State of New Jersey
Department of Environmental Protection

2024 NEW JERSEY STATEWIDE WATER SUPPLY PLAN

APPENDIX C

WATER MANAGEMENT OPTIONS: CONFINED AQUIFERS OF THE NEW JERSEY COASTAL PLAIN

Appendix C:

Water Management Options: Confined Aquifers of the New Jersey Coastal Plain

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NEW JERSEY COASTAL PLAIN CONFINED AQUIFER SYSTEM

NORTH JERSEY DISTRICT WATER SUPPLY COMMISSION

The confined aquifers of the New Jersey Coastal Plain are a major water supply source for New Jersey. DEP estimates that about 3.4 million people live in the Coastal Plain and rely on water provided by a public community system, while around 550,000 get their water from private, domestic wells. Confined aquifers supply 48% of the withdrawals made by those systems in the Coastal Plain, along with 27% from unconfined aquifers, and 25% from surface water. Groundwater withdrawals from the region's 10 confined aquifers totaled approximately 160 million gallons a day (mgd) in 2020. The future availability of water from the New Jersey Coastal Plain confined aquifers is constrained by several factors, including:

- Water Supply Critical Area 1 and 2 regulations and any future revisions to those regulations;
- water level instability within the aquifers;
- water level interference with other users;
- potential surface water and wetlands impacts in aquifer outcrop areas; and
- saltwater intrusion threats to seaward and bayward margins of the aquifers.

Increased use of the confined aquifers over the past few decades has resulted in a progressive decline in water levels in some areas and saltwater intrusion in other areas. Impacts from this progressive decline include the development of large cones of depression (cone-shaped water-level surfaces that point downward) centered around pumping wells, and a reversal in natural hydraulic gradients. The decreased pressure of fresh water can no longer resist the intrusion of denser salt water, which results in an induced incursion of brackish/saline waters from adjacent aquifer and surface water bodies (Gordon, Carleton, & Rosman, 2021). Sea level rise also increases the risk of saltwater intrusion, but this is a much more gradual process. Several locations have areas with compromised confined aquifers due to saltwater intrusion such as Raritan Bay, the New Jersey Pine Barrens of Gloucester County, Cape May County, and the Delaware River Valley.

Hydrogeologic analysis of the New Jersey Coastal Plain's confined aquifer systems has shown the highly interconnected nature of the individual aquifers and their connection to the water-table systems. Water withdrawn from most Coastal Plain confined aquifers comes principally from an overlying or underlying confined aquifer(s) and/or the water table system. The interconnected nature of water flow within the Coastal Plain emphasizes the need for a comprehensive examination of the Coastal Plain confined aquifer system from a regional water supply planning perspective and an assessment of potential additional sources of water supply. Existing regional water-resource examinations and analyses conducted as part of this Plan update have revealed that only limited supplies are available in confined aquifers without violating current regulatory restrictions or creating the risk of unsustainable water extraction. Several factors may influence where additional supplies may be available, such as potential water-table system impacts, tolerance for suppressed water-level elevations, and potential changes in water quality.

Based on the findings of regional studies and associated water demand projections, many of the State's confined aquifers are either approaching, have approached, or exceeded sustainable levels of use. Diminishing water levels, increased recharge from vulnerable water-table aquifers, and increased chloride and sodium concentrations have generated concern with relying on confined aquifers for future supplies. Desalination has been proposed as a helpful tool to increase future water supplies while addressing increased saltwater intrusion, and several regional studies have discussed the need for desalination as a water supply option (for more information, see Lacombe, Carleton, Pope, & Rice, 2009; Spitz, 1996). The State's first saltwater desalination well in Cape May City was installed in the late 1990's and has helped to decrease water withdrawals from the semi-confined Cohansey Aquifer.

Managed Aquifer Recharge (MAR) has also been proposed as a way to use confined aquifers as storage reservoirs to provide additional water to meet peak demands. MAR involves injecting water from other sources, such as other aquifers, treated surface water, or even treated wastewater, into aquifers to increase short-term supply availability while avoiding long-term confined aquifer impacts. Current challenges that limit MAR's viability as a water supply solution include the mechanics of well constructure, development, extraction, and the contrasting geochemistry of water sources and its effect on well screens.

The present discussion of the characteristics, status and trends, and potential availability of water from the various confined aquifers of the New Jersey Coastal Plain is organized into four regions:

1. Atlantic Coastal Region;
2. Cape May Peninsula;
3. Water Supply Critical Area 1; and
4. Water Supply Critical Area 2 and the Delaware Bay Region.

Note that while the confined aquifers were categorized based on larger pumping regions, several of them are geographically located in multiple regions (and aquifer discussion considers impacts to each impacted region).

ATLANTIC COASTAL REGION – AVAILABLE WATER SUPPLY FROM CONFINED AQUIFERS

Confined aquifers are the primary water supply source along the Atlantic Coast and are heavily relied upon among communities along the barrier island complex that borders the Atlantic Ocean. The primary confined aquifer water supply source for these communities is the Atlantic City 800-foot Sand Aquifer. However, minor supply is also provided by the Piney Point Aquifer.

ATLANTIC CITY 800-FOOT SAND AQUIFER

The Atlantic City 800-foot Sand Aquifer is considered a major confined aquifer in the Kirkwood Formation. The Atlantic City 800-foot Sand Aquifer is considered the primary confined aquifer supplying water to New Jersey's barrier island communities in southern Ocean County to Cape May City, but also supplies water as far inland as Egg Harbor City (Gordon et al., 2021; DePaul & Rosman, 2015; DePaul, Rosman, & Lacombe, 2009). The aquifer's updip limit extends from southern Ocean County to eastern Cumberland County. The updip limit is based on the updip limit of the overlying confined unit, but this unit is poorly defined in places. The downdip limit is offshore of Ocean, Atlantic, and Cape May counties (Gordon et al., 2021; DePaul & Rosman, 2015). The aquifer has been found to thicken downdip and to the south, from approximately 40ft at Barnegat Light to over 200ft at Cape May City in Cape May County (Zapecza, 1989).

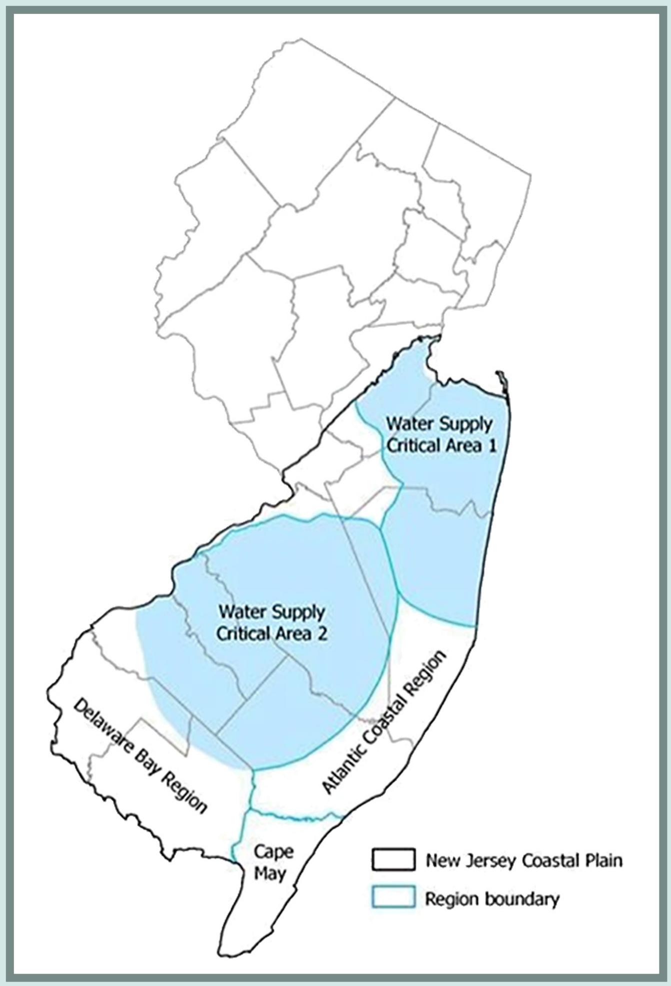

Figure C1. Water Supply Critical Areas and Major Aquifer Regions of New Jersey

The Atlantic City 800-foot Sand Aquifer has been found to receive and lose water from several different sources. Major sources of water input into the aquifer include lateral flow from offshore, lateral flow from the updip, flow from the overlying aquifer, and lateral flow from the 250 mg/L isochlor line, while the major source of water loss is from withdrawals from pumping wells (USGS, forthcoming). Recharge to the aquifer can occur from vertical flow from the overlying Kirkwood-Cohansey aquifer system and Rio Grande Water-bearing Zone or by lateral flow from the Kirkwood Cohansey aquifer system (Gordon et al., 2021).

