April 24, 2020

Mr. John Hickman
U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Division of Decommissioning, Uranium Recovery, and Waste Programs
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SUBJECT: CONTRACT NO. DE-SC0014664
INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS OF THE REMAINING LAND AREAS AT THE ZION NUCLEAR POWER STATION, ZION, ILLINOIS; DOCKET NOs. 50-295 and 50-304; RFTA No. 18-004
DCN 5271-SR-08-0

Dear Mr. Hickman:

The Oak Ridge Institute for Science and Education (ORISE) is pleased to provide the enclosed final report detailing the confirmatory survey activities for the remaining land areas at the Zion Nuclear Power Station in Zion, Illinois.

Please feel free to contact me at 865.574.6273 or Erika Bailey at 865.576.6659 if you have any comments or concerns.

Sincerely,

Nick A. Altic, CHP
Health Physicist/Project Manager
ORISE

NAA:tb

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INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE REMAINING LAND AREAS AT THE ZION NUCLEAR POWER STATION ZION, ILLINOIS

K. M. Engel
ORISE

FINAL REPORT

Prepared for the
U.S. Nuclear Regulatory Commission

APRIL 2020

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INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE REMAINING LAND AREAS AT THE ZION NUCLEAR POWER STATION ZION, ILLINOIS

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April 2020

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ACRONYMS

AA	alternative action
CB	catch basin
CFR	Code of Federal Regulations
cm	centimeter(s)
Co-60	cobalt-60
cpm	counts per minute
Cs-134	cesium-134
Cs-137	cesium-137
CU	confirmatory unit
DCGL	derived concentration guideline level
$DCGL_{BC}$	base case DCGL
$DCGL_{Op}$	operational DCGL
DQO	data quality objective
DS	decision statement
Exelon	Exelon Generating Company
FSS	final status survey
GPS	global positioning system
H-3	tritium
H_0	null hypothesis
H_A	alternative hypothesis
HTD	hard-to-detect
ISFSI	independent spent fuel storage installation
LTP	license termination plan
m^2	square meter(s)
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MeV	mega electron volt
MDC	minimum detectable concentration
MDC_{SCAN}	scan MDC
mrem/yr	millirem per year
NaI[Tl]	thallium-doped sodium iodide
Ni-63	nickel-63
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocurie per gram
PSQs	principal study questions
Q	quantile
REAL	Radiological and Environmental Analytical Laboratory
ROC	radionuclide of concern
RSS	ranked set sampling
SOF	sum-of-fractions
Sr-90	strontium-90
SU	survey unit
TAP	total absorption peak

TEDE	total effective dose equivalent
TPU	total propagated uncertainty
VSP	Visual Sample Plan
ZNPS	Zion Nuclear Power Station
ZS	Zion*Solutions*, LLC

OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE REMAINING LAND AREAS AT THE ZION NUCLEAR POWER STATION ZION, ILLINOIS

EXECUTIVE SUMMARY

U.S. Nuclear Regulatory Commission (NRC) staff requested that the Oak Ridge Institute for Science and Education (ORISE) perform confirmatory survey activities of the remaining land areas at the Zion Nuclear Power Station (ZNPS) in Zion, Illinois.

ORISE performed independent assessment activities during the periods of December 2–5, 2019, and January 6–9, 2020. Confirmatory survey activities included gamma walkover surface scans, gamma direct measurements, and soil sampling. The areas investigated included all or a portion of survey areas 00150, 10201, 10202, 10203, 10206, 10207, 10208, 10209, 10211, 10213, 10214, 10219, 10220, 10221, 12102, 12103, 12112, 12113, 12201, 12203, 12204, and 12205. Seven locations were identified during surface soil scans as distinguishable from background and were marked for investigation. A total of 37 soil samples were collected: 30 random samples, three judgmental samples, and four rainwater catch basin (CB) drain sediment samples. Six of the random samples were subsurface soils; the remainder of the random samples were surface samples.

Of the seven identified areas with elevated gamma radiation levels, three were judgmentally selected for sampling. One of the judgmentally-sampled areas contained a piece of concrete-like debris, which was left with site personnel, while the soil from around the concrete was collected as a confirmatory oil sample. Three of the areas identified with elevated gamma radiation were investigated by the site, as directed by NRC staff. One of these areas had a discrete particle. A gamma walkover scan was performed after the discrete particle was sampled, and showed gamma radiation levels to be similar to the surrounding area. ORISE does not have the results of the investigation performed of the other two areas. The seventh area had widespread, elevated gamma radiation levels that increased closer to the independent spent fuel storage installation (ISFSI), which was expected as it contains the site's spent fuel.

The collected confirmatory survey data did not present any anomalous issues that would preclude the final status survey (FSS) data from demonstrating compliance with the release criterion—with

the exception of the two judgmental locations identified (in SU 10220I and 12112) but not investigated by ORISE. NRC staff directed the site to investigate these areas; therefore, it is recommended that NRC staff evaluate the results of these investigations. Furthermore, the confirmatory survey data supports the SU classification. Laboratory analytical results for the sediment samples collected form the CBs in SU 00150 are presented for NRC staffs' evaluation.

INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE REMAINING LAND AREAS AT THE ZION NUCLEAR POWER STATION ZION, ILLINOIS

1. INTRODUCTION

The Zion Nuclear Power Station (ZNPS) consisted of two reactors, Unit 1 and Unit 2 that operated commercially from 1973 to 1997 and 1974 to 1996, respectively. Cessation of nuclear operations was certified in 1998 after both reactor units were defueled and the fuel assemblies had been placed in a spent-fuel pool. Both units then were placed in safe storage pending the commencement of site decommissioning and dismantlement. In 2010, the U.S. Nuclear Regulatory Commission (NRC) operating license was transferred from Exelon Generating Company (Exelon) to Zion*Solutions*, LLC (ZS) to allow the physical decommissioning process, which is expected to be completed within 10 years. The end-state and primary decommissioning objective at ZNPS is the transfer of all spent nuclear fuel to the independent spent fuel storage installation (ISFSI) and to reduce residual radioactivity within structures and soils to levels below the criteria specified in 10 *Code of Federal Regulations* (CFR) 20.1402, permitting release of the site for unrestricted use. Upon successful completion of the decommissioning activities, control and responsibility for the site will be transferred back to Exelon, and the ISFSI will be maintained under Exelon's Part 50 license (EC 2015).

As part of decommissioning, all above-grade structures, with a few exceptions, were demolished. Structures below the 588-foot elevation (referenced from mean sea level), consisting primarily of exterior subgrade walls and floors, remain. These basement structures were backfilled as part of the final site restoration. In order to demonstrate compliance with the release criteria in 10 CFR 20.1402, ZS implemented final status survey (FSS) activities of remaining basement structures along with associated embedded piping and penetrations, buried piping, and remaining soil. FSS methodologies are outlined in Chapter 5 of ZS's license termination plan (LTP) (ZS 2018). FSS methods are based on those outlined in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000). NRC issued license amendments 191 and 178 to approve ZS's LTP in September of 2018 (NRC 2018).

NRC staff requested that the Oak Ridge Institute for Science and Education (ORISE) perform confirmatory survey activities within select impacted land areas of the site in order to use the confirmatory survey data for their evaluation of the adequacy and accuracy of ZS's FSS data as well as the final end state of the remaining land areas following backfill of several survey areas.

2. SITE DESCRIPTION

ZNPS is located in Lake County, Illinois, on the easternmost portion of the city of Zion. It is approximately 64 kilometers (40 miles) north of Chicago, Illinois, and 68 kilometers (42 miles) south of Milwaukee, Wisconsin. The owner-controlled site is composed of approximately 134 hectares (330 acres) and is situated between the northern and southern parts of Illinois Beach State Park on the western shore of Lake Michigan (EC 2015 and ZS 2018). Figure 2.1 provides an overview of ZNPS. The site and its surrounding environs are relatively flat, with the elevation of the developed portion of the site at approximately 591 feet above mean seal level. For reference, the elevation of Lake Michigan—which bounds the site on the east—is approximately 577.4 feet at low-water level (ZS 2018).

The area within the security-restricted fence contained the principal components of the power plant, including the two containment vessels, the turbine, crib house, and waste water treatment facility. The site subdivided land areas into survey areas, which were further subdivided into individual FSS survey units (SUs). Note that some survey areas were not subdivided, and the survey area corresponds to the FSS SU. The survey areas are outlined in Figure 2.2.

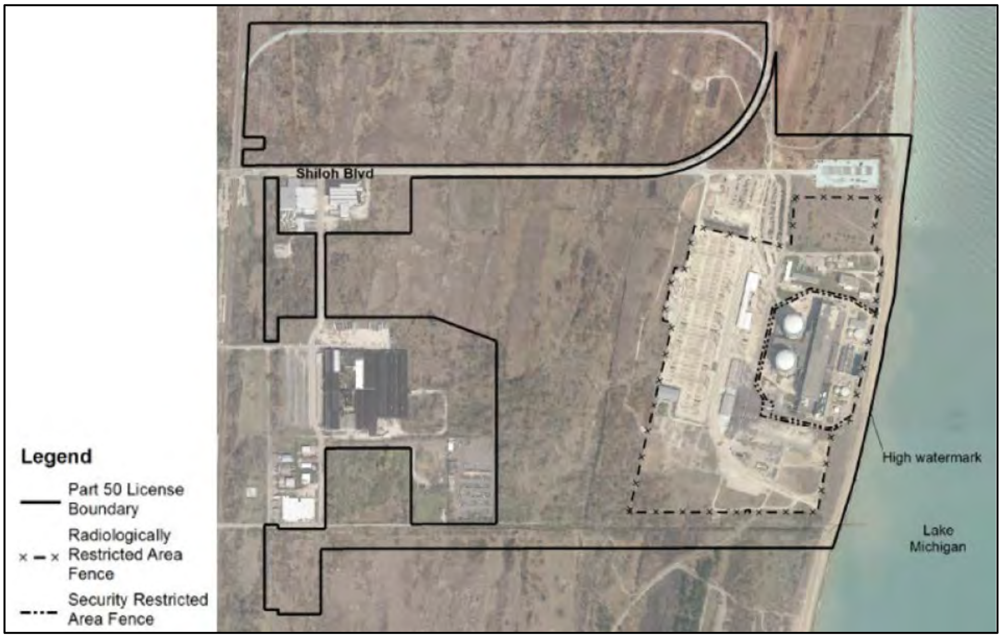

Figure 2.1. ZNPS Overview (adapted from ZS 2018)

Figure 2.2. Overview of ZNPS Survey Units (Adapted from NRC 2019)

3. DATA QUALITY OBJECTIVES

The data quality objectives (DQOs) described herein are consistent with the *Guidance on Systematic Planning Using the Data Quality Objectives Process* (EPA 2006) and provided a formalized method for planning radiation surveys, improving survey efficiency and effectiveness, and ensuring that the type, quality, and quantity of data collected were adequate for the intended decision applications. The seven steps in the DQO process were as follows:

1. State the problem
2. Identify the decision/objective
3. Identify inputs to the decision/objective
4. Define the study boundaries
5. Develop a decision rule
6. Specify limits on decision errors
7. Optimize the design for obtaining data

Confirmatory survey DQOs were originally presented in ORISE 2019 and are represented here for completeness.

