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1.0 INTRODUCTION

Maine Yankee is a former nuclear power electrical generating plant that, since ceasing generating electricity in August 1997, is being decommissioned and dismantled. The Maine Yankee facility is located in Wiscasset, Maine (**Figure 1-1**). The entire Maine Yankee site is about 820 acres, of which about 150 acres lies within the Bailey Point area, the portion of the site most impacted by construction and operation of the facility.

This Corrective Measures Study (CMS) documents and evaluates remedial activities to address non-radiological constituents in soil, sediment and groundwater associated with the Bailey Point portion of the facility. This document has been prepared as part of the Maine Yankee closure program being implemented in accordance with the Resource Conservation and Recovery Act (RCRA). The major steps include:

RCRA Facility Assessment
RCRA Facility Investigation
Corrective Measures Study
Corrective Measures Implementation

The Bailey Point RFI was recently completed and is the primary source document for data used in the CMS evaluation.

A Backlands RCRA Facility Investigation (RFI) Report, based on an investigation of the remaining approximate 640 acres, was prepared separately to allow Maine Yankee the ability to expedite ownership transfer of the backlands portion of the site. The Backlands RFI report documented both site investigation and remedial activities associated with closure of the Backlands portion of the Maine Yankee site.

1.1 Purpose

The purpose of this Bailey Point CMS is to present the evaluation and selection of remaining corrective measures necessary to close the Bailey Point portion of the Maine Yankee site under RCRA. This document has been prepared as part of the overall RCRA closure of Bailey Point. Characterization results and Risk Assessment results for Bailey Point are documented in the Bailey Point RFI Report. Several areas were remediated prior to and during the RFI to support decommissioning and demolition work. These remedial activities are documented in the CMS. The remedial activities conducted to date have been a series of soil and sediment removal actions implemented to support decommissioning activities. The soils of concern under RCRA have been removed. For this reason groundwater is the primary focus of this document. Following Maine Department of Environmental Protection (MDEP) approval of the CMS, the remaining aspects of site closure will be addressed in the RCRA closure compliance order issued by MDEP.

1.2 Regulatory Framework

This CMS supports closure of Bailey Point portion of the site in accordance with RCRA regulations (06-096 Code of Maine Rules (CMR) Chapter 851, Section 11, and Title 40 Code of Federal Regulations (CFR) Part 265). The data used in the CMS evaluation was collected in accordance with the MDEP-approved Quality Assurance Project Plan (QAPP) as amended in correspondence with the MDEP.

1.3 Report Organization

The remainder of this CMS is organized as follows:

- **Section 2** describes background information used to support the Corrective Measures Study. This section includes a description of the site geology, hydrology, use history, topography, and previous investigations, and summarizes the characterization and risk assessment results from the Bailey Point RFI Report.

- **Section 3** presents the Corrective Measure Objectives and target remediation areas for soils and groundwater. This section also summarizes areas previously remediated as well as planned removal actions.

- **Section 4** presents the technology screening and alternatives development for soils and groundwater. A description of potential institutional controls is also included in this section.

- **Section 5** presents a detailed evaluation of alternatives for soils and groundwater.

- **Section 6** presents recommended corrective measure alternatives.

Included as appendices are alternative cost spreadsheets, closure/soil remediation reports, and the long-term groundwater monitoring program.

2.0 BACKGROUND

Section 2 outlines the environmental setting for the Bailey Point portion of the Maine Yankee site and a description of the site in relation to its physical surroundings. The section provides a brief outline of site location and layout, land use history, as well as a description of site surface water, geology, groundwater, and sediment regimes within the Bailey Point area. The physical descriptions are based on historical information, which is supplemented with data collected as part of the RFI. This section concludes with a discussion of the nature and extent of impacted soil, groundwater, and sediment, and a summary of the risk assessment conducted as part of the RFI.

2.1 Site Description

This section provides a brief outline of site location and layout, land use history, as well as a description of site surface water, geology, groundwater, and sediment regimes within the Bailey Point area.

2.1.1 Location

The site is located in the town of Wiscasset, Lincoln County, Maine **(Figure 1-1)**. Site coordinates are approximately 43 degrees 57 minutes 5 seconds north latitude and 69 degrees 41 minutes 45 seconds west longitude. The site is located approximately one and one-half miles east of Route 1 and one-half mile west, across Back River, from Westport Island **(Figure 2-1)**. The land owned by Maine Yankee is divided by Old Ferry Road, the closest public road, which terminates on the shore of Back River **(Figure 2-2)**. The main plant site is located on a peninsula known as Bailey Point, which extends south into Montsweag Bay, which is part of the Sheepscot River estuary system.

2.1.2 Site Layout

The entire site is about 820 acres of which approximately 640 undeveloped acres (commonly referred to as the Backlands) exist west of Bailey Cove/Young's Brook and north of Old Ferry Road. In August 2004, 431 acres of the Backlands were sold to Ferry Road Development Co., LLC. The remaining 150 acres lie south of Old Ferry Road within the Bailey Point area, which is bounded by Bailey Cove to the west and Back River on the east.

The Back River extends in a northerly direction from a point known as Long Ledge, which is at the northern limit of Montsweag Bay, a distance of about four miles to a confluence with the Sheepscot River at the northern tip of Cushman Point (**Figure 2-1** and Figure 3 in Gerber & Rand, 1980). It varies in width from a maximum of 1,500 feet at Berry Island to a minimum of 500 feet at Cowseagan Narrows. Channel depths vary from 10 to over 60 feet at mean low water, with a maximum depth at the plant site of approximately 36 feet (Maine Yankee, 1998).

Montsweag Bay extends southward from Back River in the vicinity of Long Ledge a distance of about four miles to Phipps and Hubbard Points, where it connects with Hockomock Bay. Montsweag Bay varies in width from approximately 2,000 feet at its northern and southern limits; to about 8,000 feet midway between these points and has a mean tide level area of about 1,800 acres. Except for a relatively narrow central channel, the bay is quite shallow, with mean low water depths generally less than two feet. Extensive intertidal mud flats are exposed at low tide. The central channel varies in depth from 13 to 50 feet below mean sea level (Maine Yankee, 1998).

Tidal flows enter and leave the Back River-Montsweag Bay area at the Cowseagan Narrows on the north and through the passage separating Phipps and Hubbard Points to the south. The average tidal range in this area is about nine feet.

The plant site is located on a ridge of bedrock running northeast to southwest to form Bailey Point. The maximum elevation of this rock is a knob 75 feet above MSL located about 700 feet northeast of the plant. The general elevation of Bailey Point varies from sea level to 40 feet above mean sea level. The plant industrial area is graded to elevation 21 feet.

2.1.3 Site Use History

The Bailey Point area of the Maine Yankee site is currently zoned as Shoreland Business District based on the Town of Wiscasset Ordinances, Article VI (Zoning).CC., Revised January, 2005. Prior to construction of the Maine Yankee facility, the Bailey Point area was used for residential and farming activities. During construction and operation of Maine Yankee, this portion of the site was used to support industrial activities associated with nuclear power generation. The Bailey Point area includes terrestrial, fresh and saltwater wetlands and intertidal environments.

Construction of the Maine Yankee facility began in 1968 and commercial operation commenced in December 1972. The plant generated electricity for approximately 26 years; the plant was taken offline December 1996 and permanently ceased operation in August 1997.

For a brief period in the early 1980s Maine Yankee held an Interim Hazardous Waste Storage Facility License issued by the MDEP. After terminating that license in 1985, Maine Yankee continued to operate as a hazardous waste generator. Since Maine Yankee was a generator of hazardous waste, the site must be investigated and remediated, if necessary, in accordance with the RCRA (06-096 CMR Chapter 851, Section 11, and CFR 40 CFR Part 265), in order to close the site in a manner appropriate for future use and protection of human health and the environment. The RFI was performed to support an assessment of risk to human health and the environment and to support site closure (Maine Yankee, 2004a); the QAPP was prepared as a blueprint for the RFI (Stratex, 2001a). A separate plan was submitted to MDEP for closure of the former Interim Hazardous Waste Storage Facility, the Lube Oil Storage Room (Stratex, 2001b).

The planning process for the plant decommissioning and site restoration began in 1997. The first buildings were demolished in May 1999. Below grade sumps and drains that had received or had the potential to receive chemicals during plant operation were removed during demolition. As described in the Bailey Point RFI, sub grade concrete foundations and slabs remaining in the former industrial area were sampled from 20 locations. The majority of locations were remediated (scabbled) before sampling. Only minor petroleum contamination was detected from a few samples. Confirmatory soil samples showed no contamination that exceeded PALs. An estimated 651,000 cubic feet (47,209 tons) of concrete foundations and structures remain below grade on the Bailey Point site.

Maine borrow sources were evaluated for selecting suitably clean fill material to backfill the remaining sub grade concrete foundations and structures. Environmental site assessments were performed using the ASTM Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process (E- 1527). The purpose of the environmental site assessment process is to define good commercial and customary practice for site assessments with respect to the range of contaminants within the scope of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and petroleum products. Based on a comprehensive review of site records, operating history, interviews and site walkdown, an assessment of the presence or likely presence of any hazardous substances or petroleum products that may be indicative of an existing or past release of these constitutients into the property's environment was performed for each borrow source. Additionally, soil samples from the borrow sources were analyzed for metals (As, Ba, Cd, Cr, Pb, Hg, Se, Ag) and petroleum (DRO). Based on acceptable environmental site assessment findings and soils analyses that were not significantly greater than the ambient on-site soil characteristics, borrow sources of clean fill were selected. Borrow sources and the types of material acceptable from each source for foundation backfill, site restoration and final grading were controlled in MY's procedure Control of Backfill at Maine Yankee.

The decommissioning of the plant and site restoration was completed in June 2005.

2.1.4 Topography and Drainage

The site consists of a series of ridges and valleys striking north-south that reflect the competency and structural nature of the underlying bedrock. Deep bedrock valleys are filled with glaciomarine clay-silt soil; ridges are characterized by exposed bedrock or thin soil cover over rock. Surface drainage moves both to the north and south along the axes of the topographic valleys and also flows east and west down the flanks of the ridges. **Figure 2-3** shows a simple division of the Site into separate surface watersheds.

In the plant area, where the ground surface is relatively flat, manmade underground storm drains and catch basins were designed to control the surface runoff (**Figure 2-4**). A detailed summary of the storm drain system is provided in **Table 2-1**. The underground storm drain system and outfalls will, except for those associated with the Independent Spent Fuel Storage Installation (ISFSI), be phased out upon completion of decommissioning.

The single perennial stream on the Site originates in the formerly-proposed "ash disposal area," north of Old Ferry Road and directly north of the main access road to Maine Yankee (**Figure 2-2**). The headwaters of this stream occur at the northern end of a deeply incised gully. The gully is supported by bedrock ridges to east and west and relatively shallow bedrock at the northern and upper end of the gully. In this area there are diffuse springs and seeps that gradually coalesce to form the stream that flows into the pond south of Old Ferry Road and north of the ISFSI area. The outlet to this pond is a culvert that is buried beneath the 345 kV transmission lines and discharges on the eastern side of Bailey Cove just above high tide. Other runoff from the Bailey Point peninsula occurs through overland sheet flow and shallow gully or ditch flow.

The groundwater recharge capability during plant operation was different in the northern half of Bailey Point from the southern half of Bailey Point. This reflects two significant differences in the land cover types that existed during operation. The area north of the Staff Building had much less paving and parking lot area, and generally thicker soils than south of the Staff Building. Overland flow times of concentration were much longer in the north for stormwater runoff, reflecting a less dense drainage network, allowing for more time for precipitation to infiltrate the soil. In the south, a high percentage of the land cover type during plant operation was roof, paving, or dense gravel parking lot surface. In addition, there was a man-made stormwater system with catch basins around the plant area that efficiently moved runoff from the area (**Figure 2-2**). Most infiltration in the southern portion of the site was in grassed strips in and around the paved areas. **Section 5.3.1.3** describes the distribution of recharge on Bailey Point.

2.1.5 Geology and Hydrology

The site geology has been studied through a series of site mappings, geophysical explorations, test pits, and borings that have been completed since 1966. Past studies created over 500 subsurface explorations. The Bailey Point RFI has added several hundred more soil borings, monitoring wells and test pits. Construction activities over the years have significantly modified the original surface and probably on the order of 50% of Bailey Point is now covered with fill. About half of this fill is predominantly clay-silt and half is sand and gravel. For those areas not filled, the surface is either exposed bedrock or consists of soils derived from glaciomarine clay-silts or fine sands. There is a thin, discontinuous layer of diamicton (glacial till) overlying bedrock. The thickest deposits (up to 60 feet) of glaciomarine clay-silt on Bailey Point can be found north of the ISFSI. Typically the top 10 feet of this unit consists of stiff fissured clay-silt, which has a moderate permeability relative to the underlying soft clay-silt. The stiff clay-silt may have a higher vertical permeability than horizontal permeability. The soft clay-silt beneath the stiff clay-silt has thin horizontal sand and silt seams and has a higher horizontal permeability than vertical permeability. The soft clay-silt is a relatively low permeability material and is also moderately compressible. A thin sand zone of higher permeability is common at the bottom of this unit. The shoreline areas expose the bottom of the glaciomarine unit and scattered glacial till deposits. The upland soils on the Knoll may have some till-like materials, too. Thin soils in the developed areas such as the industrial area consist of sand and gravel fill.

Three important bedrock units lay beneath Maine Yankee: a) the basic "country" rock (a schist) of the Cape Elizabeth Formation; b) granites and pegmatites; and c) migmatized rock. The migmatites occupy a significant volume of the rock under the site. The granites, pegmatites, and migmatites seem to be generally interlayered with depth. The schist unit, as we have defined it, is relatively rare on Bailey Point. It apparently occupied those portions of the rock that have been most eroded by glacial action. The ridges are dominated by the pegmatites. There is a broad zone of granite along the western edge of Bailey Point and on the southeastern-most point of land. Near the granite and pegmatite intrusions, the schist has been re-heated, partially melted, and re-crystallized into granite-like migmatites, making the host schist into banded micaceous gneiss.

The schist is the weakest and most permeable rock unit and is highly weathered in some outcrops. The pegmatites are generally quite competent in both outcrop and rock core. However, several drill cores showed moderate weathering where the pegmatite is disaggregated to gravel-sized particles. Granite also shows weathered zones. The granite and pegmatite have steep contacts with the schist and appear to have been injected along foliation planes. The major structural features of granite and pegmatite are steeply-inclined northeasterly-trending joints and horizontal or gently inclined sheet jointing, both of which show rust-stained surfaces. The schist and migmatites exhibit well-developed north-trending foliation strike with steeply-dipping layered fabric defined by the successive alternations of micaceous, quartzitic and feldspathic interbeds.

The bedrock is generally a very competent rock and foundation material. Of 61 bedrock cores taken on Bailey Point, only 14 show broken rock zones or more than slight weathering. Of nine RCRA bedrock monitoring wells installed in core holes with moderate weathering or broken rock zones, only three had low flow pumping capacities of over 100 mL/minute. The Wiscasset area, as a whole, has an average bedrock well yield that is significantly lower than that of the coast of Maine. There are very few high yield bedrock wells in the Wiscasset area. In fact, four bedrock wells classified as "dry" have been drilled on the Maine Yankee property south of Old Ferry Road.

The groundwater regime at the Maine Yankee facility is comprised of two aquifers: (1) a discontinuous surficial aquifer in the unconsolidated glaciomarine soils and fill material and (2) a bedrock aquifer. The surficial aquifer is not present continuously across the site, as the overburden soils are thin to non-existent in some portions of the site. This is especially true in the southern portion of Bailey Point. The bedrock aquifer is present below the entire site and vicinity.

There were a total of 30 RCRA wells capable of measuring water levels in the overburden. Several wells actually spanned the bedrock interface where the highest water table was very close to this interface, but most were sealed above the bedrock surface. The water table maps for three synoptic measurements show a similar pattern with a high in the middle of the site at the knoll and contours generally parallel to existing ground surface contours. From December 2001 to April 2002 typical water level rose about 2 feet. The area near the groundwater divide—near the ISFSI—had the largest change in groundwater elevation as would be predicted by theory. The maximum decline over the summer of 2002 was about 5 feet with most water levels dropping only 1 to 2 feet.

There are 31 RCRA wells sealed in bedrock and several more that span the bedrock/soil interface. The water level in the bedrock wells generally only rose a few feet from December 2001 to April 2002. A groundwater divide occurs near the ISFSI. As with the overburden regime on the north side of Old Ferry Road, all previously measured or inferred bedrock levels to the north of the road are no more than 15 feet below ground surface. Since the ground surface of the land on the north side of the road is at least 15 feet higher than the average ground surface under the 345 kV transmission lines, groundwater is higher to the north of the road and flowing across the road to the south in the length of road from the Bailey Farm House to the Ballfield.

The Bailey Point RFI includes many more details on the geology and hydrogeology of the site. As part of the CMS, a detailed three-dimensional groundwater flow and transport model was constructed and assisted in interpreting groundwater flow and chemical transport conditions in the soil and bedrock of the site.

2.1.6 Previous Investigations

Numerous environmental and geologic investigations have been conducted at Maine Yankee prior to and since construction of the power generating facility. Section 5 of the QAPP details the assessments and investigations previously performed at the site, which formed the basis for the RFI sampling approach (Stratex, 2001a). RCRA-related assessments included a RCRA Facility Assessment (RFA) prepared by MDEP (MDEP, 1992 and 1999), and a Site History Report (SHR) (S&W, 1999), Building Assessment Plan (BAP) (Stratex, 2000 and 2001c) and visual site inspection performed by Maine Yankee (Maine Yankee, 2001 and 2002a). Several investigations were performed prior to the RFI to support decommissioning and demolition activities, including an assessment prior to enlargement of the barge access road (S&W, 2000a) and construction of the ISFSI (Maine Yankee, 2000). An investigation of the ecology in and around the submerged diffuser system was also performed to support Natural Resource Protection Act (NRPA) permitting activities (Eco-Analyst, Inc., 2001). The Lube Oil Storage Room was evaluated to support closure of Maine Yankee's Interim Hazardous Waste Storage License (Stratex, 2002 and 2005). **Table 2-2** summarizes the environmental investigations that have been conducted at Maine Yankee.

2.1.7 Pre-RCRA Removal/Remedial Actions

Several targeted remediation activities were performed at Maine Yankee prior to the RFI to support decommissioning and demolition work, including removal of kerosene-contaminated soil prior to construction of the ISFSI, removal of petroleum-stained soil during excavation work, and removal of paint from the sub-grade concrete surfaces that would remain following demolition. A summary of these remedial activities is also included in **Table 2-2**.

Throughout decommissioning, Maine Yankee continued implementation of its Spill Plan (Maine Yankee, 2002b). In accordance with the plan, all spills are addressed and remediated, if necessary, in a timely manner. For several larger spills, remedial plans were developed and implemented. **Table 2-2** includes a summary of remedial activities performed as a result of spills reported during the RFI.

2.2 Nature and Extent of Impacted Media

2.2.1 Soil

The Bailey Point RFI investigation has identified several areas of soil contamination related to some aspect of plant construction or operation. Most of the impacted soil is comprised of PAHs and petroleum hydrocarbons. The following areas of interest were identified:

- Industrial and Radiological Restricted Areas: Surface and subsurface soils contain elevated concentrations of PAHs and detected concentrations of PCBs, pesticides, and EPH. These compounds are believed to be derived from the use of PCB-containing, petroleum-based compounds, and were typically detected in association with specific sources (i.e., oil reservoirs, sumps, and drains) and industrial activities. These compounds have limited mobility in the environment and are expected to remain adsorbed to the shallow soils.

