISCR in the shallow, intermediate, and deep water-bearing zones;
  - Injections of electron donors to create and support ISAB and/or injections of chemical reductant to support ISCR in the shallow, intermediate, and deep water-bearing zones; and
  - Emplacement of FerroBlack®-H to create reactive zones to create and support ISCR in select areas and water-bearing zones.
- Part 2 of active treatment remedy as depicted on **Figure 5-1**:
  - Enhanced attenuation.

The Phase I, II, and III IRMs are selected as the first step of the active remedy based on their effectiveness to reduce Cr COCs groundwater concentration where implemented. The IRM phases will be followed by a period of enhanced attenuation as a second step of the active remedy.

The concentrations of non-Cr COCs within the active treatment areas are lower compared to Cr and are not the primary COCs of the active remedy. These COCs (listed in Section 4.1) are included in the Project Area CEA and will be managed under this institutional control. In addition, several of the non-Cr COCs will be treated using the select active remedies (e.g., *in situ* via ISAB or ISCR or *ex situ* via the above-ground GWTP) (Arcadis, 2017b; Arcadis, 2019). The concentrations of 1,4-dioxane in the limited area southeast of Site 114 will be confirmed by sampling wells in the Phase III IRM area. If found to be present at concentrations less than the GWQS of 0.4 µg/L, this COC will be removed from the Project Area CEA. If concentrations are greater than the GWQS, the geochemical conditions in that area will be evaluated in support of an MNA remedy.

5.3.2 Monitored Natural Attenuation Remedy Selection

The establishment of groundwater engineering controls and the completion of the active remedy described above, in combination with natural processes will continue to remediate residual Cr, Cr^{+6}, and non-Cr COCs in the groundwater. Data from the IRM performance monitoring and the subsequent enhanced attenuation monitoring, with respect to organic carbon distribution and persistence in the subsurface, geochemical indicators, and trends in Cr, Cr^{+6}, and non-Cr concentrations in groundwater will be used to support the transition to an MNA remedy during Part 3 of the active treatment remedy as depicted on **Figure 5-1**. As described in **Figure 5-1**, the IRM performance monitoring, followed by the enhanced attenuation monitoring will provide a dataset that spans over several years, which will provide a solid understanding of long-term concentration trends after the cessation of the IRMs, with which, a decision on the suitability to transition to MNA, can be made.

The MNA remedy will rely on a long-term groundwater monitoring program to demonstrate that the natural attenuation processes are ongoing and that the natural assimilative capacity of the groundwater and aquifer matrix to degrade the COCs is not exhausted as demonstrated by sustained favorable geochemical conditions.

5.3.3 Engineering and Institutional Controls

As discussed in Section 3.1.2, several groundwater engineering controls were established during soil remediation and restoration activities, which include a capillary break, amended backfill, and sheet pile. In addition, the presence of a competent meadow mat layer between the shallow and intermediate water-bearing zones serves as a natural control preventing the vertical migration of COCs.

Further, a CEA was established in 2018, an update to which was submitted with the Groundwater RIR (AECOM, 2021e). The contaminants listed in the updated CEA include the CCPW metals and non-CCPW COCs identified as on or emanating from Site 114 in groundwater in the Emanating from Technical Memorandum. The CEA will be updated, as needed, and maintained until the remediation goal is attained. Following the implementation of the active remedies, long-term groundwater monitoring will be conducted via the MNA remedy, and maintenance of groundwater engineering controls.

5.3.4 Contingency Remedy

Both during and after active treatment (Parts 1, 2 or 3 of the active treatment remedy as depicted on **Figure 5-1**), should the lines of evidence indicate that the GWQS for the COCs cannot be achieved in certain areas via the selected active groundwater remedies, either due to the presence of low permeability zones, technology limitations, or limitations with reagent (e.g., molasses, EVO, CaSx, FerroBlack®-H) distribution or groundwater extraction, contingency remedies, such as localized/targeted treatment using ISAB or ISCR, or FerroBlack®-H emplacement will be implemented in applicable areas. Where it is determined that the active remedy cannot be optimized further due to either limitations from an engineering perspective or subsurface limitations (i.e., presence of low permeability zones), an evaluation of technical impracticability will be conducted in accordance with the NJDEP's *Technical Impracticability – Guidance for Groundwater* (NJDEP, 2013b). Long-term monitoring will be conducted to document continued protectiveness of public health and safety, and the environment, and the existing CEA will continue to be maintained/updated for these areas. PPG acknowledges that should contingent remedies require implementation in the future during and/or after redevelopment activities, those factors of redevelopment (i.e., buildings, etc.) will be considered when evaluating potential future contingent remedies.

5.4 Summary of Groundwater Remediation Strategy

The selected remediation strategy for the shallow, intermediate, and deep water-bearing zones includes a combination of active remedies, an MNA remedy, engineering controls, and institutional controls, supplemented by robust monitoring programs. This strategy is designed to be flexible and adaptive to allow optimization of the remedial actions, or to allow for a transition from one technology to a more effective remedial option. The remediation strategy is presented in **Table 5-2** and depicted in **Figure 3-2** and includes the following:

- Active treatment of groundwater Cr^{+6} concentrations greater than 1,000 µg/L in water-bearing zones, where practicable, using a combination of one or more ISAB and/or ISCR alternatives to treat or reduce concentrations of Cr^{+6} and other COCs in groundwater, followed by enhanced attenuation.
- During Parts 1, 2 and 3 of the active treatment remedy as shown on **Figure 5-1**, implementation of contingency measures as appropriate.
- After active treatment and enhanced attenuation, transition to an MNA remedy, where continued reductions in concentrations of COCs in groundwater will continue; and
- Monitoring and maintenance of existing groundwater engineering controls and a CEA until the long-term groundwater remediation goal is achieved.

Figure 5-1 presents an illustration of the overall groundwater remediation strategy. The selected remediation strategy will achieve the groundwater remediation goal and objectives because it relies on a combination of demonstrated active treatment alternatives (Parts 1 and 2 of the active treatment remedy, as depicted on the Figure) to attenuate COCs in groundwater before transitioning to an MNA alternative during Part 3 (long-term monitoring) of the active treatment remedy as depicted on the Figure. This strategy will be coupled with a capillary break, which was installed and will be maintained to prevent the crystallization of chromate on soil surfaces, additional groundwater engineering controls (such as FerroBlack®-H amended fill and sheet pile), which have been installed and will be monitored and maintained, a CEA that was established and will be updated and maintained for the duration of the remedial action, and a long-term groundwater monitoring program. Contingency remedies are retained should the lines of evidence indicate that the GWQS for the COCs cannot be achieved via the selected active remedies. Finally, a request for an Active Category Groundwater Remedial Action Permit (RAP) will be submitted to the NJDEP for review and approval after initial groundwater monitoring data suggest that the active system remedy is effective in accordance with the requirements for the Active Category Groundwater RAP outlined in NJDEP's *Ground Water Remedial Action Permit Guidance*.

6 Description of Groundwater Remedial Action

This section provides a detailed description of the groundwater remedial action and the alternatives selected for use in each of the treatment areas and water-bearing zones. The groundwater remediation strategy was identified in Section 5.0 and is summarized on **Table 5-2** and **Figure 3-2**. The remediation strategy includes a combination of active treatment and associated monitoring, contingency remedies (as needed), engineering and institutional controls, and MNA.

6.1 Active Remedy

The selected active remedy, described in the following subsections, is based on demonstrated remediation alternatives and includes the following technologies:

- Part 1 of the active treatment remedy as depicted on **Figure 5-1**:
  - Injections of electron donors (i.e., organic carbon substrate) to create and support an environment conducive to ISAB, and/or injections of a chemical reductant to support ISCR in the shallow, intermediate, and deep water-bearing zones;
  - Injections of electron donors to create and support ISAB and/or injections of chemical reductant to support ISCR in the shallow, intermediate, and deep water-bearing zones; and
  - Injections of FerroBlack®-H as permeable reactive zones to create and support ISCR in select areas and water bearing zones.
- Part 2 of the active treatment remedy as depicted on **Figure 5-1**:
  - Enhanced attenuation.

As described in Section 3.3, active remediation is being achieved through three IRM phases. The three IRMs are designed to treat specific water-bearing zones and treatment areas using a combination of active remediation technologies including ISAB and ISCR. It is expected that residual reactive zone capacity from the active remedy will persist once injections of reagent are complete and enhanced attenuation will continue to provide treatment of COCs and reduce the potential risk of exposure to receptors. The persistence of the reactive zone capacity will be demonstrated and evaluated using a robust monitoring program.

6.1.1 In Situ Anaerobic Bioprecipitation and Chemical Reduction

In situ treatment of Cr^{+6} is a well-developed technology (United States Environmental Protection Agency [USEPA], 2000), which can be implemented via biologically-mediated precipitation (ISAB) and chemical reduction (ISCR) processes. Although biological and chemical treatment mechanisms differ, both treatment processes are designed to reductively precipitate and permanently fix/immobilize the Cr^{+6} in the aquifer, reduce Cr^{+6} concentrations in groundwater to achieve remediation goals, and support long-term treatment permanence.

PPG has conducted bench- and pilot-scale testing of several biological and chemical treatment technologies. These studies evaluated the feasibility of both ISAB and ISCR technologies for treatment of Cr^{+6}-impacted groundwater and saturated soil at the Project Area. These tests provided information relative to the anticipated Cr^{+6} treatment performance reagent longevity and use, and design information pertaining to fluid injection and transport within the shallow and intermediate and deep water-bearing zones. Findings from these tests were used to develop the IRMs.

In situ Anerobic Bioprecipitation is an established biologically-mediated remedial technology for the treatment of metals (e.g., Cr) and other COCs in groundwater. This technology uses continuous or periodic delivery of degradable organic carbon substrates, such as molasses or EVO, into the contaminated groundwater system to stimulate the native microorganisms and promote the development of an *in situ* reaction zone (IRZ).

Within the IRZ, fermentation of the organic carbon substrate promotes development of iron- and sulfate-reducing groundwater conditions that are favorable for the reduction of Cr^{+6}. Under these conditions, Cr^{+6} is reduced to Cr^{+3} through reactions with multiple biologically-generated reductants or via direct anaerobic respiration with Cr^{+6} serving as the terminal electron acceptor. The reduction of Cr^{+6} to Cr^{+3} provides three benefits from a treatment perspective:

- Cr^{+3} is less toxic than Cr^{+6} and, therefore, has higher permissible environmental concentrations;
- Cr^{+3} is less soluble than Cr^{+6} under Project Area groundwater conditions and forms a precipitate that is immobilized in the form of a hydroxide mineral that can be incorporated in a matrix of carbonate, sulfide, and other precipitates generated during the treatment process; and
- Insoluble Cr^{+3} phases are resistant to re-oxidation to Cr^{+6} phases under the soil and groundwater conditions at the Project Area.

The above benefits, combined with the pH-neutralizing effects of organic carbon fermentation, and the capability of the ISAB process to establish a reactive zone with sustained biological and abiotic reduction capacity, make Cr^{+6} treatment via ISAB a suitable groundwater remedial technology for the Project Area.

A pilot test was completed within the shallow and intermediate zones of the former Phase IRM I test area on Site 114 to test the effectiveness of an ISAB remedy for Cr^{+6}-contaminated groundwater. The performance monitoring results showed that treatment of Cr^{+6} impacts was achieved in groundwater and soil in the test area, with the treatment goals of 90% reduction of Cr^{+6} in groundwater, and the target concentration of 20 milligrams per kilogram (mg/kg) of Cr^{+6} in soil, being met (Arcadis, 2017a).

Based on the pilot test results, ISAB was selected for the Phase I and II IRM programs. Performance monitoring data from the Phase I IRM through the fourth quarter of 2020 show that Cr and Cr^{+6} concentrations were reduced by three and four orders of magnitude (compared to baseline conditions) in the majority of the Phase I treatment area, with limited exceptions (Arcadis, 2021). In the Phase II IRM area, breakthrough with respect to TOC concentrations present in treatment areas with greater than baseline TOC concentrations, and decreases in Cr and Cr^{+6} concentrations were observed in several monitoring wells during monthly treatment monitoring, and is expected to progress further as the remainder of the injection program is completed (AECOM, 2021f).

In Situ Chemical Reduction is a direct abiotic chemical reduction treatment that is implemented by introducing a reductant to chemically reduce Cr^{+6} to less soluble Cr^{+3}, which in turn geochemically binds onto soil surfaces in the target groundwater treatment zone (USEPA, 2000). This is achieved by the delivery of the chemical reductant into the subsurface, which facilitates abiotic Cr removal in the aqueous phase via conversion of Cr^{+6} to Cr^{+3}, and subsequent precipitation as either chromium hydroxide or as iron-Cr hydroxide complexes. An ISCR pilot test was conducted on Site 114 (**Table 3-3**) to evaluate the applicability of abiotic treatment for Cr^{+6} in groundwater and saturated soil. During the ISCR pilot test, two chemical reductants, FerroBlack®-H and CaSx, were tested to assess the viability of ISCR at the Site. The pilot test performance monitoring data demonstrated that Cr^{+6} and total Cr concentrations were reduced by greater than 90% and 75%, respectively, when compared to the baseline concentrations. Overall, pilot testing showed that ISCR is effective for Cr^{+6} treatment (AECOM, 2017b) and is included in the selected active remedy to complement ISAB. This technology provides reagent flexibility and can be applied alone or in combination with ISAB to optimize the remediation strategy.

Strategically located extraction wells may be used to increase the horizontal hydraulic gradient between injection and pumping wells to propagate distribution of the organic carbon substrate or chemical reagents (electron donors) to establish a reactive zone favorable for the reduction of Cr^{+6} to Cr^{+3}.

6.1.2 FerroBlack®-H Emplacement

In areas planned for FerroBlack®-H treatment, the reagent will be delivered into the target zones to establish a reducing environment within the zone of influence of the injected material. FerroBlack®-H is a proprietary reagent of Redox Solutions, LLC, and is a reductive, colloidal suspension of 1-2% by wt. soluble sulfides and 7-8% by wt. insoluble iron sulfides. The reagent will precipitate Cr^{+6} out of the aqueous phase as iron-chromium hydroxide complexes, thereby reducing the concentration of dissolved-phase Cr. The soluble iron sulfide (FeS) component serves as a short-term source of sulfides (electron donor) to promote the reduction of Cr^{+6} to Cr^{+3}, while the minimally soluble FeS particles act as a long-term source of reductant. The active mechanism of this reagent is described in further detail in Section 6.4.2.

The effectiveness of this chemical reductant was demonstrated in laboratory, bench-scale, and pilot-scale testing, and through its use as a backfill amendment across the Project Area over the last decade. A desktop evaluation demonstrating the longevity of the reductant when applied as a backfill amendment was documented in the approved December 2017 *Capillary Break Design Final Report (Revision 2)* (AECOM, 2017a). Various delivery methods for introducing the reagent into the target zones are being evaluated.

Since submission of the Draft Groundwater RAWP in March 2021, a request for a PBR Authorization to implement the remedy during the Phase III IRM was prepared and the full-scale design for the Phase III IRM was developed. During the preparation of these documents, an evaluation of the treatment extents and locations of FerroBlack®-H reactive zones was conducted. The evaluation included a geotechnical assessment of the proposed Phase III IRM on HCC Site 199, which was summarized in a memorandum, provided as **Appendix C**. The memorandum evaluates potential risks associated with the implementation of the Phase III IRM at HCC Site 199 adjacent to the HBLR tracks between Garfield Avenue and Halladay Street, and the Forrest Street Properties. The memorandum also identifies mitigation measures, limits, and controls that would facilitate safe implementation of planned IRM activities within this area. The memorandum concludes that injections of electron donors to support ISAB can be completed at HCC Site 199 during the Phase III IRM with relatively low risk to the HBLR tracks by following the recommended injection and vibration monitoring guidance provided in the memorandum. However, the memorandum also concludes that, based on current understanding and available data, the injection of FerroBlack®-H to establish the reactive zone is not recommended at HCC Site 199 due to the potential risk of disturbances to the HBLR tracks and related infrastructure; the detailed technical evaluations supporting these recommendations are included in the memorandum.

6.1.3 Enhanced Attenuation

Organic carbon substrates (e.g., molasses, EVO) delivered during the active treatment phase (Part 1 of the active treatment remedy as depicted on **Figure 5-1**) are fermented by native microbial species to yield electron donor that is used to generate energy and biomass in conjunction with the reduction of terminal electrons acceptors within the Project Area (notably iron and sulfate). These processes support short-term Cr^{+6} reduction in the presence of iron-sulfide minerals or via biological Cr^{+6} reduction. While the delivered carbon substrates are consumed and depleted via these respiration processes, the buildup of biomass as a result of continuous substrate delivery over several months into the target treatment areas serves as a reservoir for additional electron donor availability via endogenous cellular decay and biomass recycling within the reactive zones. In addition to sustained treatment benefits of reactive iron-sulfide minerals emplaced in the active treatment zone, this biomass recycling process is expected to provide a long-term source of electron donors that can perpetuate these geochemical and biological processes and extend COC attenuation even after cessation of reagent injections (Suthersan, et. al., 2013). This period, referred to as "enhanced attenuation" is a part of the active plume remediation strategy that works towards the groundwater treatment goal by providing a bridge between source-zone treatment (i.e., the IRMs) and the MNA non-active phase (ITRC, 2010), and to support the RAP application for transitioning to an MNA remedy. Therefore, it is expected that, following *in situ* active treatment (Part 1 of the active treatment remedy as depicted on **Figure 5-1**), residual injected material will continue to maintain a geochemically reducing environment for several years (AECOM, 2016). The IRMs have or will provide organic carbon reductive capacity, which is expected to remain in place and provide continued treatment for an estimated 10 to 15 years. The actual timeframe of this attenuation period and, therefore, the longevity of the substrate will be confirmed through groundwater monitoring (described in Section 7.3.1), which will provide the information to demonstrate continued attenuation of contaminant concentrations and persistence of aquifer reductive capacity.