3.1 STATE THE PROBLEM

The first step in the DQO process defined the problem that necessitated the study. NRC requested that ORISE perform confirmatory surveys at ZNPS. The objectives of the confirmatory survey were to provide NRC staff with independent confirmatory data for NRC's consideration in the evaluation of the FSS results as well as the final end state of the remaining land areas following backfill of several survey areas. Therefore, the problem statement was as follows:

> Confirmatory surveys are necessary to generate independent radiological data for NRC staff's consideration in the evaluation of the FSS design, implementation, and results for demonstrating compliance with the release criteria.

3.2 IDENTIFY THE DECISION/OBJECTIVE

The second step in the DQO process identified the principal study questions (PSQs) and alternative actions (AAs), developed decision statements (DSs), and organized multiple decisions, as appropriate. This was done by specifying AAs that could result from a "Yes" response to the PSQs and combining the PSQs and AAs into a DS(s). Given that the problem statement introduced in Section 3.1 was fairly broad, multiple PSQs arose. PSQs, AAs, and combined DSs were organized based on the SU type (i.e., the associated FSS methodology), and are presented in Table 3.1.

Table 3.1. ZNPS Confirmatory Survey Decision Process

Principal Study Questions	Alternative Actions
PSQ1: Do confirmatory survey results agree with the FSS data for the remaining land areas and are residual radioactivity concentrations associated with the remaining land areas below applicable limits?	**Yes:** Compile confirmatory data and report results to NRC staff for their decision making. Provide independent interpretation that confirmatory field surveys did not identify anomalous areas of residual radioactivity, quantitative field and laboratory data satisfied the NRC-approved decommissioning criteria, or that statistical sample population examination/assessment conditions were met. **No:** Compile confirmatory data and report results to NRC staff for their decision making. Provide independent interpretation of confirmatory survey results identifying any anomalous field or laboratory data or when statistical sample population examination/assessment conditions were not satisfied for NRC staff's determination of the adequacy and accuracy of the FSS data.
PSQ2: Do the confirmatory results support the MARSSIM classification of the FSS SUs?	**Yes:** Confirmatory results support the classification of the FSS SUs. Compile confirmatory survey data and present results to NRC staff for their decision making. **No:** Confirmatory results do not support the classification of the FSS SUs. Summarize the discrepancies and provide technical comments to NRC staff for their decision making.
Decision Statements	
Determine if anomalous confirmatory survey results or other conditions are present that preclude the FSS data from demonstrating compliance with the release criteria. Determine if confirmatory survey results support the FSS SUs MARSSIM classification.	

3.3 IDENTIFY INPUTS TO THE DECISION/OBJECTIVE

The third step in the DQO process identified both the information needed and the sources of this information, determined the basis for action levels, and identified sampling and analytical methods that met data requirements. For this effort, information inputs included the following:

- ZNPS FSS data for remaining soils.
- Derived concentration guideline levels (DCGLs), further discussed in subsection 3.3.1.
- ORISE confirmatory survey results for gamma radiation surface scans.
- ORISE volumetric soil sample analytical results.

3.3.1 Radionuclides of Concern and Release Guidelines

The primary radionuclides of concern (ROCs) identified for ZNPS are beta-gamma emitters—fission and activation products—resulting from reactor operations. ZNPS developed site-specific DCGLs that correspond to a residual radioactive contamination level above background, which could result in a total effective dose equivalent (TEDE) of 25 millirem per year (mrem/yr) to an average member of the critical group. These DCGLs—defined in ZNPS's LTP as base case DCGLs ($DCGL_{BC}$s)—are radionuclide-specific and independently correspond to a TEDE of 25 mrem/yr for each source term. The initial suite of ROCs present at ZNPS has been reduced based on an insignificant dose contribution from a number of radionuclides. As such, the $DCGL_{BC}$s have been reduced to account for the dose from these insignificant radionuclides.

In order to ensure that total dose from all site-related source terms—basement structures, soils, buried piping, and groundwater—is less than the NRC-approved release criteria, the $DCGL_{BC}$s are further reduced to operational DCGLs ($DCGL_{Op}$s). The $DCGL_{Op}$s represent the expected dose from prior investigations, and are used for remediation and FSS/remedial-action design purposes. $DCGL_{BC}$s and $DCGL_{Op}$s for surface and subsurface soil, accounting for insignificant dose contributors, are provided in Table 3.2. Note that ZS did not identify tritium (H-3) as a primary ROC. However, H-3 was included as part of this study, as requested by NRC staff.

Table 3.2. ZNPS Soil DCGLs[a] and Corresponding MDCs (pCi/g)						
ROC	Surface Soil DCGL			Subsurface Soil DCGL		Analytical MDC[c]
	Base Case	Operational	Nominal Scan MDC[b]	Base Case	Operational	
Co-60	4.26	1.091	3 to 5	3.44	0.881	< 0.1
Cs-134	6.77	1.733	Unknown	4.44	1.137	< 0.1
Cs-137	14.18	3.630	6 to 8	7.75	1.984	< 0.1
Ni-63	3,572.10	914.458	HTD	763.02	195.333	<2
Sr-90	12.09	3.095	HTD	1.66	0.425	~0.2
H-3	--[d]	--	HTD	--	--	<3

[a]Recreated from ZS 2018
[b]Approximated using the methods described in NRC 2000
[c]Based on observed analytical MDCs
[d]H-3 is not identified as a primary ROC; therefore, DCGLs are not available
pCi/g = picocuries per gram
MDC = minimum detectible concentration
HTD = hard-to-detect ROCs; scanning instrumentation not sensitive to these ROCs

Because each individual DCGL represents a separate radiological dose, the sum-of-fractions (SOF) approach must be used to evaluate the total dose from the SU and demonstrate compliance with the dose limit. Since no areas of elevated activity exceeded the $DCGL_{BC}$, Equation 4-3 from MARSSIM was used for SOF calculations:

$$\mathrm{SOF_{TOTAL}} = \sum_{j=0}^{n} \mathrm{SOF_j} = \sum_{j=0}^{n} \frac{\mathrm{C_j}}{\mathrm{DCGL_j}}$$

where

C_j is the concentration of ROC "j" and
$DCGL_j$ is the $DCGL_{Op}$ and $DCGL_{BC}$ for ROC "j."

Note that gross concentrations are considered here for conservatism and the SOF, based on the $DCGL_{BC}$, also is presented for informational purposes.

3.4 Define the Study Boundaries

The fourth step in the DQO process defined target populations and spatial boundaries, determined the timeframe for collecting data and making decisions, addressed practical constraints, and determined the smallest subpopulations, area, and time for which separate decisions must be made.

NRC prioritized confirmatory survey instigations for survey areas 10208 and 10214, along with SU 10209B.. ORISE investigated these priority survey areas/SU first and then focused on other areas as directed by NRC staff. Individual survey units were combined into larger confirmatory units (CUs) based on the MARSSIM classification, similar residual or background radiation conditions, physical characteristics, or other attributes. The survey areas prioritized by NRC staff were combined into 2 CUs: CU-1 composed of SUs 10208A, B, C, and D and 10209B and CU-3 composed of 10214A, B, C, D, E, and F. Furthermore, SU 12203A was identified as CU-2. Figure 3.1 shows the three CUs. All land areas investigated were a MARSSIM Class 1, with the exception of 10214A, B, C, and D.

Additionally, NRC staff requested that ORISE collect sediment samples from storm water catch basins (CBs) within survey area 00150 for their evaluation. Survey area 00150 is a storm water drain system that was reclassified as a Class 2 from non-impacted after the discovery of site-related ROCs identified within the drainage piping.

Confirmatory surveys activities were conducted in the remaining land areas during December 2–5, 2019, and January 6–9, 2020, in 20 survey areas located within the security-restricted fence and two survey areas located outside the security-restricted fence.

3.5 DEVELOP A DECISION RULE

The fifth step in the DQO process specified appropriate population parameters (e.g., mean, median), evaluated action levels relative to the appropriate detection limits, and developed an "if…then…" decision rule statement. Multiple PSQs were introduced in Table 3.1; therefore, multiple decision rules arose. The first PSQ relates to whether the FSS data and confirmatory data sets are in agreement with the second PSQ confirming the appropriateness of the SU classification. Decision rules for each PSQ are discussed below.