West Side of Radiological Area. Elevated concentrations of EPH/DRO in groundwater indicate a focused area of petroleum-impacted shallow soil contamination. The nature and extent of potential petroleum contamination was evaluated in November 2004. No source of petroleum hydrocarbons was observed in the area around or upgradient of MW-401B (see **Section 3.2.2.3** and **Appendix D**)

- Warehouse 2/3. Surface soils on the northwest side of Warehouse 2/3 contain elevated levels of PAHs, lead and PCBs, and detected concentrations of pesticides. The PAHs, pesticides, and PCBs have limited mobility and biodegradation potential and will remain in the surface soils. Lead also has limited mobility, as the elevated lead observed in the surface soils is not observed in the deeper soils. Subsurface soils on the southwest side of Warehouse 2/3 contain elevated levels of VOCs (xylenes, ethylbenzene, and toluene) associated with the disposal of paint thinners, paint and PCB-containing paint. These VOCs have migrated via infiltration processes to the water table and have degraded groundwater quality.

- Construction Transformer. Surface soils contain elevated concentrations of EPH and PCBs. The distribution of EPH and PCBs is focused in oil-stained surface soils adjacent to the transformer. These compounds have limited mobility in the environment and are expected to remain adsorbed to the shallow soils.

- Former Truck Maintenance Garage. Subsurface soils contain elevated concentrations of EPH. The extent of petroleum hydrocarbon contamination in this area was not completely bounded during the RFI. Post-RFI characterization has identified the limits of petroleum hydrocarbon-impacted soil. The detected petroleum hydrocarbons are lighter than most of the material identified on Bailey Point, and include kerosene and diesel components. This variety of petroleum hydrocarbons has limited solubility, but the relatively high concentrations will continue to degrade groundwater quality via infiltration and leaching processes. Biodegradation will also occur under aerobic or anaerobic conditions, provided there is a source of oxygen or other electron acceptors.

- 345 kV Transmission Line Area. Subsurface soils contain elevated concentrations of EPH and PAHs and detected concentrations of PCBs. These chemicals were included with construction debris used to fill this portion of the site as observed in test pits excavated in this portion of the site. The PAHs and

PCBs are relatively immobile and will generally remain adsorbed to the subsurface soils. The two compounds will biodegrade slowly through time. The lighter aliphatic and aromatic petroleum hydrocarbon fractions will degrade groundwater quality via infiltration and leaching processes, and EPH and DRO are detected in groundwater in this area. Biodegradation will also occur under aerobic or anaerobic conditions where there is a source of oxygen or other electron acceptors.

- Bailey Farm House. Subsurface soils from the leachfield contain elevated levels of EPH and detected concentrations of PCBs. The EPH was detected in oil-stained soils adjacent to a No. 2 fuel oil tank in the dirt floor of the Bailey Farmhouse basement and in shallow soils adjacent to and within a septic leachfield associated with the farmhouse. Low concentrations of PCBs were reported in shallow soils adjacent to and within the leachfield soils. These compounds have limited mobility in the environment and are expected to remain adsorbed to the shallow soils.

2.2.2 Groundwater

The RFI characterization of groundwater beneath the Bailey Point area has identified several areas of contamination related to some aspect of plant construction or operational activities. Most of the groundwater contamination in the Bailey Point area includes petroleum hydrocarbons (DRO) and metals (sodium, manganese and iron). The location of all RFI monitoring wells is included in **Figures 2-5A** and **2-5B**.

- DRO, aluminum, arsenic, molybdenum, manganese, sodium, and dieldrin in groundwater in several wells located throughout the RA/Industrial Area and the northern portion of Bailey Point, including ISFSI and the Pre-operation Cleaning Basin;

- DRO, boron, iron, manganese, molybdenum, and sodium in groundwater north of ISFSI and under the 345 kV transmission line area within the dredge spoil disposal area;

- TCA and related chlorinated daughter products, manganese and sodium in groundwater east and south of Warehouse 2/3; and

- BTEX compounds, vinyl chloride, aluminum, arsenic, iron, manganese, molybdenum in groundwater beneath the west side of Warehouse 2/3.

The DRO observed in groundwater is related to both historic spills and long-term industrial activities in the industrial areas of Bailey Point. The distribution of DRO across Bailey Point is shown in RFI Figures 4-16 and 4-17. The DRO in groundwater will naturally biodegrade under both aerobic and anaerobic conditions, provided a source of electron acceptors is present.

The distribution of TCA and the daughter products in the Warehouse 2/3 area is shown in RFI Figures 4-15A, 4-15B, and 4-15C. The TCA and daughter products detected on the east side of the warehouse are undergoing reductive dechlorination. This process will ultimately result in the degradation of the chlorinated compounds to ethene and ethane, provided the presence of appropriate substrate and electron donors.

The BTEX compounds present in shallow groundwater on the west side of Warehouse 2/3 are related to the presence of the BTEX compounds disposed in soil adjacent to the warehouse. The dissolved BTEX will naturally biodegrade provided the presence of electron acceptors, but the presence of the source BTEX in soils will continue to release BTEX to shallow groundwater.

The distribution of sodium throughout Bailey Point is shown in RFI Figures 4-12A and 4-12B. The elevated concentrations of sodium are related to the availability of seawater and the use of deicing salts in the southern portion of the site and the presence of marine sediments that were historically placed in the northern portion of the Bailey Point.

The distribution of iron and manganese in both soil and bedrock is included in RFI Figures 4-6A, 4-6B, 4-7A, and 4-7B. The elevated concentrations of manganese and iron are related to the reducing conditions that stabilize Mn^{2+} and Fe^{2+} in groundwater relative to oxide minerals in soil. These metal concentrations will slowly decrease through time.

Other metals (aluminum and boron) and dieldrin are present at low concentrations and are not widely distributed across Bailey Point.

The presence of molybdenum in site groundwater was determined to be a function of naturally occurring molybdenum present in the pegmatite-bearing granite bedrock. The distribution of molybdenum in soil and bedrock is shown in RFI Figures 4-11A and 4-11B

Arsenic concentrations also exceed MEGs in Bailey Point groundwater. The elevated arsenic is a function of the natural distribution of arsenic in site soils and the potential mobilization of arsenic that is present in the soils due to anthropogenic changes in site geochemistry.

2.2.3 Sediment

Sediment samples were taken from both freshwater and marine locations. The constituents detected in marine sediment within Bailey Point were metals such as arsenic, nickel and mercury, which were commonly exceeded in the reference marine sediment taken from Brookings Bay. Concentrations of other metals (i.e., copper, lead and zinc), PCBs, pesticides and SVOCs were associated with the sediment within the Forebay. The Forebay sediments were removed in fall 2003 as part of radiological remediation activities. The concentration of metals on the exterior of the Forebay berms was consistent with reference sediment.

Freshwater sediment samples collected from swale areas downgradient of potential contaminant sources in the 345 kV Transmission Line and Pre-Operation Cleaning Basin Areas exceeded maximum reference soil concentrations for nine metals (barium, boron, chromium, iron, manganese, mercury, nickel, vanadium, and zinc). Although four of these metals (manganese, nickel, vanadium, and zinc) slightly exceeded ecological screening values, a significant ecological risk does not exist within these areas because of the lack of standing water and/or critical habitat. Low levels of EPH and PAHs were detected in several of the freshwater sediment samples. The total PAH concentration in each of these samples, however, were well below the total PAH ecological screening value.

Sediment samples from the intertidal and subtidal zones around the Bailey Point area where the majority of industrial area stormwater discharges occurred, as well as a gully in the northern reach of Bailey Cove that received runoff from the construction debris/silt spreading area north of the 345 kV Switchyard were characterized as part of the Bailey Point RFI. The following areas identified contaminants that are elevated relative to benchmarks and/or reference values in the initial round of sampling:

- SVOCs at intertidal and subtidal stations at Outfall 005/006;
- A subtidal station at Outfall 009 had the highest concentration of SVOCs (primarily PAHs); and
- SVOCs at one intertidal station at Outfall 010

Based on the results of the initial outfall sediment screening presented to MDEP November 2001, it was concluded that three of the sampling locations required further investigation in the form of sediment toxicity testing and benthic community structure analysis (BCSA). Further sampling at one location was identified within the following areas:

- Outfall 005/006 intertidal;
- Outfall 009 subtidal; and
- Outfall 010 intertidal.

The additional sampling results were evaluated for potential ecological impacts, and outfall 009 was determined to have elevated PAH concentrations that required remedial action. The impacted sediments were removed in fall 2003, and confirmatory sampling for the post-removal sediments was conducted in April and September 2004.

2.3 Human Health Risk Assessment Results

Based on the site history and results of the RFI, the site was divided into 10 discrete areas for purposes of site and risk characterization (**Figures 2-5A and 2-5B**). These areas include the following:

- Foxbird Island – includes the 11.3-acre peninsula south of the plant Forebay under which the diffuser pipeline is buried.
- Forebay – is a 4.2 acre engineered structure where water discharged to the diffuser system.
- ISFSI – is a 9.5-acre bermed area making up the spent fuel storage facility.
- Former Truck Maintenance Garage – is the location of the former truck maintenance garage that was used during plant construction. The Former Truck Maintenance Garage Area includes approximately 6.1 acres.
- 115kV Switchyard – is a switchyard located west of the RA and south of Warehouse 2/3 that includes approximately 0.5 acres.
- Personnel Buildings and Parking Lot Areas – includes the Fire Pond, Parking Lots, Information Center and Personnel Building. This is a 21.6 acre contiguous area running east to west through the southern portion of Bailey Point.
- Plant Area – includes the Restricted Area (RA) and Industrial Area of the plant, a total of approximately 19.5 acres.
- Warehouse 2/3 – is 2.9 acre area located on the southwest side of Bailey Point and was used to receive and store chemicals used in plant operations.
- 345 kV Transmission Line Area – includes the 345 kV Switchyard, Silt Spreading Area, Ball Field and Pre-Op Cleaning Basin. This 45.9-acre area is located in the northern portion of Bailey Point and received several episodes of dredged fill material and land clearing debris associated with plant construction.
- Bailey Farmhouse Area – comprises an 8.4 acre area that includes the septic system/leach field and gray water leach field associated with the Farmhouse.

Based on the site background and site conceptual model, exposure to contaminated media was also evaluated for shoreline sediment, shellfish tissue, groundwater and soil and homegrown produce from four areas within Bailey Point. Exposure to soils within each study area was evaluated for a construction worker, on-site worker and resident. Exposure to sediment, fish tissue, groundwater and homegrown produce was evaluated for a hypothetical resident on the Maine Yankee site. Contaminants of Potential Concern (COPCs) were selected for each study areas based on USEPA screening criteria. Exposure Point Concentrations (EPCs) were calculated for each COPC and used to estimate an exposure dose concentration for each exposure pathway. The exposure dose concentrations were combined with toxicity information to quantitatively estimate non-carcinogenic and carcinogenic risks. Estimated cancer risks were compared to the USEPA risk range of 10^{-4} to 10^{-6} and MDEP target risk level of 10^{-5}. Non-carcinogenic risks were compared to an Hazard Index (HI) of 1. The quantitative risk estimates were based on assumptions to render the final risk estimates as overly conservative.

In general, human health risks calculated for the site worker and construction worker scenarios were below applicable MDEP risk thresholds, while in some areas risks calculated for the residential scenario exceeded the applicable MDEP risk threshold. These risk assessment findings are consistent with Maine Yankee's current intentions of restricting future use of Bailey Point to industrial/commercial use.

The total site non-cancer risks to the future resident are all below and HI of 1.0 except for Warehouse 2/3. The non-cancer risks based on exposure in this area ranged from 1.5 to 1.6 (see Table 5-14, Bailey Point RFI, MY, 2004a). The total site cancer risks for the future resident are all above the MDEP target risk and range from 3.6×10^{-5} for the Bailey Farmhouse to 2.7×10^{-4} for the Plant Area (see Table 5-15, Bailey Point RFI, MY, 2004a). Total site risks for the future resident excluding the contribution from arsenic were still above the target risk for all areas except Bailey Farmhouse and ranged from 1.7×10^{-5} for the 345 kV Transmission Line Area to 2.2×10^{-4} for the Plant Area. The risk from the ingestion of homegrown produce contributes the most to the total site risks. For residents who may also ingest shellfish total site risks may be increased by 7.2×10^{-5} to 1.4×10^{-3} depending upon the type of shellfish. It should be noted that the risk from ingestion of shellfish collected around Bailey Point are indistinguishable from background risks and are not attributed to activities conducted at Maine Yankee.

The total site risks to the on-site and construction workers are based on concurrent ingestion and direct contact exposure to soil, and are consistent with an industrial/commercial future land use. The total site non-cancer risks to the on-site worker and construction were all below an HI of 1.0 (see Table 5-14, Bailey point RFI, MY, 2004a). The total site cancer risks to the on site worker (including arsenic) ranged from 3.1×10^{-7} for Bailey Farmhouse to 1.9×10^{-5} for the Plant Area. The total site risks to the construction worker (including arsenic) ranged from 3.4×10^{-7} for Bailey Farmhouse to 1.9×10^{-6} for the Plant Area (surface soils). Removing arsenic from the risk calculation results in lower risk levels for the site/construction worker. The total site risk estimates associated with an exposure consistent with industrial/commercial future land use are at or below the MDEP target risk of 1×10^{-5} (see Table 5-15, Bailey Point RFI, MY 2004a).

While the VOC soil concentrations in subsurface soil on the west side of Warehouse 2/3 slightly exceed the site worker cancer threshold (1.5×10^{-5} with arsenic and 9.9×10^{-6} without arsenic), the VOCs have migrated into the shallow bedrock aquifer, degrading groundwater concentrations to levels in excess of Maximum Exposure Guidelines (MEGs). Since the soil contamination is acting as a source to groundwater contamination, soil remediation via removal was conducted for this area in June 2004 (see **Section 3.2** and **Appendix C**).

Site groundwater exceeds the MDEP thresholds for both cancer (10^{-5}) and noncancer (HI=1.0) risks. Based on these groundwater exceedences, appropriate remedial actions are evaluated in this CMS. The groundwater alternatives evaluated as part of the CMS all include institutional controls that will place a restrictive covenant on the use of site groundwater for as a drinking water source. Public water has been available at the site since 1995, and is the on-site source for drinking water.

3.0 CORRECTIVE MEASURES OBJECTIVES AND REMEDIATION AREAS

3.1 Corrective Measures Objectives

The Corrective Measures objectives for contaminated media at Maine Yankee are a function of the need to protect human health and the environment, and the need to maintain flexibility in future landuse options. The future landuse for Bailey Point is expected to be restricted to commercial and industrial activities, and the human health risk assessment has demonstrated that all cancer and noncancer risks associated with soil are below the MDEP risk thresholds of 10^{-5} and 1.0, respectively, for exposure scenarios associated with commercial/industrial landuse. Several areas of petroleum contamination have been identified on Bailey Point but did not contain target compounds amenable to quantitative risk characterization. Maine Yankee has developed remedial objectives under which current and future risk can be considered acceptable and in accordance with MDEP risk reduction goals. Based on the risk assessment results that indicated acceptable risk for commercial/industrial landuse and the presence of focused areas of petroleum contamination, Corrective Measures Objectives for soil are only developed for the petroleum-impacted areas.

3.1.1 Corrective Measures Objectives and Goals for Soil

The RCRA corrective measures for soil include:

- Prevent human exposure through contact, ingestion, or inhalation to petroleum-contaminated surface and subsurface soils.

- Minimize further releases of contaminants from surface/subsurface soils to groundwater.

3.1.2 Corrective Measures Objectives and Goals for Groundwater

The RCRA corrective measures for groundwater are consistent with MDEP cleanup guidelines for groundwater. The objectives include:

- Prevent human exposure through contact, ingestion, or inhalation to contaminated groundwater that presents an unacceptable risk (e.g., hazard index greater than one or excess cancer risk greater that 10^{-5}).

- Over the long term, reduce contaminant concentrations in site groundwater to below MEGs.

3.2 Target Remediation Areas

3.2.1 Target Areas Closed Out

In addition to remedial actions conducted prior to the Bailey Point RFI study, several focused areas at Maine Yankee have been remediated since the completion of the RFI. These areas include petroleum-contaminated soils in the basement of Bailey Farm House, sediments at Outfall 009, and sediments in the Forebay. These focused remedial actions were conducted prior to initiation of the CMS to support the Maine Yankee decommissioning schedule. A summary of the pre-CMS completed remedial actions, where no additional action is required, is summarized in the following sections.

3.2.1.1 Bailey Farm House

Since the late 1960s, the converted wood-framed Bailey Farm House has been used as the Maine Yankee environmental services field office, including space for the preparation of environmental samples for shipment to offsite laboratories for analysis. Chemical usage has been limited primarily to sample preparation, and these activities have significantly declined in recent years. The Bailey Farm House building was demolished in fall 2003.

Prior to the farm house demolition, soil and concrete removal was conducted in the basement of the Bailey Farm House to address the presence of petroleum hydrocarbons identified on the concrete slab of a residual 275-gallon heating oil tank and in soil beneath the concrete slab in the basement. The petroleum hydrocarbons were associated with a former 275-gallon tank that was used to store No. 2 fuel oil (**Figure 3-1**). A total of approximately 1.5 cubic yards of soil was removed along with a 20-foot by-10 foot portion of the concrete slab. Soil samples from the excavation area were screened in the field using a PID, and final PID readings ranged from non-detect to 6.1 ppm. Confirmatory soil sampling results indicated that DRO concentrations under the former fuel line were 5.5 mg/kg. Final DRO concentrations under the former tank were 54 mg/kg and 110mg/kg for the sample and duplicate, respectively giving an average value of 82 mg/kg. The PID field screening results are well below the 200-400 ppm range established for No. 2 fuel oil in the MDEP Decision Tree Guidance for Baseline 2 (MDEP, 2000). Likewise, the DRO laboratory results are also consistent with the Baseline 2 guidelines for DRO analysis of 100 mg/kg.

A total of five cubic yards of excavated soil and concrete were shipped off-site for disposal at BFI/Allied landfill, Niagara, NY in fall 2003.

3.2.1.2 Outfall 009

Outfall 009 is located along the Back River on the east side of the Maine Yankee Bailey Point peninsula, immediately south of the former Circulating Water Pump House (**Figure 2-2**). The RFI investigation concluded that a localized area of petroleum-contaminated sediment existed near Outfall 009 that required removal (Maine Yankee, 2004a). A

Remedial Plan was developed to remove contaminated sediment from the Outfall 009 area using divers, vacuum extraction and the existing forebay water treatment system (Maine Yankee, 2004a). The plan was approved by MDEP April 14, 2003 (MDEP, 2003), and sediment removal activities were conducted from September 23 to October 9, 2003.

A RCRA Closure Report documenting the remedial activities associated with Outfall 009 is included in **Appendix A**. As described in the report, approximately 70 cubic yards of sediment was removed and processed through the forebay water treatment system. Confirmatory samples for Outfall 009 were taken in April and September 2004 to allow for re-sedimentation of the outfall area.

The sediment removal has resulted in considerable reduction in the average PAH concentrations in the sediments at Outfall 009. Although there appears to be a small pocket of residual contamination, the removal has been very successful at reducing the bioaccumulation of PAHs in blue mussel tissue in the area of concern and at restoring a healthy benthic invertebrate community. Maine Yankee plans to include Outfall 009 in their Natural Resource Damage proposal that is currently being negotiated among the stakeholders for the site.

3.2.1.3 Forebay

The Forebay was part of the liquid waste discharge system that was located on the south end of Bailey Point adjacent to Foxbird Island (**Figure 2-2)**. The structure consisted of two, 225-foot, north-south oriented dikes that connected Bailey Point to Foxbird Island to the south. The dikes formed a containment structure that received large volumes (up to 420,000 gallons per minute) of circulating and service water and liquid effluents. The water from the Forebay flowed to buried piping beneath Foxbird Island that carried the water to a submerged diffuser system in Montsweag Bay, south of Foxbird Island.

In support of site decommissioning activities, the Forebay remediation was completed in December 2003. The remediation was driven by the presence of radionuclides, and the remediation activities included:

- Removal of the upper ten feet of both dikes and
- Removal of approximately 977 cubic yards of sediment.

The Forebay was backfilled and graded, and the west dike was breeched to form a 1.3-acre wetland. Final grading of the Forebay was completed in April 2004.

