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Charles D. Race
Tetra Tech, Inc., charles.race@tetratech.com

James M. Tarr
NAVFAC MIDLANT

Thomas E. Johnson
Tetra Tech, Inc.

Anna-Marie S. Christian
Tetra Tech, Inc.

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PART IV: Risk Assessment

Chapter 9

SAMPLING STRATEGY AND RISK EVALUATION OF POLYCYCLIC AROMATIC HYDROCARBONS IN SOIL NEAR A FORMER PIPELINE IN MAINE

Charles D. Race[1§], James M. Tarr[2], Thomas E. Johnston[3], Anna-Marie S. Christian[3]
[1]*Tetra Tech, Inc., 250 Andover St., Suite 200, Wilmington, MA USA 01887* , [2]*NAVFAC MIDLANT , Code OPT3-5, 9742 Maryland Avenue, Bldg Z-144, Norfolk, VA USA 23511-3095,* [3]*Tetra Tech, Inc., 661 Anderson Dr., Foster Plaza 7, Pittsburg, PA 15220*

ABSTRACT

In 1952 a 7.25-mile long jet propulsion fuel (JP-5) supply pipeline was built within a 30-foot wide easement from the fuel farm at Defense Fuel Support Point, Casco Bay to Naval Air Station Brunswick, Maine. This subterranean pipeline, which spanned 115 private properties in Harpswell, Maine, was in operation until 1991 when it was decommissioned and abandoned in place. During construction, the pipeline was wrapped with an asbestos covering and, to eliminate any potential threat to humans from exposure to this covering, a decision was made to remove the pipeline. The pipeline remained in place until the Maine Congressional delegation acquired funding in 2007 for the removal. Pipeline removal began on February 8, 2010 and was completed by May 18, 2010.

Polycyclic aromatic hydrocarbons (PAHs) were detected in soil during routine monitoring associated with pipeline removal. Whereas the source of PAHs was originally thought to have been JP-5 fuel oil releases, the project team determined that this was not the case and searched for another source of PAHs. This paper describes the planning and conduct of an environmental investigation that was necessary to evaluate the nature and extent of pipeline-related PAH contamination and potential human health risks from exposure to PAHs in easement soil. Collaboration between Maine Department of Environmental Protection (MEDEP)

[§] Corresponding Author: Charles Race, Tetra Tech, 250 Andover St., Suite 200, Wilmington, MA USA 01887, (978) 474-8437, charles.race@tetratech.com

and the Navy was a key component in minimizing investigative costs while ensuring that the health of local residents was protected. A statistically based sampling design and statistical data analyses supported the project.

Keywords: soil, pipeline, Maine, polycyclic aromatic compounds, PAHs, statistical sampling, risk assessment, background estimates.

1. INTRODUCTION

The soil investigation described herein was performed to determine an effective sampling strategy for contaminant delineation and risk characterization for residential properties located along the former Casco Bay Pipeline, and to obtain initial estimates of residential health risks, including risks from soils in the pipeline easement area. Results of the pilot soil investigation were used to determine the extent of soil containing polycyclic aromatic hydrocarbons (PAHs) and if PAH concentrations in soil pose a potential unacceptable risk to exposed receptors in compliance with the Maine Department of Environmental Protection "Remediation Guidelines for Petroleum Contaminated Sites in Maine" (MEDEP 2009). It was the Navy's intent to return the easement property back to the original property owners without encumbrances.

1.1 Site Location and Description

The Casco Bay Pipeline was an underground pipeline that extended approximately 7.25-miles from the northern boundary of Mitchell Field in the town of Harpswell, Maine to the southern boundary of the former Naval Air Station Brunswick (NASB) located in the town of Brunswick, Maine. Property use surrounding the former Casco Bay Pipeline is residential and located in a rural area characterized by woodlands and wetlands. The pipeline was situated within a 30-foot wide easement that crossed 115 private properties. The pipeline system consisted of two separate underground pipes that were used to transfer jet propulsion (JP) fuel, primarily JP-5, from about 1952 until 1991 when the pipeline was taken out of service. The two pipes were constructed of carbon steel with welded joints of 8-inch, and 10-inch diameter and were set approximately three feet apart. The pipes were wrapped in asbestos and covered in an asphalt exterior coating, and placed on approximately 6 to 8 inches of bedding materials (either imported sand or native materials) in a narrow trench and covered with up to 5 feet of native materials that were excavated during construction of the trench.

In 1991, the pipeline was drained, cleaned and taken out of service. At this time, the pipes were also pressurized with nitrogen. This treatment persisted until 1995 when the NASB fuel tank-farm located in Mitchell Field was dismantled.

1.2 Previous Sampling Activities

The Navy's pipeline removal contractor began pipeline removal on February 8, 2010 and completed removal on or before May 18, 2010. Surficial materials above the pipeline were removed and placed to the sides of the excavation to enable removal of the pipeline. Sections of the pipeline were removed, placed on polyethylene sheeting, and transferred to roll-off containers. Excavated soils were used as backfill, with MEDEP approval.

The contractor collected soil samples at 20-foot intervals for MEDEP bag-headspace field-screening with a photo-ionization detector (PID). Soil samples were also collected a few inches beneath the pipeline at locations spaced 100-feet apart. These sampling locations were called "stations." These sub-pipeline samples were analyzed for volatile petroleum hydrocarbons (VPH) and extractable petroleum hydrocarbons (EPH). Naphthalene (a PAH) is the only VPH target analyte for which detected concentrations exceeded the MEDEP "Soil Remediation Guidelines" (MEDEP, 2009) leaching-to-groundwater criterion (1,700 micrograms per kilogram [µg/kg]). This criterion was exceeded at nine of the 375 locations, two of which were co-located with relatively high concentrations of other PAHs, and the remaining seven locations were associated with low or non-detectable concentrations of other PAHs.