6.1.4 Transition from Active Remedy to MNA Remedy

The extended monitoring period following active treatment (Part 3 of active treatment remedy as depicted on **Figure 5-1**) will evaluate long-term contaminant concentration trends and will guide the transition to the MNA phase of the remediation strategy. This will be achieved through a lines of evidence-based approach, as described in the *Monitored Natural Attenuation Technical Guidance* (NJDEP, 2012a). The expected longevity of the injected reagents and assimilative reductive capacity of the aquifer will be evaluated through a monitoring program that will analyze groundwater samples for the primary COCs (Cr and Cr^{+6}) and key geochemical indicators. The two (primary and secondary) lines of evidence that will be used to assess the long-term COCs concentration trends will include the following:

Primary Lines of Evidence:

- Analysis of plume behavior (i.e., shrinking, stable, or expanding plume), through spatial and/or graphical methods.
- Trend analysis of contaminants of interest (i.e., Cr and Cr^{+6}), using concentration vs. time plots, concentration vs. distance plots, and statistical tools (e.g., Mann-Kendall test or other approved modeling software [PHREEQC, MINTEQA2, etc.]).

- Regression analysis to estimate anticipated cleanup timeframes to achieve the GWQS goal of 70 µg/L.

Secondary Lines of Evidence:

- Evaluation of the stability of redox conditions characterized by low to negative ORP, low dissolved oxygen concentrations (i.e., less than 1 mg/L), and circum-neutral pH in groundwater.
- Analysis of groundwater concentrations of TOC, sulfur species, and iron.
    - TOC serves as a bulk indicator of organic carbon within the aquifer that can be fermented and utilized as the primary elector donor for ISAB.
    - Dissolved iron concentrations are indicative of microbial activity.
    - Sulfate is reduced under the anaerobic conditions that dominate most of the Project Area and is used as an electron acceptor to generate sulfide; therefore, residual sulfate concentrations provides a useful indicator of residual capacity to general additional iron sulfide minerals for ISAB.

6.2 Monitored Natural Attenuation Remedy

MNA is a remediation technology that is demonstrated, well understood, and accepted by the NJDEP for treating organic and inorganic compounds including Cr^{+6}. Natural attenuation processes include a combination of physical, chemical, or biological processes that reduce Cr^{+6} in groundwater to the less mobile and less toxic Cr^{+3}. The primary mechanisms by which dissolved Cr^{+6} is attenuated in groundwater include sorption and desorption to soils; precipitation, coprecipitation, and dissolution; and dilution and dispersion. Under conducive geochemical conditions, dissolved Cr^{+6} is reduced to Cr^{+3} hydroxides, which, under circum-neutral pH conditions, are immobilized within the formation and remain relatively immobile. Hexavalent chromium is a strong oxidant and is reduced to Cr^{+3} compounds in the presence of electron donors such as ferrous iron, sulfide, and organic matter (Palmer and Puls, 1994).

Monitored natural attenuation is typically used in conjunction with other remedial measures or as a follow up to an active remedy (e.g., ISAB, ISCR, or enhanced attenuation), all of which have been implemented on Site 114 during IRMs since 2017, and are planned in various areas of the Project Area between 2020 and 2023.

In accordance with the NJDEP's guidance on MNA, the evaluation of MNA as a component of the groundwater remediation strategy for a site shall demonstrate the following (NJDEP, 2012a):

- Whether the COCs are likely to be effectively addressed by natural attenuation processes;
- Potential for the COCs contaminant plume to migrate; and
- Potential for unacceptable risks to human health and the environment.

For MNA to be effective, a geochemically-reducing groundwater environment is required, which is characterized by near-neutral pH conditions, low or negative ORP, low dissolved oxygen levels, and high organic carbon content. Treatment monitoring data from the ongoing Phase I IRM show that the introduction of organic carbon substrate is effective in establishing and sustaining a geochemically-reducing environment within the IRM areas at Site 114. Eight quarterly rounds of post-treatment performance monitoring data, followed by enhanced attenuation monitoring from each of the three

IRM phases, will be used to evaluate the persistence of reducing conditions and to confirm the decreasing concentration trends of Cr and Cr^{+6} toward meeting the NJDEP GWQS.

In addition, the presence of the organic carbon-rich meadow mat layer between the shallow and intermediate water-bearing zones serves as a natural source of organic reductants, which promotes reducing conditions in the intermediate water-bearing zone. Competent meadow mat with a thickness of 1 foot or more is present across portions of the Project Area, at depths ranging from approximately 10 to 25 ft bgs. In addition to this natural source of reducing capacity, hydrocarbons related to MGP impacts also promote and sustain reducing groundwater conditions.

Naturally-occurring microorganisms engender geochemical conditions favorable for the bioprecipitation of Cr^{+6}. Microbial samples were collected in 2013, prior to Phase I IRM injections at representative shallow and intermediate zone wells within the ISAB pilot test area on Site 114. Iron- and sulfate-reducing bacteria (IRB/SRB) were present at concentrations ranging from 100 cells per milliliter (cells/mL) to over 4,000 cells/mL (Arcadis, 2017b), indicating a robust microbial population in Project Area groundwater. These microbial cultures are generally ubiquitous in groundwater systems and via the Phase I and II IRM programs have been demonstrated to be effective in reducing Cr^{+6}.

Treatment and post-treatment monitoring data from the ongoing Phase I IRM show that considerable reduction of Cr^{+6} concentrations was achieved in the intermediate and deep water-bearing zones, demonstrating that the implementation of the IRMs will be effective for significantly reducing elevated concentrations of Cr^{+6} within permeable treatment zones. Upon completion of the active remedy phase and associated monitoring, cleanup timeframes (i.e., the time required for the concentrations of Cr and Cr^{+6} to attenuate to the 70 µg/L GWQS for Cr) may be estimated.

6.3 Contingency Remedy

Developing an effective treatment and performance monitoring approach will be used to evaluate baseline conditions and progress towards achieving the remediation objectives for the selected remediation strategy. Several lines of evidence will be used to determine the effectiveness of the active remedies and MNA. These lines of evidence include continued protection of human health and the environment, performance monitoring metrics, reductions in plume dimensions, decreasing concentration trends, conducive subsurface geochemistry, or mass discharge reduction.

During the active treatment remedy (i.e., Parts 1, 2, and 3 as depicted on **Figure 5-1**), should the lines of evidence indicate that the GWQS for the COCs cannot be achieved in certain areas via the selected groundwater remedies, either due to technology limitations or limitations with reagent (e.g., molasses, EVO, CaSx, FerroBlack®-H) distribution or groundwater extraction, contingency remedies, such as localized/targeted treatment using ISAB or ISCR, or FerroBlack®-H emplacement will be implemented in applicable areas where a remedy is necessary to remain protective of human health and the environment. The application for Active Category Groundwater RAP will also outline PPG's anticipated contingency remedies and conditions for implementation of same for Parts 2 and 3 of the active treatment remedy.

Where it is determined that the active remedy cannot be optimized further due to either limitations from an engineering perspective or subsurface limitations (i.e., presence of low permeability zones), a Technical Impracticability Determination will be sought in accordance with the NJDEP's *Technical Impracticability – Guidance for Groundwater* (NJDEP, 2013b). Long-term monitoring will be conducted to document continued protectiveness of public health and safety, and the environment, and the existing CEA will be maintained/updated for these areas.

With respect to HCC Site 199, it is recognized that GGM remains under the HBLR and has the potential to serve as a long-term source of Cr^{+6} to groundwater migrating onto/through Site 199. In lieu of the FerroBlack®-H reactive zone, a robust groundwater monitoring program will be implemented to monitor conditions on HCC Site 199. Upon commencement of injections, groundwater monitoring will be completed at time intervals that will provide sufficient data to confirm whether the remedial objectives are being achieved. Sampling of monitoring wells within the treatment area will determine whether the remedial action is progressing as planned and whether modifications will be necessary to optimize or improve performance. In the event that Cr and Cr^{+6} concentrations begin to show increases related to influx from the GGM, focused, limited-duration injections of organic carbon substrate and/or chemical reductant on HCC Site 199 could be proposed to abate these conditions.

6.4 Groundwater Engineering Controls

The nature and extent of Cr and Cr^{+6}-related groundwater impacts are documented in the Groundwater RIR (AECOM, 2021e). The Cr^{+6} plume remains primarily within the Project Area boundaries and has not migrated very far from the former source areas, even in areas where preferential migration pathways or lower permeability soils are present. This indicates attenuation stemming from natural mechanisms (sorption/desorption, precipitation/coprecipitation/dissolution, and dilution/dispersion) that has and will continue to affect the fate and transport of Cr and Cr^{+6} in groundwater. Active treatment achieves reduction of dissolved-phase Cr^{+6}, while the combination of MNA along with natural and engineered hydraulic controls provide long-term control and containment of residual and less accessible Cr mass.

The risks to public health and the environment have been eliminated by the excavation of shallow CCPW-impacted soils and replacement with amended or unamended clean backfill material. The placement of clean soils and the presence of a capillary break mitigate the risk of direct exposure (ingestion, dermal, inhalation) from impacted material and prevent future Cr^{+6} blooming. In addition, the use of clean backfill amended with an iron-sulfide based reducing agent (FerroBlack®-H) across most of the Project Area prevents the recontamination of shallow soils with Cr^{+6}-impacted groundwater, should rising groundwater levels occur due to precipitation or other mechanisms in the future.

During soil remediation activities, several groundwater engineering controls were installed and/or maintained, including sheet pile, capillary break, and placement of amended backfill. These controls limit the future transport of Cr in groundwater in multiple directions, including upward into the shallow zone and horizontally into areas outside the sheet pile perimeter. Natural geologic controls (competent meadow mat layer) also limit vertical migration of Cr. In addition to these controls, a CEA was established in 2018 (AECOM, 2018a; NJDEP, 2018a) and updated in 2021 (AECOM, 2021e). Collectively, the risk of exposure to contaminated groundwater is reduced through ongoing monitoring and maintenance of these engineering and institutional controls while MNA is ongoing, and until the groundwater remediation goal is met.

6.4.1 Capillary Break

A capillary rise study was conducted to support the design of a capillary break for the GA Group Sites (AECOM, 2017a). Based on the results of this study, it was determined that a 6-inch layer of OGS, or a 2.8-ft layer of DGA (unamended or amended with FerroBlack®-H [A-DGA]), would be an effective capillary break for the Project Area. A 40-millimeter (mm) HDPE impermeable liner was also established as an acceptable capillary break option (AECOM, 2017f). In areas where a capillary break was required, a design groundwater elevation of 13.2 ft NAVD88 was established for the portion of the GA Group Sites north of Carteret Avenue, and 11.0 ft NAVD88 for the areas south of Carteret Avenue

(AECOM, 2017f). The extent of the installed capillary break is depicted on **Figure 3-1**. In certain areas where the placement of OGS, DGA, A-DGA, or HDPE liner capillary break is not feasible (e.g., in areas where excavation is limited due to the presence of infrastructure), an asphalt covering of the surface, with a minimum thickness of four inches, serves as the capillary break (e.g. the former Halsted Corporation Property).

The need for a capillary break was determined based on an evaluation of:

- Cr concentrations in the shallow and intermediate water-bearing zones;
- Cr^{+6} concentrations in soil;
- Presence or absence of competent meadow mat; and
- Presence or absence of A-DGA.

Per the approved November 2017 GWMP, groundwater monitoring was proposed to demonstrate that groundwater in the remediated portions of the Project Area that are adjacent to unremediated areas remains of acceptable quality to preclude the need for a capillary break. Three annual sampling events were proposed in the GWMP, the first of which was completed in the third quarter of 2020. Analytical data and a summary of the results were transmitted via email to the NJDEP on November 9, 2020 (Document no. GW-097) (AECOM, 2020d). Concentrations of Cr and Cr^{+6} in 14 of the 16 shallow monitoring wells sampled continued to remain less than the NJDEP GWQS of 70 µg/L for Cr. The concentrations of Cr and Cr^{+6} in the two wells where exceedances of the GWQS were observed, were similar to the concentration levels in past sampling events, therefore, these exceedances were not unexpected.

Completion of the three annual rounds of groundwater monitoring under the capillary break program is expected to provide sufficient evidence that conditions continue to exist that preclude the need for a capillary break.

6.4.2 FerroBlack®-H Amended Backfill

As stated in Section 3.1.1, soil remediation (excavation and backfilling) have been completed in several portions of the Project Area. The open excavations were backfilled with DGA, which, in many areas, was amended with FerroBlack®-H, to prevent the recontamination of clean backfill with Cr^{+6}-impacted groundwater. **Figure 3-1** identifies the areas where FerroBlack®-H-amended backfill was used. The amendment was applied to clean backfill at dosages ranging from 0.7% by wt. to 2.8% by wt.

The reduction of Cr^{+6} to the less toxic, less mobile Cr^{+3} precipitates by FerroBlack®-H occurs through one or more geochemical processes, whereby:

- The soluble sulfides component of the FerroBlack®-H reacts rapidly with aqueous Cr^{+6}, providing a readily available source of electron donor (i.e., dissolved sulfides) resulting in its reduction to Cr^{+3} and the formation of an iron-chromium precipitate; and
- The insoluble phase of FerroBlack®-H, mainly comprised of minimally soluble FeS particles, provides a slow-release long-term source of both iron and sulfur species to promote the continued reduction of Cr^{+6} to Cr^{+3}, through a combination of dissolution, surface adsorption, and co-precipitation reactions. The reduction of Cr^{+6} occurs at the FeS particles surface, and results in the formation of Cr^{+3}-Fe^{+3} hydroxides or oxyhydroxide (e.g., $Cr_xFe_{1-x}(OH)_3$ or $Cr_xFe_{1-x}OOH$) at pH conditions greater than 4 standard units (s.u.) (Patterson, et.

al., 1997; Mullet, et. al., 2004; Palmer and Puls, 1994). The mineral matrix of the FeS will continue to provide a slow-release, long-term source of reductant.

Laboratory column testing studies were conducted to evaluate the effectiveness of FerroBlack®-H as a soil amendment (Brown et. al., 2008). FerroBlack®-H was applied at dosages ranging from 0.9% by wt. to 2.7% by wt., similar to the dosages applied to the backfill at the GA Group Sites. Simulated rainwater was passed through the columns over a 50-day period, which was intended to simulate 30 to 50 years of groundwater flow. After the exposure period, it was found that the COPR-containing soil that was treated with FerroBlack®-H maintained ORP values of less than -400 millivolts (mV), indicative of strong reducing conditions, and also did not result in any leachable Cr^{+6} over the period of testing. The testing demonstrated the longevity of the amendment and concluded that FerroBlack®-H would not be passivated and would continue to treat residual Cr^{+6} for the entire duration of the simulated period.

In 2012, bucket testing of several chemical reagents was conducted to evaluate effectiveness and health and safety risks for full-scale application during soil remediation across the Project Area. Based on the results of the bucket testing, FerroBlack®-H was selected for pilot-scale testing in a small portion of Site 114, based on a comparison of health, safety, odor issues, effectiveness in reducing Cr^{+6}, cost, and other considerations (AECOM, 2012b).

In order to evaluate the effectiveness of FerroBlack®-H as a backfill amendment under actual Site 114 conditions, a pilot test was conducted within a 30-ft by 30-ft excavation (measuring 18 ft in depth), constructed within the footprint of the former Morris Canal on Site 114 (AECOM, 2012b; AECOM, 2017d). Groundwater within this portion of Site 114 contained some of the highest levels of Cr and Cr^{+6} across the Project Area. The excavated test cell was backfilled with DGA amended with FerroBlack®-H, added at a loading rate of 3% by wt. Baseline and post-treatment soil and groundwater samples were collected to assess the effectiveness of the backfill amendment. The pilot test demonstrated the following:

- FerroBlack®-H-amended backfill was effective in preventing recontamination of clean soil (backfill material) with Cr^{+6};
- Groundwater concentrations of Cr and Cr^{+6} were reduced by over 98% compared to the baseline values within the test cell; and
- FerroBlack®-H was effective in maintaining a reducing geochemical environment, characterized by near-neutral pH, low or negative ORP, and low dissolved oxygen content.

The concentrations of several TAL metals were also reduced to concentrations less than their respective GWQS by the end of the performance monitoring period.

Following placement of FerroBlack®-H -amended backfill during full-scale application, shallow groundwater quality with respect to Cr and Cr^{+6} has improved across most of the Project Area where the amendment was used. Within Site 114, concentrations of Cr and Cr^{+6} in the shallow water-bearing zone have reduced to less than the GWQS of 70 µg/L in most areas, with very limited exceptions, and continue to remain less than the GWQS, as evidenced by the most recent data collected under the capillary break monitoring program (AECOM, 2020d).

The use of FerroBlack®-H as a backfill amendment has aided the establishment and maintenance of a geochemically-reducing environment, specifically near-neutral pH (6 to 8 s.u.), low or negative ORP, and low (less than 1 mg/L) dissolved oxygen content. Under these conducive geochemical conditions, the kinetics of re-oxidation of Cr^{+3} to Cr^{+6} are extremely slow, due to the poor solubility of the iron-chromium hydroxide precipitates (Eary and Ral, 1987). To date, there have been no occurrences of Cr^{+6} "rebound" in shallow groundwater in areas where FerroBlack®-H was applied to the clean backfill.

In order to quantify the expected longevity of the FerroBlack®-H applied at the Project Area, PPG performed a longevity assessment that was included as Appendix E of the approved *Capillary Break Design Report – Final* (AECOM, 2017f) and the February 2021 *Capillary Break Design Final Report (Revision 2) Addendum (Revision 1)* (AECOM, 2021a). Calculations were performed to evaluate if the applied FerroBlack®-H would be sufficient to sustain reducing conditions in the subsurface for an extended period and the results indicated that the amendment would continue to be effective for a minimum of 200 years. The dosage of FerroBlack®-H calculated from the results of the bucket testing (220 grams of FerroBlack®-H per gram of Cr^{+6}) was conservative, as this dosage did not "fail" during bucket testing and incorporates a considerable safety factor when compared with the stoichiometric requirement. In addition to the reductive capacity of the amendment alone, the presence of competent meadow mat (discussed below) and the observed downward vertical hydraulic gradients are expected to extend the longevity of this groundwater engineering control.