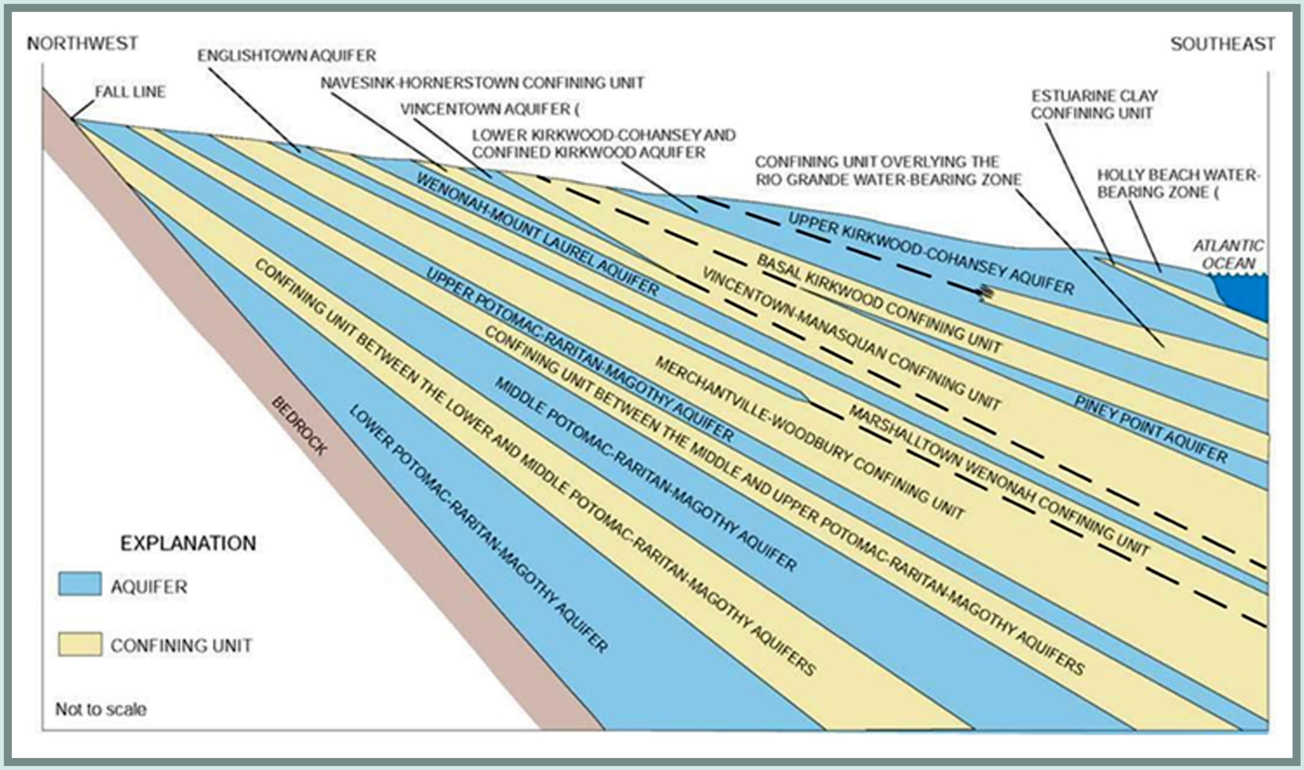

Figure C1. Generalized Cross Section of New Jersey's Coastal Plain Aquifer System (from Charles et al., 2011)

The Atlantic City 800-foot Sand Aquifer presents several significant challenges to future water supply considerations. Hydrogeologic studies have revealed that increased use will cause a continuation of ground-water level decline. As of 2013, USGS estimated the total withdrawals from the Atlantic City 800-foot Sand Aquifer were 23.8 mgd, indicating a slight decline over a 10-year period. Three major pumping centers are located along Atlantic County's barrier islands: Absecon Island, Brigantine, and Pleasantville (Gordon et al., 2021; DePaul et al., 2009). According to the most recent water-level data collected by USGS (2018 data), a large cone of depression extends beneath the coastal barrier island communities from Barnegat Light in Ocean County to Cape May City. Three small cones are also present in southern Cape May County around pumped wells for Cape May City, Wildwood City WD, Rio Grande wellfield (WCWD), and Avalon (USGS, forthcoming). All of the identified cones of depression have been identified in previous USGS studies (Gordon et al., 2021; DePaul & Rosman, 2015; DePaul et al., 2009).

USGS comparisons of aquifer well water levels between 2013 and 2018 found water levels slightly recovered in the aquifer, with water levels staying the same in Cape May City. Aquifer water level decline between 2013 and 2018 was found around several WCWD production wells. However, recovery was found in several locations including Avalon, the southern end of Long Beach Island, and low water level areas in Ventnor City, Margate City, and Longport Borough (USGS, forthcoming).

A USGS examination of different 2040 water demand scenarios for the Atlantic City 800-foot Sand Aquifer found future withdrawals could result in a mixture of decline and recovery or widespread decline, depending on the future intensity of withdrawals. Areas projected as likely to experience water level decline in the future include areas around both Hamilton Township and New Jersey American wells (USGS, forthcoming).

Increased water use from the Atlantic City 800-foot Sand Aquifer also presents the increased risk of saltwater intrusion, especially in areas in the southwest. The Atlantic City 800-foot Sand Aquifer contains freshwater throughout southern Ocean,

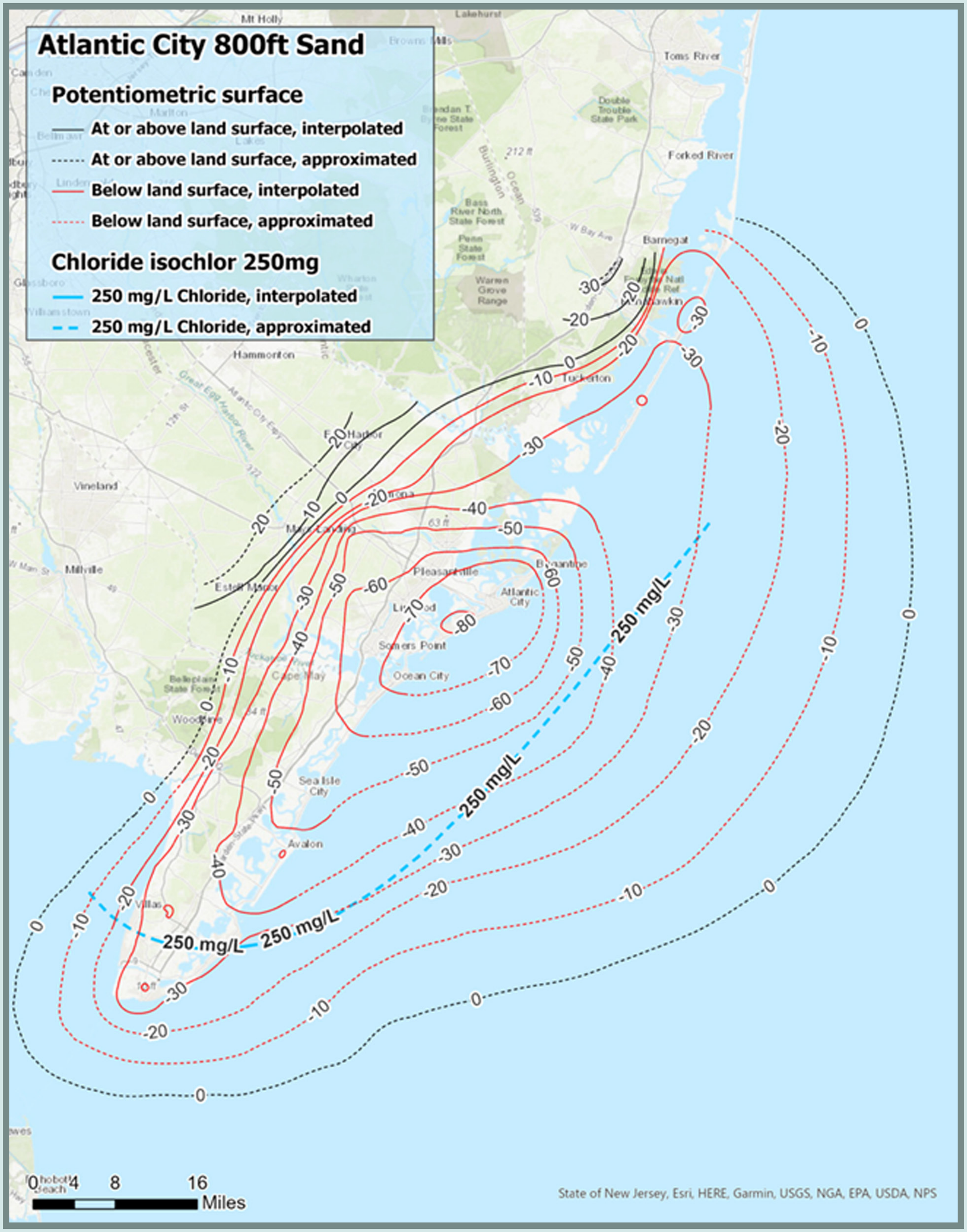

Figure C3. 250 mg/L isochlor line and potentiometric surface for Atlantic City 800-foot Sand Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published (Gordon et al., 2021; Charles, 2016). The two aforementioned references apply to all following figures.

Atlantic, and northern Cape May counties, but has been found to become more chloride-rich south of Avalon (DePaul & Rosman, 2015). Due to the regional extent of the aquifer, significant withdrawals from the aquifer in Atlantic County may result in significant water level decline in Cape May County, and vice-versa. Many municipalities in Cape May also rely on this aquifer for water supply. Therefore, the presence of a saltwater front (250 mg/L isochlor line) approximately two miles to the south-southeast of Stone Harbor Borough is a concern being closely monitored (Gordon et al., 2021).

PINEY POINT AQUIFER

The Piney Point Aquifer is considered a minor confined aquifer in the Coastal Plain. Most groundwater withdrawals from the Piney Point Aquifer are from coastal Ocean County, Buena Borough (located in western Atlantic County), and around Bridgeton City (Cumberland County) (Gordon et al., 2021). Development of the Piney Point Aquifer in Cumberland's Bridgeton was partially in response to water quality issues in the overlying Kirkwood-Cohansey Aquifer (DePaul & Rosman, 2015; DePaul et al., 2009). The aquifer's updip limit is generally 40ft thick and is located in Ocean, Burlington, Camden, Gloucester, and Salem counties, and is near the Vincentown Aquifer's downdip limit (Gordon et al., 2021; DePaul et al., 2009). Aquifer thickness varies, with the most thickness exceeding more than 200ft in southwestern Cumberland County and over 130ft in Burlington and Ocean counties. In the southwest Coastal Plain, aquifer thickness has been found to increase southward and downdip from the northwest limit of the aquifer (Zapecza, 1989).

The Piney Point Aquifer receives and loses water from several different sources. As the aquifer has no surface expression, it relies entirely on leakage from overlying and underlying aquifers. Major sources of water flow out of the aquifer include withdrawals from pumping wells and flow to the underlying aquifer (USGS, forthcoming). There is also potential for flow from the Piney Point Aquifer to the overlying aquifers. The onshore part of the 250 mg/L isochlor line is estimated to occur from eastern Atlantic County to northern Cape May County (Gordon et al., 2021; DePaul & Rosman, 2015). This line is estimated to be more than 15 miles downdip from Buena's production center (DePaul et al., 2009).