It is well known that PAHs are common constituents of charcoal, ash, and asphalt products (e.g., shingles, paving, sealers), are produced from burning wood (e.g., in fire places, wood stoves, and forest fires), and can be distributed over long distances by atmospheric deposition (ATSDR, 1996). Therefore, PAHs are ubiquitous in the environment and can have various anthropogenic sources. Wetland sediments, which contain abundant organic matter, tend to accumulate PAHs, especially if they receive runoff from asphalt-paved areas (ATSDR, 1996). In both terrestrial and aquatic depositional areas, various processes, such as photo-oxidation and microbial action, can break down PAHs (ATSDR, 1996). This would result in PAH concentrations eventually decreasing to natural or anthropogenic levels over a sufficient period of time. Degradation of PAHs is expected to occur more rapidly in surface soil than in subsurface soil and the degradation times are anticipated to be on the order of weeks to months (ATSDR, 1996).

2. MATERIALS AND METHODS

2.1 Sampling Design

Soil sampling was conducted at Stations 18+00, 23+00, and 170+00 where previous sampling by another Navy contractor in March-April 2010 indicated the presence of elevated PAH concentrations that may have been derived from the former pipeline. Two sampling strategies were used at each Station:

- A large area grid representing the 30-foot wide pipeline easement spanning the width of an individual property to 10-feet below ground surface (bgs) or to refusal/bedrock, whichever was shallower. Each large grid was designed to emulate as closely as possible the volume of soil that a resident could get exposed, i.e., and exposure unit (EU).
- A small area grid representing approximately 100 square feet and a soil depth spanning the range of 1-foot above the former pipeline bottom to 1-foot below the pipeline bottom (or top of bedrock, whichever was shallower). The small area grid was required by MEDEP to determine the extent of the PAHs in the vicinity of the PAH "hotspot". MEDEP required that the data sets generated from both the small-area and large-area sampling approaches be compared to determine which sampling approach could be used to estimate human health risk at the remainder of the pipeline, if necessary.

For each soil boring location, soil samples were selected from upper, middle, and lower depth intervals. In the small area grids, sample depth intervals were based on the depths of the previous contractor's soil sample. These samples constituted available soil from the previous sample depth and depth intervals immediately above and below the previous depth. In the EU-based grids, sample intervals were selected based on risk characterization's "surface soil" vs. "subsurface soil" to support the risk characterization. Surface soil is between 0 and 2-feet bgs; subsurface soil is between 2-feet and bedrock.

The small and large sampling grids for each Station were centered on the location of PAH contamination detected previously at each of the properties. Nine borings were randomly located within the small grid, 14 were located randomly within the large grid, and both grids shared a boring at the center of the grids. The boring locations at Stations 18+00, 23+00, and 170+00 are depicted on Figures 1, 2 and 3, respectively, in Section 3.

The intent of the resampling was to compare the small and large grid subsurface soil concentrations and other characteristics (e.g., spatial coverage) to

determine which grid best represented PAH exposure. The small grid was designed to delineate the previously identified contamination within a small area. The large grid was designed to represent a scenario in which a resident is exposed to soil in the entire easement. The small area sampling focused on subsurface soil characterization whereas the large grid incorporated surface and subsurface soil sampling because residents are exposed to surface soil as well as subsurface soil. This sampling design yielded the following nine sets of samples and corresponding PAH concentrations:

- Station 18+00 small area sampling subsurface soil only;
- Station 18+00 large area sampling surface soil;
- Station 18+00 large area subsurface soil;
- Station 23+00 small area sampling subsurface soil only;
- Station 23+00 large area sampling surface soil;
- Station 23+00 large area subsurface soil;
- Station 170+00 small area sampling subsurface soil only;
- Station 170+00 large area sampling surface soil; and,
- Station 170+00 large area subsurface soil.

2.2 Soil Sampling and Analysis

Soil cores were collected continuously from each borehole using an all-terrain vehicle-mounted direct push rig equipped with a dual-tube soil sampling system. The dual-tube sampler consisted of a 1-inch inside diameter, 3-foot-long core barrel equipped with a new acetate liner. A total of 72 soil borings were advanced and 178 soil samples were collected for chemical analysis.

Soil cores from each of the three depth intervals were mixed in separate, steam-cleaned aluminum pans, and a sample of this soil was collected for EPH analysis following the Massachusetts Department of Environmental Protection method (MADEP, 2004a). Also, because naphthalene was elevated when compared to MEDEP Petroleum Remediation Guidelines (MEDEP, 2009) at Station 23+00, sub-cores were collected for VPH method for naphthalene analysis following the MADEP method (MADEP, 2004b) in both the small area and EU-based area. Each sub-core was collected using a new sub-coring device provided by the laboratory. The sub-coring device was used to collect three 5-gram samples, approximately equally spaced over the length of each soil interval. After collection of the sub-cores, the remainder of the soil in each interval was thoroughly mixed in separate, steam-cleaned aluminum pans, and approximately 30-grams of soil was collected for EPH analysis.

2.3 Statistical Analysis Methods

A dataset to dataset comparison was required in order to evaluate the most effective sampling strategy for use on the remainder of the pipeline. For statistical and mathematical manipulations, non-detect values were represented by one-half the reported non-detect value. Duplicate results (original and duplicate) were averaged to represent the concentration at the sample location for statistical evaluations. The statistical package R version 2.9.2 (R Development Core Team, 2011) was used to conduct the statistical evaluations. Statistical methods utilized can be found in statistical references (Moore, 1995).

The small area data were compared to large area data assuming the two datasets were similar, against the alternative that the two datasets were different. The comparisons were performed using side-by-side boxplots, normal Quantile-Quantile (Q-Q) plots, histograms, summary statistics, and hypothesis tests. The contractor soil samples (3 samples total or 1 sample per Station) were excluded from this analysis because they were present in both the small area and large area data sets.

2.4 Risk Evaluation Methods

PAH concentrations were used to estimate cancer and non-cancer risks for residents whose properties include portions of the 7.25-mile long pipeline easement. A risk ratio calculation method based on default exposure assumptions (USEPA, 1989) were used as the starting point for these calculations. That method is introduced in Sections 2.4 and 2.4.1, and its adaptation to account for site-specific conditions is described in Section 2.4.2.