Three sediment samples and a duplicate sample were taken from the remaining sediments following sediment removal activities in the Forebay. A report discussing the results of the confirmatory samples is included in **Appendix B**. As indicated in the report, TAL metal concentrations were either consistent with background soil concentrations or below MDEP RAG values established for residential soils. The low DRO detections (8 mg/kg to 19 mg/kg) were also below petroleum concentrations developed for Baseline 2 sites. The low, detected concentrations of PCBs, pesticides, and SVOCs are below MDEP RAG values developed for residential soils or are low enough to be consistent with no significant risk.

3.2.2 Completed Removal Actions

Based on the results of the RFI study, Maine Yankee determined that several focused areas required remediation via soil removal and off-site disposal. These areas include Warehouse 2/3, Construction Transformer, Former Truck Maintenance Garage, and the west side of the radiological area adjacent to MW-401 (**Figure 3-2**). The removal and off-site disposal approach is a proven technology that has been successfully used at the site. The material to be excavated is primarily composed of petroleum and fuel-related VOC-contaminated soils that are readily received at asphalt recycling facilities. Another important factor in choosing the excavation and disposal approach is the availability of on-site equipment that is associated with the site decommissioning activities.

3.2.2.1 Warehouse 2/3

Warehouse 2/3 is located in the southwestern industrial portion of the Maine Yankee site, northwest of the RA (**Figure 3-2**). The warehouse has historically been used to receive and store chemical and materials associated with the operation of the facility. Soil sampling conducted as part of the RCRA Field Investigation (RFI) identified an area of soil contamination located near the southern end of the west side of the warehouse that was associated with paint/paint thinner wastes with low concentrations of polychlorinated biphenyls (PCBs). These chemicals were observed in both shallow and deep soils at this location (Maine Yankee, 2004a).

Based on the soil and groundwater sampling results, Maine Yankee developed a remediation plan for the impacted soils at Warehouse 2/3 (**Appendix C**). The plan was approved by MDEP and the contaminated soils at Warehouse 2/3 were removed in June 2004. Approximately 750 cubic yards of soil were excavated from the area on the west side of Warehouse 2/3. Approximately 500 cubic yards of excavated soil were impacted by VOCs and were shipped for disposal to BFI Niagara Recycling Landfill, Inc., Niagara Falls, NY. The soil was excavated from the ground surface to bedrock approximately nine to 11 feet bgs, consistent with the MDEP-approved Soil Remediation Plan. Additionally, four 55-gallon drums of visible waste paint/soil were segregated for disposal by Clean Harbors, Inc.

A total of 77 soil samples were collected from the sidewalls of the excavation at 10-foot intervals around the excavation, and vertically at two-foot intervals to the base of the excavation. The soil samples were screened using a PID and two samples were collected from each of the four excavation sidewalls with the highest PID readings were analyzed for VOC and PCBs. PCBs were non-detect, except for a single detection of Aroclor 1254 at one location, and all PCBs and VOCs were well below target cleanup levels. The excavation was backfilled with the segregated, clean, soil removed from the excavation and additional clean fill. The excavation area was then graded and seeded to stabilize the soils. The final remediation area for Warehouse 2/3is shown in **Figure 3-3.** The remediation report for Warehouse 2/3 is included in **Appendix C.**

3.2.2.2 Construction Transformer

The Construction Transformer (X-5) is located in the southwestern portion of the Maine Yankee site, immediately south of the 115 kV Switchyard (**Figure 3-2**). The transformer provided a source of additional power during construction of the facility, and during power outages associated with plant maintenance. Currently, the transformer is providing site power for decommissioning activities in the Industrial and RA areas of the Maine Yankee site and Independent Spent Fuel Storage Installation (ISFSI) operations. The RCRA Field Investigation (RFI) identified an area of petroleum-contaminated soil adjacent to the transformer (**Figure 3-4**).

Based on the RFI soil sampling results, the petroleum and PCB contamination in soil is confined to an area approximately 15 feet by 20 feet around the perimeter of the X-5 transformer to a depth of two feet below ground surface. Petroleum hydrocarbons (up to 12, 000 mg/kg) and PCBs (up to 600 µg/kg) have elevated concentrations in surface soils, but soil samples from two feet below ground surface have less than 110 mg/kg petroleum hydrocarbons and non-detect PCB levels. The sampling data demonstrates that the soil contamination is not significantly migrating into the subsurface soils. The lack of significant migration is a function of the minimal water solubility for the heavier petroleum hydrocarbons and PCBs (**Table 3-1**). Since these compounds do not readily dissolve in water, infiltrating rainwater and snowmelt do not readily leach these compounds from the shallow soils and transport the chemicals into the deeper soils and to the water table.

Target soil cleanup objectives are 100 mg/kg as measured by DRO, as based on the MDEP Decision Tree for Baseline 2 sites (MDEP, 2000), and the PCB concentrations are below the TSCA cleanup level of 1.0 mg/kg.

No further action is proposed for the Construction Transformer. The transformer is electrically energized and operating, and provides electricity to the Maine Yankee decommissioning activities and the ISFSI operations. Soil remediation of the transformer would require shutting the transformer down and removing the current transformer foundation, as the petroleum-contaminated soils are adjacent to the foundation material. The transformer could not be de-energized without a significant power outage. The transformer is currently isolated with a six foot high, locked fence that limits access to the transformer area. Maine Yankee is currently negotiating transfer of the property encompassing the Construction transformer.

3.2.2.3 West Side of Radiological Area (MW-401B)

Groundwater sampling results for MW-401B have consistently demonstrated elevated concentrations of petroleum hydrocarbons in groundwater above the State of Maine MEG established for diesel range organics (DRO) (50 µg/l). Monitoring well 401B is screened in the shallow overburden (6 to 16 feet below ground surface) and is located approximately 100 feet west of the Containment Building (**Figure 3-2**). The subsurface soils in the area of MW-401B are comprised of glaciomarine, clayey silts. Groundwater in MW-401B is relatively shallow and has varied from 3.89 to 4.94 feet below ground surface. The groundwater flow direction in this portion of Bailey Point is to the south or southwest (Maine Yankee, 2004a).

DRO concentrations in MW-401B ranged from 2,300 µg/l to 2,410 µg/l based on two sampling events (Maine Yankee, 2004a. Based on the post-RFI soil sampling results, Maine Yankee developed a remediation plan for soils in the western portion of the radiological area adjacent to MW-401B. The plan was submitted to and approved by MDEP. Soil excavation activities were completed in November 2004. Approximately 355 cubic yards of soil were removed from an area 40 feet by 60 feet adjacent to and north of the location of MW-401B (**Figure 3-5)**. No indication of petroleum-contaminated soils was observed in any portion of the excavation, and confirmatory samples from both the sidewalls and base of the excavation were generally non-detect for DRO. Based on these observations, the excavation was backfilled with the excavated soil. A report documenting the soil excavation and sampling activities is included in **Appendix D**.

3.2.2.4 Former Truck Maintenance Garage

The Former Truck Maintenance Garage (FTMG) was located east of the Plant Access Road adjacent to the ISFSI (**Figure 3-2**). The garage was used to conduct maintenance activities on concrete trucks and other vehicles during construction of the Maine Yankee facility. The location of the garage was confirmed by both aerial and project photographs taken during plant construction from 1968 to 1972. The garage was removed prior to operation of the Maine Yankee facility.

To assess the FTMG and the surrounding area, a phased approach was conducted. Initial studies incorporated as part of Phase 1A of the Maine Yankee RFI included the installation of test pit trenches on the east side of the FTMG building and monitoring wells MW-316, MW-303A, and MW-303B (**Figure 3-6**). Additional test pit trenches in the FTMG building footprint and west of the FTMG were excavated and MW-425 was installed on the east side of the FTMG area during Phase 1B RFI sampling (**Figure 3-6**). The Phase 1A and 1B studies demonstrated that petroleum hydrocarbons (PHC) were present in both soil (up to 2,830 mg/kg) and groundwater (up to 650 µg/l) in the FTMG area. Examination of chromatograms associated with the petroleum hydrocarbons (PHC) analysis indicated that the PHC-impacted soil was associated with lighter, diesel-range constituents, as opposed to the heavier PHC observed at other locations on Bailey Point. The soil sampling activities also identified three areas of PHC-impacted soil; one located on the north side of the FTMG building, and two areas approximately 100 feet east of the FTMG building (**Figure 3-6**). To support the Corrective Measures Study (CMS) for PHC-impacted soils in the FTMG area, a soil sampling and analysis plan was developed for the FTMG (FTMG Investigation Plan). The plan was submitted to MDEP and approved on September 20, 2003. The study included the installation of geoprobe borings, continuous soil sampling to the water table, field screening using a PID, and the use of an on-site field analytical laboratory.

The results of the geoprobe sampling study are reported in **Appendix E**. The geoprobe investigation conducted in the FTMG area has confirmed three areas of PHC-impacted soils. The concentration of PHCs at each of the three locations exceeded the 100 mg/kg MDEP cleanup criteria established for Baseline 2 (MDEP, 2000). Kerosene-contaminated soils were present in shallow glaciomarine soils adjacent to the north side of the FTMG building location. The kerosene PHCs were also detected in shallow glaciomarine soils directly below fill material (**Figure 3-6**). The soils were visibly stained and included a 30-foot by 30-foot area four to six feet thick. This zone of PHC-impacted soil represents approximately 200 cubic yards of PHC-impacted soil. Deeper PHC-impacted soil was also present in thin sand lenses at or near the water table, but the soil volume associated with the sand lenses was insignificant compared to the volume of PHC-impacted shallower soils. The source of the deeper PHCs present in the thin sand lenses was the shallow PHC–impacted soils present above the deeper sand lenses.

Two areas of PHC-impacted soil were also confirmed in shallow glaciomarine soils approximately 100 feet east of the FMTG building (**Figure 3-6**). In contrast to the kerosene PHCs observed adjacent to the FTMG building, the PHC-impacted soils east of the FTMG building are consistent with diesel fuel. Each of the two shallow areas of diesel PHC-impacted soil have approximately 90 cubic yards (20 feet by 20 feet, 6 feet thick) giving a total of 180 cubic yards of PHC-impacted soil. PHCs were also observed in the deeper, thin sand lenses at or near the water table. Consistent with the deeper PHCs associated with the kerosene-impacted soil, the volume of PHC-impacted soil present in the deeper sand lenses was insignificant when compared to the volume of PHC-impacted shallow glaciomarine soils. The source of the deeper PHC contamination present in the thin sand lenses was the shallow PHC contamination present above the deeper sand lenses.

Based on the results of the geoprobe investigation, a soil remediation plan was submitted to and approved by MDEP. Soil removal activities at the FTMG were initiated on July 14, 2004 and completed on August 9, 2004. Soil removal was conducted using a track-mounted John Deere 892 excavator with a 1.5-yard bucket. Soil was excavated from the three soil contamination areas using the excavator and placed in a large dump truck that was used to stockpile the excavated soil. A total of approximately 730 cubic yards of soil was removed from three excavations. The soil in the three areas was excavated from the ground surface to depths ranging from six to nine feet below ground surface, consistent with the MDEP-approved Soil Remediation Plan (**Figure 3-7**). The contaminated soil was shipped to Commercial Recycling Systems in Scarborough, Maine.

A total of 182 soil samples were collected from the sidewalls of the excavations at 10-foot intervals around each excavation, and vertically at two-foot intervals to the base of each excavation. Two samples were also collected from the base of each excavation. The soil samples were screened using a PID and two samples from each of the sidewalls and one sample from each end of the excavations with the highest PID values were collected for laboratory analysis. Two soil samples from the base of each excavation were also included for laboratory analysis. The soil samples were analyzed for DRO using MDEP Method 4.1.25. Several focused areas of elevated DRO were identified based on the initial confirmatory samples. Follow-up soil excavation was conducted to remove the focused areas of petroleum-contaminated soil associated with each excavation. Additional confirmatory soil samples were taken from the areas of follow-up soil removal and analyzed for DRO. Average values of DRO were calculated for each of the three excavations, and all average DRO values were less than 58 mg/kg, consistent with the MDEP Decision Tree guidance of 50 to 100 mg/kg DRO (MDEP, 2000).

Following the soil removal activities at the FTMG, oxygen release compound (ORC) was spread along the base of each of the three excavations. The ORC was utilized to remediate the DRO that was present in the deeper sand lenses at or near the water table. The remediation plan and a report documenting the soil remediation activities are included in **Appendix E**.

3.2.3 Residual Petroleum-Impacted Soils

In addition to the completed and planned soil remediation areas, results from the Bailey Point RFI identified petroleum-containing soils in locations on Bailey Point. Typically, these areas have petroleum hydrocarbons ranging from at or near the detection level (1 to 20 mg/kg) to values in excess of 100 mg/kg(Maine Yankee, 2004a). As described in all soil remediation plans submitted to and approved by MDEP, the petroleum soil removal activities completed to date have used 100 mg/kg as the target cleanup level. Based on that approach, residual petroleum hydrocarbons with concentrations less than 100 mg/kg are present in those areas where petroleum remediation has been conducted. Although the petroleum hydrocarbons present in these locations are consistent with the commercial/industrial cleanup standard approved by MDEP for the site, they exceed the 10 mg/kg cleanup standard established in the MDEP Decision Tree Guidance for stringent cleanup (MDEP, 2000). The stringent cleanup standard is established to be protective of both groundwater used as a source for drinking water, and for residential soil exposure (MDEP, 2000). A summary of the 18 locations on Bailey Point with petroleum concentrations in soil in excess of the 10 mg/kg Stringent cleanup standard and an estimate of the volume of soil in excess of 10 mg/kg of petroleum hydrocarbon are presented in **Table 3-3.**

3.2.4 Potential Groundwater Remediation Areas

Groundwater contamination at the Maine Yankee site includes both site-wide contaminants and focused areas of compound-specific contamination. DRO and metals (sodium, iron, and manganese) occur across the Site, while VOCs are focused on both the east and west sides of Warehouse 2/3. Paint-related solvents (ethylbenzene, xylenes, and toluene) occur in shallow groundwater on the west side of Warehouse 2/3 (see **Section 3.2.2.1**), and chlorinated-VOCs (1,1,1-trichloroethane and degradation products) are present in shallow groundwater on the east side of Warehouse2/3. The following sections summarize the groundwater contamination for both the site-wide contaminants and the focused areas of groundwater contamination.

3.2.4.1 VOCs on West Side of Warehouse 2/3

On the southwest corner of Warehouse 2/3, paint derivatives (ethylbenzene, xylenes, and toluene, among others) were discovered in relatively high concentrations in surface and subsurface soils (see **Section 3.2.2.1**). The fate and transport behavior of the paint-related VOCs in soil has resulted in high concentrations of the VOCs in soils at the soil/bedrock interface, and elevated concentrations of xylenes and ethylbenzene in the shallow bedrock groundwater directly downgradient of the soil contamination. Based on groundwater contours developed from groundwater elevation measurements, it appears that groundwater in this area is moving westerly towards Bailey Cove (**Figure 3-8**).

Currently, ethylbenzene exceeds the MEG of 70 µg/l in MW-404, and vinyl chloride exceeded the MEG of 0.2 µg/l in the second round of MW-405 testing, but was non-detect in the first sampling round. Other VOCs present were benzene, xylenes, and toluene. These VOCs have relatively high water solubilities and low Koc values and readily partition into groundwater (Ney, 1995) (**Table 3-1**).

Petroleum hydrocarbons, such as benzene, xylenes, and toluene, are biodegraded via biological oxidation when electron donors and electron acceptors are combined to produce energy for microbial growth (and metabolic byproducts). The petroleum hydrocarbons serve as the electron donor in microbial metabolism. Electron acceptors in groundwater systems typically include dissolved oxygen, nitrate, manganese (IV), iron (III), sulfate, and carbon dioxide. Carbon dioxide, water, nitrogen gas, manganese (II), iron (II), hydrogen sulfide, and methane are some of the metabolic byproducts typically produced from the biodegradation of petroleum hydrocarbons. The biodegradation of petroleum hydrocarbons is mainly limited by electron acceptor availability, and will proceed until all of the contaminants that are biochemically accessible to the microbes are oxidized (Wiedemeier, et.al, 1995).

Monitoring wells MW-404 and MW-405, located downgradient of the VOC soil contamination has 1.8 mg/l to 4.3 mg/l of dissolved oxygen and total iron and manganese concentrations up to 43.5 mg/l and 16 mg/l, respectively (Maine Yankee, 2004a). The presence of the large concentrations of dissolved iron and manganese and the dissolved oxygen indicates that iron (III) and manganese (IV) and dissolved oxygen are functioning as electron acceptors resulting in the biodegradation of the petroleum hydrocarbon compounds.

These VOCs are present in the unsaturated soil nearby and we expect that once the source is removed (see **Section 3.2.2.1**), the VOC and related parameter concentrations will decrease to background concentrations via biodegradation and natural attenuation processes.

3.2.4.2 Chlorinated VOCs on East Side of Warehouse 2/3

Maine Yankee historically stored trichloroethane (TCA), a solvent, in 55-gallon drums at Warehouse 2/3. A leaking drum of TCA reportedly resulted in a small amount of TCA released to the ground on the east side of Warehouse 2/3. Although very little residual soil contamination by TCA remains, there is an identifiable TCA plume in the bedrock groundwater (**Figure 3-9A**). The upgradient portion of the impacted area is defined by MW-420, while the downgradient area of the plume is defined by MW-422A/B, MW-423A/B, and MW-429 (**Figure 3-9A**). The lateral plume boundaries are determined by MW-421 and MW-407A/B (**Figure 3-9A**). The center portion of the plume is determined by MW-311 and MW-409A, while the historic source area is characterized by MW-408 (**Figure 3-9A**).

Soils in the historic source area were characterized by a geoprobe soil sampling study that determined that little or no VOCs were currently present in the former source area. The lack of significant residual TCA in soil adjacent to the east side of Warehouse 2/3 is a function of the relatively low Koc and high solubility for TCA which have enhanced the effectiveness of leaching and infiltration processes. The TCA has migrated through the overburden soils via infiltration processes, and has degraded groundwater quality in the shallow bedrock aquifer. The observed concentrations of TCA and other chlorinated VOCs is well below the solubility concentration, indicating only the presence of a dissolved phase, and no separate dense non-aqueous phase liquid (DNAPL). A DNAPL would only be indicated when TCA concentrations in groundwater were within 1% of the solubility limit (9,500 µg/l). The highest observed TCA concentration is 670J µg/l, orders of magnitude below the 1% solubility value.

In addition to TCA, the monitoring wells also have daughter compounds 1,1 dichloroethane (1,1-DCA), 1,1-dichloroethene (1,1-DCE), and vinyl chloride (VC) associated with the reductive de-chlorination and abiotic degradation of TCA (McCarty, 1997). TCA degrades to these daughter compounds once dissolved in groundwater. Thus, monitoring wells near the source area would be expected to have a high ratio of TCA to degradation compounds, and monitoring wells downgradient of the source would be expected to have lower ratios. **Figures 3-9A, B and C** show overlays of contoured 1,1-DCA, 1,1-DCE, and VC groundwater concentrations relative to contours of TCA. The center of the TCA plume is on the east edge of Warehouse 2/3, the known source area for the TCA release(s). The centers of the 1,1-DCA, 1,1-DCE and VC plumes are shifted at least as far south as MW-409A, and possibly farther. The State of Maine MEGs for the four constituents of concern in this plume are 200 µg/l for TCA, 70 µg/l for

1,1-DCA, 0.6 μg/l for 1,1-DCE, and 0.2 μg/l for VC. MEGs are exceeded for all four parameters but by the largest magnitude with 1,1-DCE where the concentration at MW-409A is 190 μg/l.