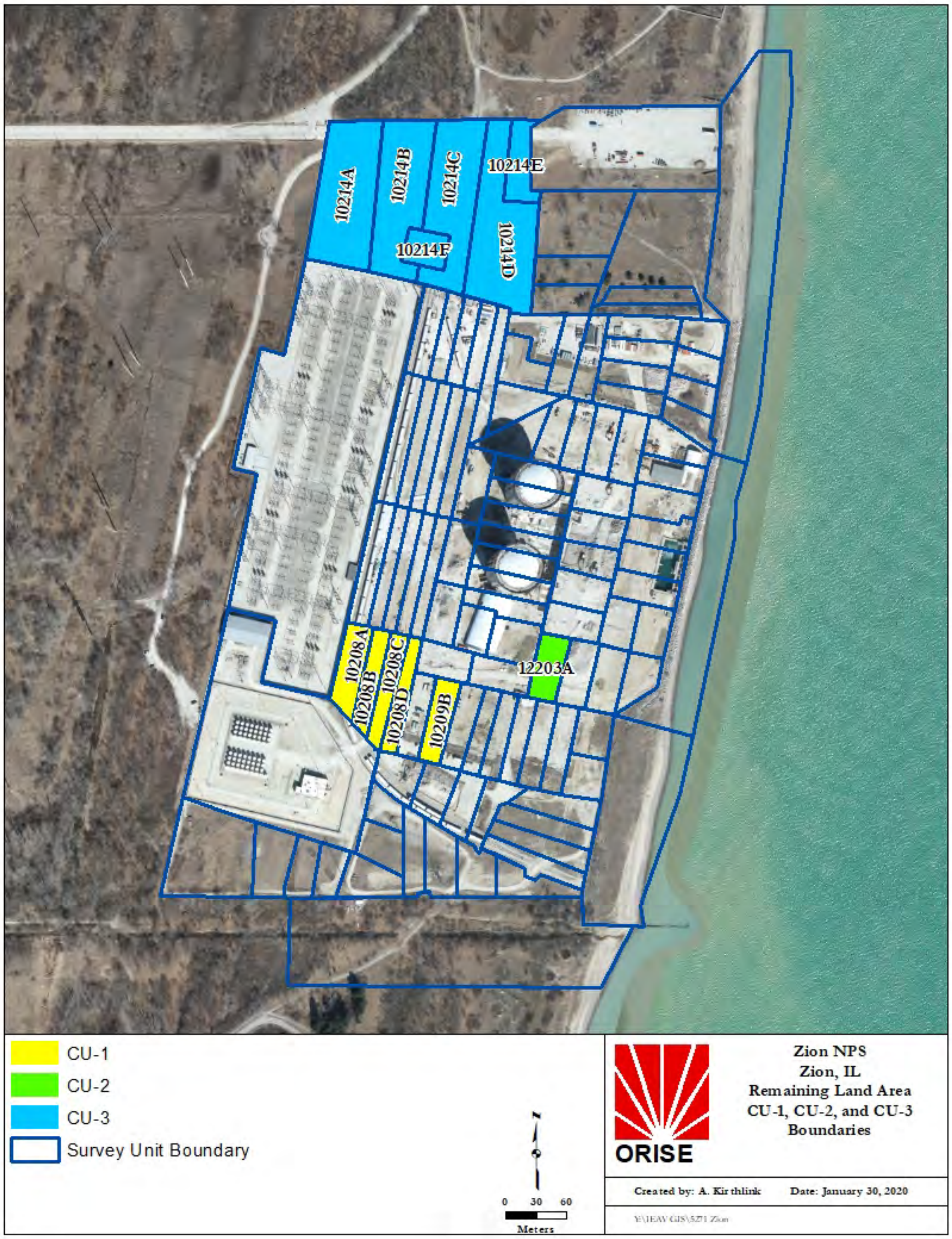

Figure 3.1. Confirmatory Units 1, 2, and 3

3.5.1 PSQ1: FSS and Confirmatory Data Agreement

Confirmatory survey samples are not intended to demonstrate compliance with the release criterion directly, but, rather, to support NRC staffs' determination that the FSS results are appropriate for the intended use. The general confirmatory survey approach to support this determination focused on collecting systematic data from specific survey areas and covering large areas of land with quality investigations (i.e. surface scans). Two types of confirmatory samples were collected as part of this study: judgmental and random. Judgmental samples were collected based on on-site investigations, such as gamma walkover surveys, to evaluate discrete locations of contamination, and were typically compared to a single-point failure criterion (such as an elevated measurement comparison). Random samples were collected to compare against the random/systematic FSS data set. The intention of the comparison was to identify biases—either positive or negative—and evaluate whether the bias could result in the incorrect decision to release a SU when it does not meet the release criterion. Bias between the data sets may be either systematic (i.e., one data set is consistently higher than the other) or discrete. The acceptable bias was dependent on numerous factors, which are discussed further in Section 3.6.1.

Generally, a positive bias between the confirmatory survey data and the FSS data is more of a concern than a negative bias. As such, confirmatory survey investigations described herein are designed to identify positive biases—typically through an appropriate statistical analysis. However, these formal statistical analyses are of limited use when the investigated SU contains radionuclide concentrations less than or approximately equal to the analytical minimum detectable concentration (MDC) (i.e., a visual comparison of the data sets is sufficient to determine if a significant bias is present that would influence the FSS results). NRC provided ORISE with preliminary FSS data for survey areas 10206, 10207, 10208, 12101, 12102, 12103, 12203, 12204, 12205, 12112, and 12113. The data for these survey areas did not indicate the presence of significant radionuclide concentrations in excess of background levels. As a result, a simple random confirmatory data set was sufficient for evaluation of the FSS data. Additionally, this random data set provided NRC with an independent, unbiased estimate of the residual CU radiological concentrations. The decision rule addressing PSQ1 was stated as

> If unacceptable biases are not identified or each individual sample result is below the $DCGL_{BC}$, then conclude that the FSS data are acceptable for demonstrating compliance with the release criterion; otherwise, perform further evaluation(s) and provide technical comments/recommendations to NRC for their evaluation and decision making.

3.5.2 PSQ2: SU Classification

The classification of the survey areas also was assessed as part of the confirmatory survey process based on the requirements outlined in the LTP, and primarily relates to Class 2 and Class 3 survey areas as well as non-impacted areas because a Class 1 SU will not receive a higher classification. FSS investigation levels—for surface scans and quantitative measurements, such as soil sample analytical results—that trigger additional evaluations were established, and are presented in Section 5.6.4.6 of the LTP. These investigation levels are reproduced in Table 3.3. The site may perform additional remediation or reclassify and resurvey all or a portion of an SU. For confirmatory surveys, ORISE focused on identifying locations that potentially exceeded the soil sample investigation levels. These locations were used to confirm whether an SU should have been reclassified as part of the FSS process. The decision rule related to SU classification was stated as follows:

> If soil concentrations indicate that a Class 2 or Class 3 should be reclassified to a higher classification, then summarize confirmatory data for NRC staff's evaluation and decision making.

Table 3.3. ZNPS Investigation Levels [a]

SU Classification	Soil Surface Scanning Investigation Levels	Soil Sample Investigation Levels
Class 1	> $DCGL_{Op}$ or > MDC_{SCAN} if the MDC_{SCAN} is greater than the $DCGL_{Op}$	> $DCGL_{Op}$
Class 2		
Class 3		> 0.5 * $DCGL_{Op}$

[a]Recreated from ZS 2018
MDC_{SCAN} = scan MDC

3.6 Specify Limits on Decision Errors

The sixth step in the DQO process examined the consequences of making an incorrect decision and established bounds of decision errors. Decision errors were controlled during the survey design, on-site field investigations, and the data assessment. There were two orders of control, each discussed in the subsections below.

3.6.1 Hypothesis Testing

The first order of control was related to the evaluation of the FSS data relative to the confirmatory survey data. Hypothesis testing adopts a scientific approach where the survey data are used to select between the baseline condition (the null hypothesis, H_0) and an alternative condition (the alternative hypothesis, H_A). The null hypothesis, or the assumed base condition, was stated normally based on which base condition carries the greatest risk, such as releasing a contaminated area or, alternatively, expending budgeted resources on investigations of likely clean areas. The confirmatory survey was the last step in the site survey and investigation process. As such, the procedures and processes used to generate the FSS data received some level of review both by the licensee and NRC. Therefore, the null and alternative hypotheses were as follows:

> H_0: The confirmatory ROC concentration population mean/median (μ_{CU}) was less than or equal to the FSS mean/median (μ_{FSS}). Mathematically, the null hypothesis was stated as: $\mu_{CU} - \mu_{FSS} \leq 0$.
>
> H_A: The confirmatory ROC concentration population mean/median (μ_{CU}) was greater than the FSS mean/median (μ_{FSS}). Mathematically, the alternative hypothesis was stated as: $\mu_{CU} - \mu_{FSS} > 0$.

For hypothesis testing, there were two types of decision errors to consider: Type I (typically designated as alpha, or α) and Type II (typically designated as beta, or β). A Type I error occurs when the null hypothesis is rejected when it should not be, also known as a false positive, and reflects the confidence level in the decision (confidence is defined as $1-\alpha$). A Type II error is incorrectly failing to reject the null hypothesis when it is false, also known as a false negative. The ability to reject the null hypothesis when it is false is known as the power of the test (power is defined as $1-\beta$). The Type I error rate was set to 0.05 (i.e., there is a 5% chance of concluding the confirmatory population mean is greater than the FSS population mean when actually it is not). The *a priori* Type II error rate was no greater than 0.1 (i.e., there is no greater than a 10% chance of concluding the confirmatory population mean is less than the FSS population mean when actually it is greater). The actual Type II error rate, and subsequent power, achieved is dependent on the number of samples collected and the concentration variability in the sample set.

3.6.2 Field and Analytical MDCs

The second order of control was to optimize the confirmatory field measurement and laboratory analytical MDCs. Field scanning and analytical MDCs were minimized by following the procedures referenced in Sections 4 and 5, respectively. As shown in Table 3.2, detector MDC_{SCAN}s for gamma-emitting ROCs were expected to be above the soil $DCGL_{Op}$s. Any anomalies above background identified while performing the surveys or subsequent data assessment were thoroughly investigated and discussed with NRC staff. Additionally, analytical MDCs were approximately 10% of the $DCGL_{Op}$—with the exception of strontium-90 (Sr-90), which was approximately 50% of the $DCGL_{Op}$, as indicated in Table 3.2.

3.7 Optimize the Design for Obtaining Data

The seventh step in the DQO process was used to review DQO outputs, develop data collection design alternatives, formulate mathematical expressions for each design, select the sample size to satisfy DQOs, decide on the most resource-effective design of agreed alternatives, and document requisite details. Specific survey procedures are presented in Section 4.

4. PROCEDURES

The ORISE survey team performed visual inspections, measurements, and sampling activities within the accessible portions of the SUs requested by NRC staff during the periods of December 2–5, 2019, and January 6–9, 2020. Survey activities were conducted in accordance with the project-specific confirmatory survey plan, the *Oak Ridge Associated Universities (ORAU) Radiological and Environmental Survey Procedures Manual,* and the *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORISE 2019, ORAU 2016a, ORAU 2019a). Appendices C and D provide additional information regarding survey instrumentation and related processes discussed within this section.

4.1 Reference System

ORISE referenced confirmatory measurement/sampling locations to global positioning system (GPS) coordinates using the Illinois East state plane 1201 NAD 1983 (meters). Measurement and sampling locations were documented on detailed survey maps.