6.4.3 Competent Meadow Mat

Competent meadow mat is present across large portions of the Project Area, as shown on **Figure 3-1**. The meadow mat is an organic carbon-rich layer comprised primarily of peat, and acts as a natural source of organic carbon (reductant), thereby acting as a chemical barrier that maintains a reducing environment in the subsurface where it is present, which promotes reduction of Cr^{+6} to Cr^{+3}. In areas where an upward vertical hydraulic gradient exists, the presence of competent meadow mat also functions as a physical barrier due to its low permeability, and limits upward vertical flow of impacted groundwater from the intermediate zone into the shallow zone (e.g., Halladay Street North).

6.4.4 Sheet Pile

Steel sheet piling was installed around the perimeter and on the interior of Site 114, and along Sites 132, 135, 137, and 143 (**Figure 3-1**) to stabilize the excavation and to limit off-site migration of impacted groundwater during soil remedial activities in the Project Area. The sheet pile around the former MGP facility (i.e., the eastern half of Site 114) was installed by PSEG as part of soil remedial activities to address MGP-related impacts in the northeast portion of Site 114 (Area A sheet pile). In accordance with PSEG's *Remedial Action Work Plan Addendum for On-Site Soils, Former Halladay Street Gas Works, Jersey City, New Jersey* (PSEG, 2012), the sheet pile surrounding this eastern portion of Site 114 is an engineering control for the MGP-related contaminants and is required to stay in place as part of the MGP remedy.

The sheet pile installed by PPG as part of CCPW-remediation activities on Site 114 was interlocked with the Area A sheet pile installed by PSEG for the MGP remediation. The sheet pile installed by PSEG is a permanent, sealed structure. Collectively, the sheet pile installed by PPG and PSEG is intended to serve as a long-term engineering control to prevent off-site migration of CCPW- and MGP-related constituents. A majority of the sheet pile installed around Site 114 was sealed using impermeable sealants (primarily Wadit and Adeka A-30), which are applied to the sheet pile interlocks before being driven into the ground. The Wadit sealant is both chemical and water-resistant and can tolerate temperature extremes, up to depths of 130 ft bgs. Laboratory tests have demonstrated the water tightness of this sealant (TU Dortmund, 2008).

Extensive studies and evaluations on the potential for corrosion of the sheet pile have been completed by AECOM, on behalf of PPG, using literature sources and site-specific testing. These activities were summarized in the August 28, 2020 Technical Memorandum titled *Evaluation of Corrosion Potential* *and Estimated Design Life of Steel Sheet Pile Separating Garfield Avenue Group Site 114 and Site 199* (AECOM, 2020b). This Memorandum concludes that corrosion of sheet pile below the water table is negligible. Permanently submerged surfaces are not subject to significant corrosion primarily due to the low level of oxygen available. Therefore, the portion of the sheet pile that is at potential risk of corrosion is only the portion above El. 7.9 ft NAVD88 (i.e., within the shallow water-bearing zone). The sheet pile will not be identified as a groundwater engineering control for the shallow water-bearing zone at the Project Area, as described further below.

In summary, the presence of a permanent, sealed sheet pile barrier around the perimeter of Site 114 limits the off-site migration of contaminated groundwater from the intermediate and upper portion of the deep water-bearing zones onto adjacent properties and roadways.

The sheet pile is not intended to be a component of the groundwater remedy for the shallow water-bearing zone for the following reasons:

- The groundwater contamination on Site 199 along the northern Site 114 boundary is planned for active treatment as part of the Phase III IRM. The presence of FerroBlack®-H amended backfill on the Site 114 side of the sheet pile serves as an effective engineering control to prevent the recontamination of shallow groundwater on Site 114. As documented in the approved December 2017 *Capillary Break Design Final Report* (Revision 2) (AECOM, 2017f), the amendment is expected to last several hundred years. Analytical data collected since completion of backfilling activities from shallow monitoring wells within Site 114, adjacent to Site 199, demonstrate that potential flow of Cr-contaminated groundwater from Site 199 is not impacting shallow groundwater quality on Site 114.
- Active treatment and performance monitoring under the Phase III IRM program will address the Cr concentrations on Site 199 near the former Morris Canal.
- In other areas of Site 114, shallow groundwater quality has improved significantly since the placement of clean amended and/or unamended backfill following source material excavation. Limited pockets of low-level Cr GWQS exceedances exist in the shallow zone within Site 114 that are expected to naturally attenuate (**Figure 4-1**). These isolated areas do not present a risk for off-site migration, as evidenced by the presence of clean downgradient wells.
- In the areas outside of Site 114, where excavation and backfilling activities have been completed, groundwater concentrations of Cr and Cr^{+6} continue to remain less than the GWQS of 70 µg/L. Shallow groundwater contamination in areas that are yet to be remediated (e.g., Site 133 West, Site 137 South, etc.) will be addressed once the source material is removed and clean backfill placed. Shallow groundwater quality in these areas will be monitored under the FerroBlack®-H PBR monitoring program in accordance with the GWMP.

6.5 Groundwater Institutional Controls

As stated in Section 2.2., three CEAs have been or will be established in the Project Area:

1. CEA for the shallow, intermediate, deep, and portion of the bedrock water-bearing zones within the Project Area (AECOM, 2021e);
2. Virtual CEA for historic fill within Site 114 (AECOM, 2021e); and
3. CEA for former MGP (PSEG, 2014b).

These CEAs serve as institutional controls for CCPW and non-CCPW COCs, so that impacted groundwater will not be used without permission from the NJDEP. Thus, these CEAs are part of the groundwater remediation strategy for the Project Area to reduce potential future risk to human health. The CEAs will be updated in the future as needed.

7 Groundwater Remedial Action Implementation

7.1 Permits and Notifications

7.1.1 Permit-By-Rule (PBR)

Several DGW PBR authorizations related to groundwater remedial action were previously issued for remediation at the Project Area. Relevant PBRs are summarized below.

Table 7-1 List of Approved Permits-By-Rule for Groundwater

Description	Date Submitted	Date Approved by NJDEP
PBR authorization to inject molasses and Rhodamine WT dye tracer for the *in situ* bio-precipitation pilot study in the former IRM #1 area of Site 114.	1/8/2014	1/28/2014
Modification to the January 28, 2014 bioprecipitation New Jersey Pollution Discharge Elimination System (NJPDES)/DGW PBR to perform a second round of injections of molasses.	8/8/2014	8/12/2014
PBR authorization to perform an *in situ* chemical reduction pilot test using CaSx and FerroBlack®-H in the former IRM #1 area and the Phase 1C area of Site 114.	6/15/2014	Conditionally approved on 4/10/2015; Final approval on 6/2/2015
PBR authorization to perform injections of organic carbon substrates (molasses and EVO) on Site 114 (Phase I IRM).	6/30/2017	9/21/2017
Modification to the Phase I PBR include: 1) Use of new multipurpose injection/extraction wells for a supplemental shallow zone injection event; and 2) Authorization to conduct a hydraulic fracturing pilot test on Site 114 in the transitional intermediate/deep water-bearing zone.	5/22/2019	5/23/2019
PBR authorization to perform injections of organic carbon substrates (molasses and EVO) on Site 114 (Phase II IRM).	2/28/2019	5/9/2019
Modification to the Phase II IRM PBR for authorization to remove DNAPL from injection wells and commence reagent injections without DNAPL recovery to 0.01 ft before commencing reagent injections.	1/19/2021	1/21/2021

Description	Date Submitted	Date Approved by NJDEP
PBR authorization to perform in situ injections of organic carbon substrates (molasses and/or EVO) and chemical reagents (CaSx and FerroBlack®-H) (Phase III IRM).	4/20/2021	7/9/2021

Copies of the PBR application requests and NJDEP authorizations for the three phases of IRMs are included in **Appendix B**.

7.1.2 Remedial Action Permit

An application for an Active System Groundwater RAP will be submitted to the NJDEP for review and approval as soon as the requirements for the Active Category Groundwater RAP outlined in NJDEP's *Ground Water Remedial Action Permit Guidance* (https://nj.gov/dep/srp/guidance/srra/rem_action_permit_guidance_gw.pdf) have been met. It is expected that these requirements will be met upon completion of the treatment monitoring programs for the three IRM phases, and at a minimum after four quarters of post-treatment monitoring data are available for the Phase III IRM. The data from these robust area-wide groundwater monitoring required under the PBRs for the three IRM Phases are expected to support that the active system remedy is effective. PPG will submit the request for an Active System Groundwater RAP at the same time as the Draft RAR.

7.1.3 Other Permits

7.1.3.1 Temporary Access Permit

Any intrusive work planned on or within the ROW of the NJ Transit property (Site 199 [Block 21501, Lot 1.01]) will be performed under a temporary access permit (TAP) obtained from the NJ Transit Authority.

7.1.3.2 Sidewalk or Road Opening Permits

Work proposed within public roadways or ROWs will be performed after obtaining the necessary approvals from the City of Jersey City (i.e., road opening or sidewalk opening permits). Traffic control measures will be implemented in accordance with the City's requirements.

7.1.4 Public Notification Requirement

For remedial actions implemented under the PBRs where the discharge will last longer than 180 days, a public notice is required. The public notice allows interested persons to submit written comments up to 30 calendar days after issuance of the public notice. A copy of the public notice will be sent to the Municipal Clerk and to local health officials for the City of Jersey City and Hudson County.

7.2 Health and Safety

A Health and Safety Plan (HASP) has been prepared for the PPG program. The HASP establishes general health and safety protocols to be followed by personnel during various field activities. The HASP describes training, medical surveillance, personal hygiene practices, hazard exposure monitoring, and other relevant topics. The HASP is intended to be a dynamic document that is updated annually or more frequently if conditions change.

7.3 Access

The Project Area is comprised of PPG-owned and non-PPG-owned properties. PPG-owned properties will be fenced for security purposes. Access to properties not owned by PPG will be negotiated with the appropriate parties. The Project Area is currently (as of October 2021) monitored by a security guard present at the entrance 24 hours a day, 7 days a week.

7.4 Effectiveness Evaluation

7.4.1 Groundwater Monitoring

Upon commencement of the remedial action, groundwater monitoring will be completed at time intervals that will provide sufficient data to confirm whether the remedial objectives are being achieved (implement remedial action ahead of redevelopment activities, reduce risks to human health and environment and reduce Cr concentrations and mass flux/mass discharge). Sampling of the former source and plume area performance monitoring wells will serve to monitor the remedial action, determine whether it is progressing as planned, and whether modifications are necessary to optimize or improve performance, as recommended in the NJDEP's *In Situ Remediation: Design Considerations and Performance Monitoring Technical Guidance Document* (NJDEP, 2017d). Sampling will also be used to assess whether the remedial action may cause unintended consequences, such as GWQS exceedances of other COCs and, if so, what modifications to the remedial action may be warranted. Sampling of downgradient performance monitoring wells will determine whether the remedial action is causing a mass flux/mass discharge of contaminants outside of the Project Area and, if so, appropriate modifications may be considered. Performance and compliance monitoring will demonstrate whether potential receptors continue to be protected during and after the remedial action.

Once the active remedy is complete in a water-bearing zone, and the remedy is transitioned to MNA monitoring of select performance, compliance and sentinel wells in that zone will be completed to demonstrate continued progress of the long term objective (i.e., continued progress to meeting the GWQS for Cr and other COCs). The following sections describe the conceptual monitoring plans for the active systems and MNA remedies.

7.4.1.1 Active System Remedy

A conceptual monitoring plan and schedule for the active system remedy are presented in **Table 7-2**. This plan includes monitoring that will be conducted in accordance with the PBRs for Phases I, II, and III IRMs and monitoring that will be conducted to evaluate the enhanced attenuation remedy.

<u>*In situ* Treatment Monitoring (via IRM PBRs)</u>

Monitoring parameters, schedule, and frequency for the Phase I, Phase II, and Phase III IRMs effectiveness evaluation were defined in the respective PBR authorizations (**Appendix B**).

The objectives of the IRM groundwater monitoring program are to evaluate the following:

- Distribution of reagent (biological or chemical) within targeted zones;
- Effectiveness of Cr^{+6} reduction; and
- Establishment and maintenance of reducing conditions during and post-treatment.

The timing of sampling in the IRM groundwater monitoring plan is critical to evaluate the effectiveness of the remediation and to reduce risk to human health and the environment. Therefore, sampling will occur prior to, during, and following treatment applications. Groundwater monitoring for the three IRM phases is comprised of the following:

- Baseline sampling prior to system startup;
- Operational monitoring;
- Treatment monitoring; and
- Post-treatment performance monitoring.

<u>Enhanced Attenuation (Post-PBR Monitoring)</u>

The objective of the enhanced attenuation phase monitoring is to monitor the capacity of the aquifer for continued reduction of COC concentrations after a significant amount of time has elapsed following active injection cessation.

The following COCs will be analyzed under this phase of monitoring:

- Cr^{+6} and CCPW metals; and
- PCE and its breakdown products (trichloroethylene [TCE], cis-1,2-dichloroethene, and vinyl chloride) in shallow well 114-MW41A (on Site 199).

In addition, key geochemical indicators such as iron, sulfates, sulfides, TOC, and field geochemical parameters (pH, ORP, dissolved oxygen, temperature, turbidity, and specific conductivity) may be collected to support the evaluation of Cr/Cr^{+6} attenuation.

The monitoring well network for the enhanced attenuation phase is expected to include a subset of the PBR monitoring well network and will be defined upon evaluation of the two-year post-treatment performance monitoring data for each IRM phase. The well network will consist of background wells, source area wells, plume area wells, and sentinel wells, and will provide optimal spatial coverage and be used to demonstrate that the contaminant plume is not migrating beyond the limits of the existing CEAs for the Project Area. The monitoring well network will be defined in the Active System Groundwater RAP.

As presented in **Table 7-2**, monitoring for the enhanced attenuation remedy is proposed semi-annually for the first year following completion of the two-year post-treatment performance monitoring for the in situ treatment remedy, and annually thereafter. As discussed in Section 6.1.3, the IRMs have or will provide organic carbon reductive capacity which is expected to remain in place and provide continued treatment for an estimated eight to ten years. The actual timeframe of this attenuation period and therefore, the longevity of the substrate, will be confirmed through groundwater monitoring which will provide the information to demonstrate continued attenuation of contaminant concentrations and persistence of aquifer reductive capacity. A robust dataset of contaminant concentrations and subsurface geochemistry information will be available upon completion of the enhanced attenuation period to evaluate the transition to an MNA remedy, consistent with the lines of evidence approach described in the NJDEP MNA Guidance (and described in Section 6.1.3). This extended monitoring period of PBR performance monitoring (quarterly) for the IRMs followed by enhanced attenuation monitoring (semi-annual to annual) will account for seasonal fluctuations in the water table and seasonal variability in contaminant concentrations.

7.4.1.2 MNA Remedy

As noted in the previous section, monitoring data from the three phases of the IRMs, and the enhanced attenuation program, will be used to demonstrate continued contaminant concentration reduction to support a transition to an MNA remedy. These data will be evaluated to gain an understanding of:

- Cr and Cr^{+6} concentration reductions compared to pre-treatment concentrations;
- Concentration trends (i.e., increasing, decreasing, stable);
- Groundwater geochemistry;
- Attenuation rates and estimated cleanup timeframes (i.e., how many years to meet the 70 µg/L GWQS for Cr); and
- Plume behavior (i.e., stable, decreasing, increasing).

The analytical suite for the MNA program is expected to include Cr^{+6} and CCPW metals, as well as appropriate geochemical parameters that will be analyzed or monitored routinely or as required will help assess the continued attenuation of Cr and Cr^{+6} in groundwater (NJDEP, 2012a).

This dataset is expected to provide sufficient information to evaluate the persistence of reducing conditions, even after ceasing active treatment and, therefore, will serve as a gauge for the reductive capacity of the aquifer and the longevity of the biological reductant(s). A long-term groundwater monitoring (LTM) program will be established in the RAP for MNA to support regular monitoring of natural attenuation capacity within the aquifer.

The monitoring well network for the MNA program will include background, former source and plume area(s), and sentinel monitoring wells. It will include a combination of monitoring wells from the individual IRM phases, selected to provide adequate spatial coverage, and will be used to demonstrate that the contaminant plume is not migrating beyond the limits of the CEA. Sampling frequency for the MNA program will be guided by the NJDEP's Groundwater Remedial Action Permit Guidance at the time of implementation and may include a frequency shown in the table below. It is noted that sentinel wells and plume fringe wells monitored for the MNA remedy will help verify that the contaminant plume is not migrating beyond the horizontal boundaries of the CEA and could support reducing the extent of the CEA in the future.

Table 7-3 Groundwater Monitoring Plan for Monitored Natural Attenuation

Phase	Performance Well Sampling Frequency	Sentinel Well Sampling Frequency
Upon issuance of MNA RAP	Annually, for years 1-4	1/2 of the travel time to nearest receptor or annually, whichever is more frequent
After 4 years	Biennially, for years 5-8	1/2 of the travel time to nearest receptor or biennially, whichever is more frequent
After 8 years	Every 4 years or every 8 years, dependent upon contaminant concentrations	1/2 of the travel time to nearest receptor or same frequency as the performance wells, whichever is more frequent

7.4.2 Maintenance and Monitoring of Groundwater Engineering Controls

Capillary Break

In areas where A-DGA does not exist, and where a capillary break was not required, based on the criteria laid out in the December 2017 *Capillary Break Design Final Report (Revision 2)* (AECOM, 2017e), groundwater monitoring for select parameters (defined in the GWMP) will be conducted annually, for a total of three years. The purpose of this monitoring is to verify that a capillary break is still not needed. The need for a capillary break will be re-evaluated if the data indicate these conditions have changed.

For areas where a capillary break does exist, the extent of the capillary break and notification procedures for penetrating the capillary break will be communicated to the property owners in the Active System Groundwater RAP. This will require the property owner or responsible party to notify PPG prior to breaching the capillary break so that PPG can coordinate repairs. In the event that the capillary break is compromised, it will be repaired or replaced, until such a time that the NJDEP agrees that a capillary break is no longer required, based on monitoring data (AECOM, 2017e). Repairs to the capillary break will be documented in the biennial certification report for the Active System Groundwater RAP.