As of 2013, Piney Point Aquifer withdrawals were approximately 5.2 mgd, which reflects a slight increase over a 10-year period. Most withdrawals from the aquifer occur in Ocean County (Gordon et al., 2021). According to the most recent water-level data collected by USGS (2018 data), several cones of depression were found, which include: (a) one underlying Seaside Park in Ocean County close to where the aquifer is most utilized in New Jersey; (b) a deep cone of depression centered in south of Bridgeton City, Cumberland County; and (c) a smaller cone of depression centered in Buena Borough (USGS, forthcoming). These cones of depression have also been found in previous USGS studies (Gordon et al., 2021; DePaul & Rosman, 2015).

USGS comparisons of aquifer well levels between 2013 and 2018 found the cones of depression in Bridgeton City and Buena Borough deepened. Sizable decline was also found in wells nearby Berkeley Township MUA. However, recovery was found in several wells in Seaside Park Borough and Seaside Heights Borough and a well located north of a center of depression centered in Barnegat Light (USGS, forthcoming).

The Piney Point Aquifer provides sufficient yield for public supply in its northeastern extent (west Atlantic, Ocean, and Burlington counties) and may continue to serve as a viable source of moderate quantities of water in its northern extent as either a replacement or alternative supply source. However, the southwest extent of the aquifer appears limited in potential for additional major water supplies due to its limited extent and rapid decline in water levels in reaction to pumping. This has been confirmed based on recent water level decline around Bridgeton City wells following the development of the aquifer in Bridgeton City in 2003 (Gordon et al., 2021). This was also found based on USGS comparisons of different 2040 water demand scenarios, which projected future water level decline in Gloucester, Cumberland, Camden, and Salem counties, and decline around Bridgeton City wells (USGS, forthcoming). In addition, the aquifer is completely confined, which suggests that water withdrawals will come at the expense of storage in overlying and underlying aquifers.

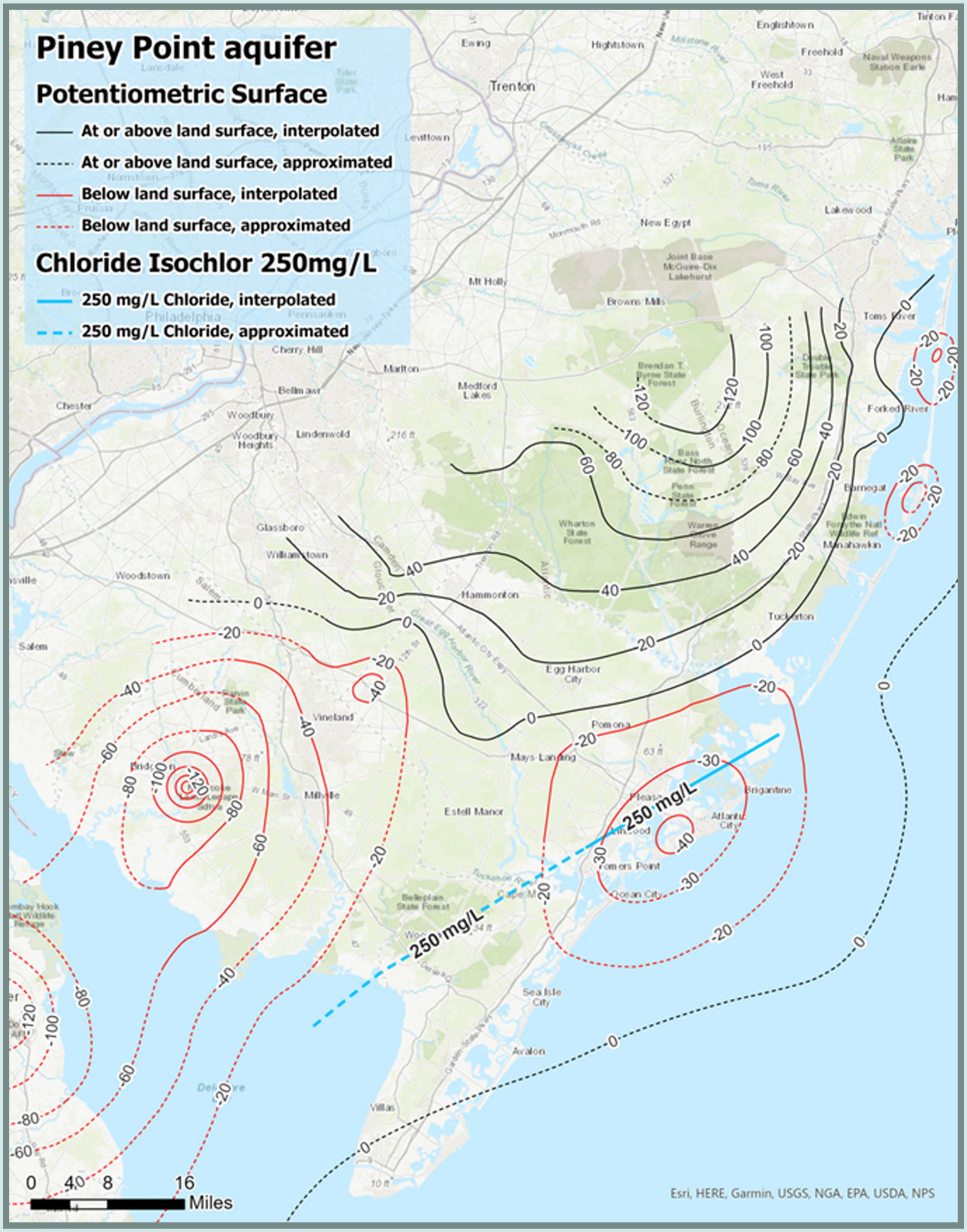

Figure C4. 250 mg/L isochlor line and potentiometric surface for Piney Point Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.

CAPE MAY PENINSULA – AVAILABLE WATER SUPPLY FROM ALL AQUIFERS

Cape May County is a peninsula that is surrounded by saltwater. It is likely its freshwater aquifers are exposed to saltwater under the Delaware Bay. Withdrawals from the semi-confined Cohansey Aquifer and the Atlantic City 800-foot Sand Aquifer have lowered water levels, increasing the saltwater intrusion inland. As a result, supply wells in the southern part of the peninsula, such as Wildwood, Cape May City, and Lower Township have been abandoned due to saltwater intrusion. With the establishment of a desalination plant in 1998, Cape May City Water Department has reduced its withdrawals from its confined Cohansey Aquifer wells by treating brackish water withdrawn from the Atlantic City 800-foot Sand Aquifer (DePaul & Rosman, 2015). While both the semi-confined Cohansey Aquifer and the Atlantic City 800-foot Sand Aquifer provide the majority of water supply for the Cape May Peninsula, minimal supply is also provided by the Rio Grande Water-bearing Zone in the Wildwood/Belleplain confining unit. As the Atlantic City 800-foot Sand Aquifer was previously discussed in the Atlantic Coastal Section, water supply issues surrounding both the semi-confined Cohansey Aquifer and the Rio Grande Water-bearing Zone will be discussed below.

SEMI-CONFINED COHANSEY AQUIFER

The semi-confined Cohansey Aquifer in Cape May County is considered the youngest and uppermost aquifer of the confined aquifers in the New Jersey Coastal Plain. Having a confinement limit located in northern Cape May County, groundwater is typically withdrawn in the southern peninsula in Middle and Lower townships (DePaul & Rosman, 2015; Gordon et al., 2021). The aquifer's updip limit is located in northern Cape May County and Delaware Bay, and the downdip limit is located in Cape May County east of the Atlantic Ocean shoreline (Lacombe & Rosman, 2001). While the Atlantic City 800-foot Sand Aquifer has been considered as an alternative to help meet Cape May's water supply demands, a 2007 USGS study found that increased withdrawals from the 800-foot sand aquifer would result in significant water level decline in both Cape May and Atlantic counties, regardless of where the wells were located.

Water quality data for the semi-confined Cohansey Aquifer suggests that Cape May County has exceeded sustainable withdrawal levels, highlighting the need to maintain aquifer water levels to reduce the risk of further saltwater intrusion. Although the Cohansey aquifer contains freshwater in most of mainland Cape May County, saltwater has been found in southern parts of the peninsula. Locations where saltwater has been detected include back bays and barrier islands north of Wildwood, parts of the west coast of the peninsula, and beneath near-shore and offshore areas of Delaware Bay and the Atlantic Ocean. The 250 mg/L isochlor line is estimated to be near Villas, Cape May County (Gordon et al., 2021; DePaul & Rosman, 2015).

Withdrawals from the semi-confined Cohansey Aquifer were estimated at 3.3 mgd in 2013, which declined over a 10-year period. The largest users were wells near Rio Grande, followed by wells in Lower Township (both for public supply) (Gordon et al., 2021). However, other significant sources of water withdrawal from the aquifer include Wildwood Water Utility and Lower Township Municipal Utilities Authority (MUA) (Lacombe & Rosman, 2001; Lacombe & Rosman, 1997). A comparison of aquifer well water levels between 2013 and 2018 found that aquifer water levels remained stable, with most wells having small to moderate net water level changes (5ft or less) (USGS, forthcoming). According to the most recent water-level data collected by USGS (2018 data), a long-term cone of depression is located beneath major withdrawal areas in the southern part of the peninsula, including Lower Township, Cape May City Borough, and parts of southern Middle Township (USGS, forthcoming; Gordon et al., 2021; DePaul & Rosman, 2015; DePaul et al., 2009). USGS examination of potential water supply alternatives for the Cape May peninsula found that all alternatives resulted in additional saltwater intrusion, unless they include injection of reclaimed, treated wastewater. Generally, wells located along the 'spine' or central region of Cape May peninsula have the best long-term sustainability.

Figure C5. 250 mg/L isochlor line and potentiometric surface for the Cohansey Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.