4.2 Surface Scans

Ludlum model 44-10 2-inch by 2-inch thallium-doped sodium iodide (NaI[Tl]), hereafter referred to as NaI, detectors were used to evaluate direct gamma radiation levels for land areas. Accessible areas associated with the survey areas were scanned with medium- to high-density coverage. All detectors were coupled to Ludlum Model 2221 ratemeter-scalers with audible indicators. Ratemeter-scalers also were coupled to hand-held GPS data-loggers to electronically record detector response concurrently with geospatial coordinates. Locations of elevated response that were audibly distinguishable from localized background levels, suggesting the presence of residual contamination, were marked for further investigation via volumetric sampling. As the survey activities progressed, scan density was reduced to allow more survey areas to be scanned, as directed by NRC. Scan density was limited in some survey areas because of standing water and impassable muddy areas.

4.3 MEASUREMENT/SAMPLING LOCATIONS

Soil samples were collected from both randomly- and judgmentally-selected locations. Two different soil sample data sets were generated: one for a formal, statistical comparison and one to estimate the mean. In both cases, Visual Sample Plan (VSP), version 7, was used to assess the sample size required for decision making and to randomly place locations throughout the CUs. The sample size determination for each of the scenarios is discussed in the subsections below. The total number of judgmental measurements was based upon findings during gamma surface scans or NRC direction.

4.3.1 Simple Random Sampling (CU-2)

Simple random sampling was performed to generate the confirmatory data set used for the statistical comparison outlined in Section 3.6. The number of samples required to implement the test at the specified level of confidence/power depended on the radionuclide variability, which is the width of the gray region. For this effort, the gray region was considered to be the range of confirmatory mean/median radionuclide concentrations where decision errors are likely. As such, the width of the gray region was dependent on how large of a difference between the confirmatory survey data and FSS data would be tolerable before rejecting the null hypothesis. The upper bound of the gray region was no larger than the difference between the DCGL and the FSS SU mean. The SU radionuclide variability was used as inputs to the sample size calculation, resulting in 12 samples.

4.3.2 Ranked Set Sampling (CU-1 and CU-3)

A ranked-set-sampling (RSS) process, following EPA guidance, was used to select a sample set for an unbiased estimate of the mean (EPA 2002). RSS provides a methodology to determine the necessary number of soil samples to estimate the mean concentration of a population. However, it does not require the assumption of a normal distribution. The process combines random sampling with the use of a field screening method capable of distinguishing the relative magnitude of a parameter of interest in a population in combination with professional judgment to select sampling locations. For this effort, 1-minute, static NaI gamma counts collected at each of the randomly-selected locations provided the measurable field screening method that correlated with the relative concentrations of the gamma-emitting ROCs. The professional-judgmental component was the ability to assess the magnitude of gamma radiation levels (count rates) between randomly-selected locations. The count rate data obtained from the group of random gamma measurement locations then was used to select specific locations for collecting the confirmatory soil samples.

The RSS systematic-planning process used a replication method on a larger random population from which the locations for the resulting samples were selected. Replication refers to the number of cycles (r) for performing a set size (m) of field measurement. The set size was maintained at three locations ($m = 3$) to minimize ranking errors. The number of assessment locations per cycle is dependent on the set size and is simply m^2. Therefore, in a given cycle, samples were collected from each set based on the following ranking criteria:

- **Set 1:** The lowest gamma count value of three locations within Set 1 is sampled.
- **Set 2:** The middle gamma count value of three locations within Set 2 is sampled.
- **Set 3:** The highest gamma count value of three locations within Set 3 is sampled.

The number of repetitive cycles was dependent on the total number of soil samples (n) required and is a function of n and m—simply defined as $n = m \times r$. VSP was used to calculate the number of required samples. Inputs to this calculation were the desired confidence level of the estimated mean, allowable uncertainty of the estimated mean, and expected variability. Conservative planning inputs for estimating the mean at the 95% confidence level within 0.2 units above/below the true mean yielded six samples (i.e., $n = 6$). Therefore, with six required soil samples, the number of repetitive cycles was 2 ($r = n/m = 6/3 = 2$). The total number of assessment locations per CU was defined as $m^2 \times r$ (where $r = 2$ in this case), which was $3^2 \times 2 = 18$.

4.4 SOIL SAMPLING

Surface soil sampling locations were randomly selected from the study area, as discussed in Sections 4.3.1 and 4.3.2. Seven locations were identified during surface scans with elevated direct gamma radiation levels distinguishable from background. However, as directed by NRC staff, only three judgmental samples were collected for analysis. The licensee investigated the other locations identified per NRC's request.

Prior to soil sampling, a 1-minute, static gamma radiation measurement was performed and then the surface soil sample was collected from a depth of 0 to 15 centimeters (cm) followed by a static gamma radiation measurement at the 15-cm depth. Subsurface samples were collected down to 0.5 meters or refusal at six RSS locations following the collection of the surface sample.

Surface soil samples were collected using clean hand trowels. Subsurface soil samples were collected using a manual soil auger. All sampling equipment was rinsed in the field after the collection of each sample to prevent cross-contamination. Table 4.1 provides a summary of the soil samples collected.

Table 4.1. Summary of Volumetric Samples Collected

Sample Collection Type	Depth/Type	No. Collected
Random	Surface-Soil	12
RSS	Surface-Soil	12
	Subsurface-Soil	6
Random	CB-Sediment[a]	1
Judgmental	Surface-Soil	3
	CB-Sediment	3
Total		37

[a]CB = catch basin

4.5 SEDIMENT SAMPLING

Four (three judgmental and one random) sediment samples were collected from storm water CBs located within survey area 00150. The judgmental samples were collected from CBs 5, 6, and 7 based on proximity to the former plant buildings. CB-9 was randomly selected from the balance of CBs. Sediment samples were collected with a long-handled dipper. Water was removed, to the extent possible, prior to collection of the sample.

5. SAMPLE ANALYSIS AND DATA INTERPRETATION

Samples and data collected on site were transferred to the ORISE facility for analysis and interpretation. Sample custody was transferred to the Radiological and Environmental Analytical

Laboratory (REAL) in Oak Ridge, Tennessee. Sample analyses were performed in accordance with the *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2019b). Soil samples were homogenized and analyzed by gamma spectrometry for gamma-emitting fission and activation products. Per NRC staff direction, six soil samples were analyzed for hard-to-detects (HTDs) Sr-90, nickel-63 (Ni-63), and H-3. One of the six samples was selected based on the gamma spectrometry results; the other five were randomly selected. Analytical results were reported in units of picocuries per gram (pCi/g).

Random soil sample results were graphed in quantile (Q) plots for assessment, and are discussed further in Section 6. The Q-plot is a graphical tool for assessing the distribution of a dataset. The Y-axis represents the ROC concentrations in units of pCi/g for sample data. The X-axis represents the data quantiles about the mean value. Values less than the mean are represented in the negative quantiles; the values greater than the mean are represented in the positive quantiles. A normal distribution that is not skewed by outliers (i.e., a background population) will appear as a straight line, with the slope of the line subject to the degree of variability among the data population. More than one distribution, such as background plus contamination or other outliers, will appear as a step function. Additionally, the FSS data were plotted along with the confirmatory data on a Q-plot to evaluate for biases. Biases—positive or negative—would be indicated by diverging data groupings. Select soil sample analytical results also were plotted using strip charts, often referred to as one-dimensional scatter plots, and are further discussed in Section 6 as well.

6. FINDINGS AND RESULTS

The results of the confirmatory survey are discussed in the following subsections.

6.1 SURFACE SCANS

An overview of all the gamma walkover NaI detector response ranges for each SU investigated is illustrated in Figure A.1 in Appendix A. Figures A.2 through A.23 present the gamma walkover data for each survey area. Overall, the gamma responses ranged from approximately 1,100 counts per minute (cpm) to 38,000 cpm. Table 6.1 provides a summary of the notable results of the gamma walkover survey.

Table 6.1. Summary of Elevated Gamma Radiation Levels Identified During Scans					
SU	NaI[Tl] Response (cpm)		Sample Collected	App. A Figure	Notes
	Elevated Area	Surrounding Area			
10208A-D	15,000 to 18,000	7,000 to 13,000	Yes	A.7	Widespread area north of ISFSI[a]
10219	18,000 to 38,000	11,000 to 13,000	No	A.12	Widespread area south of ISFSI
10209C	18,000	7,000 to 11,000	Yes	A.8	Discrete area (<0.1 m^2)[b], concrete
10220I	11,000 to 13,000	5,000 to 7,000	No	A.13	Localized area (~1 m^2)
12112	20,000	5,000 to 9,000	No	A.17	Discrete area (<0.5 m^2)
12113	7,000 to 11,000	5,000 to 7,000	Yes	A.18	Localized area (~1 m^2)
12204A	38,000	5,000 to 7,000	No	A.21	Discrete area (<0.1 m^2), particle[c]

[a]ISFSI = independent spent fuel storage installation
[b]m^2 = square meter
[c]The ORISE NaI reading on the sample collected by Zion*Solutions* was > 500,000 cpm.

Higher gamma counts over a widespread area were experienced in survey areas near the ISFSI, such as the southern portions of survey areas 10208A–D and the northern portion of SU 10219. The ISFSI is known to have stored radioactive material; thus, elevated gamma count rates near the facility were not unexpected. Five other areas had elevated gamma radiation levels distinguishable from background: survey areas 10209C, 10220I, 12112, 12113, and 12204A. Two of the locations were localized (less than 1 square meter [m^2]) and had slightly-elevated gamma radiation levels compared to surrounding gamma radiation levels, while the other three locations were discrete (0.1 to 0.5 m^2) and had significantly-elevated gamma radiation levels compared to surrounding gamma radiation levels. All seven locations were marked for further investigation or sampling. Initially, judgmental samples were collected as elevated areas were identified; however, as the survey activities progressed, NRC directed that samples not be collected by ORISE at identified elevated areas so that ORISE could maximize scan coverage. Instead, as directed by NRC staff, the site would investigate any areas identified with elevated radiation levels.

Because of instrumentation issues in the field, the gamma walkover data was not recorded in survey areas 10213, 12103, 12201, and 12203. No anomalies were noted in those survey areas during the gamma walkover survey.

6.2 RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

Figures A.24 through A.26 in Appendix A display the locations for the soil samples collected. Soil sample coordinates and pre- and post-sample static gamma counts are presented in Tables B.1, B.2, and B.3 in Appendix B. Analytical results for individual soil samples are presented in Tables B.4 through B.8.