FerroBlack®-H-amended Backfill

Groundwater monitoring in areas where FerroBlack®-H-amended backfill was used, is complete, or is underway for most of the Project Area. Progress of groundwater monitoring in these areas has been documented in past quarterly reports submitted to the NJDEP, as required by the PBR for site-wide application of FerroBlack®-H. As additional areas are excavated and backfilled, four quarters of groundwater monitoring will be conducted, and samples will be analyzed for the parameters defined in the 2017 GWMP and the PBR for site-wide application of FerroBlack®-H. Longevity calculations estimate that the FerroBlack®-H amendment will be effective in reducing Cr^{+6} for a minimum of 200 years (AECOM, 2017d). Biennial groundwater monitoring of select shallow zone monitoring wells will be conducted to monitor the long-term effectiveness of this engineering control. Specific inspection and repair procedures for the amended backfill, if necessary, will be described in the application for an Active System Groundwater RAP.

Competent Meadow Mat

The meadow mat is a naturally occurring subsurface feature that is present across a large portion of the Project Area. The presence of competent meadow mat is documented and well understood. No regular monitoring or maintenance is required for this natural engineering control.

Sheet Pile

The potential for migration of contaminated groundwater across and/or underneath the sheet pile wall will be monitored by sampling monitoring wells on either side of the sheet pile. If warranted, an engineered permeable reactive barrier may be considered as a contingency remedy to prevent off-site migration of impacted groundwater, should it occur. Extensive studies and evaluations on the potential for corrosion of the sheet pile have been completed by AECOM, on behalf of PPG, using literature sources and site-specific testing. These activities were summarized in the August 28, 2020 Technical Memorandum titled Evaluation of Corrosion Potential and Estimated Design Life of Steel Sheet Pile Separating Garfield Avenue Group Site 114 and Site 199 (AECOM, 2020b). The sheet pile is not proposed as an engineering control for the shallow water-bearing zone. Groundwater monitoring proposed in the Phase III IRM area will provide the information needed to verify that contaminated groundwater is not flowing past the sheet pile wall, thereby demonstrating the effectiveness of the sheet pile as an engineering control in the intermediate and deep (where present) water-bearing zones.

7.4.3 Field Procedures

Drilling, well installation, and well development will be conducted in accordance with the requirements set forth in N.J.A.C. 7:9D, by a NJ-licensed drilling subcontractor.

Groundwater sampling will be conducted in accordance with the NJDEP Field Sampling Procedures Manual (FSPM) (NJDEP, 2005), and the June 2010 Field Sampling Plan-Quality Assurance Project Plan (FSP/QAPP) (AECOM, 2010a), included as **Appendix D** to this RAWP. Groundwater analytical samples will be handled in a manner consistent with the sample container, holding time, and preservation requirements specific to the analytical method used. Sampling procedures will be consistent with the Standard Operating Procedures defined in the FSP/QAPP.

Field instruments will be calibrated on a daily basis, in accordance with the instrument specifications, and calibration data will be recorded in field data sheets. Instruments that may be used during groundwater sampling activities include water level indicators, oil/water interface probes, and water quality indicators.

Groundwater samples collected for regulatory compliance (e.g., performance monitoring data from the IRMs) will be collected using low-flow purging and sampling techniques, consistent with the FSP/QAPP and the NJDEP's *Low Flow Purging and Sampling Guidance* (NJDEP, 2003) or using improved sampling procedures approved by the NJDEP at the time of compliance sampling. Field water quality parameters (pH, ORP, dissolved oxygen, specific conductivity, temperature, and turbidity) will be recorded on dedicated low-flow sampling form. Samples will be collected into appropriately preserved sample containers provided by the analytical laboratory and stored in coolers at 4 degrees Celsius before being relinquished to the laboratory.

Deviations from the FSPM and/or the June 2010 FSP/QAPP will be documented in a field change notification and submitted for approval to the NJDEP prior to field implementation. Field change notifications for the Phase II and Phase III IRMs (FCN 20 and FCN 22) are included in **Appendix D**, along with the email approvals from the NJDEP.

7.4.4 Data Management

7.4.4.1 Laboratory Analytical Data Reporting

Full laboratory data deliverables, as defined in Appendix A of the Technical Requirements for Site Remediation (NJDEP, 2018b) will be submitted for the Cr^{+6} and Cr^{+6}-associated analyses (i.e., ORP and pH). Reduced laboratory data deliverables will be submitted for other analytes of interest (metals, VOCs, etc.). Electronic data deliverables (EDDs) of the validated analytical data will be uploaded to a PPG program-specific environmental database (EQuIS®).

7.4.4.2 Data Validation

Each analytical data package will undergo a formal review process. One hundred percent of the analytical data will be reviewed, either as a "full" validation or a "limited" validation (as defined in Section 13.1 of the FSP/QAPP), for a check of completeness, data usability, and data reliability.

The discovery of significant anomalies or discrepancies during data validation may result in the in-depth review of the raw data, and the incorporation of additional review elements.

Validation of aqueous samples will be performed in accordance with the FSP/QAPP and the following NJDEP validation protocols:

- NJDEP Office of Data Quality SOP 5.A.10, Rev. 3 (September 2009), SOP for Analytical Data Validation of Hexavalent Chromium – for USEPA SW846 Method 3060A, USEPA SW846 Method 7196A, and USEPA SW846 Method 7199;
- NJDEP Office of Data Quality SOP 5.A.16, Rev. 1 (May 2002), Quality Assurance Data Validation of Analytical Deliverables for Inorganics (based on USEPA SW846 Methods); and
- ICP-AES Data Validation, SOP No. HW-3a Rev. 0 (July 2015).

Once the validation for a data package is complete, a data validation memorandum will be prepared. This memorandum will summarize the samples reviewed, the level of validation completed, non-conformances with the established criteria, and validation actions (i.e., application of data qualifiers).

The final laboratory analytical reports, along with the data validation memoranda will be included in relevant submittals.

7.5 Site Restoration

Following completion of the active remedy, remediation wells and select monitoring wells will be decommissioned in accordance with the N.J.A.C. 7:9D regulations by a NJ-licensed drilling subcontractor. As necessary, modification to the decommissioning of remediation wells may be evaluated and a request made to the NJDEP for approval. Select monitoring wells will be retained for inclusion in the MNA monitoring program, as needed.

The remediation network piping (injection, extraction, conveyance) and other subsurface pipes (electrical conduits) will be disconnected and abandoned in-place or removed upon completion of injection and extraction operations. In addition, above-grade infrastructure, including mobile injection units, well vaults and well casings will be disconnected and removed.

Areas where the HDPE capillary break liner was compromised due to drilling will be patched and repaired by a qualified subcontractor. Liner repairs will be documented in the biennial certification reports for the Active System Groundwater RAP.

7.6 Variances from NJAC 7:26E(5)

No variances are required for the work proposed in this RAWP.

8 Schedule and Reporting

8.1 Schedule

In accordance with the 1990 ACO and JCO, implementation and completion of the work to remediate soil and groundwater at the HCC Sites is proposed in accordance with a judicially-enforceable Master Schedule. The Master Schedule was most recently updated on July 30, 2021 and reflects the following milestones relevant to groundwater remediation:

- Groundwater IRM, Phase III: The PBR application for implementation of the Phase III groundwater IRM was submitted to the NJDEP BCAIN on April 20, 2021, with final approval issued on July 9, 2021. The Phase III treatment system began operating September 2021 and is expected to run for 12 to 14 months, after which a two-year post-treatment monitoring period will commence.

- Groundwater RAR: The Master Schedule milestone for the submission of a groundwater RAR is November 2023.

- Groundwater RAP: An application for an Active Category Groundwater RAP will be submitted with the RAR, i.e., as soon as the requirements for the Active Category Groundwater RAP outlined in NJDEP's *Ground Water Remedial Action Permit Guidance* (https://nj.gov/dep/srp/guidance/srra/rem_action_permit_guidance_gw.pdf) have been met. It is expected that these requirements will be met upon completion of the treatment monitoring programs for the three IRM phases, and at a minimum after four quarters of post-treatment monitoring data are available for the Phase III IRM. The data from these robust area-wide groundwater monitoring required under the PBRs for the three IRM Phases are expected to support that the active system remedy is effective.

8.2 Reporting

8.2.1 Remedial Action Progress Reports

During the implementation of remedial activities under the JCO, written Remedial Action Progress Reports (RAPRs) will be submitted to NJDEP within six weeks following the end of each quarter. Progress reporting will continue until the Active Category Groundwater RAP is issued. The progress report will include the following items, as applicable:

- Description of actions taken toward achieving compliance with the 1990 ACO and JCO during the previous quarter;

- Description and a schedule of actions which are expected to be initiated or completed during the following quarter; and

- Description of delays encountered or anticipated that may affect the future schedule and a description of the efforts made to mitigate these delays.

8.2.2 Active Remedy Reporting

8.2.2.1 *In situ* Treatment Reporting under IRM PBRs

Quarterly Progress Reports

As specified in the PBRs for each IRM Phase, quarterly brief progress reports will be prepared and submitted to the NJDEP for review and comment in accordance with the PBR requirements for each IRM Phase during implementation of the groundwater IRMs. These progress reports will include in bullet format: details describing the activities completed within the reporting period, issues encountered, deviations from the PBR, samples collected (along with analytical data tables, figures, and supporting appendices), and work planned for the next quarter.

In order to enhance understanding of the progress of the IRM Phases, PPG intends to consolidate the PBR reporting into one quarterly report for the three IRM phases beginning in the first quarter of 2022. PPG will request a PBR modification if needed. In the consolidated quarterly report, PPG will depict the progress of the remediation in plan-view using appropriate graphics to convey progress to stakeholders on a high level (e.g., “heat maps”).

In addition to the progress reporting, PPG will more extensively evaluate progress of the remedy on an annual basis. In the fourth quarter progress reports, PPG will provide a remediation progress summary using snapshots of a 3-dimensional representation of the remediation. PPG will provide an opportunity for a technical discussion on a semi-annual or periodic basis with NJDEP and other stakeholders to review the 3-dimensional representation and answer specific questions regarding the overall understanding of remedial progress and the need for possible contingencies.

Final Report

A final completion report to close out the PBR will be prepared upon completion of each phase of the IRMs. This report will document the work performed under the approved PBR, including deviations from the PBR, and a discussion of the effectiveness of the IRM. This report will be submitted to the NJDEP within the applicable consolidated quarterly report.

8.2.2.2 Enhanced Attenuation Monitoring Reporting and Long-Term Groundwater Monitoring

PPG will continue to provide progress reporting for the IRM portion of the active remedy as per the PBRs (i.e., quarterly). The groundwater remediation timeline shown on **Figure 5-1** shows that PPG expects that the Active Category Groundwater RAP will be issued concurrent with the close-out of the PBRs. Thus, progress reporting subsequent to the PBRs will follow NJDEP regulations and guidance for demonstrating remedial action protectiveness (i.e., biennial certifications). Reporting of the enhanced attenuation remedy and long-term groundwater monitoring for the biennial certification will include analytical data tables, result maps, laboratory reports, data validation reports, and a discussion of results and concentration trends observed over all three IRM phases to support the lines of evidence to transition to MNA.

8.2.3 MNA Remedy Reporting

After transition to a MNA Category Groundwater RAP, biennial certification reports will continue, which will be submitted in accordance with the MNA Category Groundwater RAP reporting requirements.

8.2.4 Reporting Associated with November 2017 GWMP

Reporting for the groundwater analytical data collected under the FerroBlack®-H PBR and the capillary break monitoring programs will continue until completed (in 2022), in accordance with the November 2017 GWMP.

8.2.5 Final Reporting

PPG will submit an RAR, prepared in accordance with N.J.A.C. 7:26E-6.7 (later replaced by N.J.A.C. 7:26E-5.7 per the August 6, 2018 amendment), and an application for an Active Category Groundwater RAP to the NJDEP for review and approval as soon as the requirements for the Active Category Groundwater RAP outlined in NJDEP's *Ground Water Remedial Action Permit Guidance* (https://nj.gov/dep/srp/guidance/srra/rem_action_permit_guidance_gw.pdf) have been met. It is expected that these requirements will be met upon completion of the treatment monitoring programs for the three IRM phases, and at a minimum after four quarters of post-treatment monitoring data are available for the Phase III IRM. The data from these robust area-wide groundwater monitoring required under the PBRs for the three IRM Phases are expected to support that the active system remedy is effective.

Per a September 2, 2020 NJDEP Listserv email correspondence, the Active Category Groundwater RAP is applicable to sites where the remedy includes an active groundwater treatment system. The Listserv indicates the NJDEP considers technologies such as remedial injections (with durations of greater than 180 days) and reactive barriers as an acceptable long-term remedial action where an Active Category Groundwater RAP can be issued. Requirements specified in NJDEP Ground Water Remedial Action Permit Guidance (NJDEP, 2017c) for the Active Category Groundwater RAP include the following, which will be met by PPG prior to the request for the Active Category RAP:

1. The active ground water treatment system is effectively operating and functioning as designed. A minimum of four (4) consecutive quarterly rounds of ground water samples should be collected to demonstrate this.

2. All soil contamination in the unsaturated zone has been remediated to the applicable numeric Migration to Ground Water Soil Remediation Standard for all AOCs associated with the CEA.

3. The ground water plume is not migrating horizontally or vertically into an uncontaminated aquifer zone adjacent to or below the contaminant plume.

4. The ground water plume is contained and not impacting the sentinel well(s).

5. Financial Assurance (FA) has been established for the operation and maintenance of any engineering control necessary for the period that the control(s) will be operating. The FA must be established for the duration the engineering control will be in place.

6. The ground water remedial action is demonstrated to be protective of public health and safety and of the environment. This includes an evaluation of all potential receptors as required by N.J.A.C. 7:26E.

The RAR will include the following:

- Description of remedial activities performed, including IRMs;
- Descriptions of deviations from the RAWP;
- Discussion of the remediation goal and objectives that were achieved;
- Description of site restoration activities;
- Remedial action costs incurred;
- Applicable regulatory forms; and
- Certification signed by the person who supervised or directed the preparation of the final RAR.

The overall performance of the IRMs, waste management, laboratory documentation, data quality assessments, supporting tables and figures, and other related information will be summarized and/or included as appendices to the RAR.

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Tables

N.J.A.C. 7:26E (last amended August 6, 2018) regulations are the primary source of Remedial Action Work Plan (RAWP) requirements. This document is not to be used as a replacement for the Technical Regulations.

Regulation	Description	Document Location	
N.J.A.C. 7:26E-5.5	**Remedial Action Workplan**	**Report**	**Location**
5.5(a)	The person responsible for conducting the remediation shall prepare and submit to the Department prior to implementation, a remedial action workplan for each area of concern requiring a remedial action, unless a final remediation document for unrestricted use is filed with the Department within one year after the earliest applicable requirement to remediate, pursuant to N.J.A.C. 7:26C-2.2.	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	throughout
5.5(b)	The person responsible for conducting the remediation shall include the following in each remedial action workplan for each area of concern:	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	see below
5.5(b)1.	A summary of the findings and recommendations from the remedial investigation report prepared pursuant to N.J.A.C. 7:26E-4.9;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 2.0 Summary of Groundwater Remedial Investigation
5.5(b)2.	A description of any interim remedial measures previously implemented;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 3.3 Summary of Completed and Ongoing Remedial Actions: Groundwater Interim Remedial Measures
5.5(b)3.	The identification of each area of concern where the remedial action will be implemented, including: i. The horizontal and vertical extent of the area to be remediated correlated to the extent of contamination; and ii. The volume of the contamination to be treated or removed for each environmental medium;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 4.4 Remediation Areas
5.5(b)4.	A detailed description of the remedial action and the remedial technology to be used for the area of concern, including the results of any bench scale, pilot test or design studies;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 6.0 Description of Groundwater Remedial Action and Section 3.2 Groundwater Bench- and Pilot-Scale Tests Supporting Selection of Remedial Action
5.5(b)5.	Identification of all applicable remediation standards;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 4.2 Remediation Criteria
5.5(b)6.	A plan to evaluate the effectiveness of the remedial action;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 7.4 Effectiveness Evaluation
5.5(b)7.	A perimeter air monitoring and action plan to be implemented during a remedial action, if applicable, designed to monitor and control off-site excursion of dust, vapor and odors;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	not applicable

Regulation	Description	Document Location	
N.J.A.C. 7:26E-5.5	Remedial Action Workplan	Report	Location
5.5(b)8.	A list of all required permits;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 7.1 Permits and Notifications
5.5(b)9.	A fill use plan that complies with N.J.A.C. 7:26E-5.2, if applicable;	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	not applicable
5.5(b)10.	A plan to restore the site after implementing the remedial action, if applicable; and	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 7.5 Site Restoration
5.5(b)11.	The proposed completion date of the remedial action and a schedule of the remedial action for the initiation and completion of each remedial action task, pursuant to the required regulatory timeframe at N.J.A.C. 7:26E-5.8.	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	Section 8.1 Schedule
5.5(c)	The person responsible for conducting the remediation shall submit a revised remedial action workplan or remedial action workplan addendum prepared pursuant to this section:	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	not applicable at this time
5.5(c)1.	When a remedial action does not perform as designed; or	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	not applicable at this time
5.5(c)2.	To upgrade or change the selected remedial action.	Groundwater Remedial Action Work Plan, Garfield Avenue Group Sites, Draft	not applicable at this time