Carcinogenic risks are expressed in the form of dimensionless probabilities referred to as incremental lifetime cancer risks (ILCRs). The ILCR per sampled location was derived by dividing the detected concentration at each sampling location by the risk-based concentration (RBC) equivalent to 1 x 10^{-6} ILCR. The MEDEP Petroleum Remediation Guidelines (MEDEP, 2009) risk-based residential screening values (ILCR = 10^{-6}) were used as the RBCs. The following equation shows how this calculation was carried out:

$$\mathrm{ILCR} = \sum_{i=1}^{n} \left(\frac{C_i}{\mathrm{RBC}_i} \times 10^{-6} \right)$$

where: ILCR = Incremental lifetime cancer risk.
C_i = Detected concentration for compound i.
RBC = 1 x 10^{-6} ILCR equivalent concentration for compound i.

The exposure assumptions used as the basis for the ILCRs computed in this manner are conservative and are considered to represent an overestimate of actual risks. For this project 1 x 10^{-5} ILCR or more was considered to be unacceptable.

Non-carcinogenic risk estimates are presented in the form of hazard quotients (HQs) and Hazard Indices (HIs). The HQ for each sampled location was derived by dividing the detected concentration for each chemical by the non-carcinogenic RBC. Compounds potentially resulting in non-carcinogenic (systemic) effects were evaluated using the following equations:

$$HQ_i = \frac{C_i}{RBC} \qquad HI = \sum_{i=1}^{n} HQ_i$$

where: HQ_i = Hazard quotient for compound i.
C_i = Detected concentration for compound i.
RBC = HQ=1 concentration equivalent for compound i.

For this project a HI greater than 1 was considered to be unacceptable. Sixteen PAH concentrations (excluding naphthalene) were measured in each sample from the three Stations. Naphthalene was also analyzed using the EPH method at Stations 18+00 and 170+00 but it was analyzed using the VPH method at Station 23+00. Naphthalene concentrations at Station 23+00 were shown through previous sampling by the contactor to be relatively high when compared to MEDEP Petroleum Remediation Guidelines (MEDEP, 2009) including risk-based residential soil guidelines and Leaching to Groundwater guidelines. Naphthalene has a low enough boiling point that it behaves as a volatile petroleum hydrocarbon as well as a semivolatile hydrocarbon. A list of the PAHs and whether they are considered to be carcinogenic or non-carcinogenic is presented in Table 1.

The toxicity equivalency factor (TEF) indicates its carcinogenic toxicity relative to benzo(a)pyrene carcinogenic toxicity as well as the MEDEP risk-based residential screening values for carcinogens and non-carcinogens. The measured PAH concentrations were used to estimate human health risks from exposure to PAHs in soil for each of these data sets.

2.4.1 Initial Risk Estimation Methodology

To compute carcinogenic and non-carcinogenic risks, the first step was to compute the exposure point concentration (EPC) for each PAH. The EPC is the concentration that represents the level of PAHs to which a hypothetical receptor is exposed within an exposure unit. The soil exposure unit, in this case, is the volume of soil to which the hypothetical resident is exposed through various pathways, such as dermal contact, incidental ingestion, and inhalation. To

estimate the EPC, data from all samples within the exposure unit were used. Instead of computing ILCRs directly, however, an upper bound on the range of concentrations for each chemical in each exposure unit (EU) was computed as described below and this value was used to compute the ILCR. The project team recognized that sampling provides only an estimate of the true EPC and that repeating the sampling event would almost certainly yield a different estimate every time it was repeated.

Table 1. Targeted PAHs and their carcinogenicities.

PAH	**Carcinogenicity**	**Toxicity Equivalency Factor, TEF**	**MEDEP RAGS Residential Values**	
			ILCR = 1E-6, mg/kg	**HI=1, mg/kg**
2-Methylnaphthalene	Non-carcinogenic	Not applicable	NA	4.7E+02
Acenaphthene	Non-carcinogenic	Not applicable	NA	4.8E+03
Acenaphthylene	Non-carcinogenic	Not applicable	NA	5.1E+03
Anthracene	Non-carcinogenic	Not applicable	NA	2.2E+04
Benzo(a)anthracene	Carcinogenic	0.1	2.6E-01	NA
Benzo(a)pyrene	Carcinogenic	1	2.6E-02	NA
Benzo(b)fluoranthene	Carcinogenic	0.1	2.6E-01	NA
Benzo(g,h,i)perylene	Non-carcinogenic	Not applicable	NA	3.7E+03
Benzo(k)fluoranthene	Carcinogenic	0.01	2.6E+00	NA
Chrysene	Carcinogenic	0.001	2.6E+01	NA
Dibenzo(a,h)anthracen	Carcinogenic	1	2.6E-02	NA
Fluoranthene	Non-carcinogenic	Not applicable	NA	5.0E+03
Fluorene	Non-carcinogenic	Not applicable	NA	4.1E+03
Indeno(1,2,3-	Carcinogenic	0.1	2.6E-01	NA
Naphthalene	Non-carcinogenic	Not applicable	2.0E+02	1.9E+03
Phenanthrene	Non-carcinogenic	Not applicable	NA	3.5E+03
Pyrene	Non-carcinogenic	Not applicable	NA	3.7E+03

Therefore, the initial approach was to place an upper bound (i.e., a 95 percent upper confidence limit [UCL]) on the range of EPCs that would be obtained if multiple sampling events occurred within the EU. This approach is a standard approach that uses statistics to estimate the EPC for each chemical within each of the nine data sets. ProUCL software, version 4.00.05 (USEPA, 2010), was used for these calculations.