Monitoring well MW-408 is located in the vicinity of the former drum handling area and has the highest TCA concentration and TCA ratio to degradation compounds. Both MW-311 and MW-409A have lower TCA concentrations and lower TCA to degradation compound ratios. These observations indicate that the source area for the TCA is in the former drum handling area adjacent to the northeast corner of the warehouse. The TCA has migrated via infiltration into the thin soils and shallow bedrock in this area, resulting in the observed region of groundwater contamination along the east side and to the south of Warehouse 2/3. As TCA has dissolved into the site groundwater in the source area, degradation reactions in the shallow bedrock groundwater have resulted in a decrease of TCA and an increase of DCA, DCE, and VC over time, most prominent at MW-409A.

The transformation of TCA to the daughter compounds provides one line of evidence that the TCA is undergoing natural degradation in the environment, and as demonstrated in many recent cases, will ultimately result in natural attenuation (McCarty, 1997). Other important lines of evidence of natural degradation include the presence of electron acceptors, electron donors, and the oxidation state of the groundwater.

The degradation pathways for 1,1,1-TCA includes reductive dechlorination:

1,1,1-TCA → 1,1-DCA → Chloroethane → Ethane,

and the abiotic transformation to 1,1-DCE. 1,1-DCE will degrade to VC via reductive chlorination, or oxidize to CO_2. Similarly, VC will degrade via reductive dechlorination to ethene or oxidize to CO_2. Oxidative degradation of 1,1-DCA and chloroethane to CO_2 is also possible (USEPA, 1999). Reductive dechlorination is most efficient under reducing conditions, and with the more chlorinated species. Oxidative degradation occurs most effectively under more oxidizing conditions and with the lower chlorinated compounds (McCarty, 1997).

To assess the oxidation state and the degradation conditions of the aquifer in the vicinity of Warehouse 2/3, parameters associated with natural attenuation including electron acceptors (nitrate and sulfate), compounds indicative of electron acceptors ($Fe^{2+}$and methane), and additional degradation compounds (ethane and ethene) were analyzed in groundwater samples from the Warehouse 2/3 area including MW-408, MW-409A, MW-407A, MW-429, ME-422A, and MW-423A (**Table 3-3**). Oxygen reduction potential (ORP) and dissolved oxygen (electron acceptor) were also measured in the field at each of the monitoring wells (**Table 3-3**). Sulfate is present at all of the monitoring wells (21 mg/l to 64 mg/l) and nitrate is present at all of the wells except MW-409A and MW-407A. Methane was not detected in any of the wells. The data indicate that the greatest reducing conditions occur at MW-409A, where low values of ORP and dissolved oxygen and non-detect nitrate levels occur, along with elevated concentrations of Fe^{2+}, relative to that observed in the other monitoring wells. The iron reducing conditions observed at

MW-409A are correlated with the highest concentrations of daughter compounds and indicate that reductive dechlorination of 1,1,1-TCA is occurring. The continued reductive dechlorination of 1,1-DCE and 1,1-DCA would be expected to produce VC, chloroethane, ethane, and ethene in wells downgradient of MW-409A. These compounds are not detected in the downgradient monitoring wells, and the aquifer conditions are indicative of a more oxidizing environment as indicated by the lack of Fe^{2+}, measurable nitrate, and greater ORP and dissolved oxygen concentrations (**Table 3-3**). The highest concentration of 1,1,1-TCA in the monitoring wells downgradient of MW-409A (MW-422A and MW-423A) is 6 μg/l, and 1,1-DCA and 1,1-DCE have concentrations less than 1 μg/l in the downgradient wells. These observations indicate that downgradient of MW-409A the predominant degradation process is oxidation of 1,1-DCE and 1,1-DCA to CO_2 and chloride. The reductive and oxidative degradation processes have resulted in significant natural degradation and attenuation of the chlorinated compounds to concentrations below the State of Maine MEGs in the downgradient monitoring wells.

3.2.4.3 Metals on Bailey Point

There are several groundwater regimes on Bailey Point including the upper regime that encompasses the phreatic surface and a deep bedrock regime. Flow generally moves perpendicular to ground surface topography in the soils and shallow bedrock. In the deeper bedrock, flow is generally down the axis of the peninsula from north to south. As bedrock flow approaches the edge of the shore, it turns toward it and flows upward to discharge in the nearshore area.

Iron, manganese, and, to a much lesser extent, arsenic are naturally occurring geologic materials that have dissolved into the groundwater. The metal solubility is a function of Eh-pH conditions that occur at the site and the biodegradation of organic material. The Eh-pH conditions of the site have been established by the burying of former organic marsh deposits with marine dredge spoils, by the presence of petroleum spills and VOC spills, and by other oxygen-consuming contaminants. These metals are not likely to become lower in concentration with time. Molybdenum is more complicated and may have exceeded the State of Maine MEG over a large area of Bailey Point due to a possible combination of having entered the groundwater through petroleum lubricants containing molybdenum and a natural occurrence from minerals in the granite and pegmatite bedrock.

Another contaminant source on the site is residual sodium that is moving from the solid phase to the liquid phase and degrading the groundwater quality. This sodium has a number of sources on the site and occurs broadly over the site in concentrations exceeding the State of Maine MEG.

Iron and Manganese

The distribution of iron and manganese in groundwater across Bailey Point is illustrated on **Figures 3-10A/B and 3-11A/B**, which are isocon maps of the total iron and manganese in the Bailey Point groundwater. Although the State of Maine does not have a standard for iron in groundwater and there is no MCL for iron, the USEPA PRG for iron (11 mg/l) is exceeded in the north-central and northwestern portion of Bailey Point. The State of Maine MEG for manganese is 0.5 mg/l, and much of the Bailey Point groundwater exceeds the MEG. The highest manganese concentrations are coincident with the highest iron concentrations in the northwestern portion of Bailey Point (**Figures 3-10A/B and 3-11A/B**). The source of iron and manganese in groundwater is the natural geologic materials.

Both iron and manganese occur in several valence states that typically are a function of the redox potential of the environment. Iron occurs as Fe^{2+} or Fe^{3+}, while Manganese occurs as Mn^{2+}, $Mn^{3+}$and Mn^{4+}. For both iron and manganese, the divalent species (Fe^{2+} and Mn^{2+}) are readily dissolved in water, while the more oxidized forms of iron and manganese are typically stabilized in solid phases (Hem, 1985). The distribution of iron and manganese in groundwater is typically controlled by the presence of iron- and manganese-bearing hydrous oxide minerals (i.e., limonite, goethite, and MnOOH), and the pH and redox potential established in the groundwater.

The Eh-pH conditions of the northern portion of the site have developed as a function of the history associated with this portion of the site. This northern area of Bailey Point is a former salt marsh and wetland area that was filled with primarily excavated soil and dredge spoils. As the organic material associated with the salt marsh and wetland decayed beneath the fill material, pH was decreased by the formation of organic acids, and oxygen was consumed by the degradation of the organic material, resulting in both a reducing and low-pH environment. These Eh-pH conditions gave rise to significant solubilities for iron and manganese, and naturally occurring iron and manganese in the soils occurring in hydrous oxide minerals have dissolved into the groundwater. The zone of very high iron and manganese concentrations in the northern portion of Bailey Point coincides with the known location of the former salt marsh under the dredge spoils fill area. Based on these conditions, iron and manganese are not likely to decrease in concentration in this area in the foreseeable future.

Locally, iron and manganese concentrations can also be high in the vicinity of organic fill (such as the area of construction demolition debris placed under the 345 kV transmission lines) and near releases of petroleum or fuel-related VOCs. Elevated concentrations of fuel-related VOCs (ethylbenzene, xylenes, and toluene) occur in MW-404 adjacent to Warehouse 2/3, and both manganese and iron are elevated in this monitoring well. The oxidative degradation of the fuel-related VOCs often will result in a decrease of the redox potential of the local environment and dissolve iron and manganese from natural geologic materials.

Molybdenum

Molybdenum is a constituent of petroleum-based lubricants, it is part of some steel alloys (such as high strength tools and high temperature steel), and it can occur naturally. The natural occurrence of molybdenum is typically in aplites or pegmatites associated with the water-rich fluids that occur during the late stages of the crystallation of some granites. The molybdenum-bearing minerals associated with the late-stage aplites and pegmatites include molybdenite (molybdenum sulfide), powellite (calcium molybdate) and wulfenite (lead molybdate). Molybdenite has been identified in the Tunk Lake area of Maine and in southwestern New Brunswick, but there is no literature describing its occurrence in the Wiscasset area (Yang *et al.*, 2003).

The State of Maine MEG for molybdenum is 35 µg/l. The range of molybdenum in Maine Yankee groundwater is non-detect to 3,170 µg/l. **Figures 3-12A** and **3-12B** show the distribution of molybdenum on Bailey Point. Although the number of data points in the middle of Bailey Point is small, the contouring of the most recently collected sample data suggests a large area of Bailey Point exceeds the MEG for molybdenum.

Most of the monitoring wells with elevated molybdenum are screened in bedrock that is commonly granite or aplite/pegmatite-rich granite. Similarly, shallow-deep paired wells typically have much higher molybdenum concentrations in the deep well that is screened in bedrock relative to the shallow well screened in the overburden (e.g., MW302A/B, MW303A/B, MW 304A/B, and MW305A/B). These relationships indicate the potential for a natural source of the molybdenum (Maine Yankee, 2004a).

Sodium

Figures 3-13A and **3-13B** show the distribution of sodium in groundwater. Because of all the sources for sodium, most of Bailey Point has groundwater with sodium concentrations exceeding the MEG. The highest concentrations are in the northwest portion of the Point, coincident with the high iron and manganese concentrations and related to the filling of marine dredge spoils in that area. In areas of Bailey Point away from potential sodium sources, concentrations are typically in the 10 mg/l to 25 mg/l range (Maine Yankee, 2004a). The gradual purging of the groundwater of high sodium is taking place from east to west in the shallow wells in the fill, as groundwater in that fill is generally flowing from east to west. The State of Maine MEG for sodium is 20 mg/l, which is relatively close to background values of sodium that would normally occur in wells within about 100 feet of the ocean in Maine (Hem, 1985, Gerber, 1986 and Gerber and Rand, 1982).

Miscellaneous Metals

There were isolated exceedences of MEGs and MCLs of some additional metals in the Bailey Point groundwater, including aluminum, arsenic, boron, lead, silver, and thallium.

Aluminum and arsenic are most likely derived from natural geologic materials. MEG exceedences for both parameters are less than three times the respective standard. Arsenic is well known in metasedimentary rocks of Maine as a naturally occurring contaminant. It is often elevated in areas affected by petroleum spills or decaying organic deposits that produce low oxygen and reducing conditions. Aluminum is very abundant in soils and rock. Where monitoring wells are located in clayey soils or broken rock zones, aluminum-bearing minerals can be transported into the well in colloidal form. Both acidic and basic conditions favor the dissolution of aluminum, with the lowest aluminum concentrations associated with more neutral pH conditions. Elevated aluminum was found in wells with high pH as well as wells with pH below 7, suggesting a pH control on the elevated aluminum groundwater concentrations in lower and higher pH samples (Maine Yankee, 2004a).

Boron is a natural constituent of seawater. Elevated boron concentrations were observed in groundwater in the northwestern corner of Bailey Point, under the 345 kV line (Maine Yankee, 2004a). These elevated boron levels are associated with high sodium in that area, which was derived from the seawater that formed the pore water of the deposited, dredged marine sediments in this area. The presence of elevated boron concentrations in this area is consistent with the presence of the marine sediments, and will eventually flush from the system (see Section 5.3.1.5 for discussion of boron flushing).

A single lead exceedence of the MCL occurred at MW-305A located in the northern portion of Bailey Point downgradient of the current ISFSI. The detected lead concentration in MW-305A was 18.6 µg/l relative to the MCL of 10 µg/l. There is no known or suspected source of lead contamination at this location, and other monitoring wells in the area do not have elevated lead concentrations (Maine Yankee, 2004a). Silver exceeded its MEG (49.9 versus 35 µg/L) only from MW-405 (southwest corner of Warehouse 2/3). Small concentrations of silver were found in some of the soil samples in this area next to Warehouse 2/3, but not enough to draw any connections. Thallium was found at MW-313 (2.9 µg/L) and MW-322 (3.3 µg/L) to slightly exceed the MEG (0.5 µg/L). Concentrations ranging from 1.4 µg/ to 1.9 µg/l were observed in the reference wells located in the Backlands, but follow-up sampling of those same Backland wells had non-detect thallium concentrations (Maine Yankee, 2004b). There are no known sources of thallium on the site and other monitoring wells in the vicinity of MW-322 and MW-313 were either non-detect for thallium or had thallium concentrations less than 1 µg/l (Maine Yankee, 2004a).

Based on the limited distribution and lack of a site-related source of lead, silver, and thallium, no additional sampling is planned for these constituents.

3.2.4.4 DRO on Bailey Point

The most prevalent groundwater contaminant on the Maine Yankee site is petroleum hydrocarbons. Numerous lubricant and fuel spills have been documented, and all of the identified spills have been and will be remediated to an industrial standard according to the MDEP Decision Tree (MDEP, 2000). The distribution of DRO on Bailey Point is shown on **Figure 3-14**. The highest DRO concentrations in groundwater occur in the 345 kV silt spreading area and in the western portion of the RA area (**Figure 3-14)**

The solubility of petroleum hydrocarbons in groundwater is a function of the size or carbon number of the specific petroleum hydrocarbon mixture, and decreases with increasing carbon number for both aliphatic and aromatic petroleum hydrocarbons (**Table 3-1**). Aromatics with the same carbon number as aliphatics typically have water solubilities two to three orders of magnitude greater than the corresponding aliphatics (**Table 3-1**). Similarly, the Koc for aromatics is two to three orders of magnitude lower than that for aliphatics of the same carbon number (**Table 3-1**). These relationships indicate that aromatics will be preferentially leached from DRO-contaminated soils, and that groundwater concentrations in excess of 500 µg/l are mostly composed of aromatics due to the limited solubility of aliphatic fractions (solubility of total aliphatic fraction C8-C21 is less than 500 µg/l). Once dissolved in groundwater, the petroleum hydrocarbons will biodegrade oxidatively if a source of oxygen or other electron acceptor is available.

The highest concentrations of DRO were found in the northern portion of Bailey Point at several locations including the north end of the 345 kV switchyard, wells to both east and west of the former concrete truck maintenance garage, the area from the northern side of the ISFSI to the reflecting pond, and the northwestern portion of the fill under the 345 kV line area. Concentrations are typically in the range of several hundred micrograms per liter. Based on simple linear interpolation contouring, most of Bailey Point appears to have groundwater concentrations greater than 50 µg/l DRO.

The DRO distribution shown on Figure 3-12 demonstrates that most of the RA and Industrial Area has relatively high concentrations of DRO, most of which are in the hundreds of micrograms per liter. The highest observed concentration of DRO in the RA is MW-401B (2,350 µg/l of DRO). Two petroleum sources were identified in deep fill material in the RA: 1) in the PAB alleyway in November 2002 (the contaminated soil was removed in December 2002), and 2) in deep fill material south of the Spray building (contaminated soil removed during removal of the PCC/SCC piping in April 2004). These sources have likely contributed to elevated DRO groundwater concentrations in several adjacent and downgradient wells (MW-312, B-202, B-205, and B-206), but are not sources for the elevated DRO observed in MW-401B (Maine Yankee, 2004a).

Another area with relatively high DRO concentration is just west and downgradient of the area of the kerosene spill that originated at the spare generator enclosure. MW-413 had 1,700 µg/l of DRO (Maine Yankee, 2004a). MW-414 to the north of MW-413, but probably unrelated as to source, had a DRO concentration of 940 µg/l. MW-413 is apparently measuring the residual effects of the kerosene leak. The chromatogram of MW-413 indicates a relatively fresh source consistent with the kerosene as a source, compared with the chromatograms of most other samples, which are indicative of older, more degraded sources. One other relatively high DRO result was found in MW-318 (930 µg/l), which is located just southeast of the area of the main transformer where transformer oil was released as a result of the failure of the Maine Transformer in 1991.

Because many of the petroleum sources may be somewhat dispersed, limited in size, and associated with the construction activities during the 1960 and early 1970s, most of the readily leachable fraction of petroleum has most likely been removed from the original source material and dissolved in groundwater. Additional leaching of petroleum hydrocarbon constituents to the groundwater is expected to be slow, but relatively constant.

An important factor in the distribution of DRO in groundwater is the potential for natural biodegradation. Petroleum hydrocarbons, such as DRO, are biodegraded via biological oxidation when electron donors and electron acceptors are combined to produce energy for microbial growth (and metabolic byproducts). The petroleum hydrocarbons serve as the electron donor in microbial metabolism. Electron acceptors in groundwater systems typically include dissolved oxygen, nitrate, manganese (IV), iron (III), sulfate, and carbon dioxide. Carbon dioxide, water, nitrogen gas, manganese (II), iron (II), hydrogen sulfide, and methane are some of the metabolic byproducts typically produced from the biodegradation of petroleum hydrocarbons. The biodegradation of petroleum hydrocarbons is mainly limited by electron acceptor availability, and will proceed until all of the contaminants that are biochemically accessible to the microbes are oxidized (Wiedemeier, et.al, 1995).

Recent groundwater sampling to support the CMS has demonstrated that significant concentrations of electron acceptors and metabolic byproducts are present in groundwater across the Site (**Table 3-2**). The presence of both electron acceptors and metabolic byproducts indicates that natural biodegradation of dissolved DRO is occurring in groundwater.

4.0 TECHNOLOGY SCREENING AND ALTERNATIVE DEVELOPMENT

This section identifies and screens applicable technologies, and develops remedial alternatives for remediation of soil and groundwater associated with the Maine Yankee site. This process was completed in accordance with USEPA Guidance (USEPA, 1988), and included identifying those technologies that attain the corrective measure objectives identified in **Section 3.1** of this report. The result of the screening and alternative development is a list of potential remedial technologies that can be combined to form a range of corrective measure alternatives.

The demonstrated performance and applicability of each technology is established by considering site and waste characteristics. Site characteristics include site geology, hydrogeology, availability of space, and resources necessary to implement the technology. Waste characteristics include contaminated media, types and concentrations of waste constituents, and physical and chemical properties of the waste (e.g., oxidation/reduction state, solubility, and mobility).

The technology screening process reduces the number of potentially applicable technologies by evaluating each technology as to its:

- Effectiveness in providing protection to human health and the environment, and to the reduction in toxicity, mobility, or volume of the waste;
- Implementability, as a measure of both the technical and administrative feasibility of constructing, operating, and maintaining a remedial technology; and
- Cost, as compared among technologies.

Technically feasible technologies passing this initial screening process are grouped into potential remedial alternatives that will be evaluated in **Section 5.0**.

4.1 Technology Screening and Alternative Development for Soils

The nature and extent of contaminants of concern in Bailey Point soils limit the range of cost-effective remedial alternatives. Overall, source removal has been identified as the preferred technology for the majority of areas of concern. This is due to a number of factors including:

- Readily available excavation equipment currently mobilized;
- Cost-effective Disposal contracts in place;
- Co-mingling of soils impacted with radiological constituents with soils impacted with non-radiological constituents;
- Decommissioning Schedule; and
- Nature of Contaminants of Concern (i.e., DRO, PAHs).

Based on the above considerations, soil removal and offsite disposal has been the primary technology employed at the site. A description of the specific soil removals that have been implemented is summarized above in **Section 3.2.1** Areas Closed Out (Bailey

Farmhouse, Outfall 9, Forebay and ISFSI), and **Section 3.2.2** Completed Removal Actions (i.e., Warehouse 2/3, Former Truck Maintenance Garage, and West Side of the Radiological Area). While the areas closed out and the completed and planned removal actions have had a target cleanup concentration of 100 mg/kg DRO, these areas and other locations across Bailey Point have DRO concentrations in excess of the Stringent MDEP Decision Tree concentration of 10 mg/kg. The primary contaminant of concern in these areas is DRO. The primary objective for remediation would be to reduce the volume and concentration of the source(s) to both reduce the source to groundwater contamination and minimize the potential for exposure to surface and subsurface soils. A summary of these areas is included in **Table 3-3**.