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Title/Year	*Technology*	*Matrix*	*Objectives*	*Description*	*Results and Conclusions*	*Reference(s)*
Bucket Testing of Backfill Amendment Reagents (2012)	ISCR	Soil and Groundwater	• Assess effectiveness of six amendment reagents at varying doses; • Evaluate safe handling procedures and odor issues for full-scale application; and • Evaluate clean fill blending methods and provide recommendations for full-scale use.	The bench-scale bucket testing consisted of seven tests and a control sample. Tests involved blending of clean backfill (i.e., DGA) with reagents at varying dosages, and saturating the amended soils with Cr^{+6}-contaminated groundwater collected from the Site (in the former Morris Canal area). The reagents tested included FerroBlack®-H, calcium polysulfide, ferrous sulfide, and sodium hydrosulfide. The pilot test was intended to simulate conditions that would likely occur after excavations were backfilled, and groundwater recharges into the area.	While all reagents tested exhibited varying levels of effectiveness in reducing the concentration of Cr^{+6}, certain reagents resulted in elevated concentrations of other metals (e.g., mercury and selenium), and certain reagent mixes exhibited odor issues when blending. FerroBlack®-H was selected for pilot-scale testing, at a dosage of 220 grams of FerroBlack®-H per gram of Cr^{+6}, based on a comparison of health, safety, and odor issues, effectiveness, cost, introduction of undesirable metals, ability to treat metals other than Cr^{+6}, and ability to reduce the solubility of Cr.	AECOM, 2012b. *Backfill Amendment Pilot Test – Final Report. 900 Garfield Avenue – PPG Site 114, Jersey City, New Jersey*. 27 February 2012.
Backfill Amendment Pilot Test (2012)	ISCR	Soil and Groundwater	• Assess the effectiveness of the selected backfill amendment reagent under actual Site conditions (i.e., pilot test) over a period of several months; and • Provide data for full-scale application of the treatment method.	FerroBlack®-H amended backfill was applied to a 30 ft by 30 ft test cell (measuring 18 ft in depth) constructed within the former Morris Canal area. Approximately 6 gallons of FerroBlack®-H was added per ton of certified clean backfill, corresponding to a loading rate of 3% FerroBlack®-H by weight. A baseline groundwater sample was collected as an initial indication of water quality recharging into the test cell. A baseline soil sample was also collected, from the bottom of the excavated test cell. In addition, three monitoring wells were installed, one upgradient of the test cell, one within the test cell, and one downgradient of the test cell. Four performance monitoring soil and groundwater sampling events were completed, and samples were primarily analyzed for Cr^{+6}, TAL metals, pH and ORP.	Soil: • The primary goal of preventing clean soils (i.e., amended DGA) from being recontaminated with Cr^{+6}, was achieved. • The soil data also showed no significant increases in the concentrations of other metals as a result of use of the amendment. NJDEP SRS for all metals were met in soil. Groundwater: • Cr and Cr^{+6} levels in groundwater samples collected from within the test cell reduced by over 98% compared to the baseline conditions. • The concentrations of several TAL metals within the test cell were reduced to below their respective NJDEP GWQS by the end of the performance monitoring period. • Cr and Cr^{+6} concentration reductions (of over 75%) were recorded in the two wells located outside the test cell. • Groundwater geochemistry data indicated that the application of FerroBlack®-H was effective in maintaining a reducing subsurface environment, characterized by negative ORP and a low dissolved oxygen content, which are conducive to the reduction of Cr^{+6}. Testing also demonstrated that the amendment can be applied safely without adverse impacts to residents or Site workers.	AECOM, 2012b. *Backfill Amendment Pilot Test – Final Report. 900 Garfield Avenue – PPG Site 114, Jersey City, New Jersey*. 27 February 2012. AECOM, 2017d. *Backfill Amendment Test Cell Permit-By-Rule Final Report. PPG Garfield Avenue Group, Hudson County Chromium Sites, Jersey City, New Jersey.* 5 December 2017.

Title/Year	*Technology*	*Matrix*	*Objectives*	*Description*	*Results and Conclusions*	*Reference(s)*
Morris Canal Permit-By-Rule Pilot Test (2012)	ISCR	Soil and Groundwater	• Assess the effectiveness of the selected backfill amendment reagent under actual Site conditions in a larger area compared to the test cell over a period of several months; • Reduce concentrations of Cr and Cr^{+6} in Site groundwater; and • Evaluate effectiveness of the amended backfill for Site-wide application.	The pilot test involved application of a 2.8% (by weight) solution of FerroBlack®-H to clean backfill (DGA) to fill the excavation within the treatment area, within the footprint of the former Morris Canal. Excavation of the treatment area resulted in the removal of approximately 22,500 tons of Cr^{+6}-impacted soils and concrete. This was followed by the placement of approximately 28,400 tons of FerroBlack®-H amended backfill, up to a depth of 26 ft bgs. One shallow and one deep monitoring well were installed within the treatment area. Performance monitoring samples were collected and analyzed for Cr^{+6}, TAL metals, pH and ORP.	• Cr and Cr^{+6} concentrations in the shallow monitoring well in the treatment area were below the NJDEP GWQS for Cr (70 ppb), compared to a pre-treatment groundwater concentration of 62,800 ppb of Cr^{+6}. • Cr and Cr^{+6} concentrations in the deep monitoring well in the treatment area were reduced by over 80% compared to pre-treatment levels. • Concentrations of other metals were reduced in comparison to baseline/pre-treatment levels, to varying degrees. The pilot test was considered successful, and provided useful data for full-scale design.	AECOM, 2017e. *Morris Canal Permit-By-Rule Final Report. PPG Garfield Avenue Group, Hudson County Chromium Sites, Jersey City, New Jersey.* 5 December 2017.
MGP Waste and FerroBlack®-H Bucket Test (2013)	ISCR	Soil and Groundwater	• Evaluate the use of FerroBlack®-H as a backfill amendment reagent in portions of the Site where former MGP residuals are present.	The bucket test consisted of testing FerroBlack®-H amended fill with a groundwater test solution (prepared to simulate a "worst case" scenario, i.e., consisting of equal parts of MGP-impacted groundwater and visibly green (i.e., Cr-impacted) groundwater. Air monitoring was also conducted to assess generation of VOCs and hydrogen sulfide gases. Baseline soil and groundwater samples were collected for comparison. Post-exposure groundwater samples were collected and analyzed for Cr^{+6}, TAL metals, pH, ORP, SVOCs, VOCs, ferrous and ferric iron, and dissolved oxygen.	• The results of the bucket testing indicated that Cr^{+6} was reduced in the MGP-contaminated test groundwater sample, in the presence of FerroBlack®-H. • Generation of undesired gases was not observed. • Concentrations of other TAL metals, VOCs and SVOCs were not significantly impacted by the presence of FerroBlack®-H. The pilot test concluded that the application of FerroBlack®-H to clean backfill does not adversely impact areas with MGP-contaminated groundwater, that Cr^{+6} reduction was still achieved, and that the reagent may be applied in areas where both Cr and MGP impacts are present.	AECOM, 2013. *MGP Waste and FerroBlack®-H Bucket Test – DRAFT*. 5 September 2013.
Groundwater *In-situ* Bioprecipitation Pilot Test (2014)	ISAB	Groundwater	• Demonstrate the effectiveness of the ISAB technology for the treatment of Cr^{+6} impacts within the shallow and intermediate zones; and • Collect Site-specific data from hydraulic injection/tracer testing to support full-scale design.	Two injection events were conducted between March and September 2014 to introduce organic carbon (molasses) into the shallow and intermediate zones within a test area on Site 114 (IRM #1). A dye test comprised of injection of a Rhodamine dye was also conducted concurrently to support evaluation of injection volumes and distribution. Baseline soil and groundwater samples were collected for comparison with post-treatment sample data. Following active treatment, performance monitoring was conducted over a 12-month period. Groundwater samples were collected and analyzed for Cr^{+6}, TAL metals, pH, ORP, total organic carbon,	• The pilot test demonstrated that injections into the shallow and intermediate zones were feasible, at flow rates between 0.5 to 1 gallon per minute. • In areas where organic carbon concentrations increased as a result of injections, rapid Cr^{+6} reduction was observed, by up to five orders of magnitude in comparison to baseline levels. • Cr^{+6} concentrations in soil were reduced by three to four orders of magnitude in comparison to baseline levels. • pH was neutralized in the shallow zone, which supports long-term stability of the precipitated trivalent chromium (Cr^{+3}).	ARCADIS, 2017a. *Completion Report: ARCADIS Groundwater Bioprecipitation Pilot Test. Garfield Avenue Site 114 and Former Halladay Street Gas Works, Jersey City, New Jersey*. April 2017.

Title/Year	*Technology*	*Matrix*	*Objectives*	*Description*	*Results and Conclusions*	*Reference(s)*
				and select anions of interest (sulfates, sulfides, nitrate, and nitrite).	The effectiveness and permanence of Cr^{+6} treatment was demonstrated by reduced Cr^{+6} concentrations throughout the 12-month performance monitoring period. The pilot test was considered successful and provided useful design parameters for full-scale implementation.	
Groundwater *In-situ* Chemical Reduction Pilot Study (2016)	ISCR	Groundwater	• Reduce Cr^{+6} in groundwater to the less mobile and less toxic Cr^{+3}; and • Secondary objectives included evaluating the effectiveness of chemical reductants on the concentrations of other TAL metals, assess the changes to groundwater pH, and evaluate the ability to distribute the reagents in the subsurface.	The pilot test network, comprised of injection and monitoring wells, was set up adjacent to the *In-situ* bioprecipitation pilot test (described above), in the IRM #1 area of Site 114. An additional intermediate zone test area was established in the Phase 1C area of Site 114. FerroBlack®-H was injected into the shallow zone treatment area, and calcium polysulfide (in IRM #1) as well as FerroBlack®-H (in Phase 1C) was used for injections into the intermediate zone treatment area. Baseline soil and groundwater samples were collected for comparison with post-treatment sample data.	• In the shallow zone, concentration reductions of Cr and Cr^{+6} of over 90% were observed after the 12-month performance monitoring phase. • In the intermediate zone of IRM #1, Cr^{+6} was reduced by 100%, and Cr was reduced by over 75%. • Concentration reductions in the Phase 1C area were less significant, ranging from 50% to 75% compared to baseline levels. • Reductions in the concentrations of several other TAL metals were also noted as a result of the chemical injections. • In soil, Cr^{+6} concentrations reduced by over 50% in areas where the reagent was distributed. The pilot test was considered successful, with both reagents tested (i.e., FerroBlack®-H and calcium polysulfide) demonstrating their effectiveness in reducing Cr^{+6} in groundwater and in establishing a reducing environment in the subsurface, which persisted through the end of the performance monitoring period.	AECOM, 2017b. *Groundwater Chemical Reduction Pilot Study Completion Report – Final. PPG Garfield Avenue Group, Hudson County Chromium Sites, Jersey City, New Jersey*. 11 September 2017.
Hydraulic Fracturing and FerroBlack®-H Emplacement in Low-Permeability Zones Pilot Test (2019)	Hydraulic Fracturing and ISCR	Soil and Groundwater	• Evaluate effectiveness of hydraulic fracturing techniques to deliver reagents to low permeability zones below the meadow mat; • Estimate the radius of influence for emplacement of FerroBlack®-H within low permeability zones; and • Evaluate the potential for effects of fracturing on the meadow mat above the target fracture zones.	HPT and VAP characterization of the pilot test area was completed prior to implementation to identify high- and low-permeability zones. A target treatment zone of 40 to 50 ft bgs was selected upon review of the HPT/VAP data. Three fracture wells and one monitoring well were installed for the purposes of the pilot study. Aquifer testing and hydraulic conductivity characterization were completed via performance of pre-and post-fracture slug tests at select monitoring wells in order to evaluate changes in hydraulic conductivity (K) of the intermediate and deep water-bearing zones adjacent to these wells in response to the fracturing pilot test.	• The pilot test demonstrated that hydraulic fracturing techniques can be used to emplace FerroBlack®-H into low permeability zones within the intermediate and deep water-bearing zones. • The estimated radius of influence for the technique within the low permeability zone ranged from 15-25 feet. • Data and observations from the pilot test indicate that the injected FerroBlack®-H did not affect the overlying shallow zone, and by inference, did not affect the meadow mat unit. The pilot test demonstrated proof of concept of hydraulic fracturing technology for the emplacement of chemical reductant(s) within low-permeability soils.	AECOM, 2019. *Technical Memorandum – Hydraulic Fracturing and FerroBlack®-H Emplacement in Low-Permeability Zones Pilot Test. Hudson County Chromate Site 114, Jersey City, New Jersey*. 6 November 2019.

Title/Year	*Technology*	*Matrix*	*Objectives*	*Description*	*Results and Conclusions*	*Reference(s)*
				FerroBlack®-H was injected at each of the three fracture wells at two pre-determined depths within the low-permeability zones. Target fracture depths were selected based on soil boring information, penetrometer readings, HPT logs, and VAP data. Tiltmeters were deployed to monitor ground surface deformation during the injections. Soil borings were advanced at two locations to confirm the delivery of FerroBlack®-H into the target zones.	However, large-scale applicability was not evaluated. Reagent distribution is likely to be influenced by heterogeneities in the formation, and most distributions and not expected to be uniform or radial.	

Acronyms:

bgs	below ground surface
Cr	total chromium
Cr^{+3}	trivalent chromium
Cr^{+6}	hexavalent chromium
DGA	Dense-graded aggregate
ft	feet
GWQS	Groundwater Quality Standards
HPT	hydraulic profiling tool
ISAB	in-situ anaerobic bioprecipitation
ISCR	in-situ chemical reduction
MGP	manufactured gas plant
NJDEP	New Jersey Department of Environmental Protection
ORP	oxidation-reduction potential
ppb	parts per billion
ppm	parts per million
SRS	Soil Remediation Standards
SVOC	semivolatile organic compound
TAL	target analyte list
VAP	vertical aquifer profiling
VOC	volatile organic compound

Table 5-1

Comparative Analysis of Groundwater Remedial Alternatives

Groundwater Remedial Action Work Plan, Final

Garfield Avenue Group Sites, PPG, Jersey City, New Jersey

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Alternative	**Comparative Criteria [1]**							**Total Score**	**Application of the Remedial Technology**
	Overall Protection of Human Health and the Environment	Achievement of Remedial Goals and Objectives	Long-Term Effectiveness and Permanence	Short-Term Effectiveness (Compatibility with Redevelopment)	Implementability	Comparative Cost (Low/Medium/High)	Regulatory Acceptance		
No Action									
Alternative 1: No Action	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three Classification Exception Areas (CEAs) will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater engineering controls (ECs) are in place to prevent groundwater from impacting soil remediation areas. - However, under the "no action" alternative, the current ECs and ICs would not be maintained to prevent exposure to contaminated groundwater.	- Contaminant reduction only occurs via natural mechanisms (no active or monitored natural attenuation [MNA] remedy is applied to reduce contaminant of concern [COC] concentrations), thus COC concentrations will remain above New Jersey Department of Environmental Protection (NJDEP) Groundwater Quality Standards (GWQS).	- Contaminant and mass reduction only occurs via natural mechanisms (no active or MNA remedy is applied to reduce COC concentrations), thus this alternative is not effective in the long-term.	- No infrastructure required.	- Not Applicable	None	- Least likely. - Contaminant and mass reduction only occurs via natural mechanisms (no active or MNA remedy is applied to reduce COC concentrations), thus this alternative is not effective in the short or long term.	23	The no action alternative is not recommended. A combination of active remediation and MNA will be most effective in meeting the remedial goal and objectives.
Alternative 1 Score	5	5	5	1	1	1	5		
Active Remediation									
Alternative 2: FerroBlack®-H Permeable Reactive Barrier (PRB)	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Provides treatment of COCs at the barrier location as groundwater passes through under natural flow conditions. - Controls the mass flux leaving the Project Area boundaries.	- A PRB is successful in controlling mass flux leaving the Project Area limits and providing contaminant reduction within the zone of influence of the barrier, but does not provide contaminant mass reduction across the entire Project Area. - Contaminant mass reduction is permanent within the zone of influence of the barrier. - PRB extends duration of the remediation compared to Alternatives 4 through 7 because it relies on natural groundwater flow to reach the barrier before treatment occurs. - Long-term monitoring required to prove effectiveness.	- Can be installed in the short-term. - Location of barrier can be coordinated with redevelopment plan. - Effective in the short-term.	- Implementable. - Success of technology is demonstrated by successful in-situ chemical reduction (ISCR) pilot test implementation (Table 3-3), and use of material as a backfill amendment during soil remediation. - If alternative is constructed on properties not owned by PPG, access agreements will be necessary.	Medium	- Likely acceptable to control mass flux leaving the Project Area boundaries.	14	Technology would be best applied as a contingency measure in applicable areas, to provide containment if needed, in the future.
Alternative 2 Score	1	2	2	2	2	3	2		
Alternative 3: Extraction Barrier	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Provides mass removal at the barrier location as groundwater passes through under natural flow conditions. - Controls the mass flux leaving the site boundary for as long as pumping continues.	- An extraction barrier is successful in controlling mass flux leaving the Project Area and providing contaminant reduction within the zone of influence of the barrier, but does not provide contaminant mass reduction across the entire Project Area. - Contaminant mass reduction is permanent within the barrier. - Extraction barrier extends duration of the remediation compared to Alternatives 4 through 7 because it relies on natural and induced groundwater flow to reach the barrier before treatment occurs. - Long-term monitoring required to prove effectiveness.	- Can be installed in the short-term and can utilize existing groundwater treatment plant (GWTP). - Location of barrier can be coordinated with redevelopment plan. - Effective in the short-term.	- Implementable. - Pump and treat is a widely used alternative at contaminated groundwater sites. - If alternative is constructed on properties not owned by PPG, access agreements will be necessary	Medium-High	- Likely acceptable to control mass flux leaving the Project Area boundaries.	18	Technology would be best applied as a contingency measure in applicable areas, to provide containment if needed, in the future.
Alternative 3 Score	1	3	4	2	2	4	2		
Alternative 4: Pump and Treat	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Comprehensive and permanent contaminant reduction and mass removal. - Controls the mass flux leaving the site boundary for as long as pumping continues.	- Pump and Treat is effective and provides permanent mass removal, but only within the zone of influence of the extraction well. - Moderate-term monitoring	- Based on estimated number of extraction wells expected necessary to achieve the remedial goal and objectives, this alternative is not compatible with the redevelopment plan.	- Implementable. - Pump and treat is a widely used alternative at contaminated groundwater sites. - If alternative is constructed on properties not owned by PPG, access agreements will be necessary.	High	- Likely acceptable. - Permanence of the remediation will be monitored.	21	Pump and treat is recommended for mass removal and plume stabilization. Pump and treat could be paired with another remedial technology such as In-situ Anerobic Biopercipitation (ISAB) or ISCR to expedite the remediation.