Some complicating factors were encountered when using ProUCL. One factor was the dearth of detectable PAH concentrations. Approximately 75 percent of all measured PAH concentrations based on 178 samples collected for

this investigation were less than detectable levels. The ProUCL calculations generally require at least five detectable results in each data set before a statistically based EPC can be computed. There were not enough PAH detections to support the calculation for all PAHs when the total number of data points was divided by station, depth (i.e., surface or subsurface), and sampling grid (i.e., large or small). In samples for which PAHs are not detectable, it is possible that PAHs are present at low, unquantifiable concentrations. Therefore, the project team considered the EPCs computed by ProUCL to be non-representative of an actual EPC and decided to abandon the EPCs computed by ProUCL for a different approach as described below.

2.4.2 Risk Management Methodology

The following text describes the rationale to estimate a realistic EPC for each of the data sets. PAHs are produced during many different combustion processes, such as internal combustion engine operations, backyard burning, building fires, and forest fires, that tend to deposit PAHs onto surface soil. PAHs as a group are relatively immobile in soil and all of these potential activities can explain why surface soil PAH concentrations were generally greater than subsurface concentrations. Therefore, it was concluded that low concentrations of PAHs outside the easement represent background PAH concentrations. Access to the property outside of the easement, however, was not available for sampling because of access constraints on private property. Therefore, to determine what the level of background PAH benzo(a)pyrene equivalents (BAPEs) might be, the PAH concentrations were ranked by their BAPEs by substituting one-half the detection limit for non-detected carcinogenic PAH values. By doing so, it became evident that most carcinogenic BAPEs on a sample-by-sample basis were less than 1×10^{-5} and would be considered to represent an acceptable level of risk if they were equal to the actual EPC. Therefore, the mean concentration of all BAPEs representing cancer risk less than 1×10^{-5} was computed and to this mean was added 2.6 (the approximate 95 percent Student's t-factor) times the standard deviation of the individual concentrations. The resulting value, 110 μg/kg, represents an upper end of the distribution of the individual concentrations. Most PAH concentrations within the easement were less than 110 μg/kg regardless of whether they represented surface or subsurface soil. This was an additional indication that BAPEs less than 110 μg/kg (equating to a cancer risk of approximately 4×10^{-6}) represent a general low level of PAHs not related to pipeline operations. Additional data to support this assertion are in a compilation of soil data from a related investigation (Tetra Tech, 2012) in which soil samples were collected for PAH analysis in areas known to be uncontaminated outside the pipeline easement. For these additional data the BAPEs were well below 110 μg/kg, indicating that 110 μg/kg is a conservatively high upper estimate of BAPE

concentrations in an uncontaminated area such as the property outside the easement.

By estimating the general, low level of risk from soil PAH exposure that is not related to pipeline operations, it was possible to compute a realistic risk estimate for a resident exposed to soil over the entire property. If one assumes that a resident has equal probability of being exposed to soil from any particular portion of the residential property, then the actual risk incurred from living on the property is an average of risks associated with all soil within the property boundaries. This means that the risk from exposure to soil in the easement and risk from exposure to soil throughout the rest of the property can be combined using a simple area-weighted average representing the relative sizes of the two areas. The soil depth to which a resident could be exposed is assumed to be the same across the entire property. The only missing information was an estimate of the relative sizes of the easement and the rest of the property at each of the sampled stations. A review of town records indicate that all residential properties along the pipeline are about 2-acres or larger with some of the properties being on the order of 20-acres or more. Using the conservative value of 2-acres, the proportion of the area associated with the easement would be 0.5-acres divided by 2-acres, or 0.25 of the total area.

A simple arithmetic average of all data points within each large sampled area was computed. It was assumed that each data point from the large samples area carried equal weight in representing the easement portion of the EPC. The average PAH concentrations (i.e., the EPC) were computed for each PAH and the BAPEs for each sampled area. These BAPEs were converted to the equivalent ILCR for the sampled area and also for the overall residential property. This is described in more detail in Section 3.4.

3. RESULTS AND DISCUSSION

3.1 Soil Analytical Results

The following 17 PAHs were detected: 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene (see Table 2).

Five PAHs, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthacene, and indeno(1,2,3-cd)pyrene exceeded Maine screening values for residential soil using an Incremental Lifetime Cancer Risk (ILCR)

equal to 1 x 10^{-6}. The five PAHs exceeded these criteria in eight out of a total of 178 pilot soil samples, which represents approximately 4.5 percent of the samples. The eight samples that exceeded residential criteria were located at the following pilot soil sample locations:

- Station 18+00: two borings - SB10 (1.3-2.3 feet bgs), and SB20 (0-2 feet bgs)
- Station 23+00: four borings - SB06 (1.3-2.3 feet bgs), SB11 (0-2 feet bgs), SB15 (2 samples – 1-2 ft bgs, 2-3 feet bgs), and SB17 (0-2 feet bgs)
- Station 170+00: one boring - SB21 (0-2 feet bgs)

Benzo(a)pyrene was detected in a total of 15 other soil samples at concentrations ranging from 37 to 158 µg/kg. These values do not exceed the 260 µg/kg benzo(a)pyrene criterion (MEDEP, 2010) for a single contaminant (ILCR equal to 1 x 10^{-5}).

PAH concentrations did not exceed MEDEP Leaching-to-Groundwater criteria in any of the soil samples except one of the contractor's soil samples located at Station 23+00 where naphthalene was detected at 6,440 µg/kg. Naphthalene's criterion is 1,700 µg/kg.

The concentrations of carcinogenic PAHs exceeding the residential soil guidelines (ILCR equal to 1 x 10^{-5}) were normalized to benzo(a)pyrene equivalent (BAPE) concentrations. This normalization facilitates a spatial comparison of the eight samples where multiple PAHs exceeded residential guidelines of ILCR equal to 1 x 10^{-6} (exceedances) at the three stations. The following seven PAHs are used to calculate the BAPE concentration: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo (a,h)anthracene, and indeno(1,2,3-cd)pyrene.