RIO GRANDE WATER-BEARING ZONE

The Rio Grande Water-bearing Zone is described as a thin confined aquifer that is located midway in the confining bed overlying the Atlantic City 800-foot Sand Aquifer (Zapecza, 1989). Considered of minor importance as a potable water source in New Jersey, the aquifer is the least utilized of the 10 Coastal Plain confined aquifers, being primarily used in southern Cape May County. The aquifer is thickest in southern Cape May County (can be greater than 100ft), while it is usually less than 40ft thick in coastal southern Ocean and Atlantic counties (Gordon et al., 2021; DePaul & Rosman, 2015; Zapecza, 1989). The updip extent of the aquifer approximately coincides with the extent of the Atlantic City 800-foot Sand Aquifer, extending from southern Ocean County through eastern Cumberland County (Gordon et al., 2021; DePaul & Rosman, 2015). Water levels in the Rio Grande Water-bearing Zone have also been found to coincide with water levels in the underlying Atlantic City 800-foot Sand Aquifer (Lacombe & Rosman, 2001).

The aquifer's fresh groundwater is located under mainland coastal regions and barrier islands spanning from southern Ocean County to most of mainland Cape May County. However, interaction with saltwater is likely, as saline water is located in southern Cape May County and likely under near shore areas, barrier islands, and back bays from Avalon to Cape May City. As of 2015, the 10,000 mg/L isochlor line was not determined for this aquifer, but may be located near the isochlor line for the Atlantic City 800-foot Sand Aquifer (DePaul & Rosman, 2015; DePaul et al., 2009).

While suitable for meeting limited localized water demands in Cape May County, the Rio Grande Water-bearing Zone is not considered a viable water supply alternative due to its limitations in thickness and its high transmissivity with the underlying Atlantic City 800-foot Sand Aquifer. As of 2013, the Rio Grande Water-bearing Zone withdrawals were approximately 0.5 mgd, which is a slight decline over a 10-year period. The most significant withdrawals were by purveyors in Long Beach and Little Egg Harbor Township (southern Ocean County), and in Middle Township (Cape May County) (Gordon et al., 2021). According to the most recent water-level data collected by USGS (2018 data), a cone of depression is centered beneath coastal New Jersey and extends from the Cape May peninsula northward past Ship Bottom in southern Ocean County. This cone is consistent with the water level decline found in a cone of depression in the underlying Atlantic City 800-foot Sand Aquifer. A newly developed cone of depression was also found in the center of the Cape May peninsula around Wildwood City Water Department (WCWD) Rio Grande wellfield in southern Middle Township. Well water levels located around the WCWD were found to decline between 2013-2018. However, slight recovery was found among wells located in northern Cape May, Atlantic, and Ocean counties. USGS examination of different 2040 water demand scenarios projected some water level decline for most areas of the water-bearing zone, especially around Little Egg Harbor Township wells (USGS, forthcoming).

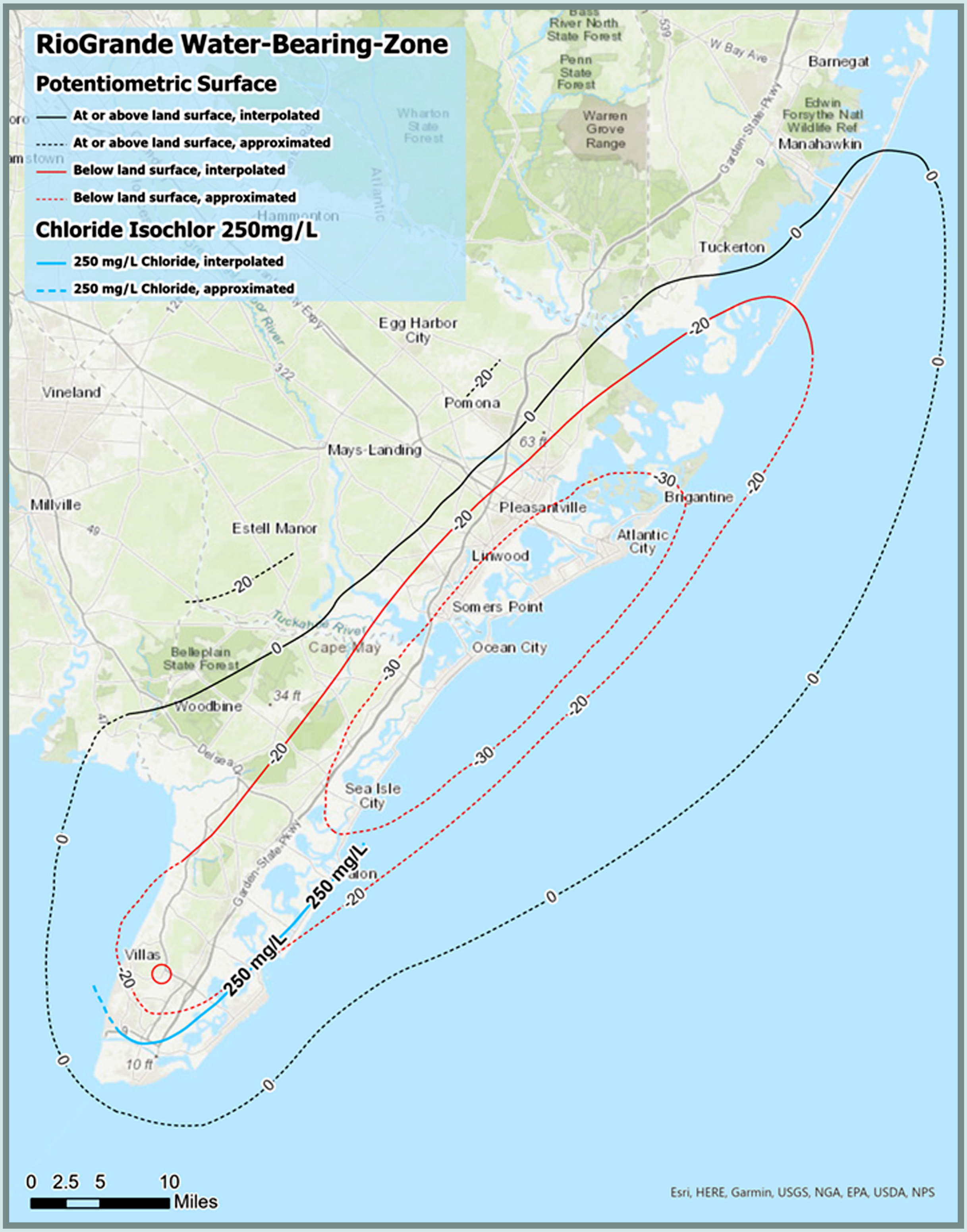

Figure C6. 250 mg/L isochlor line and potentiometric surface for Rio Grande Water-bearing Zone from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.

WATER SUPPLY CRITICAL AREA 1 – AVAILABLE WATER SUPPLY FROM CONFINED AQUIFERS

The State declared two areas of "critical waters supply concern" in the New Jersey Coastal Plain during the 1980's and 1990's in response to regional progressive water-level declines and saltwater intrusion within the confined aquifers. Designated as Water Supply Critical Areas 1 and 2, reductions in use and imposed restrictions on future use were mandated by the State and surface water options were offered as alternatives to replace ground-water supply. Critical Area 1 was established in 1989, but due to lack of access to alternative water supplies, compliance by most purveyors was delayed until 1991 (Gordon et al., 2021). Water Supply Critical Area regulations allow for the assessment of progress for each Critical Area's management plan and the opportunity for the plan to be restructured after 10 years.

Re-examination of Critical Area 1 began in 2001 which involved USGS modeling efforts, evaluation of ground-water level trends, and an assessment of the availability of water supply alternatives. Based on the findings, it was concluded that a small amount of additional groundwater may be available from Critical Area 1's confined aquifers at optimal locations, the water-supply alternatives identified in the 1996 New Jersey Statewide Water Supply Plan would continue to be endorsed, and additional water may be available to meet seasonal needs through use of MAR and redistribution of annual pumping schemes (Spitz, Watt, & DePaul, 2008). Examples of efforts to decrease confined aquifer withdrawals in Critical Area 1 include increased use of surface-water withdrawals (from sources such as the Manasquan Reservoir, which began operation in 1990), and withdrawals from shallower, unconfined aquifers (Gordon et al., 2021; DePaul et al., 2009).

The area between the boundaries of Water Supply Critical Areas 1 and 2 (includes Mercer, north Burlington, southwest Middlesex, and west Monmouth counties), may also be subject to confined aquifer withdrawal constraints. Since this area is located near the outcrop area for several confined aquifers, the level of concern over withdrawal impacts is higher since the interaction between surface water and water-table aquifers may be more direct. Constraints are determined based on if the drawdown impacts from these locations extend into the Critical Area and if the withdrawals impact surface water sources, other users, and known contaminated sites.

The aquifers regulated in Critical Area 1 include: Wenonah-Mount Laurel Aquifer, Englishtown Aquifer System, and the Upper and Middle and Undifferentiated PRM Aquifers (Gordon et al., 2021). The primary confined aquifers in Critical Area 1 used for water supply include the Middle and Undifferentiated Potomac-Raritan-Magothy (PRM) Aquifer, the Englishtown Aquifer, the Wenonah-Mount Laurel Aquifer (see Critical Area 2), and the Vincentown Aquifer, which will be discussed below.

MIDDLE AND UNDIFFERENTIATED PRM AQUIFER

The Middle and Undifferentiated PRM Aquifer extends from the Raritan Bay to Maryland in the southwest. Locally referred to as the Farrington Aquifer, the aquifer is considered well defined from its outcrop area to approximately 20 miles downdip. Beyond this distance, the aquifer cannot be distinguished from underlying sediments. In southern New Jersey, the aquifer can be traced from the outcrop subsurface to approximately 10-12 miles downdip, where it becomes indistinguishable from the Lower PRM Aquifer. In locations where the confining unit is absent, the Middle PRM overlies bedrock or weathered bedrock (Gordon et al., 2021; DePaul & Rosman, 2015; Zapecza, 1989). Although the majority of withdrawals occur in Burlington, Middlesex, Mercer, and Ocean counties, the aquifer's thickness has been found to vary between less than 50ft near its outcrop to over 150ft near the junction of Middlesex, Mercer, and Monmouth counties (Gordon et al., 2021; Rosman, Lacombe, & Storck, 1995; Zapecza, 1989). USGS has found the overall water levels within the Middle PRM Aquifer to be either stable or increasing in the cones of depression located in Critical Areas 1 and 2 (Gordon et al., 2021; DePaul & Rosman, 2015).