Table 5-1
Comparative Analysis of Groundwater Remedial Alternatives
Groundwater Remedial Action Work Plan, Final
Garfield Avenue Group Sites, PPG, Jersey City, New Jersey

AECOM

Alternative	**Comparative Criteria [1]**							**Total Score**	**Application of the Remedial Technology**
	Overall Protection of Human Health and the Environment	Achievement of Remedial Goals and Objectives	Long-Term Effectiveness and Permanence	Short-Term Effectiveness (Compatibility with Redevelopment)	Implementability	Comparative Cost (Low/Medium/High)	Regulatory Acceptance		
Alternative 4 Score	1	2	3	5	2	5	3		
Alternative 5: ISAB	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Comprehensive and permanent contaminant reduction. - Eliminates mass flux leaving the site boundary.	- ISAB is effective and permanent as demonstrated by reduced hexavalent chromium (Cr^{+6}) concentrations in groundwater during the Phase I Interim Remedial Measure (IRM) performance monitoring period. - Once reagent injections are completed, residual reductive capacity in the aquifer will continue to treat COCs.	- Short-term temporary infrastructure required. - Can be integrated with redevelopment.	- Implementable - Effectiveness has been demonstrated by a successful pilot test and ongoing performance monitoring for IRM Phases I and II. - If alternative is constructed on properties not owned by PPG, access agreements will be necessary.	Medium	- Already accepted for IRM Phase I and II. - Permanence of the remediation will be monitored.	14	ISAB is an effective source zone remedy, as demonstrated in the IRM Phase I and II as well as past pilot testing.
Alternative 5 Score	1	2	2	3	2	3	1		
Alternative 6: ISCR with Calcium Polysulfide (CaSx)	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Comprehensive and permanent contaminant reduction. - Eliminates mass flux leaving the site boundary.	- ISCR with CaSx is effective and permanent as demonstrated by reduced Cr^{+6} concentrations in groundwater and an established reducing environment in the subsurface, which persisted through the end of the monitoring period (one year) in a successful pilot test (Table 3-3). - Moderate-term monitoring	- Short-term temporary infrastructure required. - Can be integrated with redevelopment.	- Implementable - Effectiveness has been demonstrated by a successful pilot test and ongoing performance monitoring for IRM Phase II. - If alternative is constructed on properties not owned by PPG, access agreements will be necessary.	Medium-High	- Already accepted for IRM Phase I and II. - Permanence of the remediation will be monitored.	15	ISCR with CaSx is an effective source zone remedy, as demonstrated in past pilot testing.
Alternative 6 Score	1	2	2	3	2	4	1		
Alternative 7: ISCR with FerroBlack®-H	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Comprehensive and permanent contaminant reduction. - Eliminates mass flux leaving the site boundary.	- ISCR with FerroBlack®-H is effective and permanent as demonstrated by reduced Cr^{+6} concentrations in groundwater and an established reducing environment in the subsurface, which persisted through the end of the monitoring period (one year) in a successful pilot test (Table 3-3). Long-term effectiveness has also been demonstrated through use of this reagent as a backfill amendment during soil remediation. - Moderate-term monitoring	- Can be integrated with redevelopment.	- Implementable, as demonstrated by a successful pilot test. - If alternative is constructed on properties not owned by PPG, access agreements will be necessary.	Medium	- Likely acceptable. - Permanence of the remediation will be monitored.	15	ISCR with FerroBlack®-H is recommended as a source zone treatment technology, either as a standalone option, or in combination with a pump and treat remedy for site-wide coverage.
Alternative 7 Score	1	2	2	3	2	3	2		
Alternative 8: Hydraulic Fracturing for ISCR	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Facilitates reagent placement in low permeability units. - Fracturing is a delivery method, therefore this remedy must be combined with ISAB or ISCR to achieve remedial goal and objectives.	-There is limited data on the success of hydraulic fracturing for treatment of mass in low permeability units. Successful implementation of hydraulic fracturing may vary based on heterogeneities and in-situ stresses of the formation.	- Short-term temporary infrastructure required. - Can be integrated with redevelopment.	- Successful implementation of hydraulic fracturing may vary based on heterogeneities and in-situ stresses of the formation. The pilot test demonstrated that it could be used to emplace reagent in the low permeability unit, but success will vary across the Project Area. - If alternative is constructed on properties not owned by PPG, access agreements will be necessary.	High	- Challenging. - Effectiveness and permanence of the remediation will be monitored.	26	Hydraulic fracturing is not recommended. Heterogeneities in the formation make this technology technically impracticable.
Alternative 8 Score	1	5	4	3	4	5	4		
Alternative 9: Enhanced Attenuation	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Once reagent injections (chemical or biological) are completed, residual reductive capacity in the aquifer will continue to treat COCs. - Continues active treatment after in-situ injections are complete.	- Once reagent injections (chemical or biological) are completed, residual reductive capacity in the aquifer will continue to treat COCs for an estimated 8-10 years.	- No additional infrastructure is required after ISAB or ISCR is complete. - Can be integrated with redevelopment.	- Implementable as demonstrated by successful ISAB and ISCR pilot tests and subsequent performance monitoring. - If components of alternative (e.g., monitoring wells) are constructed on properties not owned by PPG, access agreements will be necessary.	Low (no additional cost after ISCR or ISAB)	- Likely acceptable with ISCR or ISAB. - Permanence of the remediation will be monitored.	10	Enhanced attenuation is an effective remedy after the successful implementation of ISAB or ISCR. Alternative relies on the residual reductive capacity of the aquifer to continue to treat COCs.

Table 5-1
Comparative Analysis of Groundwater Remedial Alternatives
Groundwater Remedial Action Work Plan, Final
Garfield Avenue Group Sites, PPG, Jersey City, New Jersey

AECOM

Alternative	**Comparative Criteria** [1]							**Total Score**	**Application of the Remedial Technology**
	Overall Protection of Human Health and the Environment	Achievement of Remedial Goals and Objectives	Long-Term Effectiveness and Permanence	Short-Term Effectiveness (Compatibility with Redevelopment)	Implementability	Comparative Cost (Low/Medium/High)	Regulatory Acceptance		
Alternative 9 Score	1	2	2	1	1	1	2		
Monitored Natural Attenuation									
Alternative 10: Monitored Natural Attenuation only	- Groundwater is not currently used, nor expected to be used in the future, as potable water; the area is served by municipal water supply system. - Three CEAs will provide notice to future receptors that groundwater is not suitable for potable water. - Groundwater ECs are in place to prevent groundwater from impacting soil remediation areas.	- Once active remedy (i.e., reagent injections (chemical or biological) followed by enhanced attenuation) are completed, natural mechanisms will continue to treat COCs to meet NJDEP GWQS.	- Once active remedy (i.e., ISAB or ISCR, followed by enhanced attenuation) is completed, natural mechanisms will continue to treat COCs to meet NJDEP GWQS in the long term.	- Least amount of infrastructure required. - Can be integrated with redevelopment.	- Implementable, only monitoring is required. - If components of alternative (e.g., monitoring wells) are constructed on properties not owned by PPG, access agreements will be necessary	Low	- Likely acceptable after active remedy implemented. - Need to prove plume is stable and exposure risk is mitigated through robust monitoring program. - Permanence of the remediation will be monitored. - Need to accept a long cleanup timeframe.	13	MNA is a proven effective alternative to achieve the remedial goal and objectives.
Alternative 10 Score	1	2	2	1	1	1	5		

Notes
1. Comparative criteria ranking system is described below.
Scores are assigned from 1 (most favorable) to 5 (least favorable). The lowest overall score is most favorable.

(green)	Most favorable	1
(yellow)		2
(light orange)		3
(orange)		4
(red)	Least favorable	5

Acronyms:
CaSx: calcium polysulfide
CEA: Classification Exception Area
COC: contaminant of concern
Cr^{+6}: hexavalent chromium
EC: engineering control
GWQS: Groundwater Quality Standards
GWTP: groundwater treatment plant
IRM: Interim Remedial Measure
ISAB: in-situ anaerobic bioprecipitation
ISCR: in-situ chemical reduction
MNA: monitored natural attenuation
NJDEP: New Jersey Department of Environmental Protection
PRB: permeable reactive barrier

Table 5-2. Groundwater Remediation Strategy Summary
Groundwater Remedial Action Work Plan, Final
Garfield Avenue Group Sites
PPG, Jersey City, NJ

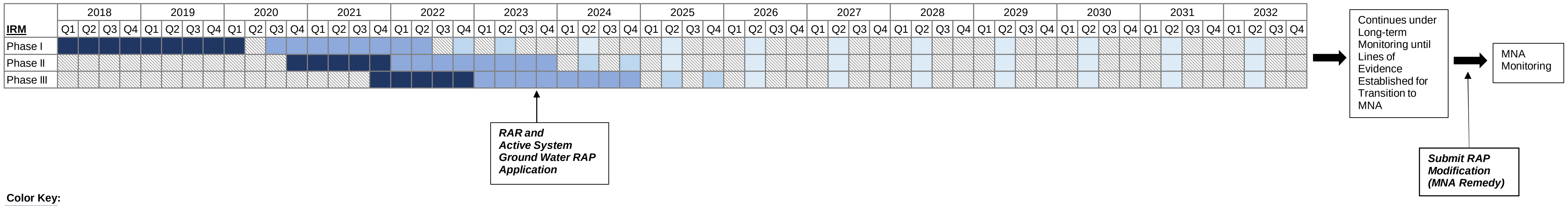
AECOM

Water-Bearing Zone	**Groundwater Remediation Strategy**				
	Active Remedy[1]		**MNA Remedy**	**Contingency Remedy**	**Institutional and Engineering Controls, Maintenance, and Monitoring**
	In-Situ Treatment Goal: Actively treat Cr^{+6} concentrations greater than 1,000 µg/L where practicable Expected Timeframe: 2017 - 2024	**Enhanced Attenuation and Long-Term Monitoring** Goal: Actively treat Cr^{+6} concentrations and other COCs and evaluate lines of evidence for transition to MNA Expected Timeframe: Estimated 8-10 years beyond in-situ treatment[2]	**Monitored Natural Attenuation** Goal: Naturally attenuate residual concentrations of Cr and other COCs Expected Timeframe: or TBD[3]	**During Active Remedy, as necessary** Goal: Contingency remedy to be implemented, if needed, during active remedy or after Active Category RAP-GW issued by NJDEP[4] Expected Timeframe: 2017 - 2062[5], if necessary	**Various (see below)** Goal: Monitor and maintain groundwater engineering controls and Classification Exception Area until groundwater quality standards are achieved Expected Timeframe: 2018 –TBD[3]
Shallow	ISAB (IRM Phase I) ISAB (IRM Phase III – Site 199 only)				Capillary Break FerroBlack®-H-amended Backfill Meadow Mat Classification Exception Area Long-term Groundwater Monitoring
Intermediate	ISAB and/or ISCR (IRM Phases I and II) ISAB, ISCR, FerroBlack®-H Emplacement (IRM Phase III)	ISAB and/or ISCR Enhanced Attenuation	MNA	Localized ISCR, ISAB, FerroBlack®-H Emplacement or Technical Impracticability Determination[6]	Sheet Pile Classification Exception Area Long-term Groundwater Monitoring
Deep	ISAB and/or ISCR (IRM Phases I and II) ISAB and/or ISCR (IRM Phase III) FerroBlack®-H Emplacement (IRM Phase III)[6]				Sheet Pile (where present) Classification Exception Area Long-term Groundwater Monitoring
Bedrock[7]	N/A		MNA	Technical Impracticability Determination	Classification Exception Area Long-Term Groundwater Monitoring

Notes:
[1] = Refer to Figure 3-2 for the horizontal extents of each IRM phase in each water-bearing zone.
[2] = Once ISAB and/or ISCR injections and associated performance monitoring are completed via in-situ active treatment, residual abiotic or reductive capacity in the aquifer will continue to treat COCs under an enhanced attenuation active remedy. The duration of the enhanced attenuation and associated long-term monitoring may be shortened if lines of evidence point to a transition to MNA sooner than the estimated timeframe presented on this table.
[3] = MNA remedy will continue as necessary to reach the groundwater quality standards, thus groundwater institutional and engineering controls will be monitored and maintained during this time period.
[4]= Both during and after active treatment (Parts 1, 2 or 3 of the active treatment remedy as depicted on Figure 5-1), should the lines of evidence indicate that the GWQS for the COCs cannot be achieved in certain areas via the selected active groundwater remedies, either due to the presence of low permeability zones, technology limitations, or limitations with reagent (e.g., molasses, EVO, CaSx, FerroBlack®-H) distribution or groundwater extraction, contingency remedies, such as localized/targeted treatment using ISAB or ISCR, or FerroBlack®-H emplacement will be implemented in applicable areas.
[5] = Estimated timeframe provided; timing will be guided by monitoring data and may be shorter or longer, as appropriate
[6] = FerroBlack®-H emplacement will provide in-situ treatment for targeted areas within the lower portion of the deep water-bearing zone on Site 114.
[7] = Additional groundwater remedial investigation is necessary in the bedrock water-bearing zone in the southwest corner of Site 114 to complete delineation of Cr^{+6} and Cr impacts, thus a final remedial decision for the bedrock water-bearing zone will be determined upon completion of the RI.

Acronyms:
CaSx = calcium polysulfide; COC = contaminant of concern; Cr = chromium (total); Cr^{+6} = chromium (hexavalent); EVO = emulsified vegetable oil; GWQS = Groundwater Quality Standard; IRM = Interim Remedial Measure; ISAB = in-situ anaerobic bioprecipitation; ISCR = in-situ chemical reduction; MNA = monitored natural attenuation; N/A = not applicable; NJDEP = New Jersey Department of Environmental Protection; RAP-GW = Remedial Action Permit - Groundwater; TBD = to be determined;
µg/L = micrograms per liter

Table 7-2. Groundwater Monitoring Plan for Active Remedy
Groundwater Remedial Action Work Plan, Final
Garfield Avenue Group Sites
PPG, Jersey City, New Jersey



Color Key:
- Treatment monitoring (monthly) (Part 1 of active treatment remedy as depicted on Figure 5-1)
- Post-treatment performance monitoring (quarterly) (Part 1 of active treatment remedy as depicted on Figure 5-1)
- Monitoring of enhanced attenuation* (semi-annual) (Part 2 of active treatment remedy as depicted on Figure 5-1)
- Monitoring of enhanced attenuation* (annual) (Part 2 of active treatment remedy as depicted on Figure 5-1)

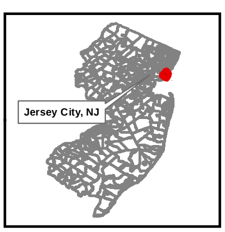
Notes:
1. Analysis for the treatment and post-treatment performance monitoring will be in accordance with the PBR authorizations for each IRM phase.
2. For the post-PBR monitoring program, samples will be analyzed for: Cr^{+6}, and CCPW metals. During the Phase III IRM program, groundwater samples collected from Site 199 will also be analyzed for PCE and its breakdown products (i.e., TCE, cis-1,2-dichloroethene and vinyl chloride).
3. Key geochemical indicators (e.g., sulfates, sulfides, iron, total organic carbon, etc.) and field parameters (pH, ORP, dissolved oxygen, specific conductivity, temperature, and turbidity) will be collected during all sampling events.

* - enhanced attenuation refers to the phase of continued decrease of contaminant concentrations (Cr and Cr^{+6}) through natural processes following active treatment (AECOM, 2016).

Cr^{+6} = hexavalent chromium
CCPW = Chromate Chemical Production Waste
CCPW metals = antimony, chromium, nickel, thallium, and vanadium
IRM = interim remedial measures
MNA = monitored natural attenuation
ORP = oxidation-reduction potential
PBR = permit-by-rule
PCE = tetrachloroethylene
RAP = remedial action permit
RAR = remedial action report
TCE = trichloroethylene

Reference:
AECOM, 2016. *GW-050: Concepts for Groundwater Interim Remedial Measures for the Garfield Avenue Group Sites, Jersey City, New Jersey*. 2 December 2016.

Figures



Notes:
1. New Jersey State Plane North American Datum 1983 Coordinates, U.S. Survey Feet.
2. Image Source: USGS Topographic Quadrangle: Jersey City, NJ, 1967 - Photorevised 1981.
3. Latitude Coordinates: 403730 - 404500; Longitude Coordinates: -740730 - -740000.
4. USGS - United States Geological Survey

AECOM

PPG GARFIELD AVENUE GROUP JERSEY CITY, NEW JERSEY 60550261. GA.GW.RI.RPT.D			FIGURE 1-1 USGS SITE LOCATION MAP
DATE: 3/1/2017	DRAWN BY: JL	CHECKED BY: AS	

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Map Sources:
1. New Jersey State Plane North American Datum 1983 Coordinates (NAD83), U.S. Survey Feet.
2. New Jersey 2017 High Resolution Orthophotography, Web Map Service, http://geodata.state.nj.us/imagerywms/Natural2017?.