The locations of the eight exceedances from the pilot soil investigation and the contractor's original "hot spot" sample are depicted on Figures 1 through 3. A description of the exceedance locations at each of the three pilot study areas follows:

- At the Station 18+00 study area (Figure 1), BAPE exceedances were measured at two samples within five feet of the former pipeline. One of the samples is located within the small area grid at boring SB10 and the remaining sample is located within the large area grid at boring SB20. Both samples were collected from surface soils (0 to 2.3 feet bgs).
- At the Station 23+00 study area (Figure 2), BAPE exceedances were measured in five samples within the large area grid. Four were within five feet of the former pipeline and the one was located between five and 10

feet from the former pipeline. Two of the five exceedances were from surface soil.

- At the Station 170+00 study area (Figure 3), BAPE exceedances were measured at one sample at boring SB21 located in the large area grid approximately six feet of the former pipeline. This sample was from surface soil.

These results indicated that most (5 out of 8) exceedances were from surface soils. The highest BAPE concentrations at each of the three stations were in the contractor's samples. These samples were collected within a few inches of the pipeline during the excavation process. In comparison, the soil investigation samples were collected at the three stations after pipeline removal and restoration of the easement area.

3.2 Statistical Analysis Results

The data were analyzed to determine whether they are similar or different. The percentage of non-detected concentrations for all the chemicals at each of the three stations was greater than 50 percent; therefore, the two-proportion test was used to determine whether there was a difference between the percentage of samples above the action level. A cancer risk action level of 10^{-5} (incremental lifetime cancer risk [ILCR]) was used for carcinogens and a non-cancer risk action level equal to 1 (hazard index [HI]) was used. The ILCR is the incremental probability of an individual developing cancer over a lifetime, as a result of exposure to a contaminant (MEDEP, 2009). The HI is the sum of hazard quotients (HQs) for substances that affect the same target organ or organ system. The HQ is the ratio of the potential exposure to the substance and the level at which no adverse effects are expected. If the HQ is calculated to be equal to or less than 1, then no adverse health effects are expected as a result of exposure. If the HQ is greater than 1, then adverse health effects are possible.

The actual numerical comparisons were based on chemical-specific concentrations equivalent to these action levels. The assumed null hypothesis for the two-proportion test was that the proportion of samples greater than the action level in the small area dataset is statistically similar to the proportion of samples greater than the action level in the large area dataset. The alternative hypothesis was that the proportion of non-detected concentrations in the small area dataset is statistically different than the proportion of non-detected concentrations in the large area dataset. If the probability value (p-value) associated with the proportion test was less than 0.05, it was concluded that the proportion of samples greater than the action level in the small area dataset is different than the

Table 2. Data Summary Table, Pilot Soil Investigation, Casco Bay Pipeline, Harpswell, Maine

Parameter[1,2]	Frequency of Detects	Minimum Detection (µg/kg)	Maximum Detection (µg/kg)	Average (µg/kg)	Sample Max. Detected	Residential[3] (ILCR=10-6, HQ=0.2) (µg/kg)	Residential[3] (ILCR=10-6, HQ=0.2) No. >	Residential[3] (ILCR=10-5, HQ=1) (µg/kg)	Residential[3] (ILCR=10-5, HQ=1) No. >
2-METHYLNAPHTHALENE	7/178	15	54	8.74	CBP-23-SB15-2-3	94000	0	470000	0
ACENAPHTHENE	37/178	2.4	595	16.7	CBP-170-SB21-0-2	970000	0	4800000	0
ACENAPHTHYLENE	16/178	2.7	113	8.63	CBP-23-SB15-0-2	1000000	0	5100000	0
ANTHRACENE	56/178	2.9	1260	33.9	CBP-170-SB21-0-2	4300000	0	22000000	0
BENZO(A)ANTHRACENE	46/178	7.4	3810	82.5	CBP-18-SB20-0-2	260	8	2600	1
BENZO(A)PYRENE	50/178	3.7	2610	67.4	CBP-18-SB20-0-2	26	23	260	8
BENZO(B)FLUORANTHENE	77/178	6.85	4120	89.3	CBP-18-SB20-0-2	260	8	2600	1
BENZO(G,H,I)PERYLENE	51/178	3.3	1260	36	CBP-18-SB20-0-2	750000	0	3700000	0
BENZO(K)FLUORANTHENE	60/178	2.5	1250	34.3	CBP-18-SB20-0-2	2600	0	26000	0
CHRYSENE	45/178	5.8	2660	68.2	CBP-18-SB20-0-2	26000	0	260000	0
DIBENZO(A,H)ANTHRACENE	32/178	2.4	309	13.6	CBP-18-SB20-0-2	26	8	260	1
FLUORANTHENE	45/178	14	5190	147	CBP-170-SB21-0-2	1000000	0	5000000	0
FLUORENE	34/178	3.5	579	16.8	CBP-170-SB21-0-2	830000	0	4100000	0
INDENO(1,2,3-CD)PYRENE	75/178	3.6	1430	40.2	CBP-18-SB20-0-2	260	8	2600	0
NAPHTHALENE	13/118	11.2	102	10.1	CBP-170-SB21-0-2	200000	0	1900000	0
PHENANTHRENE	47/178	6.6	4770	104	CBP-170-SB21-0-2	700000	0	3500000	0
PYRENE	46/178	11	4080	122	CBP-170-SB21-0-2	750000	0	3700000	0
NAPHTHALENE[4]	4/60	536	1330	96.5	CBP-23-SB15-2-3	200000	0	1900000	0

Notes/Abbreviations: (1) - Sample and sample duplicate values averaged. (2) EPH analyte except as noted (see note 4). (3) - Criteria Reference: Maine Remedial Action Guidelines, January 13, 2010. (4) VPH analyte. No.> - No. of samples exceed criterion. µg/kg – micrograms per kilogram.