4.1.1 Identification and Screening of Applicable Technologies for Soil

Because of the potential volume and depth of impacted soils, it is appropriate to evaluate technologies other than removal and offsite disposal. The primary technologies that have been identified include:

Institutional Controls - This would include limiting exposure to impacted soils through use restrictions placed on the property deed and municipal zoning. Use restrictions would apply to both soil and groundwater and are discussed below under **Section 4.4**.

Soil Removal - Soil removal would include excavation followed by offsite disposal or onsite treatment. This has been the primary remedial technology implemented at the site to date to address RCRA areas of concern. The reason being is the readily available equipment and relative cost effectiveness compared to insitu treatment or containment options given the nature of predominately petroleum-contaminated soil present at the site.

The following two technologies are potentially applicable. However, they have been screened out due to their relative technical and cost effectiveness compared to the technologies described above:

Insitu Oxidation - Insitu oxidation is the process of enhancing contaminant degradation by introducing oxygen to subsurface soils. This would include addition of an oxygen-releasing compound in conjunction with soil removal or as a separate technology.

Bioremediation/Land Farming - This technology would include onsite landfarming of impacted soils following removal. Landfarming would entail removal, addition of nutrients (e.g., fertilizer) and periodic tilling to keep soils aerated.

Solidification/stabilization: Solidification through the addition of pozalanic materials has been eliminated since it would be more costly without greater effectiveness at achieving remedial goals.

Containment/Capping: This would include a clay or asphalt cap to reduce infiltration. This has been screened out based on the lack of effectiveness at achieving remedial goals.

Thermal Technologies: Both low temperature and high temperature thermal, as well as, asphalt batching would be significantly more costly than soil removal without providing increase effectiveness at meeting remedial goals.

Other technologies such as soil flushing, vitrification, and steam stripping are potentially applicable to the contaminants of concern. However, these technologies are substantially more expensive than the technologies considered without increased benefit. Therefore, they have not been considered. Phyttyoremediation, which is the use of select plants and trees to remediate contamination in soils and groundwater, could potentially have some application. However, phytoremediation can be dismissed based on the very low likelihood of increased effectiveness over technologies considered, as well as the extended timeframe for implementation in comparison to the Maine Yankee Decommissioning schedule.

4.1.2 Development of Soil Remedial Alternatives for Bailey Point

The technologies that have been carried forward include soil removal and offsite disposal. The alternatives that have been developed for soil include the following:

Alternative Soil-1: No Additional Action with Institutional Controls to manage future land use.

Alternative Soil-2: Excavation to target cleanup level of 10 mg/kg and offsite disposal of petroleum-contaminated soil.

4.2 Technology Screening and Alternative Development for Groundwater

The groundwater contaminants in groundwater at the Maine Yankee site include VOCs (both chlorinated and non-chlorinated), DRO and metals. The technology screening and alternative development for groundwater recognizes that the three classes of contaminants are present in site groundwater.

4.2.1 Identification and Screening of Applicable Technologies for Groundwater

Table 4-1 identifies general response actions and potential remedial technologies for groundwater at the Maine Yankee site. The general response actions for groundwater include the following:

- No Further Action,
- Institutional Action,
- Groundwater Monitoring,

- Groundwater Collection,
- Groundwater Treatment, and
- Groundwater Disposal

Technology screening is presented in **Table 4-2**. Technologies judged not effective or implementable were eliminated from further consideration. The No Further Action response action was retained as a baseline for comparison for other potential alternatives.

One technology was retained under the Institutional Action response. Institutional Controls include the use of restrictive covenants, fencing, or permits to limit use and exposure to contaminated groundwater and may be used alone or in combination with other alternatives where contaminants remain onsite.

Groundwater monitoring was retained under the Environmental Monitoring general response action. Numerous monitoring wells are currently located at the Maine Yankee site and would be available to be incorporated into a groundwater monitoring program.

Under the Groundwater Collection response action both collection trenches and extraction wells were retained. The collection trenches would be used for the low permeability glaciomarine soils where extraction wells would be ineffective. Extraction wells would be utilized in the bedrock and portions of the overburden that are more sand-rich and have greater permeability.

A number of potential treatment technologies were screened under the Ex Situ Groundwater Treatment response action. Air stripping, UV/oxidation, and Publicly Owned Treatment Works (POTW) were eliminated based on their ineffectiveness on the specific groundwater contaminants. While air-stripping and UV/oxidation would be effective for the VOCs in groundwater, the heavier petroleum hydrocarbons would not be removed by the technologies. Due to combination of metals and organics present in groundwater, the POTW approach would also not be effective. Due to the high concentration of iron and manganese in the groundwater, precipitation/flocculation/oxidation and microfiltration technologies were retained to remove these contaminants as a pre-treatment option before the organic treatment. Reverse osmosis was retained for the removal of sodium. Carbon absorption was retained, as it is the most effective treatment option for the dissolved petroleum hydrocarbons present in site groundwater and would also be effective for the minor VOCs present as well.

Due to the low permeability of the soil and bedrock across the site, all of the in situ treatment technologies were eliminated except for natural attenuation.

The disposal options that were retained include groundwater discharge and surface water discharge. The POTW technology was eliminated due to the potential long-term operation of the treatment system, uncertainties associated with the POTWs ability to receive the treated water into the future, and the likely need to pre-treat the water.

4.2.2 Development of Groundwater Remedial Alternatives

This section of the CMS presents four remedial alternatives that were developed for the VOC, DRO, and metal contamination in Site groundwater. The alternatives are developed based on the screening evaluation completed in Section 4.2.1 and **Table 4-2**. The major technical components of the alternatives are summarized in **Table 4-3** and are described below.

Alternative GW-1: No Further Action/Institutional Controls. The alternative consists of no remedial activities, and represents the minimum proposed remedial action for groundwater. Institutional controls would be implemented to prevent future groundwater use, as public water is currently available at the Site.

Alternative GW-2: Long-Term Monitoring/Institutional Controls. This alternative would provide for a long-term groundwater monitoring plan to document natural attenuation of groundwater contaminants. The natural attenuation processes (e.g., abiotic degradation, biodegradation, dispersion, sorption, and dilution) would gradually reduce contaminant concentrations in groundwater to below MCLs and MEGs. An environmental monitoring plan would be developed to verify the continued effectiveness of the alternative. Institutional controls would be implemented to restrict future groundwater use, as public water is currently available at the Site.

Alternative GW-3: Groundwater Extraction and Treatment/Institutional Controls. This alternative would capture and extract contaminated groundwater around the Maine Yankee site. The capture and extraction of contaminated groundwater would be accomplished using a combination of overburden and bedrock wells and shallow extraction trenches. The extracted groundwater would be treated onsite in a multi-stage system to meet drinking water quality regulations, and then discharged back into the ground in the soil on the site. The treated groundwater would be discharged to infiltration trenches located upgradient of the extraction wells/trenches. Institutional controls would be implemented to restrict future groundwater use during the operation of the extraction/treatment system, as public water is currently available at the Site.

4.3 Initial Screening of Soil and Groundwater Remedial Alternatives

In accordance with USEPA Guidance the remedial alternatives developed in **Sections 4.1** and **4.2** are screened against effectiveness, implementability, and cost based on the criteria presented in **Table 4-4**. The objective of this screening is to eliminate from further consideration alternatives that have undesirable results, while still preserving a range of options that will undergo a more thorough and extensive analysis in the Detailed Analysis of Corrective Measures.

Because estimation of remedial time frames for each alternative requires conceptual design details developed in the Detailed Analysis of Alternatives, specific time frames are not discussed in this section, but rather in **Section 5.0.** Similarly, conceptual design details of institutional controls (e.g., area to be covered, etc.) will be developed as part of the Detailed Analysis of Alternatives, and also discussed in **Section 5.0**. **Tables 4-5** through **4-9** present the matrices that highlight the screening of each alternative for effectiveness, implementability, and cost. Each table includes a recommendation of whether or not to retain the alternative for detailed analysis. Since the institutional controls include several components, a summary of the general approach for the implementation of site-wide institutional controls is provided in **Section 4.4** below.

4.4 Site Wide Institutional Controls

Maine Yankee intends to place an institutional control on all of Bailey Point limiting future land use to commercial/industrial activities. The institutional controls, which would apply to the entire Bailey Point parcel, would include a combination of the following: a restrictive covenant that would track with the property deed; a closure order issued to Maine Yankee by the MDEP, and Maine Yankee written procedures.. The objectives of institutional controls are (1) to provide access restrictions and thus prevent exposure to impacted soils and groundwater, (2) to control the future development and disturbance of the site, and (3) to prevent the installation of water supply wells within the area of impacted groundwater. The institutional controls would include a requirement that a plan be developed in the event that contaminated soils in Bailey Point were disturbed. The management plan would address health and safety, excavation and backfill procedures, contaminated groundwater management and disposal, and contaminated soils management and disposal as appropriate to the particular action being implemented and area requiring subsurface excavation. The institutional control would specify that the owner of the property at the time a particular action requiring excavation of contaminated soils was planned would have the responsibility for developing an appropriate management plan and submitting the plan to MDEP for approval. Maine Yankee has developed written procedures that provide guidance and environmental controls for soil excavation, investigations and management of soil. These written procedures will be the primary tools for implementing soil management controls. Groundwater use would also be prohibited on Bailey Point. These institutional controls would also be implemented through the placement of a restrictive covenant.

The future effectiveness of institutional controls would depend on its continued implementation in the future. Institutional controls, such as restrictive covenants, are subject to changes in ownership, political jurisdiction, legal interpretations and regulatory enforcement. If implemented effectively, institutional controls provide moderate protection against direct contact with contaminants at low cost. Institutional controls are also frequently necessary until remedial goals can be achieved, such as the case with natural attenuation of constituents in groundwater. For these reasons, institutional controls are a component of the soil and groundwater remedial alternatives evaluated for Bailey Point.

To ensure that the institutional controls are effectively monitored and enforced, Maine Yankee will submit an annual letter to MDEP certifying that no groundwater use has occurred on the site, that no residential use of the property has occurred, and that any excavation activities that may have occurred were conducted consistent with the requirements specified in the restrictive covenant and MDEP Closure Order.

5.0 DETAILED EVALUATION OF ALTERNATIVES

This section presents the detailed analysis of alternatives that were retained from the initial screening in **Section 4.0**. **Section 5.1** discusses the approach to the detailed analysis and **Sections 5.2** and **5.3** present the detailed analysis of alternatives retained for soil and groundwater, respectively. As part of the detailed analysis of alternatives for groundwater, a groundwater model is developed in **Section 5.3.1**.

5.1 Approach to the Detailed Analysis

The detailed analysis is intended to provide Maine Yankee with sufficient information to select the appropriate alternatives for soil and groundwater at the Site. Specifically addressed are petroleum-bearing soils and groundwater across Bailey Point. In accordance with RCRA guidance (USEPA, 1994), corrective measures are evaluated against the following nine evaluation criteria:

- Protection of human health and the environment
- Ability to attain media cleanup standards
- Control sources of releases so as to reduce or eliminate, to the extent practicable, further releases that might pose threats to human health and the environment
- Compliance with applicable standards
- Long-term reliability and effectiveness
- Reduction of toxicity, mobility, or volume (TMV) of wastes
- Short-term effectiveness
- Implementability
- Cost

Protection of human health and the environment. This criterion is an assessment of whether each alternative achieves and maintains adequate protection of human health and the environment. The overall appraisal of protection draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with applicable standards.

Compliance with applicable standards and ability to attain media cleanup standards. These two evaluation criterion are used to determine whether an alternative would meet all federal, state and local applicable or relevant and appropriate standards (ARARs). Particularly important for the Maine Yankee site are requirements associated with achieving drinking water quality regulations, compliance with regulations concerning the management of wastes associated with each alternative, and requirements associated with groundwater monitoring.

Long-Term effectiveness and permanence. This criterion is used to consider the risk remaining at the site after response objectives have been met. The primary focus of this evaluation is the extent and effectiveness of the actions or controls that may be required to manage the risk posed by residual contamination . Factors to be considered and addressed are magnitude of residual risks, adequacy of controls, and reliability of controls. Magnitude of residual risk is the assessment of the risk remaining after remediation. Adequacy and reliability of controls is the evaluation of the controls that can be used to manage residual contamination that remain at the facility. The evaluation may include an assessment of institutional controls to determine whether they are sufficient to ensure that and exposure to human and environmental receptors is within protective levels.

Reduction of toxicity, mobility, and volume. This evaluation criterion addresses whether an alternative uses, as their principal element, technologies to permanently treat and significantly reduce the toxicity, mobility, or volume of the hazardous substances. This criterion is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, reduction of the total mass of toxic contaminants, irreversible reduction of contaminant mobility, or reduction of total volume of contaminated media

Short-term effectiveness. This evaluation criterion addresses the effects of the alternative during construction and implementation phase until remedial objectives are met. Alternatives are evaluated with respect to their effects on human health and the environment during implementation of the remedial action. The following factors are considered under this criterion:

- Protection of the community during remedial actions
- Protection of workers during remedial actions
- Environmental impact during remedial actions
- Amount of time to achieve remedial objectives
- Air quality impacts to surrounding receptors resulting from remedial action

Implementability. The implementability criterion addresses the technical and administrative feasibility of executing an alternative and the availability of various services, and materials required during its implementation. Technical feasibility includes construction, operation, reliability of technology, ease of undertaking additional remedial action if necessary, and monitoring. Administrative feasibility considers activities such as ability to obtain permit approvals from applicable regulatory agencies.

Cost. To conduct the detailed cost analysis of alternatives, the expenditures required to complete each measure are estimated in terms of both capital and annual O&M costs. Once capital and O&M costs are estimated, a present-worth cost is calculated for each alternative for comparison.

Capital costs consist of direct and indirect costs. Direct costs include the cost of items such as pre-construction site preparation, equipment, remedial construction, and waste disposal. Indirect costs include items such engineering expenses, license or permit costs, and contingency allowances.

Annual O&M costs are the post-construction costs required to ensure the continued effectiveness of the remedial action. Examples of annual O&M cost items include groundwater monitoring, operating labor, maintenance materials and labor, residue disposal, administration, insurance, taxes, licensing and contingency funds.

Expenditures that occur over different time periods are analyzed using present worth, which discounts all future costs to a common base year. Present –worth analysis allows the cost of remedial action alternatives to be compared on the basis of a single figure representing the amount of money that, if invested in the base year and disbursed as needed, would be sufficient to cover the projected costs associated with the life of the remedial alternative.

The detailed description of the technologies or process for each alternative includes preliminary site layouts, and a discussion of the limitations, assumptions, and uncertainties for each component. These descriptions are intended to provide the conceptual design of each alternative and are used for cost purposes only.

The cost estimates presented below have been developed strictly for comparing the alternatives. The final costs of the project and the resulting feasibility will depend on a number of factors such as actual labor and material costs, competitive market conditions, actual site conditions, final project scope, the implementation schedule, the firm selected for final engineering design, and other variables. Therefore, final project costs will vary from the cost estimates. Because of these factors, project feasibility and funding needs must be reviewed carefully before specific financial decisions are made or project budgets are established to help ensure proper project evaluation and adequate funding.

The cost estimates are order-of-magnitude estimates having an intended accuracy range of +50 percent to –30 percent. The range applies only to the alternatives, as they are defined in **Section 4** and does not account for changes in the scope of the alternatives. Selection of specific technologies or processes to configure remedial alternatives is intended not to limit flexibility during remedial design, but to provide a basis for preparing cost estimates. The specific details of remedial actions and cost estimates would be refined during final design.

5.2 Evaluation of Soil Corrective Measures

Based on the initial screening, two corrective measure alternatives were retained for further detailed analysis for remediation of soil at the Former Truck Maintenance Garage:

Alternative Soil-1: No Additional Action with Institutional Controls to manage future land use.

Alternative Soil-2: Excavation of petroleum-containing soil with a target cleanup concentration of 10 mg/kg DRO, backfill, and off site disposal.

5.2.1 Alternative Soil-1

Description. This alternative includes no additional action for the subsurface soil contamination, but includes the use of institutional controls to manage exposure to petroleum-contaminated subsurface soils. The institutional controls would provide access restrictions and thus prevent exposure to impacted soils and control the future development and disturbance of the site. The restrictive covenant will limit future site use of the Bailey Point portion of the site to Commercial/Industrial uses. Groundwater extraction would also be prohibited on Bailey Point as part of the groundwater remedial alternatives (see **Section 5.3**). These institutional controls would be implemented through the placement of a restrictive covenant.

Alternative Evaluation. **Table 5-1** presents the detailed analysis for Alternative Soil-1 against the nine evaluation criteria. The cost estimates for Alternative Soil-1 are included in **Table 5-2**, and cost backup information is included in **Appendix F.**

5.2.2 Alternative Soil-2

Description. This alternative includes excavation and removal of approximately 125,000 cubic yards of petroleum-contaminated soil from 18 areas across Bailey Point. The areas of soil contamination are illustrated in **Figures 5-1 and 5-2**. The corrective measure objective for the soil remediation associated with Alternative Soil-2 is 10 ppm, consistent with the Stringent Cleanup described in the Maine Decision Tree for petroleum-contaminated soils (MDEP, 2000).

Following excavation, removal, and backfill, the soil would be disposed offsite.

To support the soil remediation, a remediation plan will be developed and submitted to MDEP for approval. The plan will include confirmatory soil sampling for DRO following soil excavation.

This alternative would also include the use of institutional controls to prohibit groundwater use on Bailey Point as part of the groundwater remedial alternatives. These institutional controls would be implemented through the placement of a restrictive covenant.

Alternative Evaluation. **Table 5-1** presents the detailed analysis for Alternative Soil-2 against the nine evaluation criteria. The cost estimates for Alternative Soil-2 are included in **Table 5-3**, and cost backup information is included in **Appendix F.**

5.2.3 Comparative Analysis of Soil Alternatives

In this section, the detailed evaluations are used to compare the relative performance of the two soil alternatives for the petroleum-contaminated soils on Bailey Point against each of the nine evaluation criteria. The comparative analysis allows the advantages and disadvantages of each alternative to be ranked as part of the decision-making process.

The ranking system for each of the nine criteria is based on a relative ranking of high, medium, or low. **Table 5-4** presents the comparative analysis of the two soil alternatives.

5.3 Evaluation of Groundwater Corrective Measures

Based on the initial screening, three corrective measure alternatives were retained for further detailed analysis for remediation of groundwater at the Maine Yankee Site:

Alternative GW-1: No Further Action/Institutional Controls. The alternative consists of no remedial activities, and represents the minimum proposed remedial action for groundwater. Institutional controls would be implemented to restrict future groundwater extraction, as public water is currently available at the Site.

Alternative GW-2: Long-Term Groundwater Monitoring. This alternative was developed to provide a long-term groundwater monitoring plan to document natural attenuation of groundwater contaminants. The natural attenuation processes (e.g., abiotic degradation, biodegradation, dispersion, sorption, and dilution) would gradually reduce contaminant concentrations in groundwater to below MCLs and MEGs. A groundwater-monitoring plan would be developed to verify the continued effectiveness of the alternative. Institutional controls would be implemented to restrict future groundwater use, as public water is currently available at the Site.

Alternative GW-3: Groundwater Extraction and Treatment: This alternative includes containment and extraction of groundwater across Bailey Point. Groundwater extraction wells and trenches would be placed throughout Bailey Point to capture contaminated groundwater. The extracted groundwater would be treated onsite in a multi-stage system to meet drinking water quality regulations, and then discharged back into the ground in the soil on the site. A groundwater-monitoring plan would be developed to verify the continued effectiveness of the alternative. Institutional controls would be implemented to restrict future groundwater use, as public water is currently available at the Site.

5.3.1 Site Groundwater Model

The evaluation of groundwater contaminant distribution and the prediction of future distribution with time under various assumptions has been accomplished by the development of a new complex 3-dimensional groundwater flow and transport model. The development and calibration of this model is described in **Section 5.3.1.4**. **Sections 5.3.1.5** through **5.3.1.8** describe the future prediction of the distribution of chemicals of interest under various scenarios.