Table 6.2 summarizes the ROC concentrations of the randomly-collected soil samples. All random samples collected from CUs 1, 2 and 3 had a SOF value—based on the $DCGL_{Op}$—less than unity, which means that individual ROC concentrations were less than their respective $DCLG_{Op}$. H-3 (in judgmental sample 5271S0075) and Ni-63 (in random sample 5271S0097) were the only HTD ROCs that were identified in the confirmatory soil samples above the analytical MDC. The random soil sample data sets in survey areas 10208 and 10209 (CU-1) and survey areas 10214 (CU-3) provided NRC with an unbiased estimate of the residual mean ROC concentration. Gamma shine from the ISFSI impacted the NaI measurements collected during the field ranking process, introducing ranking error. The RSS approach is as efficient as simple random sampling, regardless of the accuracy in the field ranking (Presnell 1999). As a result, there was a slight increase in the uncertainty of the estimated mean for CU-1, relative to what was planned, although the uncertainty is not greater than that resulting from the collection of six random samples. Because there was no significant residual contamination identified in the sample set for CU-1, the increased uncertainty does not limit confirmatory survey decisions. The confirmatory soil sample data set for SU 12203A (CU-2) was collected for evaluation against the FSS data set, as described below.

Table 6.2. Summary of ROC Concentrations in Random Confirmatory Soil Samples

Statistic	ROC Concentration (pCi/g)						SOF_{Op}[a,b]
	Co-60	Cs-134	Cs-137	Ni-63	Sr-90	H-3	
CU-1 (Survey Areas 10208 and 10209)[c]							
Min	-0.006	-0.0031	0.005	--	--	--	<0.01
Max	0.022	0.016	0.04	--	--	--	0.03
Mean	0.005	0.004	0.02	--	--	--	0.01
St. Dev.	0.012	0.008	0.01	--	--	--	<0.01
CU-3 (Survey Area 10214)[c]							
Min	-0.008	-0.0086	0.000	--	--	--	<0.01
Max	0.013	0.019	0.072	0.37	0.37	0.6	0.14
Mean	0.01	0.004	0.03	--	--	--	0.04
St. Dev.	0.004	0.003	0.01	--	--	--	0.02
CU-2 (SU 12203A)							
Min	-0.015	-0.0083	-0.029	0.26	-0.04	0.3	<0.01
Max	0.034	0.045	0.086	0.70	0.17	1.5	0.09

Table 6.2. Summary of ROC Concentrations in Random Confirmatory Soil Samples							
Statistic	ROC Concentration (pCi/g)						SOF$_{Op}$[a,b]
	Co-60	Cs-134	Cs-137	Ni-63	Sr-90	H-3	
Mean	0.0008	0.009	0.01	--	--	--	0.01
St. Dev.	0.01	0.02	0.03	--	--	--	0.02

[a]The SOF calculation does not include the fractional contribution of HTD radionuclides
[b]SOF was calculated using the DCGL$_{op}$
[c]Sample locations were selected using the RSS design process

Figure 6.1 provides a Q-Q plot of gamma-emitting ROCs for the ORISE confirmatory data set and the Zion FSS data set. All soil sample concentrations for cesium-134 (Cs-134) were below the analytical MDC and will not be discussed further. Review of Figure 6.2 indicates that the ORISE data set distribution is biased low—or approximately equal, as is the case for Cs-137—relative to the FSS data set below the first quantile. Above the first quantile, the Zion FSS data is positively biased. Further evaluation via a formal statistical test is unnecessary because the data provided in Figure 6.1 indicate the ORISE confirmatory ROC concentration population is less than or equal to that of Zion.

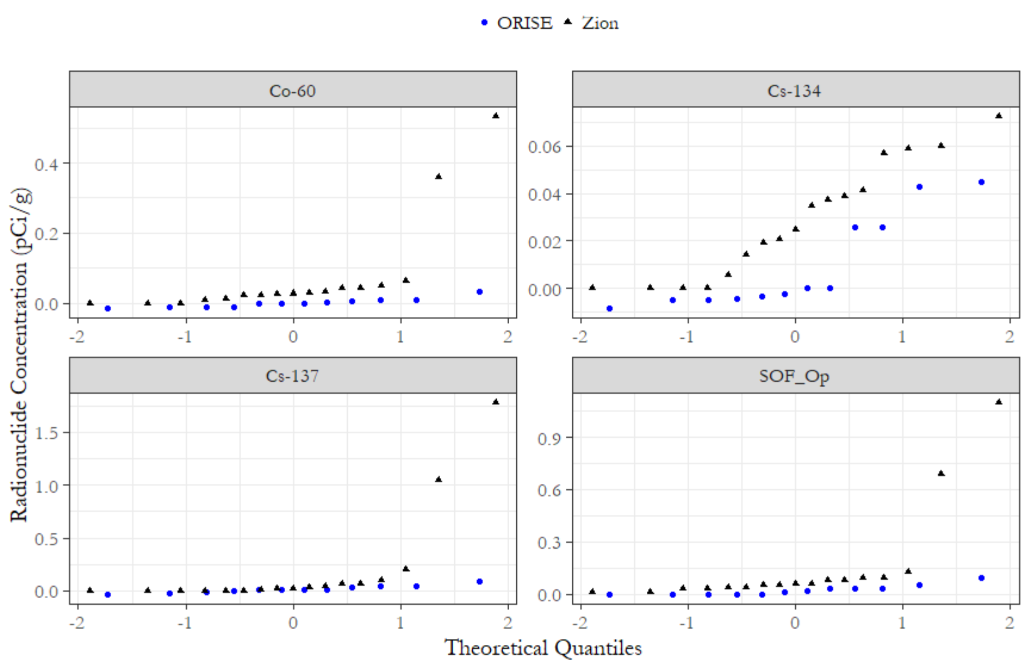

Figure 6.1. Q-Q Plot for ORISE Confirmatory Survey and Zion FSS Soil Sample Results from CU-2 (SU 12203A)

Figure 6.2 presents a strip chart of the judgmental confirmatory soil sample concentration results. Individual analytical results for judgmental surface soil samples are presented in Table B.7 in Appendix B. Soil sampling locations are illustrated on the maps in Figure A.24 through A.26 in

Appendix A. One judgmental soil sample in SU 10209C was above the $DCGL_{Op}$ for Cs-137; however, the concentration was below the corresponding $DCGL_{BC}$. This judgmental sample (5271S0075) represented the soil surrounding a piece of concrete debris that was identified as having elevated direct gamma radiation. As requested by NRC staff, the debris (collected as sample 5271S0074) was not submitted for laboratory analysis and was left with site personnel. A discrete area of elevated radiation was identified in SU 12204A. As directed by NRC, ORISE did not collect a sample; instead, site personnel investigated the area. The area was remediated as a result of the investigation. ORISE performed a post-sample collection gamma walkover scan to confirm the source of the elevated radiation was no longer present as shown in Figure A.22.

None of the ROC concentrations in the subsurface samples were above their respective analytical MDCs. Individual analytical results for the subsurface soil samples are presented in Table B.6.

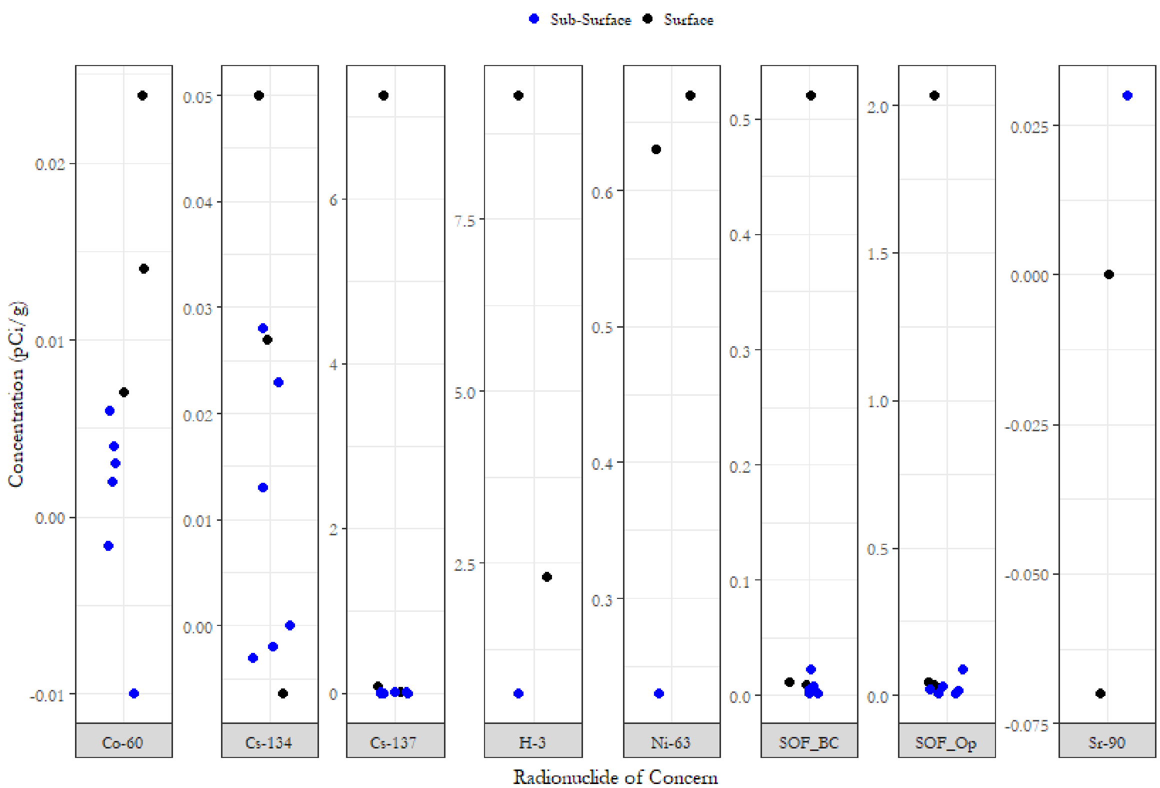

Figure 6.2. Strip Chart for Confirmatory Survey Judgmental Soil Samples

6.3 RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES

Figure 6.3 presents a strip chart of the CB drain sediment sample concentration results. Individual analytical results for sediment samples are presented in Table B.8 in Appendix B. Sediment sampling locations are illustrated in Figure A.27 in Appendix A. Cs-137 was identified in concentrations above the analytical MDC in sediments collected from CB-6 (5271S0109), CB-5 (5271S0110), and CB-9 (5271S0111). Cobalt-60 (Co-60) was identified at a concentration above the analytical MDC in sediments collected from CB-9. All Cs-134 concentrations were less than the MDC. All gamma-emitting ROC concentrations in the sediment samples were less than 0.4 pCi/g.