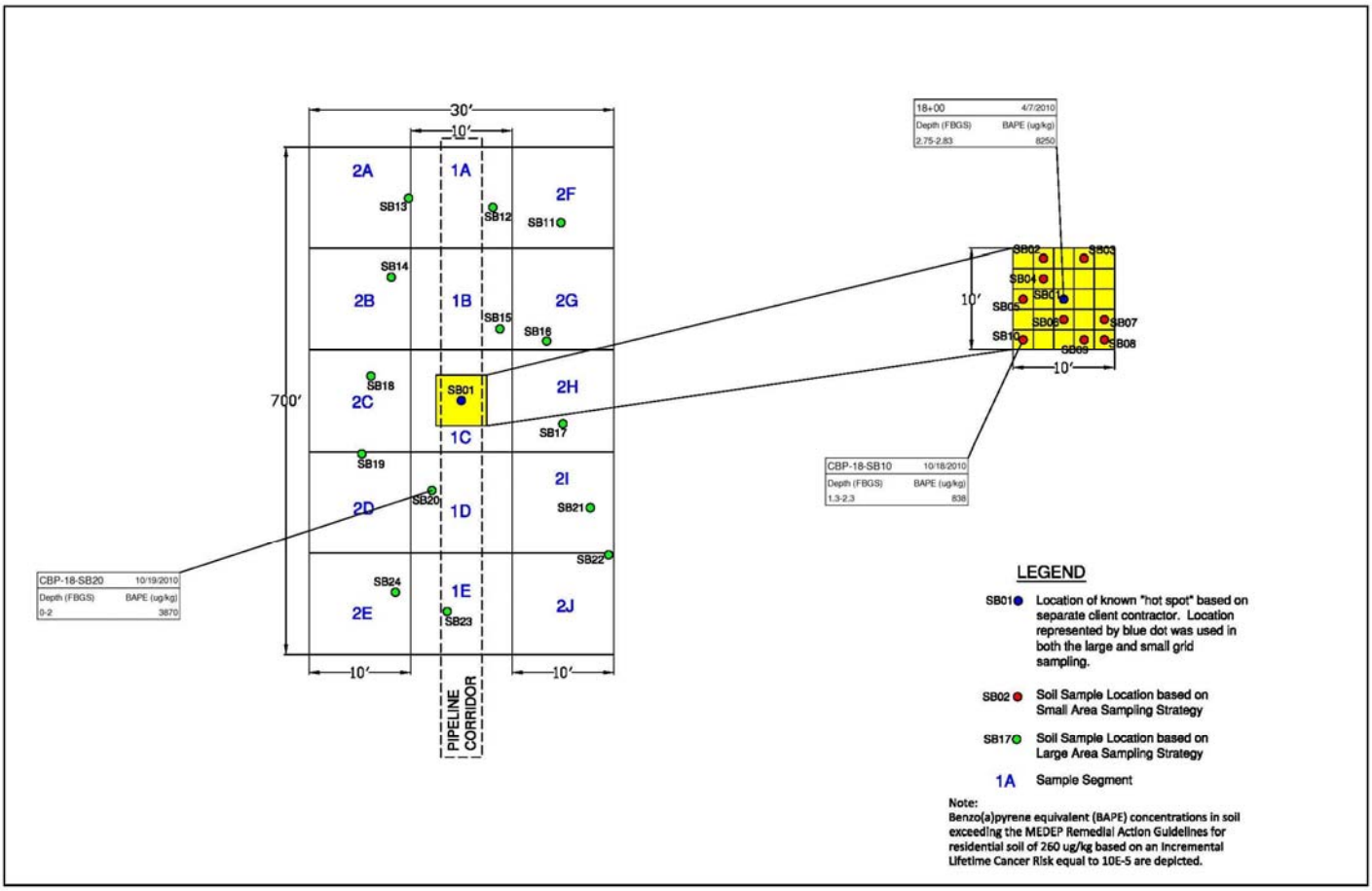

Figure 1. BAP Equivalents Exceeding 260 µg/kg MEDEP Residential Soil Guideline at Station 18+00 Pilot Soil Study Area.