The use of Monitored Natural Attenuation (MNA) as a groundwater remediation approach requires that groundwater contaminant concentrations are likely to decrease to below regulatory levels (e.g., MCLs and MEGs) within a reasonably foreseeable time frame. Guidance under the CERCLA program suggests that 100 years is a maximum appropriate time frame to achieve compliance with regulatory standards. The ability to predict concentration changes beyond 100 years is very difficult and largely speculative in most geologic settings, except those having very low permeability.

In lieu of modeling, long-term monitoring of groundwater concentration changes can be measured. After several decades of measurements projections can be made of future likely concentrations if there are no changes in recharge, source terms or boundary conditions. These projections can be approximated as straight lines on semi-log graphs (time on a linear X-axis and concentration on a log Y-axis) as concentration decay in an aquifer is an exponential decay process. However, unless one knows that the aquifer starts everywhere in a steady-state or declining state of concentration, extrapolation of long-term monitoring results can be misleading at best. In aquifers where the plume is still expanding and the peak concentrations have not yet passed through the entire aquifer, measured concentrations can actually go up rather than down with time. Therefore, modeling is required to provide an approximate determination that concentrations within the full extent of the aquifer will indeed decrease below regulatory levels within the 100-year time frame. Since the monitoring wells at Maine Yankee cannot realistically cover the entire aquifer—particularly the deep bedrock aquifer—modeling will allow an interpolation and prediction capability for all parts of the groundwater regime.

Groundwater modeling requires the artful application of scientific principles. There are many types of groundwater models and many ways of using any given model. The inappropriate use of boundary conditions, recharge rates, or model hydraulic parameters can render any model useless for prediction of future conditions. The most common models are mathematical models that break the space occupied by an aquifer into "discrete" physical volumes such as rectangular blocks. The hydraulic head in each block is related to the heads in the blocks on its six adjacent sides according to Darcy's law and the law of conservation of mass. Additional physical laws are involved in solute transport but, again, what happens in each block is a function of what happens in neighboring blocks. A mathematical equation is constructed that describes the behavior of groundwater in each block relative to each other surrounding block. The entire series of equations describing the behavior in all the blocks can be solved if the head is known at one or more blocks. A variety of matrix solution approaches are available to solve for the heads in each block in a confined aquifer. In unconfined aquifers, the matrix solution approaches are combined with iterative solution processes to solve for the head. Solute transport solution approaches are more complex mathematically, but still use the same conceptual framework. The object of efficient groundwater modeling is to break the aquifer volume into discrete blocks that are of appropriate size and spatial arrangement so that major transitions across blocks having different physical properties or "parameters" are represented appropriately and that the macroscopic properties of a block can realistically represent the average of the large microscopic variations that exist within any given block. This is where the "art" of modeling comes in as it represents experience with having done many models that have been verified with real data.

Modeling consists of five basic steps:

1) Development of a conceptual model of how the aquifer system works, including how water enters and leaves the model, how different strata control and direct water movement, and where valid boundaries of little or no flow occur;
2) Dividing the aquifer ("discretizing") into discrete physical 3-dimensional blocks such that each block is assumed to have homogeneous physical properties to describe how it stores and transmits water and contaminants;
3) Defining the physical properties of each block such as hydraulic conductivity, porosity, etc.;
4) Calibration which involves varying the properties of individual blocks within realistic ranges so that measured groundwater heads and concentrations can be simulated within acceptable error ranges; and,
5) Prediction of future scenarios such as the change in concentration with time in the aquifer if surface sources are removed.

The sections below describe each of these steps in detail for the Maine Yankee Bailey Point model. Although several groundwater flow and transport models have been developed for portions of the Maine Yankee site in the past (Gerber and Rand, 1980; RGGI, 1989; Stratex, 2002), the evaluation of RCRA corrective measures required the development of a more complex and refined model. Previous models did not cover all of Bailey Point within one model, did not handle the boundary conditions sufficiently well, and previous models did not have the benefit of the large number of RCRA groundwater monitoring well water elevation measurements for calibration. This new model has the correct geographic coverage, a large number of monitoring wells for calibration, and boundary conditions that are appropriate for the simulations involved.

5.3.1.1 Conceptual Model

As with previous RGGI and Stratex groundwater models for the Maine Yankee site, the new model is a 3-dimensional, finite-difference flow and transport model. The US Geological Survey MODFLOW model (both the 1996 and 2000 versions) was used for the flow model. The MT3DMS model was used for solute transport. The models are used within the pre- and post-processing environment of Groundwater Vistas^{TM}, Version 3.49, by Environmental Simulations, Inc.

The new model has seven layers, the bottom four of which are bedrock in all locations (**Figure 5-3**). Therefore, for thick soil sections, there are three layers available to discretize the hydrostratigraphy in the vertical dimension. In layers of thin soil, one-foot layers of bedrock are used in place of soil. Bedrock has been divided into four layers of increasing thickness with depth in order to provide a transition from thinner soil sections to thicker bedrock sections. Layers are numbered from top to bottom, from one to seven. Layer four, which is the normal top layer of bedrock has a higher hydraulic conductivity than other deeper bedrock layers, to reflect the greater degree of fracturing generally found on site in the upper 20 feet of bedrock. Soil layers are differentiated by significantly different hydraulic conductivity in each layer and usually have different geologic origins. The marine dredge spoil area north of the Knoll is treated as a single layer to facilitate solute transport simulations. However, thick insitu units such as soft glaciomarine clay-silt may be broken into two thinner layers rather than being treated as one thick layer. Where significant sand layers exist between bedrock and the clay-silt units, these layers have been defined separately according to their interpreted thickness and extent. The area of thick marine muds in the Back River was divided equally into three layers.

There are three major boundary condition types used in this model. Constant head boundary cells (essentially infinite sources or sinks of surface water) have been defined only for the area subject to tidal action. For long-term simulations, the tide surface is treated as the average position of the tide or approximate Mean Sea Level. With only a few exceptions, as described below, only the top layer of the model has constant head cells. Where the depth of water is more than a few feet, the seawater head is translated to an equivalent freshwater head by multiplying water depths by 1.025 (the relative density of seawater compared to freshwater) and then subtracting the water depth. Therefore, the value of the head in the constant head cells next to the shore is 0.00' elevation, whereas in the deepest part of the Back River, the value is 1.00'.

Freshwater streams, seeps, and ponds are simulated as "drains" which are a modified type of constant head boundary. A drain cell is not activated if the predicted head in that cell is below the bottom of the cell in which the drain is located and below the defined bottom of the drain. However, a drain does allow groundwater to discharge from the model into a drain cell where the head is predicted to be higher than the bottom of the drain in its defined cell. The rate of flow out of the model is a function of the "conductance" which is based on the width and length of the drain within the cell, and the vertical hydraulic conductivity of the bottom of the drain. The conductance is multiplied by the area of the cell and the difference in head between the defined bottom of the drain and the predicted head in that cell to obtain the flow out of the drain. Most of the drains are in the top layer of the model, except as described below. The drains in the calibration model are shown on **Figure 5-4**. They cover all of the perennial and intermittent surface water features above the tide. The containment foundation sump drains are also simulated as "drains" in all but the post-decommissioning simulations. The drain conductance is one of the significant calibration parameters for the model.

The active zones of the model are bounded on all sides by "no-flow" boundary conditions. On the bottom, the no-flow boundary is the bottom of layer seven. To the west, the no-flow boundary is chosen as the centerline of Bailey Cove and the thread of its tidal stream that extends to the north. To the east, the no-flow boundary is the deepest part of Back River and also the approximate center of Back River. The southern no-flow boundary cuts through the south end of the forebay (the northern part of Foxbird Island flows toward this and meets the flow coming from the south end of Bailey Point in about this location) and then through the center of the cove south of Bailey Point to the east of the forebay.

The northern no-flow boundary is located on an approximate groundwater flow line in the "backlands" north of Old Ferry Road, where flow goes either to the east or to the west with little or no flow across this boundary to north or south. This applies the approximately correct amount of recharge to the area north of Old Ferry Road that contributes to the Bailey Point groundwater flow. The existing ground surface is treated as the top of the top layer of the model, except where groundwater is predicted to be lower than ground surface, where, in some areas, portions of the top several layers were defined as no-flow cells where the layer was predicted to be "dry". Dry layers are possible in layers one through four. Therefore, the top four layers of the model compute flow by multiplying horizontal hydraulic conductivity by the computed thickness of the saturated zone in the layer. This makes the model highly non-linear in that the position of the predicted head is a function of the head itself. However, this type of formulation is necessary to avoid serious errors in calculating the predicted heads that would occur if the full thickness of partially saturated layers were used to compute the mass of water movement ("flux") from one cell to the next.

The major water input to the model is precipitation. Since we are simulating long time frames, we estimate the average annual precipitation rate on each cell of the topmost layer of the model that is active. Precipitation rates were initially estimated for each cell based on the uppermost soil and land cover type using experience such as in Gerber and Hebson, 1996. Precipitation rates, along with hydraulic conductivity rates, are the major calibration parameters.

The model is conceptually designed to allow water to enter and leave through the groundwater system. It includes all of the contributing water and discharge areas that are significant to the Bailey Point groundwater regime. By the discretization of the model, all of the separate geologic units that affect flow differently are simulated differently, as appropriate to that geologic unit. Flow is allowed to extend through multiple layers of bedrock to give an indication, at least in a relative sense, of how deep certain contaminants might travel on their route from source area to discharge.

5.3.1.2 Discretization

To address the complex nature of the aquifer beneath Bailey Point, we have defined 11 different surface soil and land cover types that could have recharge rates distinct from each other. We have also defined 23 geologic units that could have hydraulic conductivity properties distinct from each other. The upper and lower surfaces of these units are highly variable in elevation throughout the model area. The drain boundary conditions are highly irregular in their spatial distribution. The distribution of various contaminants is highly irregular. Although some very simplified analyses could be done with analytic function models, the types of analyses we do here require the type of model where the domain is discretized (or physically divided) into individual cells with unique physical properties and unique upper and lower elevations.

The two most common models to apply to these types of analyses are finite element and finite-difference models. Finite element models are more complex in their mathematics and discretization, although they can be more efficient in the use of computer resources. With the powerful computers available today, however, the finite element model advantage disappears and the additional set-up difficulties of the finite element model favor the finite-difference model. Because it is one of the best documented and most widely-used flow models, and because there are several very nice graphical user interfaces developed for it, the U.S. Geological Survey model MODFLOW has been chosen for use on this project. The equations of flow and conservation of mass are discretized over the domain rather than being smooth functions. This finite-difference model sets up a series of linear equations that describe the head at the center of each rectangular block "cell" according to its relationship between the heads in each of the surrounding blocks. These relationships depend on the geometry of the cell and surrounding cells, and the hydraulic conductivities in the cell in three dimensions, plus any inputs such as recharge or withdrawals, such as from wells. When boundary conditions such as drains and constant head cells are added, the equations describing the heads at each cell can be solved.

The finite-difference grid for this project consists of square cells in plan view with 40 feet on a side. The grid is shown overlain on the base map on **Figure 5-5**. In the vertical dimension, the thicknesses of the cells are variable in the top 3 layers from as little as one foot up to 74 feet thick. Each cell encompasses a unique geologic unit of presumed homogeneous character. Where soil is very thin or non-existent over bedrock, each of the top three layers is represented by a one-foot thick layer of rock. These usually go "dry" during the flow simulation. Some thick soft clay units and some thick fill units may be divided into two layers of approximately equal thickness. The elevations of the ground surface form the top of the first layer. These elevations were derived from reverse-interpolating the contours from the latest detailed James W. Sewall two-foot contour map of the site into the MODFLOW grid.

The geologic database for Maine Yankee is stored in a Rockware™ database. Prior to defining layer elevations in the MODFLOW model, geologic surface elevations such as top and bottom of surficial units and top of bedrock were contoured in Rockware for land-based data. The output was then reverse-interpolated into the established MODFLOW grid and initial layer top and bottom elevations were established in this manner down to top of bedrock. For the marine data, the NOAA charts and Maine Yankee survey data were used to establish the top of the tidal river bottom. The top of rock under the tidal zone was derived from analysis of various sources such as Maine Yankee drilling and geophysical surveys and published bottom reflection profiles (Schnitker, 1972). Small and localized corrections were made to the initial layering where interpolation from the original data did not produce reasonable results. Once the elevations of the top and bottom of the first three layers were established, the rock layering was established as follows: layer 4 is 20 feet thick; layer 5 is 20 feet thick; layer 6 is 160 feet thick; layer 7 is 195 feet thick.

Drain elevations set along stream bottoms of variable elevations were defined for discrete "reaches" by using the Groundwater Vistas™ digitizing capability to set the beginning and ending elevations of the reach. Groundwater Vistas™ then interpolated the elevation of the drain bottom for each cell between the beginning and ending of the reach. Since the vertical cell layering was performed using a different method, portions of some drains were defined in different cell layers than just the top layer where they were usually intended, since drain elevations have to physically occur within a cell with the proper elevation range. This does not significantly affect the operation of the model, however.

5.3.1.3 Parameterization

Once the conceptual model is designed and the discretization is accomplished, the basic properties of each cell have to be defined. For MODFLOW this includes hydraulic conductivity in the x-, y-, and z-dimensions and precipitation recharge rate for the top cells of the model. The elevations of the constant head boundary and drain boundary cells and the conductance of the drain boundary cells must also be defined. Preliminary values based on experience were used in the initial calibration, and then values were varied through sensitivity analyses and experimentation until the calibration was satisfactory.

Groundwater Vistas™ makes it relatively easy to define "zones" within each layer having the same properties. Since the conceptual model and layering of the model were done in tandem, each zone property was defined in the cells within each layer that had the properties of that zone. Geologic maps and other types of maps were used as background maps under the grid to help in delineation of the zones. Maps showing zones of equal hydraulic conductivity are given for layers 1 through 5 as **Figures 5-6 through 5-10**. **Table 5-5** shows the values derived from calibration that apply to each zone. Similarly, the recharge rates were defined according to the top layer geologic zonation and land use. The recharge rate distribution is shown on **Figure 5-11** and the calibrated values are listed in **Table 5-6**. Using inverse parameter estimation techniques for calibration does not guarantee that a correct unique set of parameters will be found to define the problem, particularly with a site such as Bailey Point with such a heterogeneous geology. In fact, as described below, two slightly different sets of parameters gave very similar calibration statistics.

For solute transport modeling, additional parameters must be defined. The parameters for the simulations summarized here include porosity and dispersivity for the conservative solute transport simulations. Porosity was a calibration parameter for the chloride simulations north of the Knoll. Dispersivity is a scale-dependent phenomenon that is a measure of the heterogeneity of each geologic unit. Although important to the spread of the contaminants laterally and longitudinally with time, it is not greatly important to the concentration distribution within the heart of a contaminant plume. The graphs of Rajaram and Gelhar (1995) were used to guide the choice of dispersivity values. These parameters are summarized in **Table 5-7**. For the simulation of TCA east of Warehouse 2/3, a linear distribution (K_d) parameter was applied and is discussed below. Since no transient simulations have been performed for the CMS, specific yield and storativity values are not used.

5.3.1.4 Calibration

Models can be calibrated through a variety of means. The usual calibration process for flow models is to match observed ground water elevations in monitoring wells with predicted groundwater elevations at that same horizontal and vertical point in the model. Hydraulic conductivity values and recharge rates are varied to bring observed values and predicted values into alignment. This is the first level of calibration. Once reasonable calibration is achieved in this way other checks are made such as comparing measured and predicted output of drain reaches or reaches of constant heads. When insitu hydraulic conductivity test results or pumping tests are available this helps to narrow the range of variability in the hydraulic conductivity testing. When flow from drains or reaches of streams are made, they can be used to check the predicted flux from model results. Finally, when there is information that can compare the concentration of contaminants at specific places in the model at different points in time, this information can also be used to assist in the calibration of both flow and solute transport parameters.

To develop a set of calibration water levels, we use monitoring wells placed within the model area that have been surveyed accurately and have one or more groundwater elevations measured in time that can be compared with US Geological Survey groundwater monitoring wells. The USGS index wells have a length of record that overlaps the Maine Yankee readings and is long enough to determine a long term average position of the water table and is in the same geologic terrain as the Maine Yankee well it is being compared against. If there are two or more Maine Yankee ground water elevations for a given well, each one is compared to a USGS level measurement of the same time. The USGS level measurement of that time is compared to the long term USGS well average on a proportional basis of deviation from the mean. These proportional deviations are then averaged to adjust the Maine Yankee well to estimate its long-term average position. Since our simulations span many years, it is the long-term average groundwater elevation that we calibrate to. For wells with only one measurement, we compare it with a similar well at Maine Yankee in a similar terrain that has a reading at the same time but has multiple measurements that have been compared with a USGS monitoring well. We then use our professional judgment to estimate the range of the well with the single reading and what the long-term average position might be. This process was used to estimate average annual groundwater positions for 71 wells within the model area as shown on **Table 5-8**.

Once the long-term average position of the water table was estimated for each monitoring well that would be used for calibration, the well was assigned to that position within the model with Groundwater Vistas™ based on using the common Maine State Grid Coordinate system on which the model and databases were developed. Twenty-three well calibration points are located in layer 1 of the model; nine in layer 2; 36 in layer 4; and three in layer 5. For the final calibrated model flow model, the calibration statistics for a one final set of parameters (called "calib9v2" in the data sets) is shown on **Table 5-**

8 and the comparison of predicted heads as a function of estimated average annual heads ("observed" heads) is given on **Figure 5-12**. The residual (observed minus predicted head) mean error is only 0.22 feet with a residual standard deviation of 3.9 feet and a ratio of residual standard deviation to range of 0.05. This is considered a relatively good calibration, as usually anything less than 0.15 residual standard deviation to range ratio is considered acceptable.

The residuals with the largest absolute value residuals are north of Old Ferry Road in the area of the formerly proposed coal ash disposal area. In this area there is a very narrow but deeply incised clay-silt filled valley in what is otherwise a terrain of exposed and shallow bedrock. Since the model does not extend far to the north in this area and the boundary conditions of the Back River are not accurately represented in the northeast corner of the model, these larger errors are not a major concern. This area is significantly to the north of the area of our solute transport simulations and the main concern is to get the general groundwater flux across Old Ferry Road to be approximately correct.

There are other means of calibrating the model beyond just matching heads in monitoring wells. One of the calibration measures is to reproduce approximately the flow from the containment foundation sump as measured in the past. This is not a simple task for this site and it requires a lower-than-average bedrock transmissivity zone in the containment area to simultaneously limit the drawdown to the sides of the containment and match the flow into the sump. A separate data set ("calib9v1") with very similar overall calibration statistics to those shown in **Table 5-8** gives a slightly larger flow into the containment sump and a slightly better fit with measured data in some parts of the site. The main differences in the data sets are the somewhat different hydraulic conductivities in the granite and slightly different distribution of hydraulic conductivity around the containment. Version 1 of the flow model has a predicted containment sump flow of 0.9 gpm; version 2 has a predicted flow of 0.34 gpm. The sump flow was measured to be about two gallons per minute in January 1989 (RGGI, 1989).

Another important test of a three-dimensional model is to produce the same direction of groundwater vertical gradients at the location where multiple levels of monitoring wells exist. As shown on Table 3-3 of the Bailey Point RFI report, there are a number of well clusters with previously measured vertical gradients (Maine Yankee, 2004a). Although these are not necessarily accurate for the long-term average groundwater table condition, we have compared the gradient directions predicted by our two model versions. Both versions 1 and 2 match measured gradient directions for all well clusters.