As of 2013, total groundwater withdrawals from the aquifer were estimated at 58.7 mgd, which has declined over a 10-year period. Primary pumping centers in the northern end of the aquifer include southern Mercer, western Middlesex, eastern Monmouth, and northern Ocean counties. In the South, primary pumping centers are located in north Burlington, Camden, and Gloucester counties, and portions of Salem County (Gordon et al., 2021; DePaul & Rosman, 2015). According to the most recent water-level data collected by USGS (2018 data), a long-term regional cone of depression is located in the center of Critical Area 2 along with a second cone of depression that includes Critical Area 1 (most of southeast Monmouth and north Ocean counties). Within the cone of depression in Critical Area 2, two smaller cones are starting to develop in Westhampton Township and New Hanover Township. Between 2013 and 2018, the center of the cone of depression in Critical Area 2 was

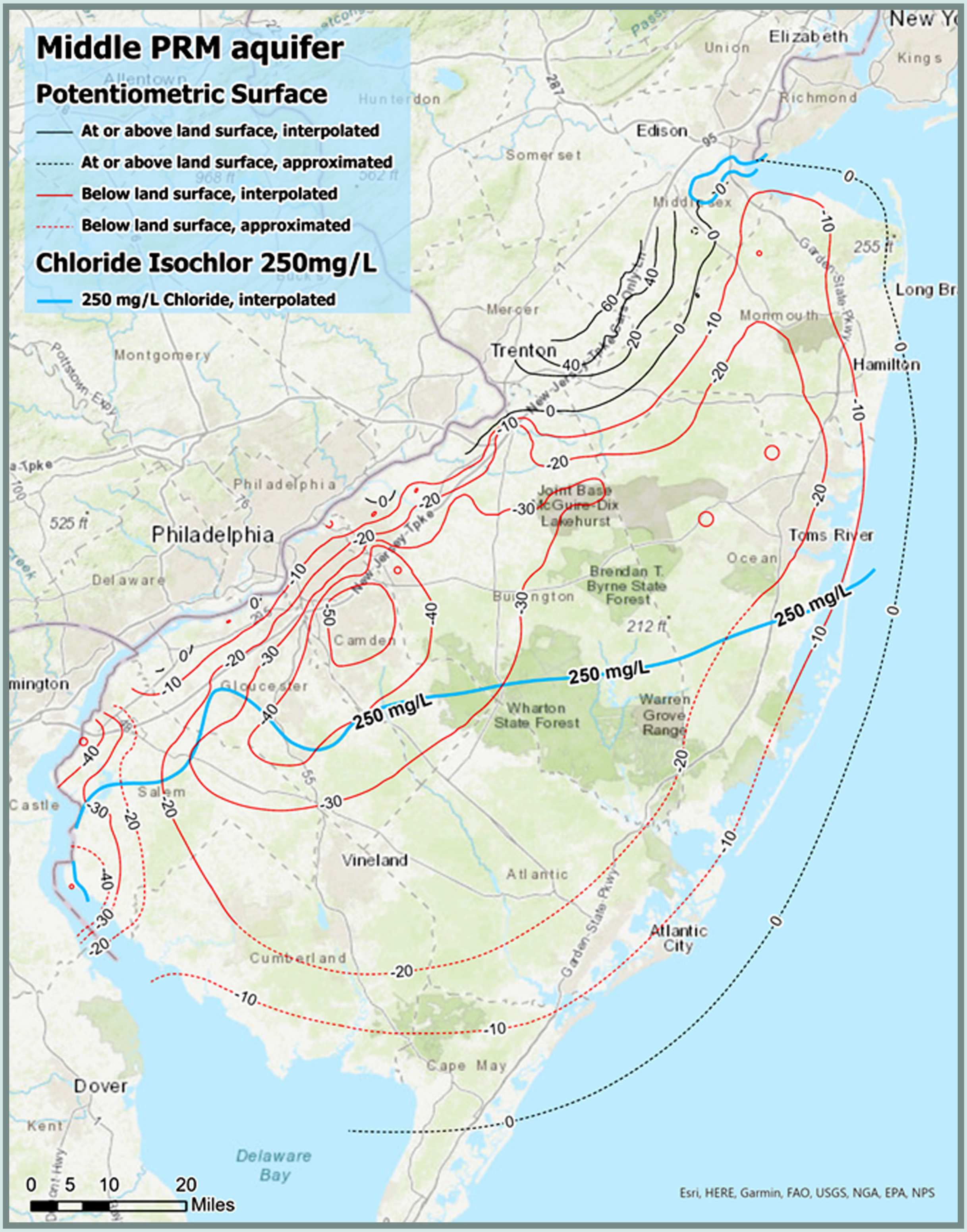

Figure C7. 250 mg/L isochlor line and potentiometric surface for Middle PRM Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.

found to deepen and migrate north from Gibbsboro to Cherry Hill, while the center of the regional cone of depression in Critical Area 1 was found to deepen and migrate from Lakewood to Brick Township (USGS, forthcoming).

The potential for additional water supply from this aquifer is very limited and localized without risking a reversal of the water level recovery that has occurred due to Water Supply Critical Area 1 regulations. USGS comparisons of different 2040 water demand scenarios found that several locations are projected to experience water level decline including areas around Jackson Township MUA wells, Salem and Hope Creek Generation Station in Lower Alloways Creek Township, NJAW Pennsgrove and Chambers Works wells in Carney's Point and Pennsville townships, and Aqua New Jersey Central Hamilton Township (Mercer County) (USGS, forthcoming).

ENGLISHTOWN AQUIFER SYSTEM

The Englishtown Aquifer System is capable of providing significant water supply in the northeast Coastal Plain, but is less productive in the Delaware Bay Region and Critical Area 2 due to its naturally occurring limits. The aquifer yields a large amount of water for both Monmouth and Ocean counties, which are located where the formation is sandy and thick (Gordon et al., 2021; DePaul & Rosman, 2015). The aquifer system thins in outcrop and in the subsurface in a southwest direction, in which the aquifer is commonly less than 40ft thick in parts of Burlington, Camden, Gloucester, and Salem counties (Zapecza, 1989). In Ocean County, the distance between the outcrop and downdip boundary is approximately 34 miles, but in southern Salem County, the lateral extent of the confined aquifer is approximately 12 miles (Gordon et al., 2021; DePaul & Rosman, 2015; DePaul et al., 2009). The Merchantville-Woodbury confining unit is located under the Englishtown Aquifer, which is considered the most extensive confining unit in New Jersey's Coastal Plain (DePaul & Rosman, 2015).

In 2013, total withdrawals from the Englishtown Aquifer System were estimated at 7.9 mgd, which is a slight decline over a 10-year period. Most withdrawals from the aquifer were made in Monmouth, central Camden, north Ocean, and north-central Burlington counties (Gordon et al., 2021). According to the most recent water-level data collected by USGS (2018 data), a large cone of depression is located in southeast Monmouth County and northwest Ocean County (which approximately follows the extent of Critical Area 1 for the Englishtown Aquifer) and a smaller cone of depression is located within the larger cone in Lakewood Township, Ocean County (USGS, forthcoming). Both cones of depression have been documented in previous USGS studies (Gordon et al., 2021; DePaul & Rosman, 2015; DePaul et al., 2009; Lacombe & Rosman, 2001). The larger cone is considered similar to the cone of the overlying Wenonah-Mount Laurel Aquifer, which showed some water level decline in this area between 2008 and 2013. This suggests a good hydraulic connection between the two aquifers via vertical leakance through the Marshalltown-Wenonah confining unit (Gordon et al., 2021).

USGS comparisons of aquifer well water levels between 2013 and 2018 found overall recovery of the aquifer throughout the State, but the most significant recovery in Critical Area 1. This recovery may potentially be due to the downward flow from the overlying Wenonah-Mount Laurel Aquifer. Some decline was found in Laurel Spring Borough (Camden County), but recovery was found in many areas including Upper Freehold Township (Monmouth County), Point Pleasant Borough (Ocean County), and wells located south from Burlington County to Camden, Gloucester, and Salem counties. However, USGS examination of different 2040 water demand scenarios found several locations where water level decline was projected, including around NJAW wells in Lakewood Township and Bay Head Borough, and around Freehold WD and Greenbriar at Marlboro wells (USGS, forthcoming).