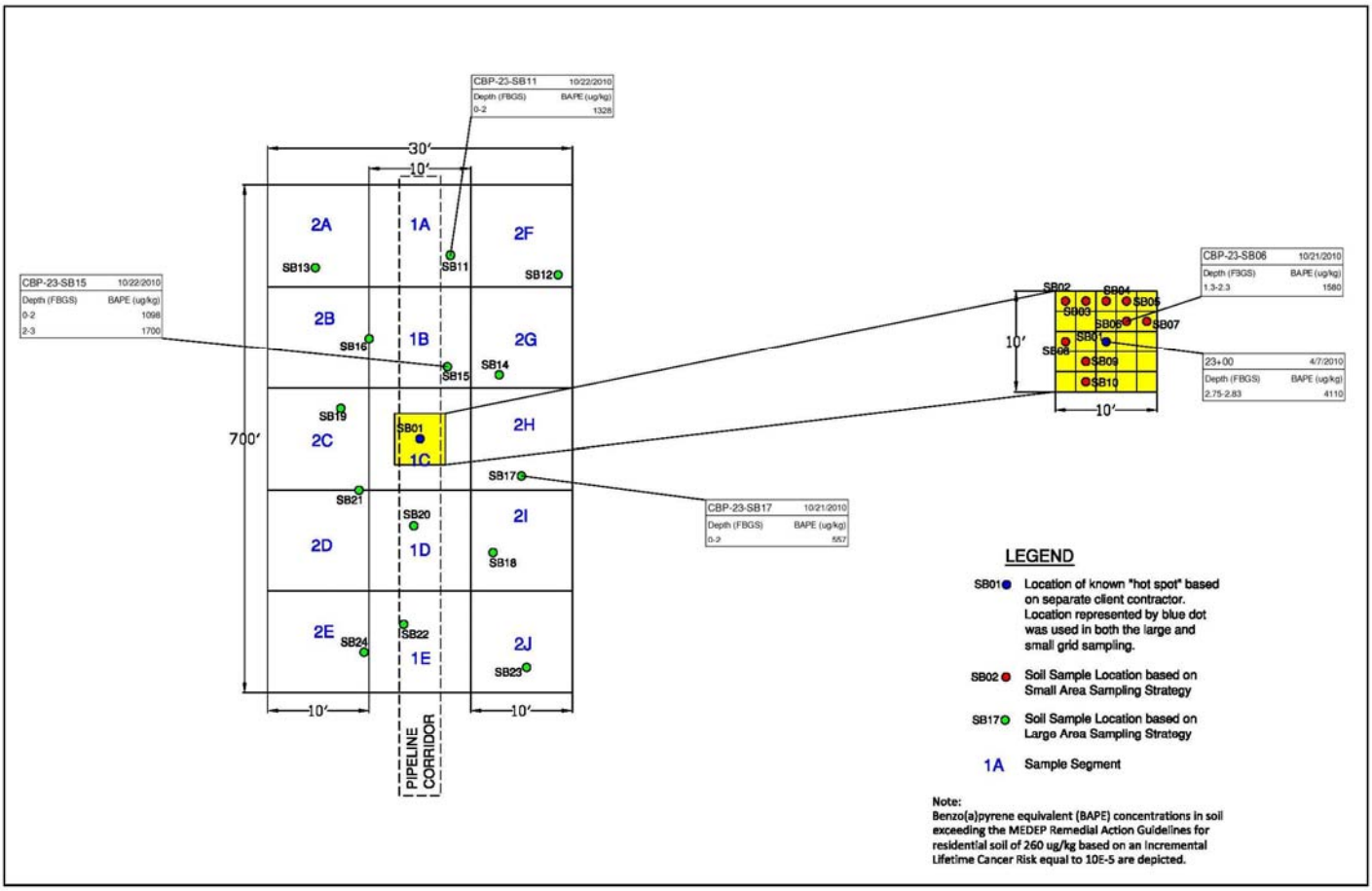

Figure 2. BAP Equivalents Exceeding 260 µg/kg MEDEP Residential Soil Guideline at Station 23+00 Study Area.

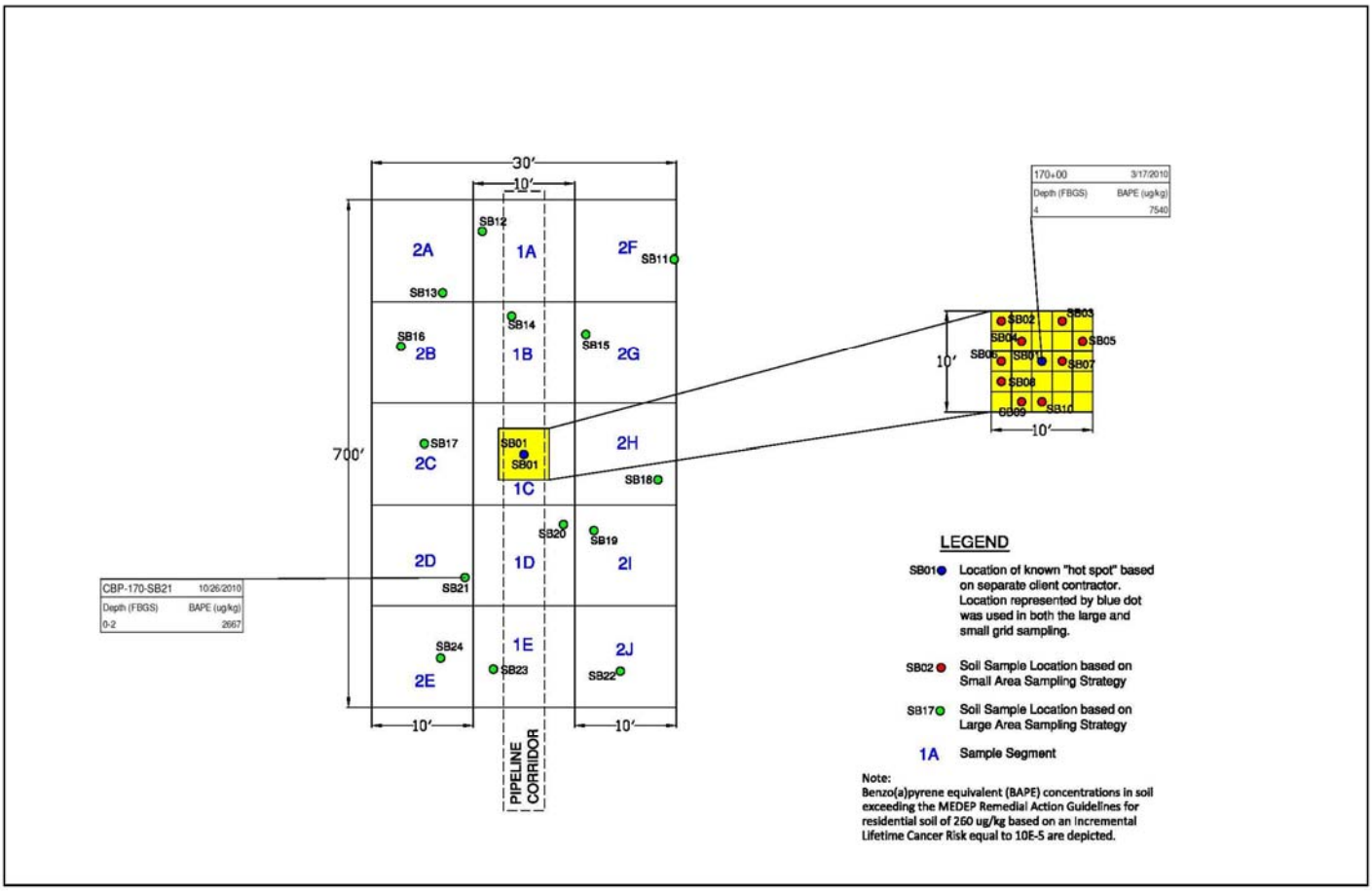

Figure 3. BAP Equivalents Exceeding 260 µg/kg MEDEP Residential Soil Guideline at Station 170+00 Pilot Study Area.

proportion of samples greater than the action level in the large area dataset. If the p-value associated with the two proportions test was greater than 0.05, it wasconcluded that the proportion of samples greater than the action level in the small area dataset is similar to the proportion of samples greater than the action level in the large area dataset. Fisher's Exact Test was computed if the normal approximation two proportion test assumptions were not valid. The normal approximation assumptions are that the proportion of samples greater than action level times sample size, and one minus the proportion of samples greater than the action level times the sample size, are greater than or equal to five for each dataset.