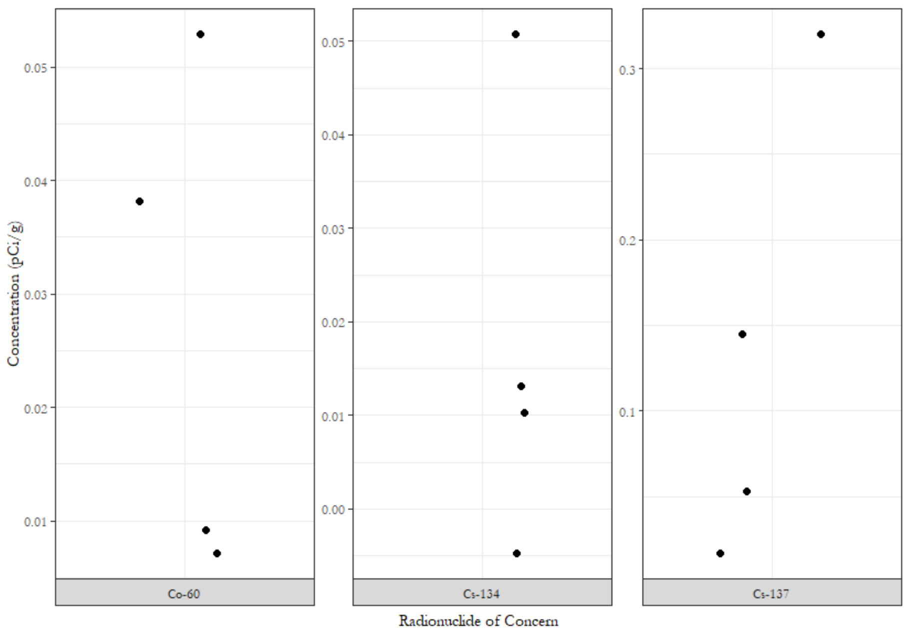

Figure 6.3. Strip Chart for Confirmatory Survey Sediment Samples

7. SUMMARY AND CONCLUSIONS

During the period of December 2–5, 2019 and January 6–9, 2020, ORISE performed independent confirmatory survey activities of surface and subsurface soils associated with the remaining land areas at ZNPS. The confirmatory surveys consisted of gamma walkover surface scans, gamma direct measurements, and surface and subsurface soil sampling. The areas investigated included all or a portion of survey areas 00150, 10201, 10202, 10203, 10206, 10207, 10208, 10209, 10211, 10213, 10214, 10219, 10220, 10221, 12102, 12103, 12112, 12113, 12201, 12203, 12204, and 12205.

Gamma scans identified seven areas of elevated radiation distinguishable from background. Two of these areas were to the north and south of the ISFSI. These areas had widespread, elevated gamma radiation levels that increased closer to the ISFSI, which was expected as it contains the site's spent fuel. Two other areas had slightly-elevated gamma radiation levels compared to surrounding gamma radiation levels, while the other three locations had significantly higher gamma radiation levels than the surrounding area.

Thirty-seven total soil samples were collected. Thirty sample locations were randomly selected, with 12 of the samples collected from CU-2 (SU 102203A) for a direct comparison against the FSS data, six random samples collected from CU-1 (survey areas 10208 and 10209), six random samples collected from CU-3 (survey areas 10214), and six samples to evaluate subsurface ROC concentrations in CU-1 (survey areas 10208 and 10209). Of the seven identified areas with elevated gamma radiation levels, three were judgmentally selected for sampling. One of the judgmentally sampled areas contained a piece of concrete-like debris, which was left with site personnel, while the soil from around the concrete was collected (5271S0075). The other three areas that were identified (excluding the area that was identified south of the ISFSI, which was attributed to gamma shine) were investigated by the site, as directed by NRC staff. One of the areas had a discrete radioactive particle that was responsible for the elevated direct gamma radiation. A gamma walkover scan was performed after the discrete particle was sampled, and showed gamma radiation levels to be similar to the surrounding area. ORISE does not have information related to the results of the other two areas investigated by the site in SU 10220I and 12112 because the FSS reports have not been finalized. Four samples also were collected from CB drains in SU 00150.

Based on the results of the collected confirmatory survey data, ORISE did not identify any anomalous issues that would preclude the FSS data from demonstrating compliance with the release criterion. Furthermore, the confirmatory survey data supports the SU classification. However, there are two locations, as mentioned previously, that conclusions cannot be made at this time because the site investigated these areas and the FSS reports are not available at this time. As such, it is recommended that NRC staff evaluate the results of these investigations. These areas are survey areas 10220I and 12112. Laboratory analyses for the sediment samples collected form the CBs in SU 00150 are presented for NRC staffs' evaluation.

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APPENDIX A: FIGURES

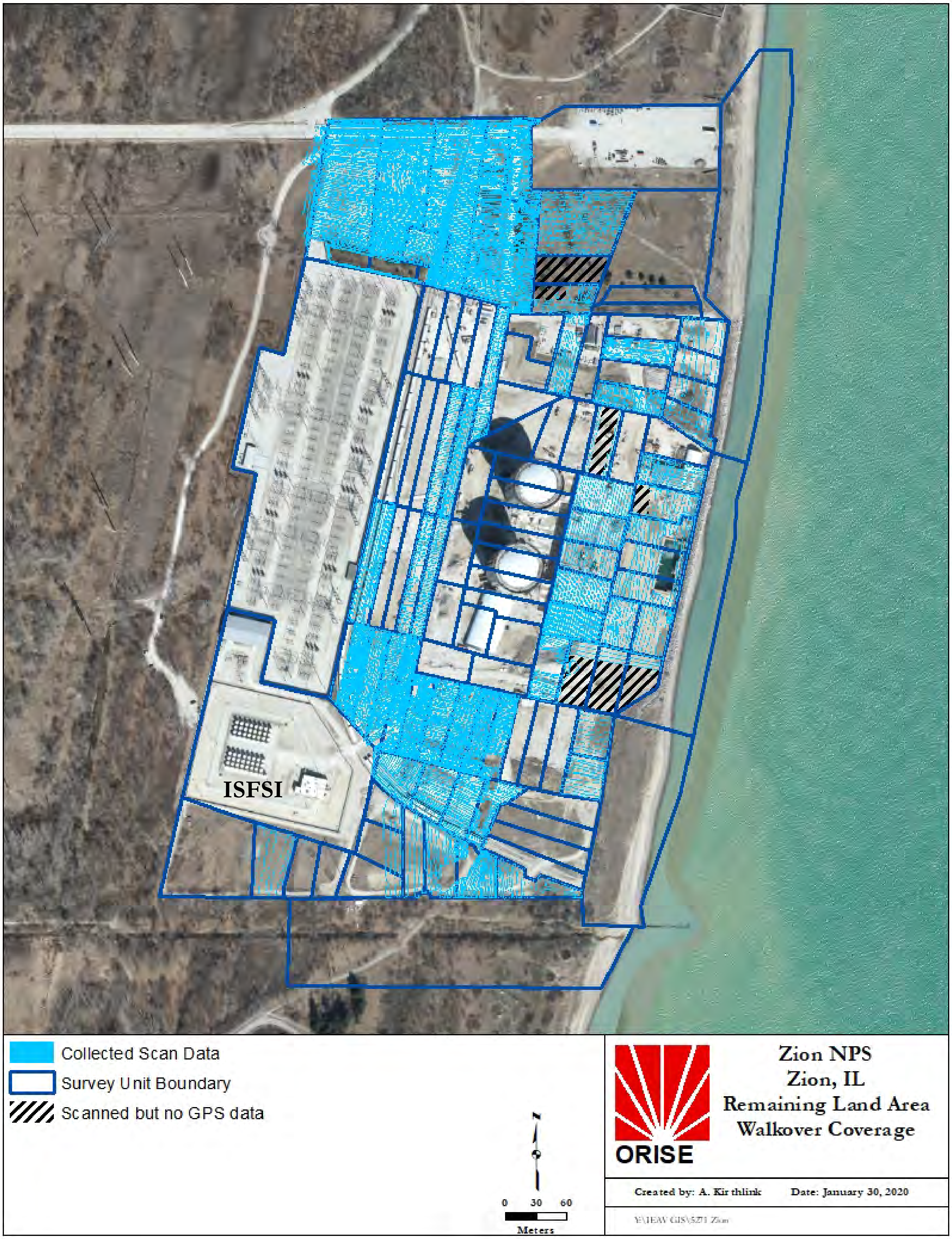

Figure A.1. Gamma Walkover Coverage for All Survey Areas Investigated (Overview)