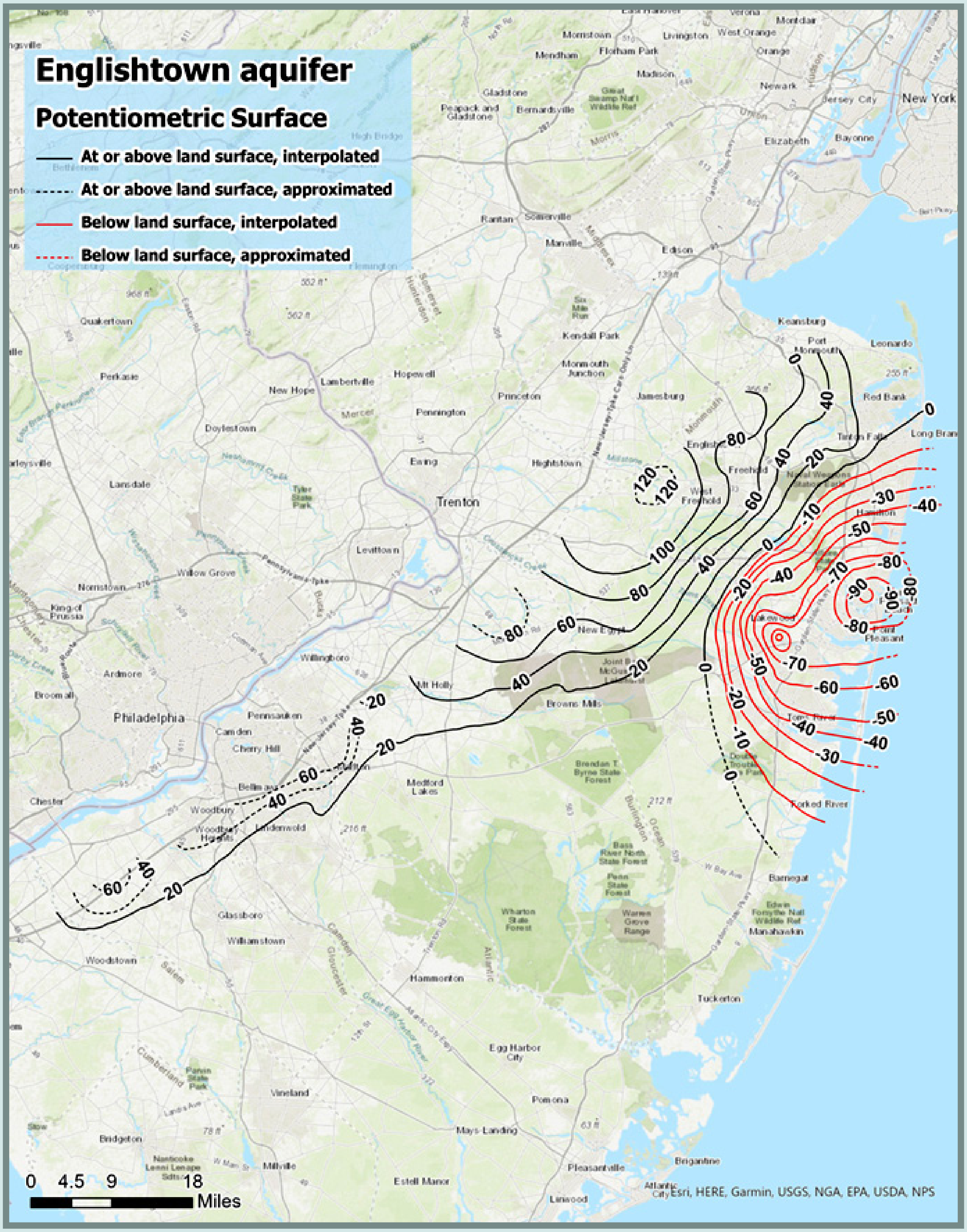

Figure C8. Potentiometric surface for Englishtown Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.

VINCENTOWN AQUIFER

The Vincentown Aquifer is not considered a significant source of water in southwest or south-central New Jersey due to its geographic extent and instantaneous yield. The aquifer beyond Monmouth and Ocean counties is silty and can only locally produce appreciable quantities of water (Gordon et al., 2021). The aquifer's extent can be traced in the sub-surface from Monmouth to Salem counties, in a narrow band three to 10 miles wide next to and parallel to the outcrop area (Zapecza, 1989). The outcrop area extends from northeastern Monmouth County to the Delaware River (adjacent to Salem County) (Rosman et al., 1995; Zapecza, 1989). The aquifer's down-dip area acts as a confining unit and its downdip limit has been estimated to be approximately six to eight miles southeast of the outcrop area (Lacombe & Rosman, 2001).

The Vincentown Aquifer is able to meet relatively small public supply demands due to limitations in aquifer thickness. The aquifer is considered well defined and thickest in northern Ocean and southern Monmouth counties, where it is used for water supply. It is considered less defined in the rest of the Coastal Plain (Gordon et al., 2021; DePaul & Rosman, 2015).

USGS estimated aquifer groundwater withdrawals in 2013 were approximately 1.6 mgd, which is a slight increase over a 10-year period (Gordon et al., 2021). According to the most recent water-level data collected by USGS (2018 data), there was slight water level recovery in the aquifer, especially in locations where it is most used. Recovery was found in northeast Burlington County and throughout Ocean and Monmouth counties where the aquifer is used for public supply. Recovery was also found in areas of northwest Ocean County and in coastal Salem County. Slight decline was found in Mantua Township MUA (Gloucester County) (USGS, forthcoming).

The Vincentown Aquifer is a minor option for meeting future water supply demand due to the listed limitations. USGS comparisons of different 2040 water demand scenarios found the potential for future water level decline in north Ocean County, Howell Township, and around Jackson Township MUA wells (USGS, forthcoming). Estimates of the overall supply from this aquifer are difficult to determine since the aquifer's water bearing sands are only within approximately 10 miles of its outcrop area. For this reason, withdrawals may impact streamflow, especially in areas close to the unconfined areas of the aquifer.

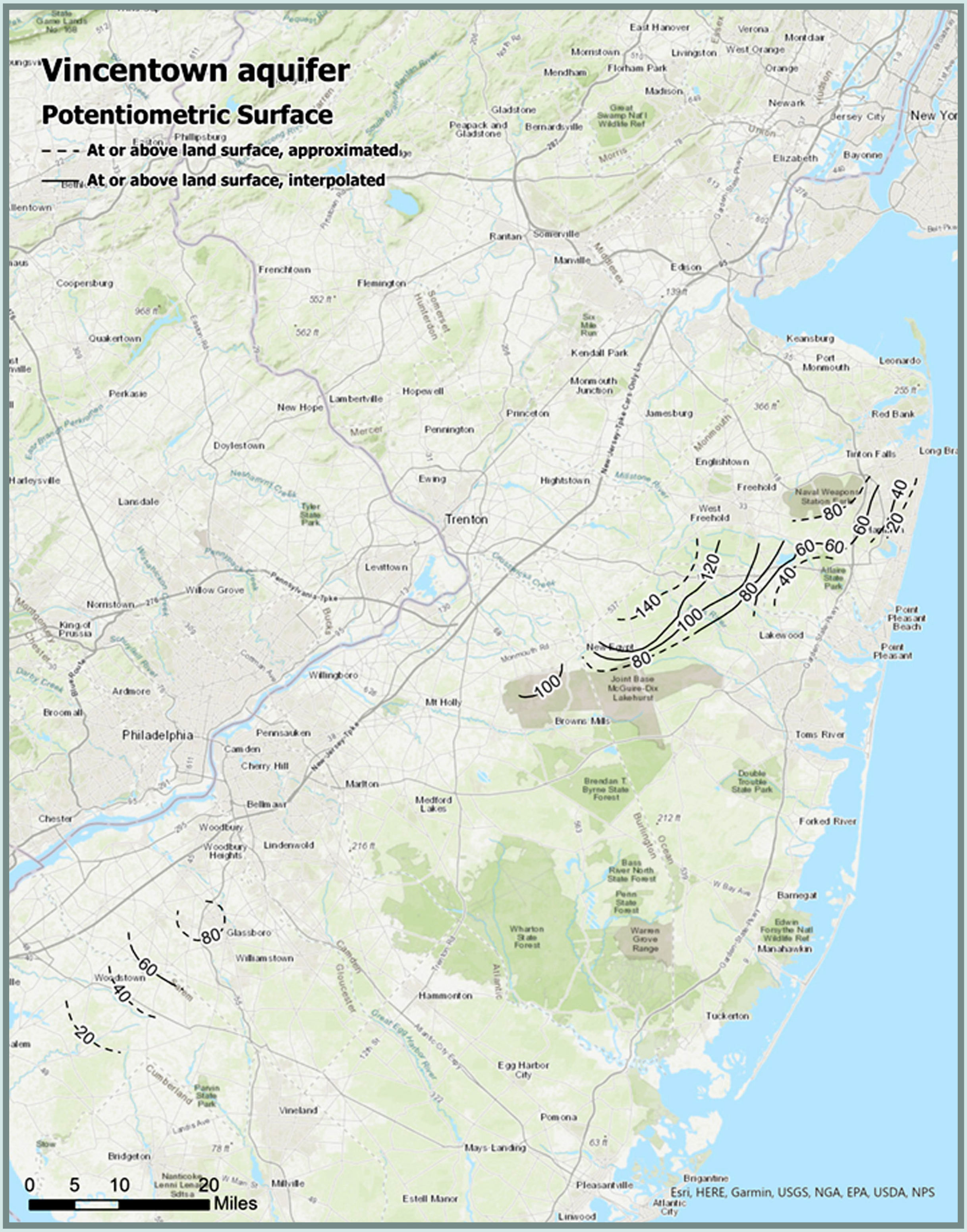

Figure C9. Potentiometric surface for Vincentown Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.

WATER SUPPLY CRITICAL AREA 2 & DELAWARE BAY REGION – AVAILABLE WATER SUPPLY FROM CONFINED AQUIFERS

Water Supply Critical Area 2 was established in 1993 to improve the management of groundwater resources from the PRM aquifer system in southwest New Jersey. It includes Camden, most of Burlington and Gloucester, and parts of Atlantic, Cumberland, Ocean, Monmouth, and Salem counties. The goal of this designation was to stabilize aquifer water levels by reducing pumping from the PRM aquifer system and prohibit future annual increase in PRM use since this aquifer system is the most prolific water source in the region. Unlike Water Supply Critical Area 1, which provides withdrawal restrictions for the Upper and Middle PRM aquifers, Water Supply Critical Area 2 provides restrictions for both of these aquifers along with the third and final aquifer in the PRM system: the Lower PRM Aquifer. Although not specifically included in the Water Supply Critical Area 2 designation, the decline in water-levels in the Wenonah-Mount Laurel Aquifer, which has been considered an alternative to the PRM aquifer system, was also a cause for concern (Gordon et al., 2021; DePaul et al., 2009).

Since the Critical Area 2 designation, water levels within the PRM aquifer system have recovered in several locations, and ground-water model simulations have suggested that stream flow recovery may also occur due to a decrease in pumping induced stream leakage to the aquifers in their outcrop areas. Re-examination of Critical Area 2 included an evaluation of ground-water level trends, USGS modeling, and an assessment of potential impacts of increased withdrawals. Based on the findings, it was concluded that while water level recovery was seen in the Upper, Middle, and Lower PRM aquifers, any withdrawal increases from 2003 values would cause aquifer water level declines below the minimum values mandated by DEP (Spitz & DePaul, 2008). The Tri-County Pipeline, an intake and treatment plant on the Delaware River at Delran, has served as an alternative water source to meet regional demand. This pipeline can provide over 30 mgd of Delaware River water for users in Gloucester, Camden, and Burlington counties (Gordon et al., 2021; DePaul et al., 2009).

Confined aquifers within the Water Supply Critical Area 2 region include the three aquifers of the PRM aquifer system (Upper, Middle and Undifferentiated, and Lower), the Wenonah-Mount Laurel (WML) Aquifer, and the Englishtown Aquifer. Since both the Middle and Undifferentiated PRM Aquifer and the Englishtown Aquifer were already discussed in the Water Supply Critical Area 1 section, water supply issues for the Upper PRM, Lower PRM, and WML Aquifer are discussed below.