The results of the two-sample proportion test show that the proportion of samples greater than the action level for the small delineation area are statistically similar to the proportion of samples greater than the action level for the larger "EU-based" area for many parameters in the small area and large area datasets. This suggests the spatial representation is not a significant factor: one represents an area of 100 square feet, and the other represents approximately one-half acre including the 30-foot wide easement.

3.3 Human Health Risk Results

The initial analysis of human health risk using the risk-ratio method indicated that cancer risk estimates exceeded the ILCR equal to 1×10^{-5} in all surface and subsurface soils. Initial non-cancer risk estimates were acceptable in all surface and subsurface soils.

Some of the "95 percent Upper Concentration Limits (UCLs)" were set to be equal to the maximum observed PAH concentrations, according to ProUCL software, and because many of the PAH concentrations were less than detectable limits in many samples of an EU-based area, valid statistical calculations were not possible. In these cases, the true EPC would be less than the maximum detected PAH concentrations, even if the receptor was only exposed to easement soils. Therefore, an attempt was made to compute a more realistic estimate of human health risk.

3.4 Risk Management Results

The human health risks calculated for each of the three stations assume human receptors will be exposed only to soil within the easement. This assumption is unlikely to be true because residents would not be physically restricted to this small area, such as a 30-foot-wide area of a residential parcel. Furthermore, it is

evident that PAH contamination is heterogeneously distributed within the easements.

To calculate a more realistic estimate of true cancer and non-cancer health risks, the EPC was estimated for the portion of the property outside the easement. This was done by first observing that most PAH concentrations within the sampled EU-based areas were less than 110 µg/kg. Next, it was assumed that PAH concentrations outside the easement are no greater than those inside the easement. This seemed reasonable because the distance from the assumed PAH contamination source (the former pipeline) is greater for locations outside the easement, and contaminant concentrations commonly decrease with distance from a contaminant source. The value of 110 µg/kg was conservatively assumed to represent the average PAH concentrations outside the easement; this equates to a cancer risk of 4×10^{-6} and appeared to be an upper limit to background PAH concentrations.

In the next step, some assumptions were made about the total area over which a resident is exposed and the amount of that area represented by the easement. Although some of the residential lots are much more than four times the size of the easements on the lots, the sampled EU-based areas were assumed to represent 25 percent of the total residential property. The average cancer risk for a land parcel comprised of 25 percent easement and 75 percent uncontaminated property would then be the sum of 0.25 times the average EU cancer risk and 0.75 times 4×10^{-6}. This area-weighted risk was computed for each station. When this was done, the results listed in Table 3 were obtained. The column labeled, "Overall Cancer Risk" is the area-weighted risk that was computed as described here. In the same table, the "Average Cancer Risk" represents a simple average of the cancer risk equivalent of the BAPE at each sample location within the EU.

Table 3. Average BAPE Concentrations and Calculated Cancer Risk for Surface and Subsurface Soil at the three Pilot Study Areas.

Station	Depth	Average of BAPE HalfND	Average of Cancer Risk	Overall Cancer Risk
18+00	subsurface	528	2×10^{-6}	8×10^{-6}
18+00	surface	303	12×10^{-5}	6×10^{-6}
23+00	subsurface	404	2×10^{-6}	7×10^{-6}
23+00	surface	243	9×10^{-6}	5×10^{-6}
170+00	subsurface	594	2×10^{-6}	9×10^{-6}
170+00	surface	227	9×10^{-6}	5×10^{-6}

Note: BAPE HalfND means BAPE is calculated substituting ½ the detection limit for non-detected analytes.

All of these results are less than the cancer risk threshold of 1 x 10^{-5}. This occurs because the larger proportion of the residential property to which a resident is exposed has a lower soil PAH concentration than the easement soil PAH concentration, and because even the easement soil PAH concentrations are heterogeneously distributed, with very localized areas of contamination dispersed among generally uncontaminated or slightly contaminated soil. Although the overall cancer risks computed in this manner are less than the MEDEP threshold of unacceptable risk, these risks are believed to be exaggerated, compared to what is anticipated to be the true cancer risks. When these calculations were repeated for non-cancer risks, all non-cancer risks for the sampled residential properties were less then HI equal to 1.

These calculations were not performed for the small area sampling because:

- The results would be similar, because the EPCs for the small area sampling were similar to the EU-based area sampling; and,
- The small area sampling represents a much smaller area than an actual residential soil exposure unit

4. CONCLUSIONS

Five PAHs, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthacene, and indeno(1,2,3-cd)pyrene exceeded Maine screening values for residential soil. This is based on an Incremental Lifetime Cancer Risk (ILCR) equal to 1 x 10^{-6}. Only eight out of a total of 178 pilot soil samples, which represents approximately 4.5 percent of the samples, exceeded this ILCR value. The exceedances were primarily detected in surface soils, rather than in subsurface soils.

The statistical analysis results show that the proportion of samples greater than the action level for the small delineation area are statistically similar to the proportion of samples greater than the action level for the larger “EU-based” area for many parameters in both the small area and large area datasets.

The human health risks calculated for each of the three stations assume human receptors will incur contact only with soil within the easement. This assumption is unlikely because residents would not be physically restricted to a small area, such as a 30-foot-wide portion of a residential parcel. Therefore, a more realistic estimate of human health risk took into account the area of two-acre land parcel and the fact that few samples had PAH concentrations greater than what appears to be general background concentrations. The results of the revised risk analysis

indicate the overall health risks to a resident are less than both the MEDEP ILCR equal to 1 x 10^{-5} and HI equal to 1.

5. ACKNOWLEDGMENTS

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