LEGEND

- Garfield Avenue Group Boundary
- Off-Site Properties
- Railroad Tracks

N W E S

0 100 200 Feet

AECOM

PPG
GARFIELD AVENUE GROUP
JERSEY CITY, NEW JERSEY
60550261

DATE: 3/26/2021 | DRAWN BY: SR | CHECKED BY: FS

FIGURE 1-2
SITE PLAN

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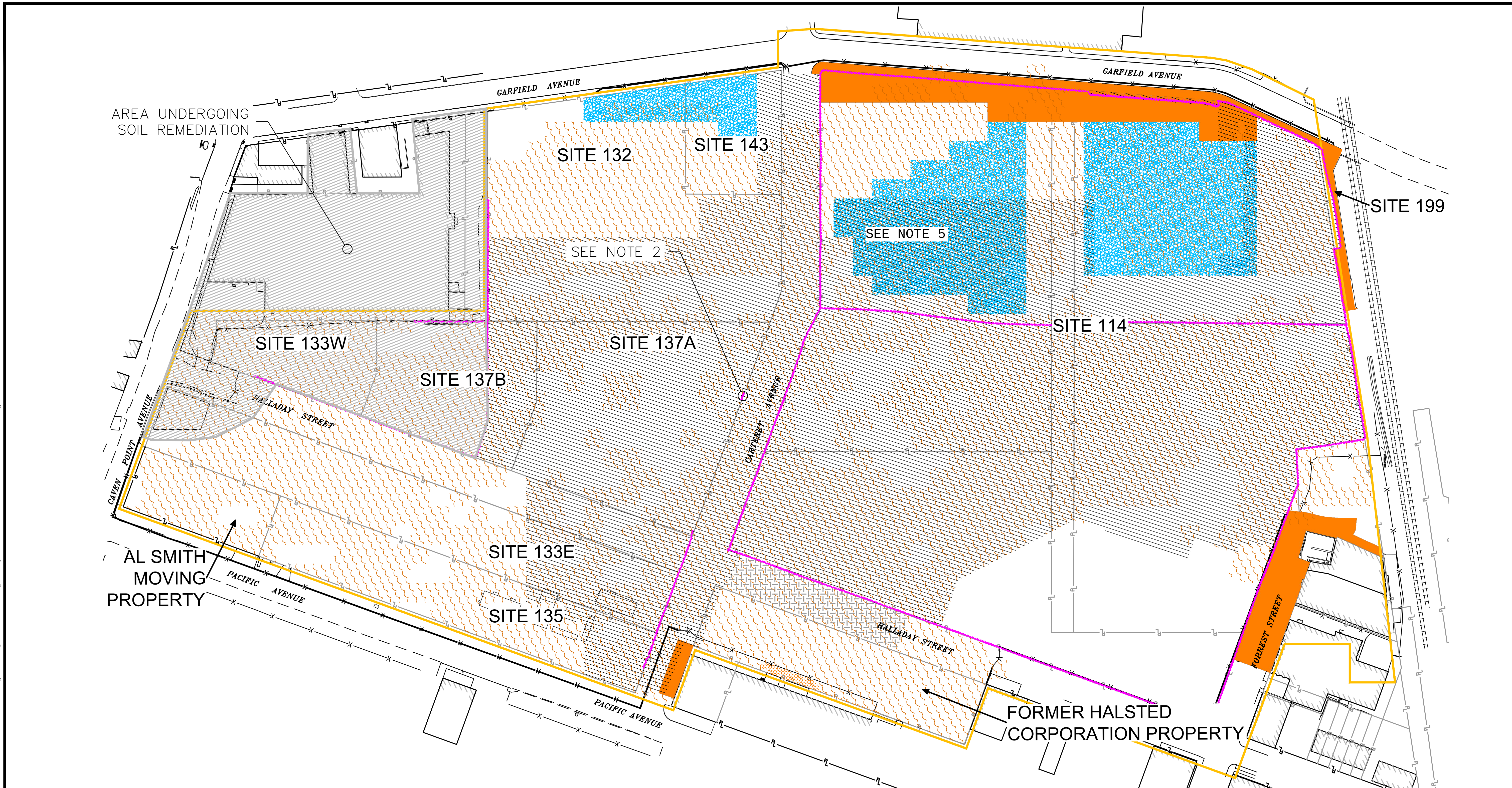


LEGEND

- PROPERTY LINE
- PHASE BOUNDARY
- SHEET PILE
- NEW JERSEY TRANSIT LIGHT RAIL
- EXISTING BUILDING
- CURB
- EXISTING BUILDING FOUNDATION
- LIMIT OF AREA INCLUDED IN EXTENT OF MM ANALYSIS
- COMPETENT MM (>1 FT THICKNESS) - BASED ON BORING LOGS AND VISUAL CONFIRMATION
- EXTENT OF FERROBLACK-H AMENDED BACKFILL PLACED FROM BASE OF EXCAVATION TO ELEVATION 11.0 (FT NAVD88)
- EXTENT OF FERROBLACK-H AMENDED BACKFILL PLACED FROM BASE OF EXCAVATION TO ELEVATION 9.0 (FT NAVD88)
- EXTENT OF OGS CAPILLARY BREAK
- EXTENT OF HDPE CAPILLARY BREAK
- EXTENT OF ASPHALT CAPILLARY BREAK (SEE NOTE 3)

NOTES:

1. GROUNDWATER ENGINEERING CONTROLS SHOWN ON THIS FIGURE ARE REFERENCED FROM THE *CAPILLARY BREAK DESIGN, FINAL REPORT (REVISION 2) ADDENDUM (REVISION 1), FEBRUARY 2021.*
2. THE IDENTIFIED SECTION OF SHEET PILE HAS BEEN LEFT IN PLACE DUE TO AN EXISTING UTILITY CROSSING; THIS SECTION OF SHEET PILE DOES NOT ACT AS AN ENGINEERING CONTROL.
3. ADDITIONAL ASPHALT CAPILLARY BREAK TO BE INSTALLED ON THE FORMER HALSTED PROPERTY, FINAL EXTENTS OF THE ASPHALT CAPILLARY BREAK WILL BE PROVIDED IN THE HALSTED REMEDIAL ACTION REPORT.
4. THE EXTENTS OF THE ENGINEERING CONTROLS DEPICTED ON THIS FIGURE ARE CURRENT AS OF AUGUST 2021.
5. PPG WILL CONTINUE TO MONITOR GROUNDWATER CONDITIONS IN SHALLOW MONITORING WELL 114-P1B-MW102S. SHOULD GROUNDWATER ANALYTICAL DATA FOR TOTAL CHROMIUM INDICATE THAT A CAPILLARY BREAK IS NO LONGER REQUIRED (BASED ON TWO CONSECUTIVE ROUNDS OF SAMPLE COLLECTION), PPG WILL PROCEED TO REMOVE THE CAPILLARY BREAK IN THIS AREA.

COMPETENT MM	-	INDICATES MM PRESENT AT A MINIMUM THICKNESS OF 1 FOOT
HDPE	-	HIGH-DENSITY POLYETHYLENE
MM	-	MEADOW MAT
NAVD88	-	NORTH AMERICAN VERTICAL DATUM 1988
OGS	-	OPEN GRADE STONE

AECOM

75 0 150
GRAPHIC SCALE IN FEET

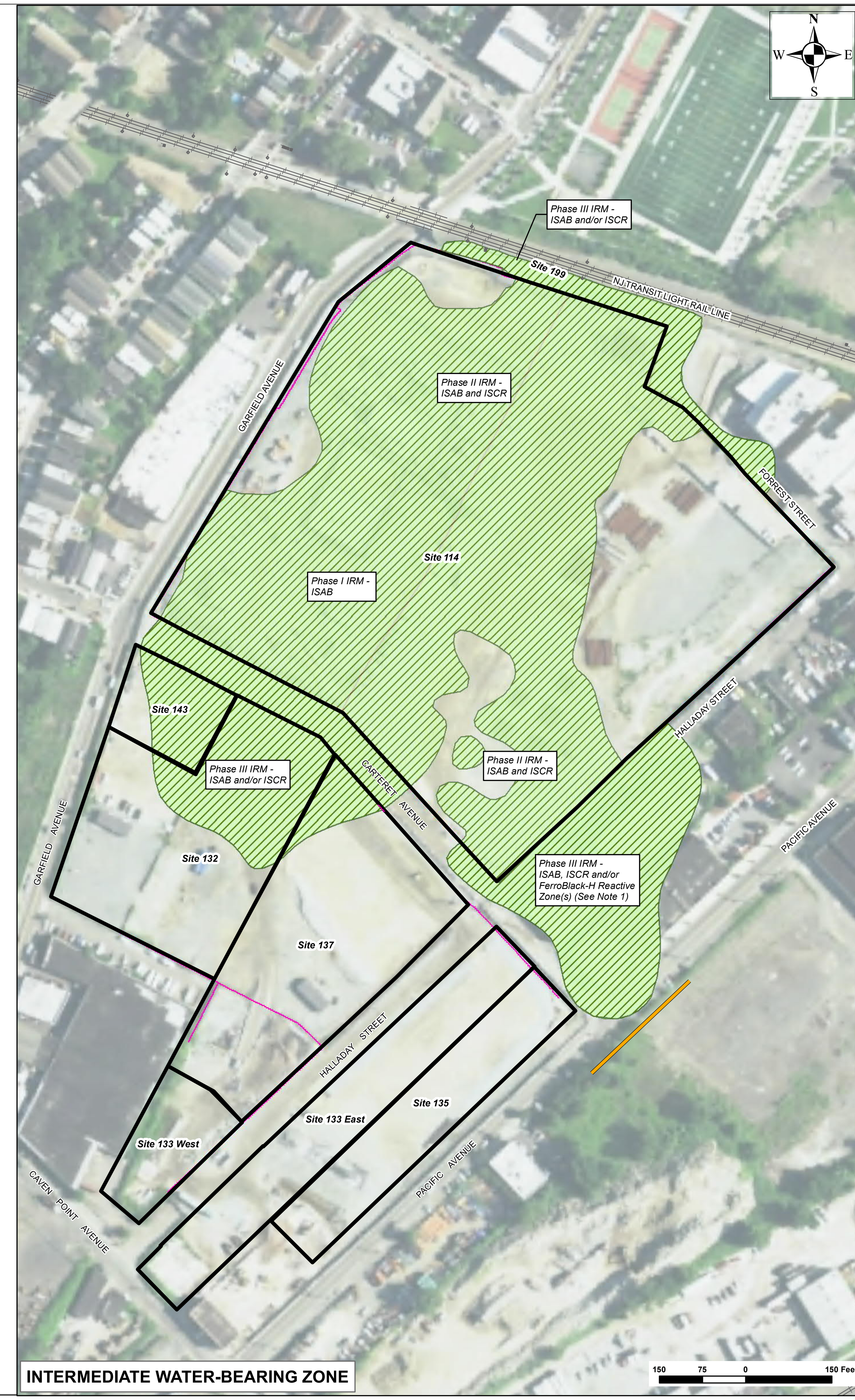
PPG
GARFIELD AVENUE GROUP SITES
JERSEY CITY, NEW JERSEY

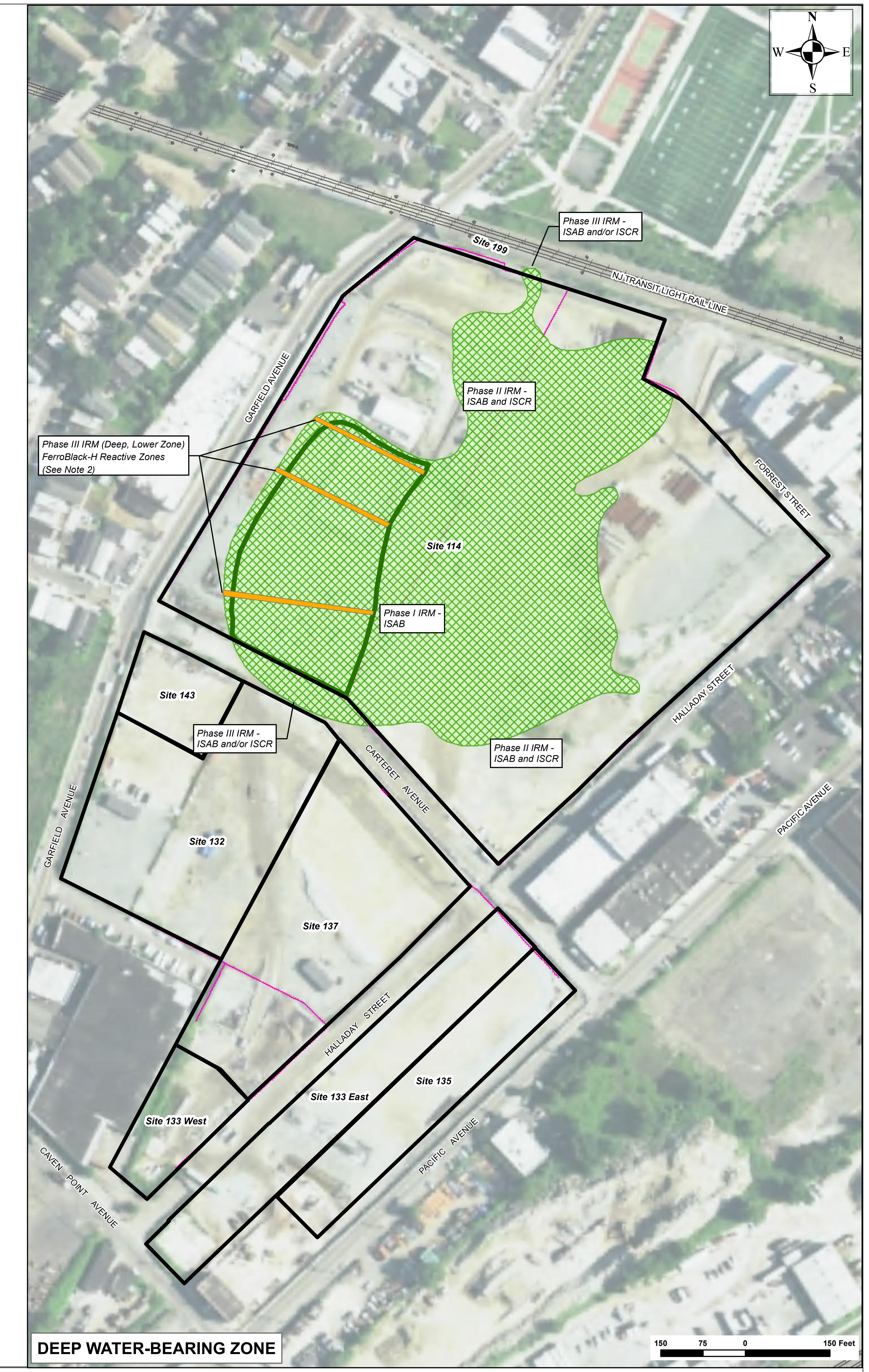
DATE: 10/27/2021 DRWN: JJA

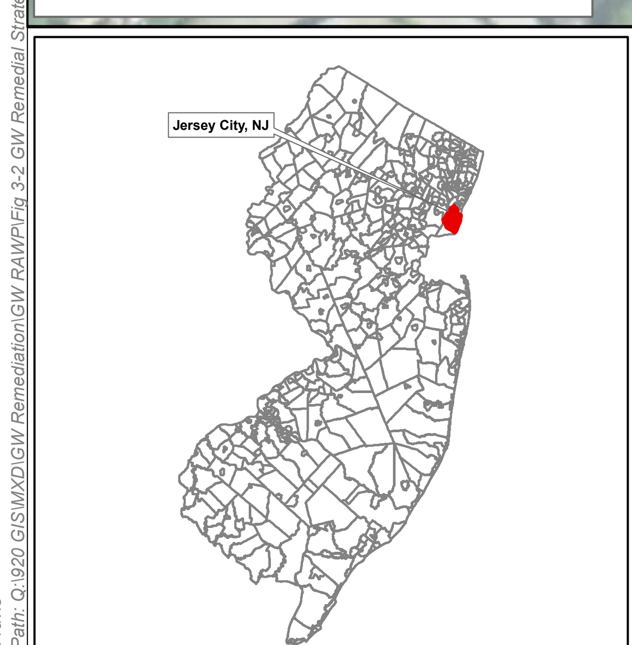
GROUNDWATER ENGINEERING CONTROLS AS-BUILT CONDITIONS

FIGURE 3-1

File: Q:\20 SHEETS\GW\GW Engineering Controls\2021-10-25_GW Engineering Controls.dwg Layout: FIGURE 3-1 User: John.Angelone Plotted: Oct 27, 2021 - 9:46am Xref's:







LEGEND

- GARFIELD AVENUE GROUP BOUNDARY
- RAILROAD TRACKS
- IN-PLACE SHEETPILE
- SHALLOW ZONE TREATMENT AREAS (ISAB)
- INTERMEDIATE ZONE TREATMENT AREAS (ISAB, ISCR AND/OR FERROBLACK-H REACTIVE ZONES)
- DEEP ZONE TREATMENT AREAS (ISAB AND/OR ISCR)
- PHASE III IRM - DEEP, LOWER (FERROBLACK-H REACTIVE ZONES) - SELECT LOCATIONS
- APPROXIMATE LOCATIONS OF FERROBLACK-H REACTIVE ZONES

Notes:

1. The treatment extents for the Phase III IRM and locations of reactive zones depicted on this map are approximate and will be finalized upon completion of as-built surveys. Additionally, placement of remediation wells are not depicted on this figure and will be finalized based on an evaluation of various factors such as presence of utilities, access to private properties, etc.
2. FerroBlack-H reactive zones on Site 114 will provide *in situ* treatment for targeted areas within the lower portion of the deep water-bearing zone on Site 114 that were not targeted under the Phase I IRM.
3. New Jersey State Plane North American Datum 1983 Coordinates (NAD83), U.S. Survey Feet.
4. New Jersey 2017 High Resolution Orthophotography, Web Map Service, http://geodata.state.nj.us/imagerywms/Natural2017?.