UPPER PRM AQUIFER

The Upper PRM Aquifer is considered the most extensive unit in the PRM aquifer system. Locally referred to as the Old Bridge Aquifer, the aquifer's outcrop area mostly coincides with the outcrop of the Magothy Formation, extending from the Raritan Bay to the Delaware River in Salem County. A significant water source across the New Jersey Coastal Plain, the aquifer's downdip is considered well defined offshore of Monmouth and Ocean counties, but is considered less defined in Atlantic, Cumberland, and Cape May counties (Gordon et al., 2021; DePaul & Rosman, 2015). Aquifer thickness varies with estimated ranges from over 200ft in east Monmouth County to approximately 50ft in Cape May County (DePaul & Rosman, 2015; Zapecza, 1989). The majority of aquifer withdrawals occur in Middlesex, Camden, and Gloucester counties, but some withdrawals in Burlington County south to Salem County occur on a narrow band from the aquifer's outcrop to approximately 12 miles downdip (Gordon et al., 2021; DePaul & Rosman, 2015).

Future water-supply withdrawals from the Upper PRM Aquifer in the southwest part of Critical Area 2 and the Delaware Bay Region are constrained by the presence of the saltwater front (250 mg/L isochlor line), which bulges close to the Delaware River in Gloucester County. In the Upper PRM Aquifer, freshwater has been found to be present throughout most of the aquifer's updip extent, but saline groundwater is present in Salem County, most of Atlantic, and all of Cumberland and Cape May counties. A regional cone of depression in Camden County has led groundwater to flow to the northeast, resulting in areas of northwest Gloucester County to be in imminent risk of saltwater intrusion. In the aquifer, the lowest chloride concentrations are located mid-dip and downdip in Monmouth, Middlesex, north Ocean, Burlington, and Camden counties, where concentrations were estimated at less than 10 mg/L. Higher concentrations (2-92 mg/L) are found in updip locations, which is likely due to anthropogenic sources (such as agricultural runoff and road deicers in local recharge areas). The aquifer's highest chloride concentrations have been found in downdip areas under Salem and Gloucester counties and limited areas in north Monmouth County (Gordon et al., 2021; DePaul & Rosman, 2015).

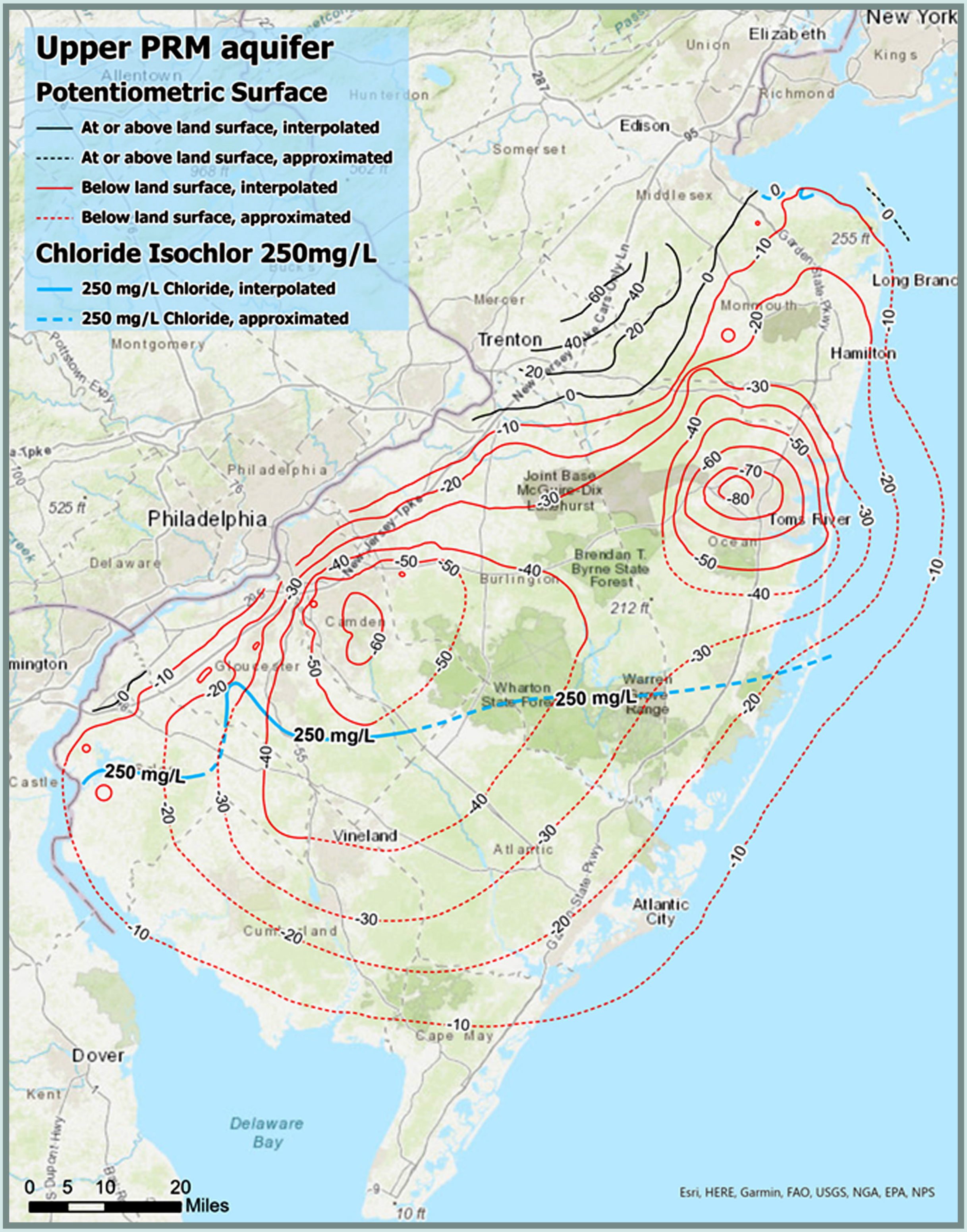

Figure C10. 250 mg/L isochlor line and potentiometric surface for Upper PRM Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.

A continuation of aquifer water level recovery is critical to counter the threat of further saltwater intrusion. As of 2013, USGS estimated groundwater withdrawals from the Upper PRM Aquifer to be approximately 49.0 mgd, which is a decline over a 10-year period. The aquifer's primary pumping centers are located in east Middlesex County near the Magothy Formation's outcrop, and in central Camden and Gloucester counties (Gordon et al., 2021; DePaul & Rosman, 2015). According to the most recent water-level data collected by USGS (2018 data), two cones of depression are located in and around Critical Areas 1 and 2, and a third cone is located in Critical Area 2 that expands from the center of Camden County towards the Delaware River to the west, Burlington County to the northeast, and Gloucester County to the south-southwest. USGS comparisons of 2013 and 2018 aquifer well water levels found water levels declined slightly in Critical Area 1 and surrounding areas of Monmouth, Ocean, and Middlesex counties, and slightly recovered in Critical Area 2 and surrounding areas of Camden, Burlington, and Gloucester counties. However, USGS examination of 2040 water demand scenarios identified several areas where aquifer water levels are projected to decline, including north Ocean County, parts of Burlington County, and the area around Suez Toms River, Aqua Woolwich, and New Jersey Sod Realty (USGS, forthcoming).

LOWER PRM AQUIFER

The Lower PRM Aquifer is considered the lowermost aquifer in the New Jersey Coastal Plain. It does not crop out in New Jersey since it is entirely overlain by a confining bed that separates the Middle and Lower PRM aquifers (Gordon et al., 2021; DePaul & Rosman, 2015). Considered to have the most limited extent of the three PRM aquifers, the aquifer is considered recognizable approximately eight to 12 miles downdip from the northwest extent of the undifferentiated outcrop of the Potomac Group and Raritan Formation (Zapecza, 1989). Significant water withdrawals from the aquifer occur in north Camden County, Burlington County, and in locations near the Delaware River (Gordon et al., 2021).

Similar to the Upper PRM, the potential for future water supply withdrawals from the Lower PRM Aquifer is limited due to its risk of saltwater intrusion. The approximate location of the 10,000 mg/L isochlor line was simulated two miles in the downdip direction from the 250 mg/L isochlor line (located in Gloucester) and three miles down in southern Salem County. Within the aquifer, chloride concentrations have been found to range from less than 2 mg/L to over 11,000 mg/L. The lowest concentrations (no more than 20 mg/L) were located in inland, downdip areas of Burlington and Camden counties. The highest concentrations (range of 143 to 850 mg/L) are found under western Gloucester County, northwest Salem County, and areas to the south and east (DePaul & Rosman, 2015).

Continuing water level recovery of the aquifer is critical for preventing future saltwater intrusion. As of 2013, total groundwater withdrawals from the aquifer were estimated at 32.9 mgd, which decreased over a 10-year period. Significant sources of withdrawal from the aquifer include Camden City Water Department, Merchantville-Pennsauken Water Commission, and New Jersey American Water (Gordon et al., 2021; DePaul & Rosman, 2015). According to the most recent water-level data collected by USGS (2018 data), there is a cone of depression in the aquifer similar to that of the overlying Middle and Undifferentiated PRM Aquifer. A comparison of aquifer well water levels between 2013 and 2018 found that water levels generally recovered in the Lower PRM Aquifer, although some decline was found in localized areas of Camden City, Mount Laurel Township, and west Alloways Creek Township. USGS comparisons of 2040 water demand scenarios identified several locations that may experience future aquifer water level decline, including NJAW Pennsgrove in Carney's Point, Pennsville WD wells, and Solvay Specialty Polymers wells (West Deptford Township) (USGS, forthcoming).