The final acid test of a model calibration occurs when you can actually compare known changes of concentrations with time with model predictions. Often these types of data do not exist on a site. Furthermore, for close comparisons the additional parameter of effective porosity must also be approximately correct for transport simulations of conservative parameters (those that travel with the groundwater and are not reduced by adsorption, ion exchange, chemical transformations, radioactive decay or biodegradation). On this site we know that marine sediments were dredged from the intake channel of the circulating water intake structure in approximately 1970, that additional dredging for the forebay was done in 1972, and that the pore water had a chloride concentration in the range of 12,000 to 17,000 mg/L. The concentration of chloride in December 2003 in selected monitoring wells in the dredge spoil disposal area is shown on **Table 3-2**. **Figure 5-13** shows the assumed location on the site where the chloride was contained in layer 1 of the model. As discussed below in **Section 5.3.1.5**, a 30-year simulation of chloride dissipation from the dredge spoil pore water gave favorably comparable concentrations with those predicted as a function of observed values with a regression r-squared value of 0.94 (**Figure 5-14a**).

Another test of the solute transport model involved simulating a sodium concentration history at the former Knoll Well that supplied the drinking water for the plant up through about 1995. The Knoll Well was tested by the Maine Department of Human Services laboratory for sodium, chloride and other chemicals annually from March 1988 to September 1995. As shown in **Figure 5-15** (right-hand Y-axis), the concentration of sodium increased in the well, then peaked and declined. The well had a high pH but a low chloride concentration of less than 10 mg/L, so the source of chloride did not appear to be saltwater. To produce this type of chemistry, we suspected that there was a spill of some cement and cement additives at the site of the construction concrete batch plant that was situated on the north portion of where the ISFSI is now located. By putting a one time initial concentration source in the top layer of the model and pumping the well for 28 years at 2 gallons per minute, we were able to produce an almost identical predicted trend in the chemistry of the well as the measured sodium trend. If the sodium were slightly retarded instead of being treated as a conservative solute, it could be easily brought into alignment with the predicted trend.

Although the final calibration of the model appeared to be good for our purposes, it was not an easy state to achieve. Because the model was set up to be highly non-linear with variable cell elevations and hydraulic properties, large variability in juxtaposed hydraulic conductivities of several orders of magnitude, and the top 4 layers were treated as potentially unconfined aquifers, the initial calibrations took a long time to find a suitable solution scheme that was stable and converged. Neither the Strongly Implicit Procedure nor the Successive Overrelaxation routines would converge even after achieving a good calibration and using the calibrated data set predicted heads as the initial head matrix. The Pre-Conditioned Conjugate Gradient Method was successful, however, using a polynomial matrix preconditioning method, maximum Eigenvalue of 2, relaxation parameter of 1 and damping factor of 0.5. We occasionally performed a number of sensitivity runs treating all layers as confined (to maintain stability) then would switch back to unconfined simulations with the best fit values from the confined runs. We allowed cells to both go dry, but also re-wet during the initial simulations, as many iterations were necessary to converge to our specified convergence criteria. Automated calibration procedures did not work well for this model as there are too many different zones and the model is too non-linear. Most of the calibration was performed through the use of experience and sensitivity analysis. The final mass balance error of the flow model was –0.69% for Version 1 and –0.84% for Version 2. These errors could be reduced further but without significant benefit to our overall conclusions.

Sensitivity analyses are routinely performed on critical model parameters to act as separate checks on the calibration and to identify those variables that are most important to the model results. For those parameters for which the results are not sensitive to a change in a model input parameter, more leeway can be allowed during inverse parameter estimation. For sensitive parameters, the model input parameters may have to be more tightly constrained. The type of sensitivity analysis presented in **Figure 5-16** is the most common way of depicting sensitivity: using the sum of the squared residuals between observed and predicted values at monitoring wells. This parameter will often show the most change when a parameter is varied but it is also heavily weighted toward the outlier values where the residuals can be large such as near the groundwater divides. Even though the sensitivity analyses might suggest that a certain parameter could be adjusted to produce a better calibration, this is not always the case. Calibration as measured by residual statistics is only one measure of calibration. Being able to reproduce historical solute transport results, matching streamflow and drain flows, matching vertical gradients, and matching the general form of the overall groundwater contours with measured contours can be much more important.

Figures 5-16A, B, and C focus on the sensitivity of hydraulic conductivity values. **Figure 5-16D** focuses on the most important precipitation recharge values. **Figure 5-16E** focuses on the drain conductance values. These figures cover the most important parameters in the Maine Yankee CMS flow model. Those graphs with the greatest differences across the graph in vertical bar height are the most sensitive parameters. For the measure of hydraulic conductivity these include: stiff fissured clay horizontal hydraulic conductivity (Kx and Ky); Ballfield fill vertical hydraulic conductivity (Kz); clay fill Kz, soft clay Kz; glaciomarine sand Kx and Ky; migmatite Kx and Ky; and granite Kx and Ky. For precipitation recharge, the most sensitive parameters are: thin soil and rock areas; sandy fill; glaciomarine stiff clay-silt; and glaciomarine fine sand. The model calibration sensitivity to the major drain conductance values is not great except for the containment foundation sump where increasing the drain conductance by a factor of 10 creates large residuals. When the parameter multiplier is 1.00, that represents the base case of the sensitivity analysis or the value used in the calibrated model. Ideally, the lowest value for the sum of square residuals should be at the 1.00 parameter value on the graph X-axis. However, as noted in the previous paragraph, other factors may be more important such as the ability to match observed historical solute transport results or matching vertical gradients and overall groundwater contour pattern. The largest model calibration residuals were in the former "ash disposal area" north of Old Ferry Road. Changing bedrock hydraulic conductivity values and soft clay vertical hydraulic conductivity values can reduce those large residuals but may create undesirable results in other aspects and areas of the model. Although some minor improvements could probably be made in the model to reduce overall residuals, the model seems on the whole to do well in matching the range of available historical data.

Predicted heads on the phreatic surface, and layers 2, 4, 5, and 7 are given on **Figures 5-17, -18, -19, -20**, and **-21**, respectively.

5.3.1.5 Attenuation North of the Knoll

The chloride and sodium concentrations in the area north of the knoll where marine dredge spoils were deposited were used to assist in calibrating the model, as described above. From a conceptual basis, the chloride concentrations measured from December 2003 data suggested that the area west of the western access road was lower in permeability and recharge rate than the fill area to the east. The exact limits of the bulk of the marine sediment deposits are not known for certain, but estimated to be those shown on **Figure 5-13**. Assuming that chloride performs as a conservative tracer, we varied the fill permeabilities and porosities and attempted to simulate the measured chloride after 32 years of letting precipitation leach chloride from the marine pore water in the fill. As shown on **Figure 5-14a**, there is good correspondence between measured and predicted chloride concentrations in 2003.

Since sodium and boron exceed the State of Maine MEGs in this area, we investigated the correspondence between the chloride and these parameters as measured (the sodium and boron were not measured at the same time as the chloride, however). **Figure 5-14b** shows that sodium tracks closely with chloride when sodium is assumed to be 0.58 times chloride, which is a typical average seawater ratio. Although sodium often exhibits some adsorption-desorption behavior (i.e., it is not always a conservative tracer), the fact that sodium and chloride appear to have the expected ratio here suggests that the sodium and chloride are in equilibrium with the soil (i.e., the soil is saturated with respect to sodium), and little exchange is taking place between sodium in pore water or groundwater and the soil. This relationship indicates that we can predict sodium concentrations by taking 0.58 times the chloride values.

Using the predicted chloride concentrations through all model layers from the initial 32-year simulation as a starting point, an additional 100 years of simulation was used to predict the continuing decline of chloride north of the knoll. The chloride isocons for the year 2103 are given in **Figures 5-22**, **-23**, **-24**, and **–25** for model layers 1, 3, 4, and 6, respectively. On these figures, are shown defined "observation wells" as OB1 through OB5. The change in concentration with time at these observation wells for sodium is given in **Figure 5-26**. This simulation is done with Version 1 of the calibrated model, which gives slightly higher concentrations at 100 years than Version 2. The graph shows that the sodium is not predicted to quite go below the 20 mg/L sodium MEG within 100 years, but it is very close. As the concentrations in the water are greatly reduced, some sodium may desorb from the soil matrix, causing somewhat slower rates of decline than shown on the graph.

Boron is another element that exceeds State of Maine MEGs in the northwest corner of Bailey Point. Like sodium and chloride, the elevated boron groundwater concentrations in the northwest corner of Bailey Point are derived from the pore water associated with the deposition of the marine sediments. **Figure 5-14c** shows the regression correlation between measured values of chloride and measured values of boron at the same well. The correlation here is not so good as with sodium (r-squared of only 0.34), but we have used the correlation coefficient as our best estimate. Boron is about 0.003 times chloride concentration, so **Figure 5-27** is our best estimate of the decline of boron with time at the same observation points as used for chloride and sodium. The boron simulations demonstrate that within 70 years all boron levels are below 1 mg/l.

Another parameter of interest in the area north of the Knoll is DRO. These are hydrocarbon constituents of past diesel, fuel oil, and kerosene spills that are spread irregularly in the area north of the Knoll. Two major documented spill sites include the area of the Former Truck Maintenance Garage (FTMG) and the "kerosene spill" off the northwest corner of the ISFSI. Those known spill sites produced some of the highest concentrations of DRO and traceable plumes trending downgradient of the spill sites. Although not shown in the figures of this report, we performed a transport simulation with an assumed source of DRO at the FTMG operating for 35 years. It clearly shows two plumes emanating from the FTMG, one to the northwest and one to the southeast. The northwest plume trends through the MW-303, -302, -413, -319, and –320 monitoring well locations, with the plume being more prominent at depth in bedrock the farther west along the plume. It does not extend north into the pond north of the ISFSI nor into the "ballfield" area. Elevated concentrations of DRO in those areas must be due to historic sources more local or upgradient of those locations. The southeast lobe passes through MW-316 and MW-425. The two lobes of the plume are a function of the groundwater divide in the FMTG area (**Figure 5-17**).

The existing distribution of DRO as measured during the RCRA field program and shown on Figure 4-17 of the Bailey Point RFI report (Maine Yankee, 2004a) was reverse interpolated into the top active layers of the model in the area north of the Knoll. The model then allowed the DRO to dissipate as a conservative tracer for 100 years with the assumption that there are no additional sources being carried downward from precipitation moving through the unsaturated zone or water table fluctuations. In other words, we assumed that the kerosene spill and FTMG soil removal efforts are effective in removing most of the remaining sources in those areas and that most of the original spills to the north of those have only very weak sources remaining. This is a reasonable assumption given the time frame of approximately 35 years since construction of the facility. Any residual petroleum hydrocarbons in soils would have had the soluble fractions of the petroleum hydrocarbons leached from the source during that time period. This is also confirmed from the results of the Bailey Point RFI where most of the petroleum hydrocarbon in soils were determined to be heavier fractions with low solubility (Maine Yankee, 2004a). Since we have little bedrock DRO concentration data for the area north of the Knoll, we have not attempted to place an existing mass of DRO in the bedrock. However, this will lead to a non-conservative result in terms of predicting the time for removal as a dissolved constituent in the total aquifer.

Figures 5-28, -29, -30, and **–31** show the predicted concentrations of DRO ten years from 2003 in layers 1, 2, 4, and 6 respectively. These figures are based on the simulations with the assumptions of the previous paragraph. **Figure 5-32** shows the change with time of concentration of DRO at the observation wells shown on the previous figures. Some of the observation wells are in the top layer of the model, but some are deep such as OB5, which is in layer 6. All of the concentrations would decline below 50 ug/L within 40 years except at OB1 where it would take 70 years. Offsetting influences on these predictions are: a) biodegradation will take place that would accelerate the decline; b) not all sources in the unsaturated zones have been found and/or removed; c) The existing mass of DRO in the bedrock is not well known and is not simulated.

Of these three offsetting influences, the natural biodegradation is believed to be the most significant. DRO in groundwater will biodegrade if electron acceptors are available in groundwater (Wiedemeier, et.al, 1995). Although dissolved oxygen concentrations are typically low in groundwater north of the knoll, sulfate levels are high (up to 2,800 mg/l) and elevated concentrations of iron (II) (up to 560 mg/l) and methane (up to 6.9 mg/l) are also observed. The presence of abundant electron acceptors (i.e., sulfate and iron (III)) and the presence of byproducts of biodegradation reactions (iron (II) and methane) clearly indicate that natural biodegradation is occurring in the aquifer (see **Section 3.2.4.4**). Although it is difficult to quantify to what extent the DRO concentrations would be biodegraded, given the abundance of electron acceptors present in groundwater, a 25 to 50% reduction in DRO concentrations would be reasonable.

5.3.1.6 DRO Attenuation South of the Knoll

We have treated the DRO contamination south of the Knoll in the same manner as we did the DRO north of the Knoll, except for the fact that boundary conditions and recharge properties change in the south in the post-decommissioning condition. The initial DRO distribution is again reverse-interpolated from the Rockware™ contoured values of measured DRO, as shown in Figure 4-17 of the Bailey Point RFI report (Maine Yankee, 2004a). These values are averaged values at a horizontal point when there are two wells with different measured concentrations, but we have spread the mass through all of the top four layers of the model in the south. Unlike in the north where most of the initial model layers were simulated as saturated, in the south, because of the presence of thick permeable fill, it was common for the top two or even three layers to be predicted to be unsaturated (in other words, saturation began at the rock layer, which is the case in much of the RA area). However, in the post-decommissioning state with a rise in water level, there will be more layers saturated and if they currently hold DRO, it will then be released to the groundwater. As with the north, we have essentially no information on the DRO concentration in the deep bedrock, nor in areas outside of the area we have sampled, so we have not placed any initial contamination there. Although this could be non-conservative, the deep bedrock has low porosity and flushes fairly rapidly.

To illustrate what this DRO plume may look like in the future, we again simulated 100 years, but after 10 years all concentrations have dropped beneath 50 ug/L. Therefore, we show **Figures 5-38, -39**, and **–40** to illustrate the predicted decline in 5 years from the initial distribution in layers 1, 4, and 6, respectively. Again, it is assumed that most of the original sources such as the PAB alleyway source, the diesel generator fuel bunker, and the main transformer fire-generated sources have all been significantly decreased through soil removals. However, some small, scattered, unknown and unfound sources may still remain and become more active once the water table rise occurs.

The plume plots after five years are relatively instructive to the fate of other contaminants within the RA/IA area (aluminum, sodium, arsenic, and molybdenum), if they behave like conservative tracers, as we have simulated the DRO. The plots show that contamination lingers longest to the east and west sides of the containment and in the deeper rock zone of layer 6. Even so, a rate of attenuation of about a factor of 10 will occur in approximately 10 years. So for other conservative contaminants that are on the order of 10 times the current MEG or MCL, they are likely to be attenuated to acceptable standards within about 10 years of post-decommissioning. For contaminants that exhibit strong adsorption or dual porosity behavior, the decline of concentration could be much slower. Only long-term monitoring would define which chemicals are exhibiting this behavior.

For the case of DRO, the deviation of the rate of concentration decrease from the conservative tracer assumption could be affected (as in the case north of the Knoll) by: a) some biodegradation will take place that would accelerate the decline; b) not all sources in the unsaturated zones have been found and/or removed; c) The existing mass of DRO in the bedrock is not well known and is not simulated.

As discussed for the area north of the knoll, biodegradation of DRO is also expected to occur in the area south of the knoll. Monitoring wells in the southern portion of Bailey Point have abundant concentrations of electron acceptors including dissolved oxygen, sulfate and nitrate, and have elevated concentrations of biodegradation byproducts (iron and manganese). The natural biodegradation reactions will act to decrease the time frame predicted by the groundwater model.

5.3.1.7 Attenuation of BTEX Compounds Southwest of Warehouse 2/3

On the southwest corner of Warehouse 2/3 elevated concentrations of various BTEX compounds such as ethylbenzene and xylenes were found in both soil and groundwater. An extensive testing program described in the Bailey Point RFI documented that the contaminated soil area was fairly small but that the two monitoring wells to the west and south had some groundwater contamination above the MEG for ethylbenzene. In order to evaluate the future potential for attenuation of this plume, we first had to simulate the plume based on an assumed history. We assumed that the groundwater plume was created by recharge with arbitrary strength of 1000 that passed through contaminated unsaturated soil in the center portion of one model cell (40'x40'), operating for 20 years with the boundary conditions that are used for the calibrated model. This produced an initial plume assumed for 2003 that extended west and south of the source area on the southwest corner of Warehouse 2/3. The contamination did not quite reach east to MW-422. The centerline of the plume rotated more to the south as the plume went down into the deeper bedrock.

In 2004, the soil holding the source material for the BTEX contamination will be excavated and removed from the site. Therefore, we can assume an essential cutoff of the source beginning with mid-2004. To simulate this and other future scenarios on the site south of the Knoll, certain boundary conditions will change. Although these did not affect conditions north of the Knoll, in the south, following decommissioning, we made the following adjustments in boundary conditions:

a) breached the west dike of the forebay, filled the forebay with clay fill soil up to about elevation 4.5' and set a new constant head at that level;
b) took out the drain that was part of the underground pedestrian walkway extending south from the southeast corner of the staff building;
c) made the volume of the Spray Building, PAB, Fuel Building, and Containment an area of very low permeability to reflect the fact that groundwater essentially has to flow around this cluster of buildings, but put a drain at elevation 18 feet to reflect the fact that when precipitation recharge fills the containment with groundwater that reaches this level on top of these structures, it will overflow into the surrounding soil;
d) Removed paving and most slabs in this area of the model, thus increasing recharge to this area;
e) Shut off the containment foundation sump drain;
f) Increased the recharge over the former fire pond to reflect the fact that the original impervious layer under the pond has been removed and it has been filled in with clay fill.

When these changes were made in the model to reflect the future boundary conditions and properties, the groundwater level was predicted to rise typically about 5 feet in the RA/IA area.

The simulation of the future of the BTEX plume was made by starting with the initial plume generated by 20 years of simulation under the old boundary conditions, but no continuing source. The existing mass is then allowed to be taken out of the aquifer by flushing through normal precipitation recharge. There are three potential offsetting effects that could change this simulation as a conservative tracer: a) there could be retardation effects due to dual porosity behavior (contaminants diffuse into the rock matrix as they pass through the rock fractures, then diffuse back into the fractures as the fracture concentration begins to decline) or desorption mechanisms in the soil and rock that would slow the attenuation; b) there could be biodegradation of the BTEX compounds that could accelerate attenuation; and c) the actual mass of BTEX in the aquifer could be more or less than predicted because of the uncertain history of the creation of the source.

Although we simulated 100 years of flushing of the BTEX plume, most of the plume was simulated as dissipating within 20 years. We have provided plots of what the plume is predicted to be 10 years following source removal. **Figures 5-33, -34, -35, and –36** show the plume relative concentrations in layers 2, 4, 5, and 6 of the model, respectively, assuming an original source strength of 1000. On these plots are shown observation well locations (OB9, OB10, OB11, and OB12) that are used to capture the predicted concentration change with time at their respective locations and model layers. **Figure 5-37** is a graph of the predicted changes of concentration with time at the observation wells. Since the initial ethylbenzene is less than a factor of 3 greater than the MEG it is easy to see that a factor of 10 reduction should occur with a period of 4 years, so this plume should attenuate rapidly unless the possible unquantifiable complicating factors mentioned above are strongly operative.

The BTEX simulations were conducted without considering biodegradation. Groundwater in the Warehouse 2/3 area does have abundant dissolved oxygen and elevated concentrations of degradation byproducts (i.e., iron and manganese) (see **Section 3.2.4.1**). The presence of both electron acceptors and degradation byproducts indicates that the BTEX is effectively biodegrading, and indicates that the decrease in BTEX concentrations in groundwater will be significantly greater than that predicted by the groundwater model.

5.3.1.8 TCA Plume East of Warehouse 2/3

The chlorinated solvent plume on the east side of Warehouse 2/3 consists of a primary, original source of TCA that has biodegraded through transition daughter products of DCA and DCE to VC. The source release probably occurred in the late 1970 to early 1980 time frame. To facilitate analysis of total mass reduction, the TCA, DCA, DCE, and VC have been added together to get a total value for each well site. The retardation characteristics of TCA, DCA, and DCE are roughly equivalent and VC is only a small percentage of the sum of the concentrations. The fraction of organic carbon that would largely control retardation characteristics is not known. It would be different for soil than for rock. For this exercise, we have simulated a 20-year development of the plume first as a conservative tracer, and then as a retarded contaminant, and finally as a biodegraded contaminant to see what simulation matches the current observed distribution the best.