IRM = interim remedial measures
ISAB = in-situ anaerobic bioprecipitation
ISCR = in-situ chemical reduction

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GARFIELD AVENUE GROUP
JERSEY CITY, NEW JERSEY
60631459

DATE: 10/26/21 | DRAWN BY: SR | CHECKED BY: FS

FIGURE 3-2
GROUNDWATER REMEDIATION STRATEGY
ACTIVE *IN SITU* REMEDIATION

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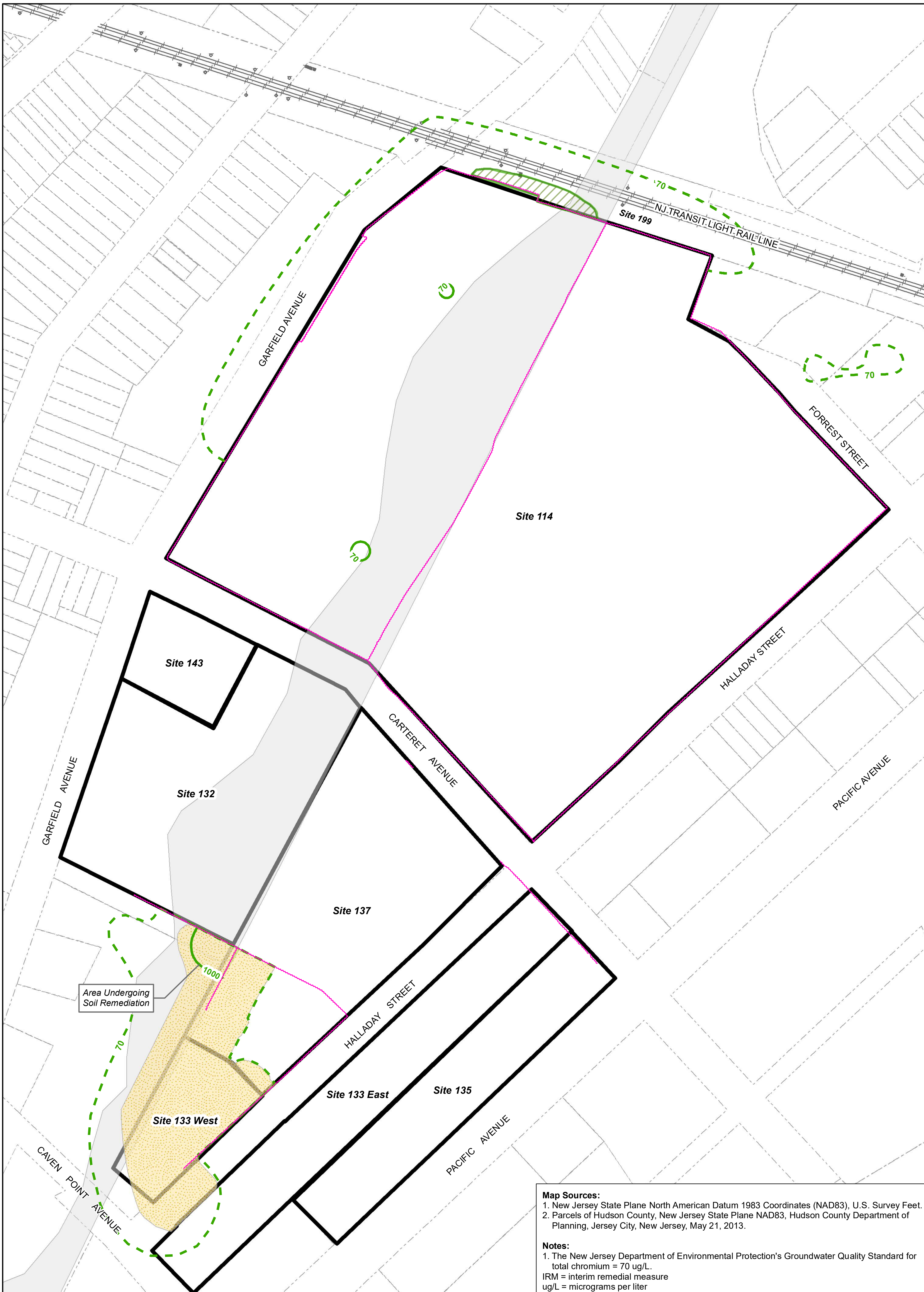
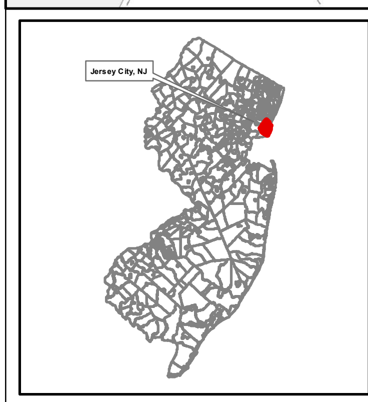


Map Sources:
1. New Jersey State Plane North American Datum 1983 Coordinates (NAD83), U.S. Survey Feet.
2. Parcels of Hudson County, New Jersey State Plane NAD83, Hudson County Department of Planning, Jersey City, New Jersey, May 21, 2013.

Notes:
1. The New Jersey Department of Environmental Protection's Groundwater Quality Standard for total chromium = 70 ug/L.

IRM = interim remedial measure
ug/L = micrograms per liter



LEGEND

- GARFIELD AVENUE GROUP SITES
- HUDSON COUNTY PARCELS
- FORMER MORRIS CANAL
- RAILROAD TRACKS
- IN-PLACE SHEET PILE
- AREA WITH RESIDUAL SOURCE MATERIAL, PLANNED FOR SOIL REMEDIATION
- TOTAL CHROMIUM IN THE SHALLOW WATER-BEARING ZONE GREATER THAN 70 ug/L (DASHED WHERE INFERRED)
- ACTIVE REMEDIATION TARGET AREA FOR GROUNDWATER IN THE SHALLOW WATER-BEARING ZONE
- AREAS BEING ADDRESSED VIA ACTIVE *IN SITU* TREATMENT (IRMs)

N W E S

0 75 150 Feet

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PPG
GARFIELD AVENUE GROUP
JERSEY CITY, NEW JERSEY
60631459

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FIGURE 4-1
TARGET ACTIVE REMEDIATION AREAS IN THE SHALLOW WATER-BEARING ZONE

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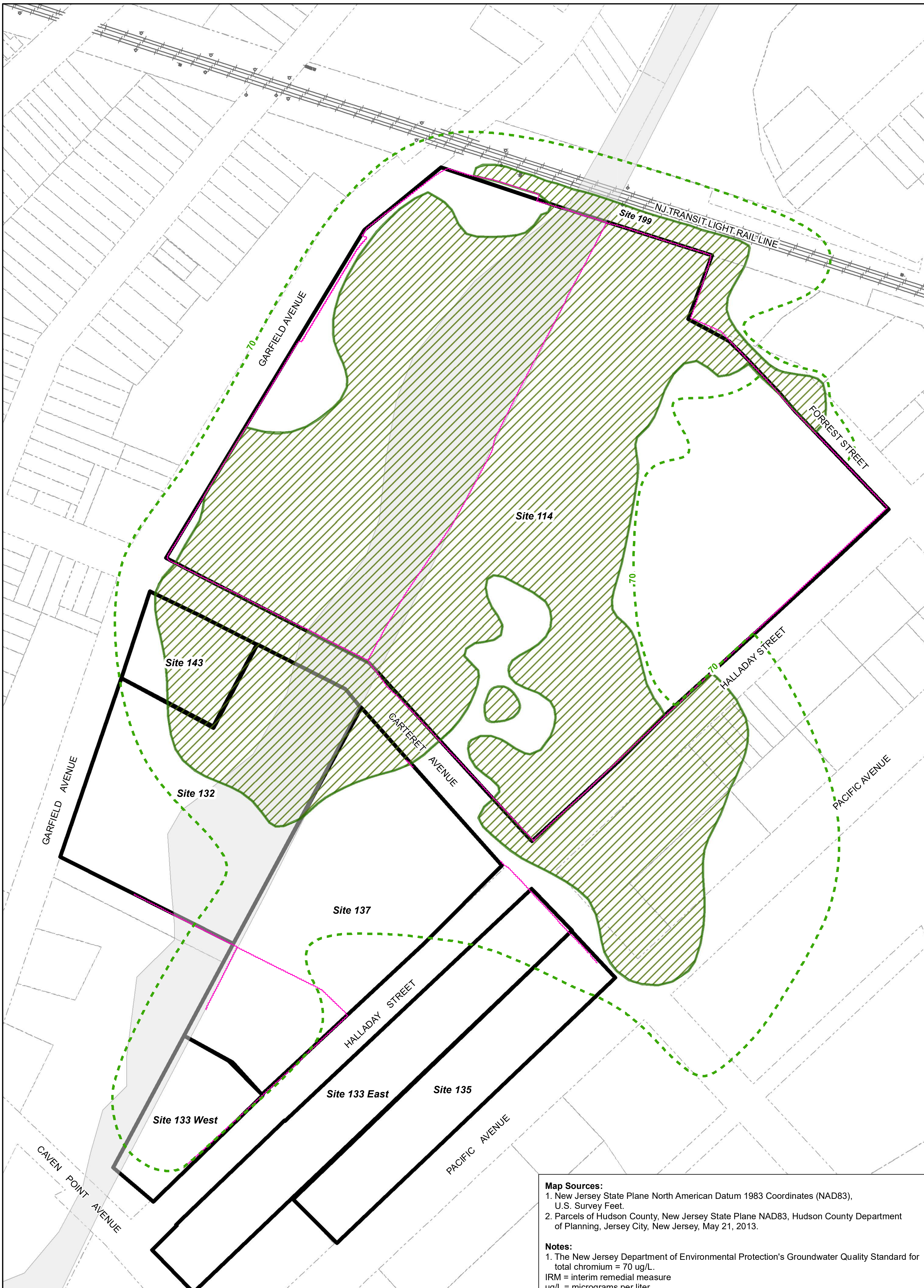
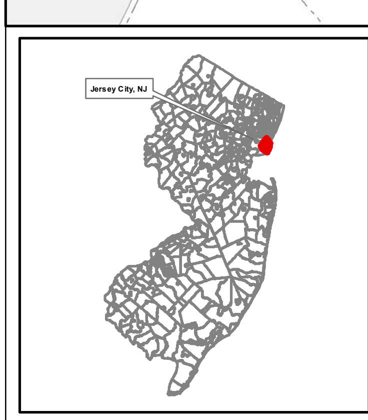
Document Path: Q:\1920 GIS\MXD\GW Remediation\GW RAWP\Fig 4-1 Target Treatment Area_Shallow.mxd





LEGEND

- GARFIELD AVENUE GROUP SITES
- HUDSON COUNTY PARCELS
- FORMER MORRIS CANAL
- RAILROAD TRACKS
- IN-PLACE SHEET PILE
- TOTAL CHROMIUM IN THE INTERMEDIATE WATER-BEARING ZONE GREATER THAN 70 ug/L (DASHED WHERE INFERRED)
- ACTIVE REMEDIATION TARGET AREA FOR GROUNDWATER IN THE INTERMEDIATE WATER-BEARING ZONE
- AREAS BEING ADDRESSED VIA ACTIVE *IN SITU* TREATMENT (IRMs)

N E S W

0 75 150 Feet

AECOM

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FIGURE 4-2
TARGET ACTIVE REMEDIATION AREAS IN THE INTERMEDIATE WATER-BEARING ZONE

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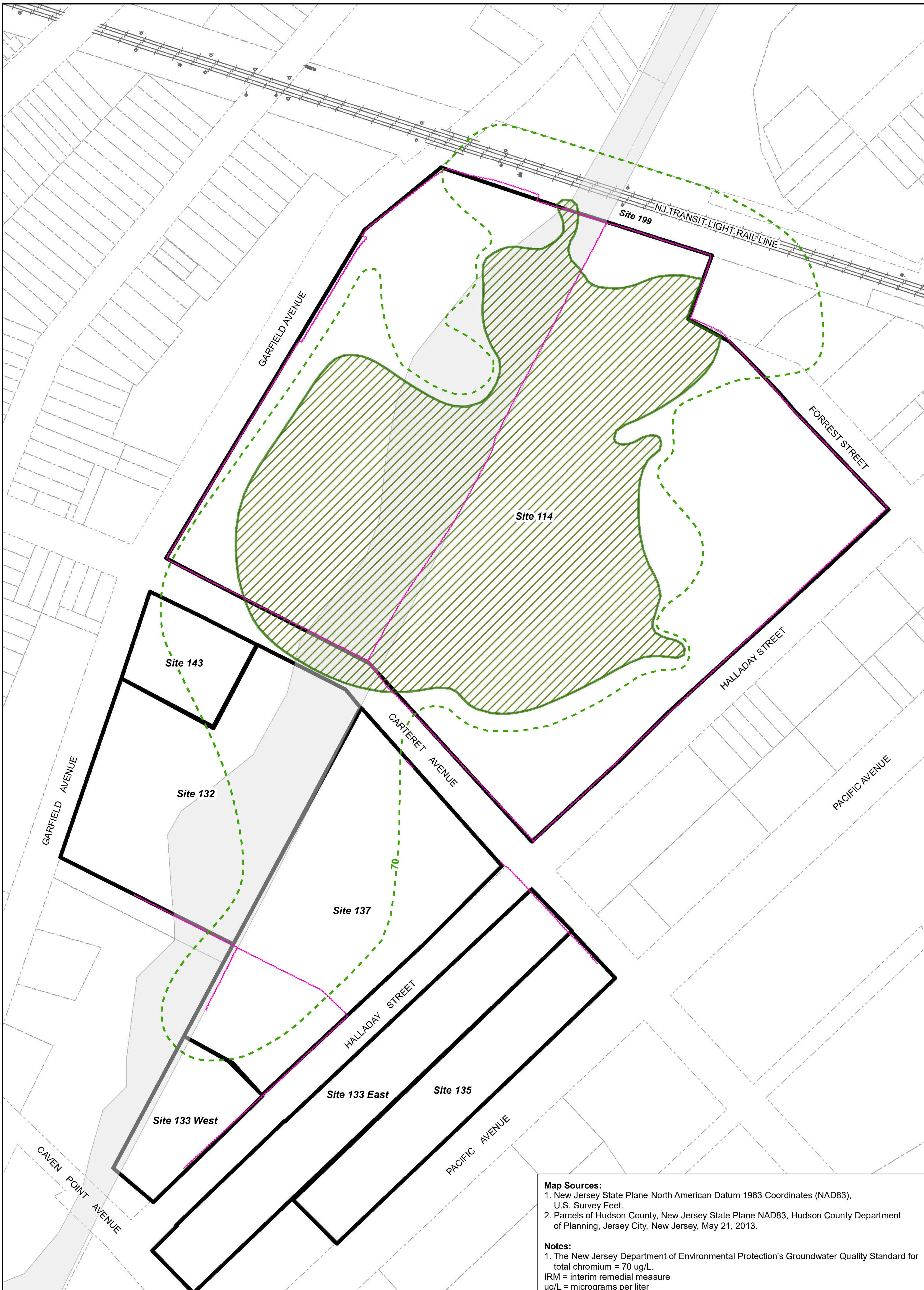
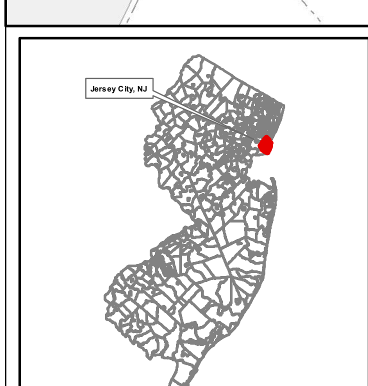


Map Sources:
1. New Jersey State Plane North American Datum 1983 Coordinates (NAD83), U.S. Survey Feet.
2. Parcels of Hudson County, New Jersey State Plane NAD83, Hudson County Department of Planning, Jersey City, New Jersey, May 21, 2013.

Notes:
1. The New Jersey Department of Environmental Protection's Groundwater Quality Standard for total chromium = 70 ug/L.

IRM = interim remedial measure
ug/L = micrograms per liter



LEGEND

- GARFIELD AVENUE GROUP SITES
- HUDSON COUNTY PARCELS
- FORMER MORRIS CANAL
- RAILROAD TRACKS
- IN-PLACE SHEET PILE
- TOTAL CHROMIUM IN THE DEEP WATER-BEARING ZONE GREATER THAN 70 ug/L (DASHED WHERE INFERRED)
- ACTIVE REMEDIATION TARGET AREA FOR GROUNDWATER IN THE DEEP WATER-BEARING ZONE
- AREAS BEING ADDRESSED VIA ACTIVE *IN SITU* TREATMENT (IRMs)

N S E W

0 75 150 Feet

AECOM

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FIGURE 4-3
TARGET ACTIVE REMEDIATION AREAS IN THE DEEP WATER-BEARING ZONE

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Figure 5-1. Groundwater Remediation Strategy

Groundwater Remedial Action Work Plan, Final

Garfield Avenue Group Sites, PPG, Jersey City, New Jersey

Groundwater Institutional and Engineering Controls

Groundwater Institutional and Engineering Controls – 2013 - 2021

(2013 to 2021)

- Classification Exception Area(s)
- FerroBlack®-H Amended Backfill
- Capillary Break
- Sheet Pile
- Competent Meadow Mat

Active Treatment

Part 1 of Active Treatment Remedy – 2017 to 2024
Phase I, II and III Interim Remedial Measures (IRMs)
(per NJDEP Permit-by-Rule [PBR] Authorizations)

(2017 to 2023)

- Targets in-situ treatment of treatable zones of Cr^{+6} within the Cr 1,000 ppb isopleth
- In-situ Anaerobic Biodegradation (ISAB) and In-situ Chemical Reduction (ISCR) via Phase I, II and III IRMs
- Robust Area-Wide Groundwater Monitoring and Reporting per PBRs

(2023)

Submit Remedial Action Report
and submit request for Active Category Remedial Action Permit, including
Area-wide Monitoring Network for Parts 2 and 3 of Active Remedy

(2024)

- Robust Area-Wide Groundwater Monitoring and Reporting per PBRs (continues)
- Closeout of PBRs

Remedial Action Report approval
Active Category Remedial Action Permit issued

Part 2 of Active Treatment Remedy – 2024 to (estimated) 2032*
Enhanced Attenuation (i.e., post-PBR period)

(2024 to 2032)

- Continued In-situ Treatment via ISAB/ISCR induced by the IRMs – "Enhanced Attenuation"
- Groundwater monitoring to demonstrate ISAB and ISCR ongoing
- Reporting as per NJDEP Guidance
- At completion of ISAB and ISCR treatment, transition to long-term groundwater monitoring

Part 3 of Active Treatment Remedy – (estimated) 2032* to (estimated) TBD*
Long-Term Groundwater Monitoring

(2032 to TBD)

- Long term groundwater monitoring and reporting per NJDEP guidance
- Remedy continues under Active Category Remedial Action Permit until transition to Monitored Natural Attenuation Category Remedial Action Permit is suitable

Monitored Natural Attenuation Treatment

(TBD to 2062)

- Continue long term groundwater monitoring and reporting per NJDEP guidance under Monitored Natural Attenuation Remedial Action Permit

* *Estimated timeframe provided; timing will be guided by monitoring data and may be shorter or longer, as appropriate*