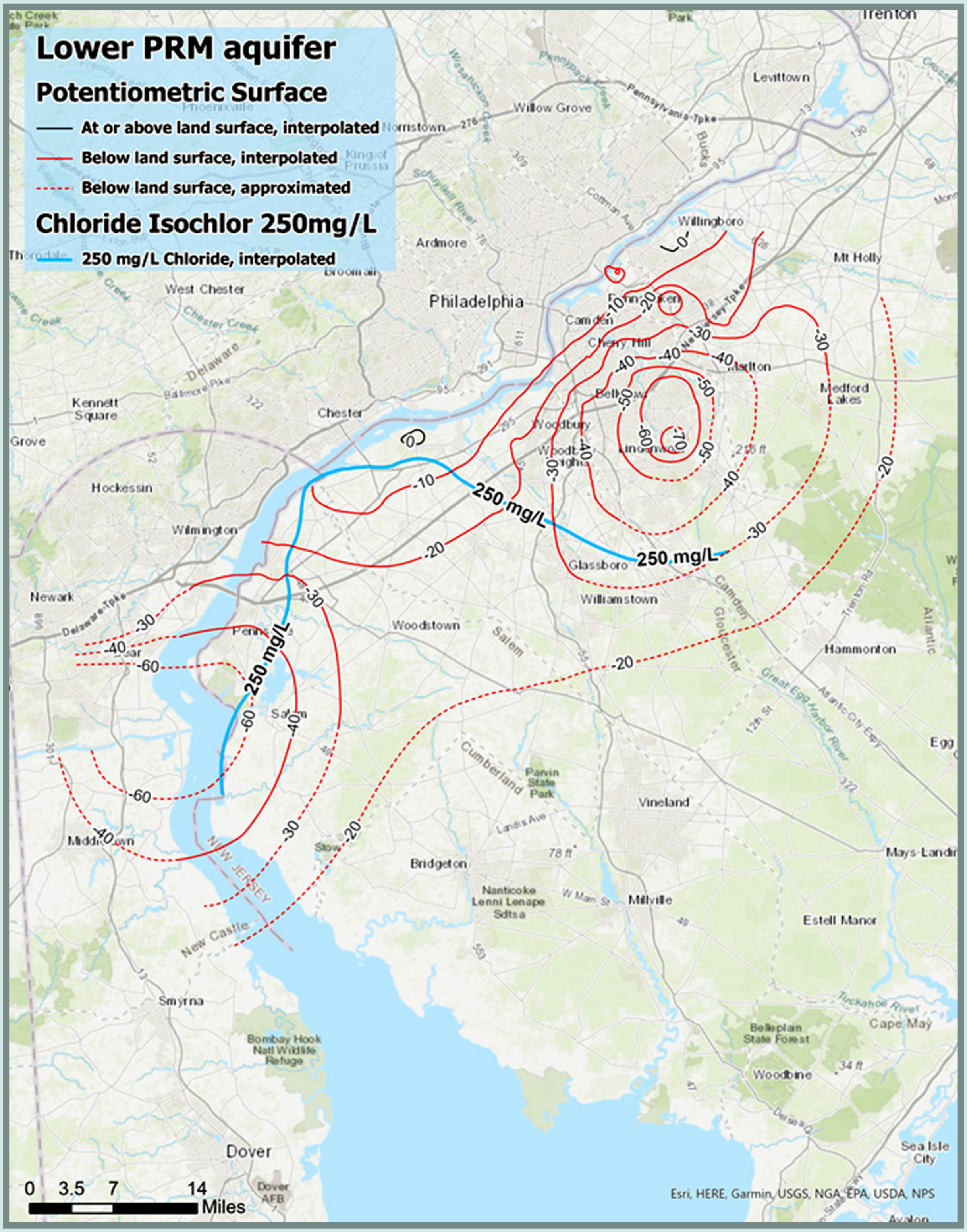

Figure C11. 250 mg/L isochlor line and potentiometric surface for Lower PRM Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.

WENONAH-MOUNT LAUREL (WML) AQUIFER

There has been increased interest in using the WML Aquifer as an alternative water source in Water Supply Critical Area 2 due to the limitations placed on the PRM aquifer system. Having significant withdrawals in Burlington, Camden, and Salem counties, the aquifer's outcrop area extends from Monmouth and Middlesex counties to Salem County in the southwest. The downdip limit of the aquifer is offshore along Monmouth and Ocean counties, and is considered poorly defined in Atlantic, Cumberland, and Cape May counties (Gordon et al., 2021; DePaul & Rosman, 2015). The aquifer is considered thickest in western Salem County and central Gloucester and Camden counties, where it is used for public supply. Southwest in Salem County, the productive sands decrease due to increased silt content (Gordon et al., 2021; DePaul & Rosman, 2015; DePaul et al., 2009). The 250 mg/L isochlor line is estimated to be approximately 2 miles inland in southwest Salem County (Gordon et al., 2021).

The WML Aquifer faces limitations to increased use including excessive drawdown, the potential for well interference, and wetlands and stream depletion in up-dip outcrop areas. As of 2013, estimated aquifer withdrawals were approximately 6.6 mgd, which has declined over a 10-year period. Major withdrawal centers for the aquifer include central Burlington, Camden, and Gloucester counties and Salem County (Gordon et al., 2021; Lacombe & Rosman, 2001). According to the most recent water-level data collected by USGS (2018 data), several cones of depression are located in: (a) western Burlington, southern Camden, and southeastern Gloucester counties; (b) southeastern Monmouth and northeastern Ocean Counties; (c) Medford Township, Burlington County; and (d) Pemberton Township, northeast Burlington County. The cone of depression in Camden and Gloucester counties was found to change significantly since 2013 and both expanded and deepened around the center. Parts of the cone of depression in Monmouth and Ocean counties were also found to deepen since 2013. However, the cones of depression in Medford Township and Pemberton Township were both found to recover (USGS, forthcoming).

USGS comparisons of aquifer well water levels in 2013 and 2018 found mixed water level trends. Significant declines were found in the largest cones of depression located in eastern Monmouth and northeastern Ocean Counties in Critical Area 1 and in the cone's center of Camden and Gloucester counties located in Critical Area 2. However, there were some substantial water level recoveries for the smaller cone of depression in Burlington County. USGS comparisons of different 2040 water demand scenarios identified several spots projected to experience a decline in aquifer water levels, including areas around Clayton Borough, Glassboro Borough, and Washington Township wells. The center of the cone of depression in Critical Area 1 was projected to recover in more conservative future water demand scenarios, but decline with more excessive water use (USGS, forthcoming).

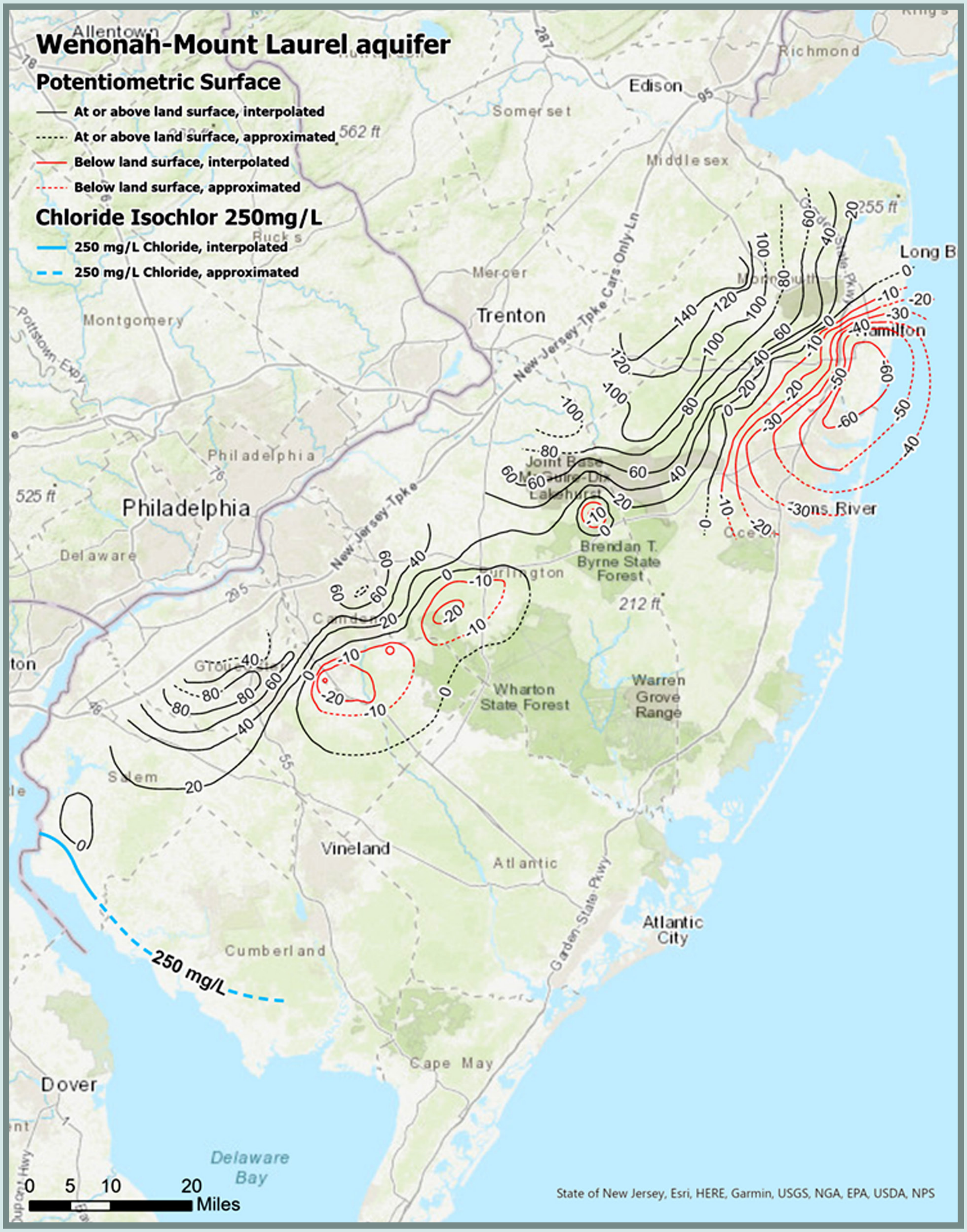

Figure C12. Potentiometric surface for Wenonah-Mount Laurel Aquifer from the USGS report on the condition of New Jersey's confined aquifers in 2013, the most recent year for which such data is published.