The conservative tracer simulation starts with a small, localized source area near MW-408. The source is placed in Layer 4 since we have found no VOCs in the soil above the rock. Starting with an arbitrary source concentration of 1000 and letting the source seep into the aquifer at a rate compatible with the recharge rates of that area, **Figure 5-41** shows the resultant plume. This simulation suggests that if the VOC plume developed without retardation or biodegradation, the concentrations at MW-422 and MW-423 should be about 10% of what they are today at MW-311. Instead, the average total VOC concentration of those two wells is a little less than 2% of MW-311.

Separate simulations assuming a linear isotherm for retardation (Kd=0.0002) and assuming a first-order decay biodegradation half life of 700 days can reproduce the approximate measured total VOC ratios of MW-311 to MW-408. However the biodegradation simulation is more appealing conceptually as it is supported by field evidence (see **Section 3.2.4.2**) that mass is being lost (rather than just stored, as is the case with retardation). Also, the simulated total VOC ratios among MW-408, MW-311, and MW-409A developed from the biodegradation simulation are more in line with what has been measured than those simulated using retardation. When retardation and biodegradation were combined, there was little difference from the result with just the biodegradation, as that process seemed to control the distribution the most. **Figure 5-42** shows the simulated spread of the VOC plume using just biodegradation and a 20-year long source near MW-408.

Once the modeling had approximately reproduced the original plume, we used the post-decommissioning model to simulate the decline of total VOC concentrations over the next 20 years. We began by using Rockware™ to grid and contour the existing total VOC concentrations in the bedrock. This distribution was reverse-interpolated into the Groundwater Vistas™ model grid in layer 4 (the top bedrock layer, 20 feet thick) and then also copied into layer 5 (then next bedrock layer down, also 20 feet in thickness). From the TCA plume source area to the discharge area, contaminants are not simulated to travel deep, so it is probably realistic not to place more mass of VOC deeper into the rock. Our post-decommissioning simulation assumes that there is no further source and that only the dissolved contaminants remain to be purged from the aquifer through advection and biodegradation. As with the DRO simulation in the south in the RA/IA area, the purging process is predicted to be fairly quick: little mass remains after 20 years. Therefore, we show the distribution after 10 years in **Figure 5-43**.

Comparing **Figures 5-42** and **5-43**, we see that there is an order of magnitude reduction in concentration of total VOCs in each 10-year period, which is similar to the predicted DRO reduction south of the knoll. As with the other simulations there are a number of unknowns that could affect the results: a) the biodegradation decay rate may not be linear but rather may decrease as concentrations decrease (this has been documented to occur with PCE) b) the source in the unsaturated zone may not be exhausted and/or some of the solvent may have diffused into the bedrock matrix and will later diffuse back out as concentrations decrease (a dual porosity behavior) that will lengthen the concentration reduction process; c) The existing mass of VOCs in the deeper bedrock is not well known and is not simulated.

5.3.2 Alternative GW-1

Description. This alternative includes no further action for groundwater contamination, but includes the use of institutional controls to manage exposure to groundwater. The institutional controls would provide access restrictions and thus prevent the use groundwater at the Site for drinking water. Public water is currently available at the Site. These institutional controls would be implemented through the placement of a restrictive covenant.

Alternative Evaluation. **Table 5-9** presents the detailed analysis for Alternative GW-1 against the nine evaluation criteria. The cost estimates for Alternative GW-1 are included in **Table 5-10**, and cost backup information is included in **Appendix F.**

5.3.3 Alternative GW-2

Description. This alternative includes long-term monitoring for groundwater at the Site. Initial evaluation of Site groundwater conditions has demonstrated that chlorinated VOCs on the east side of Warehouse 2/3 and non-chlorinated VOCs are naturally biodegrading. DRO in groundwater is also biodegrading via oxidative degradation process. Groundwater modeling simulations have also demonstrated that sodium groundwater concentrations are also decreasing with time. The evaluation recognizes that iron, manganese, arsenic and molybdenum groundwater concentrations will decrease very slowly, as the source(s) for these metals in groundwater are natural geologic materials.

The alternative includes a long-term monitoring plan to track and monitor the changes in groundwater chemistry through time. Initially, a three-year, quarterly groundwater monitoring effort would be conducted to establish baseline conditions at the Site. The plan includes a three-year, quarterly sampling of 23 monitoring wells for selected compounds including VOCs, DRO and metals (sodium, manganese, aluminum, iron, molybdenum, boron, arsenic and lead). Following the three-year initial groundwater monitoring activities, a report will be completed and submitted to MDEP documenting the baseline conditions at the site. Following completion of the initial three year monitoring program, the monitoring wells would be sampled tri-annually on five-year interval basis and years 29 and 30. Following each tri-annual sampling period, a report will be completed documenting the tri-annual sampling results with recommendations for future monitoring activities. The monitoring wells for the monitoring program are shown in **Appendix G**, **Figure G-1**, and include representative monitoring wells from the Warehouse 2/3 area, Former Truck Maintenance area, Industrial and RA areas, and 345 kV Transmission Line area. Water generated during the development and sampling of monitoring wells associated with the monitoring program would be managed in accordance with Standard Operating Procedure (SOP) 10 and SOP 13, which can be found in the approved June 2001 QAPP. Based on previous investigation results, purge water would be discharged on site at least 10 feet from the well The monitoring plan to support Alternative GW-2 is included as **Appendix G**.

Institutional controls would also be included to manage exposure to groundwater. The institutional controls would provide access restrictions and thus prevent the use groundwater at the Site for drinking water. Public water is currently available at the Site.

5.3.4 Alternative GW-3

Description. This alternative includes a groundwater pump and treat scenario for active extraction of groundwater on Bailey Point that does not meet the EPA MCLs and/or the Maine MEGs. This water would be treated onsite in a multi-stage system to meet drinking water quality regulations, and then discharged back into the ground in the soil on the site. The site consists of at least three separate "aquifers" capable of providing sufficient water for a single-family household. The three aquifers include:

1) a surficial phreatic aquifer, primary in clay-silt native soils, clay-silt fill materials, and some sand and gravel fill materials;
2) a confined fine sand native soil north and east of the Knoll, underlying low permeability clay-silt deposits; and
3) a bedrock aquifer of variable transmissivity across the site.

Capture and extraction systems are designed to capture contaminated water from all three aquifers. Bedrock wells would average approximately a 40-foot penetration into bedrock. The most cost-effective wells would probably be six-inch in diameter. The sand layer capture wells would span the sand layer. The clay-silt phreatic aquifer capture system would only penetrate to the low permeability soft clay layer or mean sea level, whichever comes first.

All three aquifers contain contaminants generated by site construction or operational activities. The primary contaminants of concern that would be captured by the extraction system would include volatile organic compounds, diesel range organics, seawater constituents like chloride and sodium, and metals like iron and manganese. The pump and treat system is not designed to capture all molybdenum, which appears to be naturally occurring in the bedrock on the site.

The likely treatment system design would consist of mechanical filtration, iron and manganese removal, reverse osmosis, and activated carbon. Treated water would be put back in the ground in areas of suitable soils at rates per unit area that would approximate those specified in the Maine State Plumbing Code for wastewater disposal. Treated water disposal systems are proposed in locations that would be suitable from an engineering and regulatory point of view and would enhance the flushing rate of contaminants from the aquifers. Some of the systems may be located somewhat closer to surface water features than normally permitted by the State Plumbing Code, but since this discharge water should be of drinking water quality, waivers will be requested. The MDEP has jurisdiction over the disposal of non-residential wastewater to the ground and their approval of the design concept would be necessary.

The three-dimensional model developed for the CMS was used to evaluate location, spacing, and depth of extraction components such as wells and cut-off trenches. The system was not optimized, but it was evaluated sufficiently to capture essentially all of the contaminated groundwater production generated by recharge on the site. The spacing of wells was designed to prevent flow vectors from going between and beyond the wells and/or trenches. Pumping rates were maintained to prevent ambient water levels from decreasing below mean sea level, to prevent saltwater intrusion.

Groundwater recharge generated by precipitation falling on Bailey Point proper is approximately 3750 cubic feet per day on an average annual basis. Additionally, there is groundwater flow into the site from north of Old Ferry Road. The pump and treat system is designed to capture approximately 3900 cubic feet per day on an average annual basis. Although the Bailey Point groundwater model was not calibrated for transient simulations, experience suggests that seasonally flows might vary from 1950 cubic feet per day to 7800 cubic feet per day.

Figure 5-44 shows the location of the specific extraction and water return elements. Tables summarize the quantities involved that affect the cost estimating process are included in **Appendix F**.

There is very little saturated thickness of surficial deposits in the southern end of Bailey Point, so the focus there is to capture known contamination in the bedrock which may still be generated by overlying unsaturated soils. Beginning with the southwestern end of Bailey Point, there would be five extraction wells in bedrock to capture volatile organics that entered the ground at the southwest corner of the Warehouse 2-3 and on the east side of Warehouse 2-3 (**Figure 5-44**). The treated water from the Warehouse 2-3 area would be put into infiltration Trench #1 (**Figure 5-44**). The contaminants detected in the industrial area would be captured by a ring of fairly closely-spaced wells beginning at the MW-401 location, extending across the south end of the former containment and turbine buildings, and extending up the southeast side of Bailey Point to the former parking lot that lay east of the Knoll (**Figure 5-44**). Due to the low transmissivity of the rock, wells are spaced from 40 to 80 feet apart in this area. The treated water from the Industrial Area and southeast point would go into Trench #2 infiltration system (**Figure 5-44**).

The next area of extraction would start east of the Former Truck Maintenance Garage (FTMG) and wrap west to the area north of the ISFSI, ending on the northwestern corner of the 345 kV Switchyard (**Figure 5-44**). East and north of the FTMG, sand layer extraction wells and bedrock wells would both be used. Sand layer wells would be spaced at 80 to 120 feet spacing; bedrock wells would be spaced from 40 to 80 feet spacing (**Figure 5-44**). North of the ISFSI, there would be three levels of extraction, including bedrock and sand layer well systems and either a cut-off trench or closely-spaced wells in the clay fill. It is important to note that dewatering in this area would induce consolidation of the clay under the ISFSI and settlement and structural calculations for the ISFSI cask foundations would have to be made to evaluate the safety of pump and treat in this area.

Using analytical well drawdown formulae, the spacing of wells in the clay-silt material would have to be from 20 to 40 feet, with refined design based on pilot testing. Because of the close spacing required, it may be more effective to excavate linear trenches backfilled with filter fabric and a crushed stone around a perforated pipe that should be no deeper than Mean Sea Level or the soft clay layer, whichever comes first. Therefore, on **Figure 5-44**, the phreatic capture systems are shown as continuous red lines. The main operational problem with extracting water from the clay will be the presence of fine clay-silt particles that must be physically filtered from the water at the well, trench, and/or treatment sites.

West of the ISFSI, the extraction system of wells and phreatic capture continues, but the sand layer is not present in this area. The system terminates on the northwestern corner of the 345 kV Switchyard. The FTMG, ISFSI, and 345 kV Switchyard capture system treated water would be disposed of in Trench #3 (**Figure 5-44**).

Water from shallow system extraction systems along the west sides of both the east and west access roads would be disposed of in Trench #4 (**Figure 5-44**).

Bedrock well and shallow system extraction from the west side of the silt-spreading and ballfield areas (along the east side of Bailey Cove), plus water captured from bedrock wells on the west side of the west access road, would be discharged into Trench #5 and #6 following treatment (**Figure 5-44**).

Institutional controls would also be included to manage exposure to groundwater. The institutional controls would provide access restrictions and thus prevent the use groundwater at the Site for drinking water. Public water is currently available at the Site. These institutional controls would be implemented through the placement of a restrictive covenant.

Alternative Evaluation. **Table 5-9** presents the detailed analysis for Alternative GW-4 against the nine evaluation criteria. The cost estimates for Alternative GW-3 are included in **Table 5-12**, and cost backup information is included in **Appendix F**.

5.3.5 Comparative Analysis of Groundwater Alternatives

In this section, the detailed evaluations are used to compare the relative performance of the four groundwater alternatives for groundwater against each of the nine evaluation criteria. The comparative analysis allows the advantages and disadvantages of each alternative to be ranked as part of the decision-making process. The ranking system for each of the nine criteria is based on a relative ranking of high, medium, or low. **Table 5-13** presents the comparative analysis of the three groundwater alternatives.

As summarized in **Table 5-13**, Alternative GW-1 is characterized with Medium/Low, GW-2 Medium/High, and GW-3 with Medium ratings. All three alternatives are protective of human health and the environment due to the use of institutional controls. While groundwater cleanup will ultimately be attained by all three alternatives, the lack of groundwater monitoring in GW-1 will never document the potential cleanup. GW-1 and GW-2 both rely on natural attenuation mechanisms to achieve groundwater clean-up objectives. GW-2 has been ranked higher than GW-1 for some criteria based on the incremental benefits of a groundwater monitoring program and groundwater modeling activities included in alternative GW-2. Specifically, groundwater monitoring combined with groundwater modeling provides a mechanism to assess progress towards attaining clean-up goals, as well as the ability to monitor effectiveness and reliability. An additional differentiating factor between alternatives GW-1 and GW-2 is that alternative GW-1 does not comply with the MDEP requirement to conduct groundwater monitoring.

The intent in implementing a groundwater extraction and treatment alternative, such as GW-3, would be to significantly shorten the cleanup time relative to GW-2, which would rely solely on natural attenuation mechanisms to reduce concentrations in groundwater. However, due to a number of technical uncertainties associated with GW-3 the clean-up time may not be significantly different than GW-2. Technical issues and uncertainties associated with GW-3 that could minimize the effectiveness of reducing the cleanup time over GW-2 include:

- Difficulty in finding sufficiently fractured bedrock zones for bedrock extraction wells such that efficient capture of bedrock groundwater flow toward the tidal zone can be achieved,
- Possible need to use slurry trench construction methods (because of difficulty in keeping trench open in normal cut-and-cover methods) to emplace buried drains in clay soil areas, with attendant loss of effectiveness in capture of groundwater,
- Physical clogging of collection pipes and pumps in the soil trenches due to infiltration of clay-silt particles present in Maine Yankee soils,
- Fouling of pumps in wells and in manholes at the end of trench runs due to alternate on/off cycling required and iron, manganese, and iron bacteria build-up,
- Fouling of collection and force mains due to iron, manganese, and iron bacteria build-up,
- Inability to get waivers to allow subsurface discharge in the zone of 100 to 300 feet from Mean High Water,
- Inability to achieve efficient capture of contaminated rock in the deep bedrock aquifer due to the necessity of limiting pumping well drawdown to avoid inducing saltwater intrusion,
- Inability to achieve significant acceleration of sodium, boron, and chloride removal in the dredge spoil area in the clay soils beneath sea level because of the very low permeability of the soils in that area.

- Inability to accelerate significantly the reduction of the remaining DRO adsorbed to soils in the unsaturated soil zone, therefore, inability to accelerate removal of DRO from groundwater, and
- Inability of pump and treat system to accelerate significantly the removal of iron and manganese under the dredge spoil area because of the presence of former salt marsh deposits under the dredge spoils and redox conditions that favor continuous release of iron and manganese from soil particles in that area.

The above issues are expected to significantly minimize the effectiveness of GW-3 potentially resulting in little or no gain in cleanup time with alternative GW-3 relative to GW-2.

The long term reliability and effectiveness of the three alternatives is also significantly different. Due to the lack of monitoring, GW-1 provides no understanding of the effectiveness of the natural degradation of groundwater that the long term monitoring included in GW-2 will provide. Groundwater monitoring included in GW-2 is a proven and reliable technology for assessing the change in groundwater conditions with time. Although the groundwater extraction and treatment included in GW-3 uses proven technologies, the specific application to the Maine Yankee aquifers may give rise to less effective results due to the issues summarized above.

Short-term effectiveness primarily evaluates the risks to workers and the community during implementation of a remedy. The short-term effectiveness and reliability for both GW-1 and GW-2 are high, as there would be little or no adverse impacts to workers or the community since little or no activity is required to implement these alternatives. Additionally, institutional controls included in all three groundwater alternatives is expected to be an effective means of preventing the use of groundwater until groundwater objectives have been achieved. The relative short-term effectiveness of GW-3 is lower due to the potential risks inherent in the construction activities related to GW-3. Similarly, the implementability of GW-3 will be much more difficult than that associated with GW-1 or GW-2 due to the significant construction-related activities associated with implementing GW-3. The need for the infrastructure associated with GW-3 will also remove a large amount of land area from consideration for other potential uses.

The costs of the three alternatives are also significantly different. The costs for alternative GW-2 are approximately ten times those of GW-1, while the costs of GW-3 are almost 60 times those of GW-2. The additional costs for GW-2 relative to GW-1 appear justified in that the additional dollars spent will provide an understanding of the change in aquifer conditions through time, and document the final conditions of the aquifer water quality. The significant increase in costs associated with GW-3 relative to GW-2 is not as well justified. While the groundwater extraction and treatment included in GW-3 may result in a shorter cleanup time, the specific factors summarized above will potentially result in cleanup times for GW-3 that are not significantly different than that for associated with GW-2.

6.0 RECOMMENDED CORRECTIVE MEASURES

This section presents the recommended corrective measures alternatives for soil and groundwater at Maine Yankee. The recommendations are based on the results of the evaluations presented in earlier sections of this CMS.

6.1 Soil

The results of the alternative ranking for soil indicates that Alternative Soil-2, *Excavation and Offsite Disposal* has the highest score (**Table 5-4**). Although Alternative 2 has the high score, the costs associated with the alternative are very high, in excess of 28 million dollars. Maine Yankee has conducted numerous soil removals for petroleum-contaminated soil across Bailey Point. These removal actions have historically targeted 100 mg/kg DRO as the soil cleanup level and have significantly reduced the volume of petroleum-contaminated soils at the site. The 100 mg/kg cleanup level for DRO is consistent with MDEP's remedial criteria for the site based on with Maine Yankee's plans to restrict future use at the site to commercial/industrial activities.

Based on the use of institutional controls to limit future land use to commercial/industrial activities, the removal of petroleum-contaminated soils to the 100 mg/kg cleanup levels completed to date, and the high cost associated with Alternative Soil-2, Alternative Soil-1 is the recommended alternative for soil.

6.2 Groundwater

The results of the alternative ranking for groundwater are shown in **Table 5-13**. Alternatives GW-2 and GW-3 were similarly ranked, while Alternative 1 was ranked lower than Alternatives 2 and 3. Due to the use of institutional controls, all of the three alternatives are protective of human health. The results of the groundwater modeling and geochemical evaluation presented in **Sections 5.3.1 and 3.2.4** indicate that groundwater will naturally attenuate and ultimately reach cleanup goals for most of the site-related groundwater contamination.

Based on the lack of groundwater monitoring associated with the no further action alternative, Alternative GW-1 was ranked lowest, and will not be considered as a stand alone approach for site groundwater. Although Alternative GW-3 could ultimately restore the aquifer faster than GW-2, the alternative has substantial technical uncertainty (see **Section 5.3.5**), significantly high costs (in excess of 60 million dollars) and, if successful, would take many years of operation and maintenance to complete. Additionally, if a pump and treat alternative were combined with the most aggressive soil remedial alternative (Soil-2), the total cost of remediation is estimated to be in excess of 89 million dollars. This appears to be cost prohibitive since significantly less costly alternatives would achieve risk-based closure criteria for the site. Alternative GW-2 is the preferred alternative for groundwater. Based on the results of groundwater modeling and geochemical evaluation that indicate significant reduction in contaminant concentrations with time via natural attenuation and the high cost and technical uncertainty associated with Alternative GW-3; Alternative GW-2 is the recommended alternative for groundwater.

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