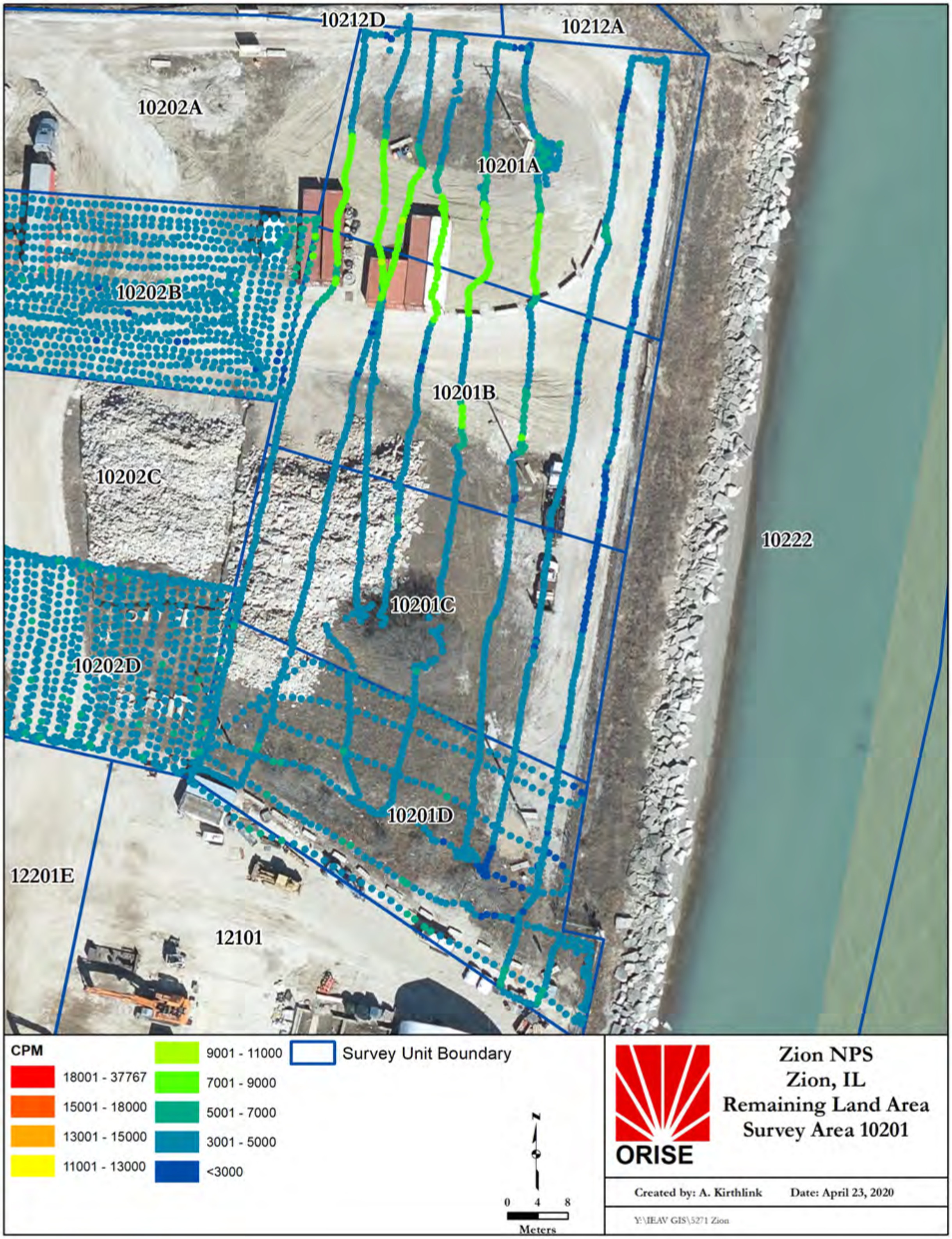

Figure A.2. Gamma Walkover Data for Survey Area 10201

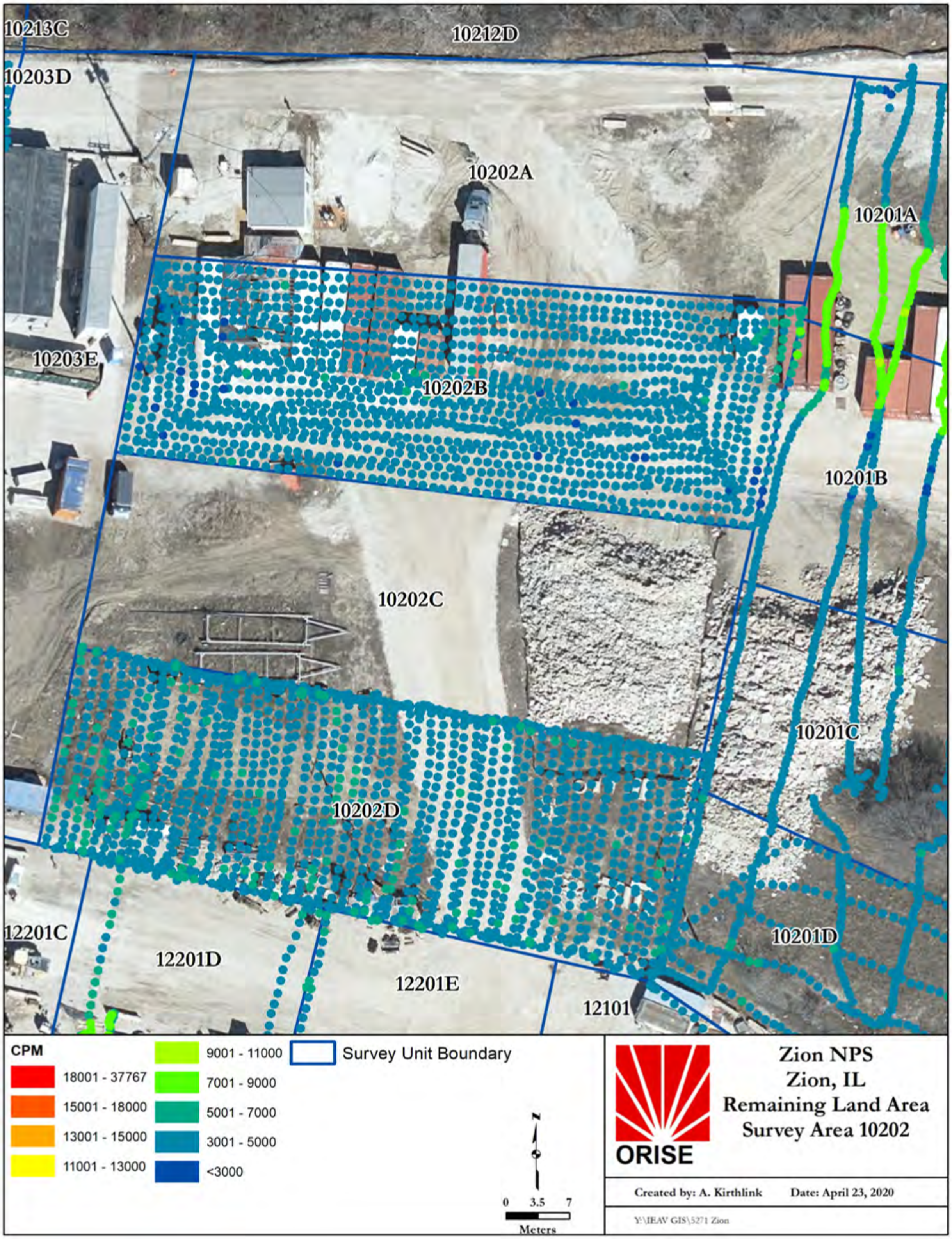

Figure A.3. Gamma Walkover Data for Survey Area 10202

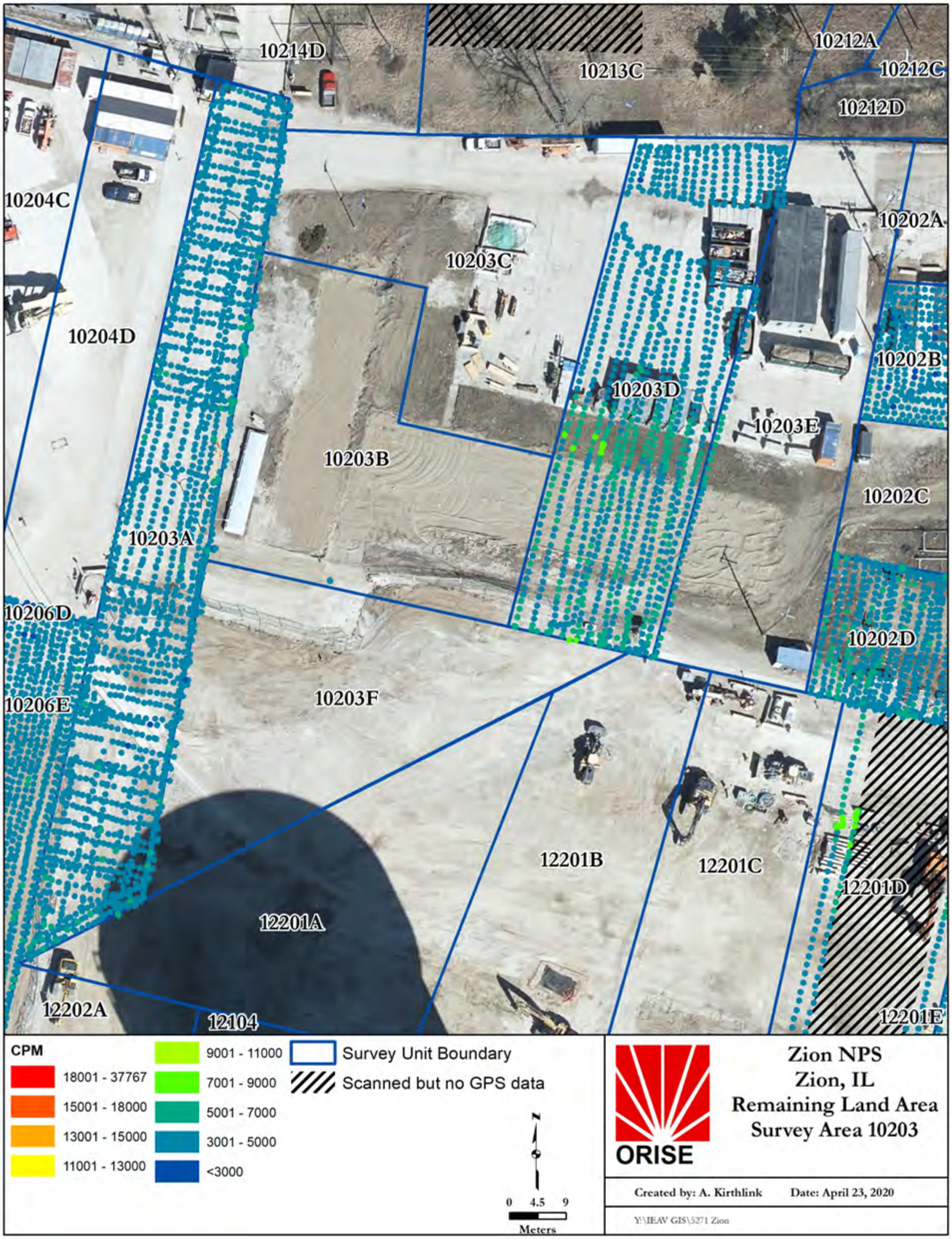

Figure A.4. Gamma Walkover Data for Survey Area 10203

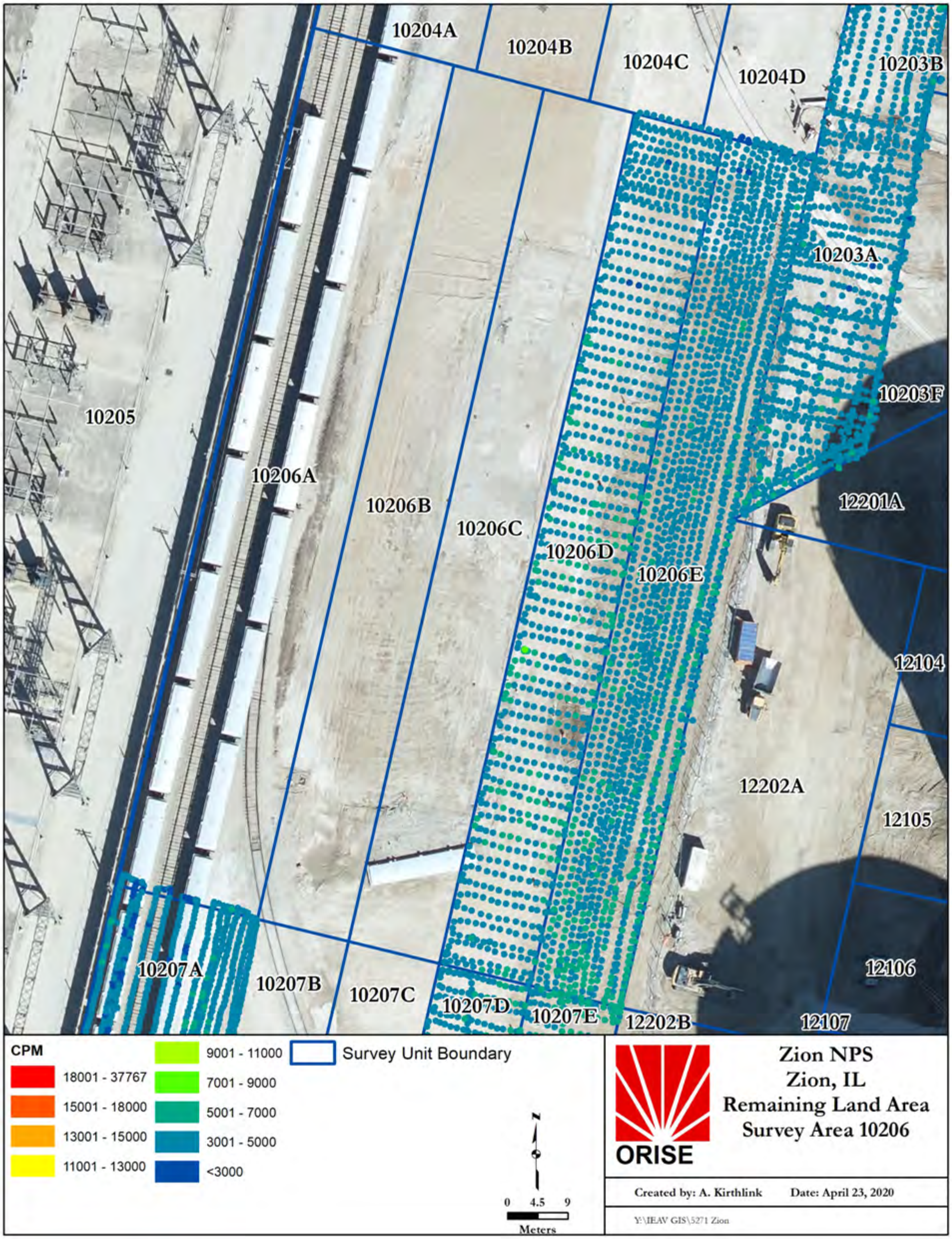

Figure A.5. Gamma Walkover Data for Survey Area 10206

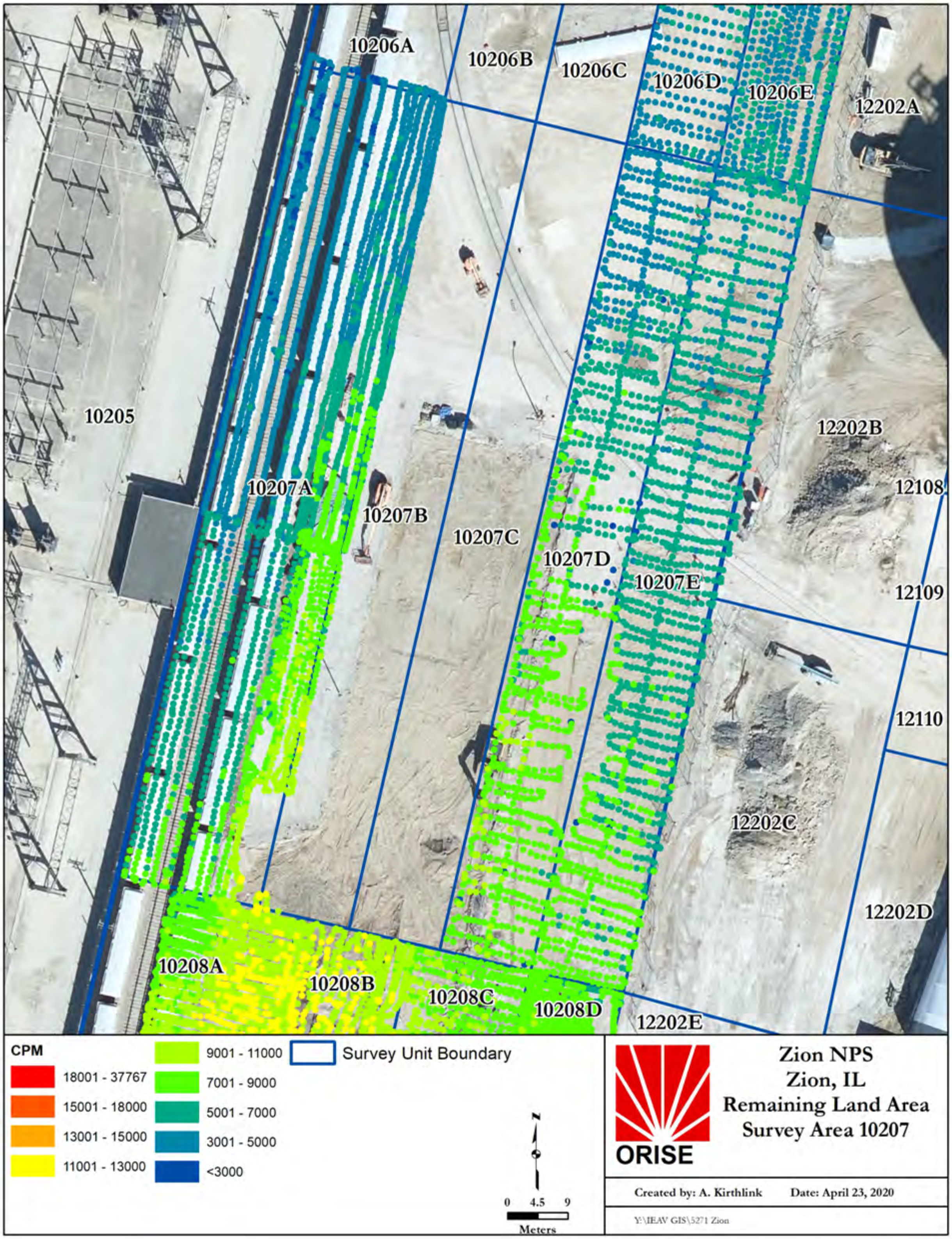

Figure A.6. Gamma Walkover Data for Survey Area 10207

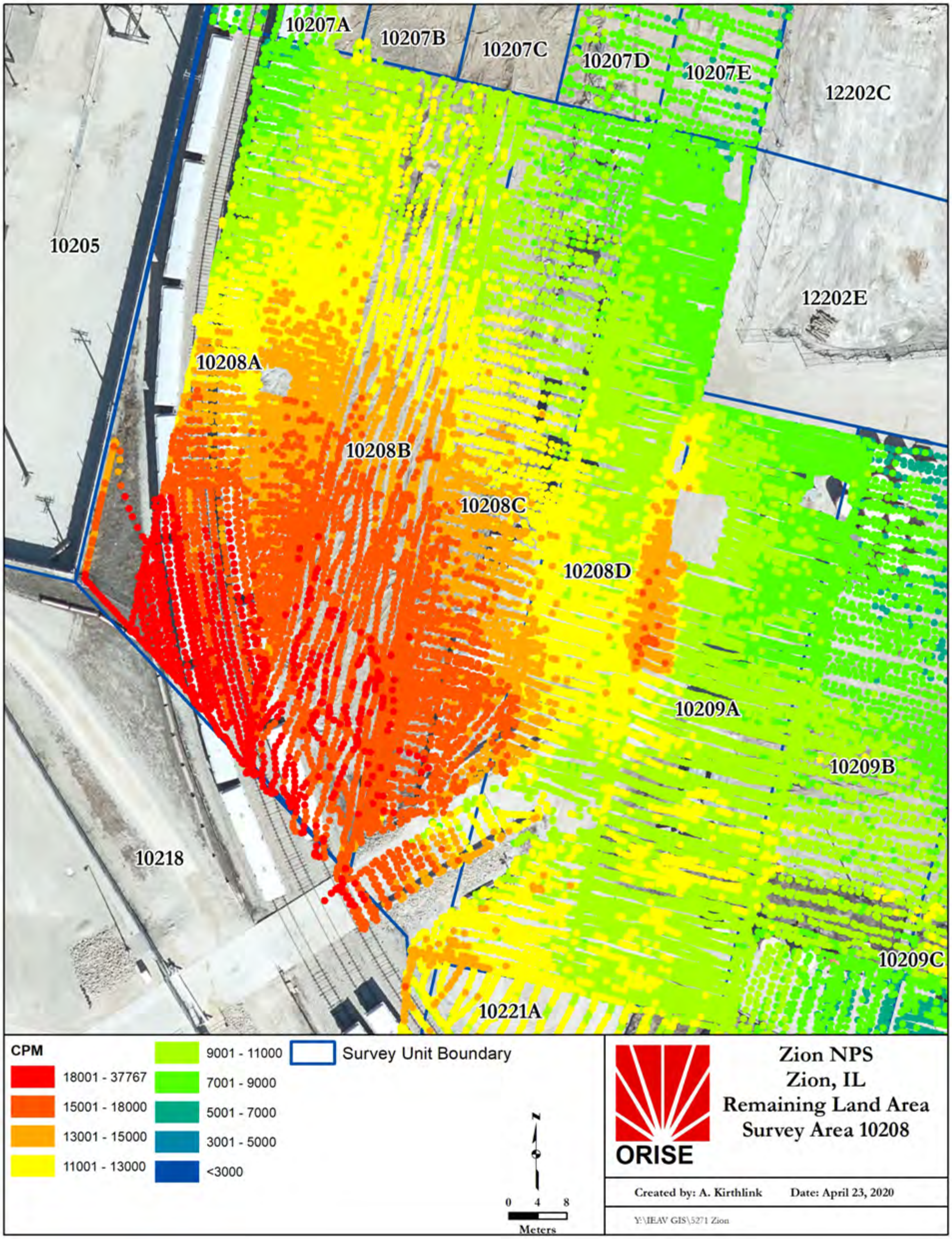

Figure A.7. Gamma Walkover Data for Survey Area 10208

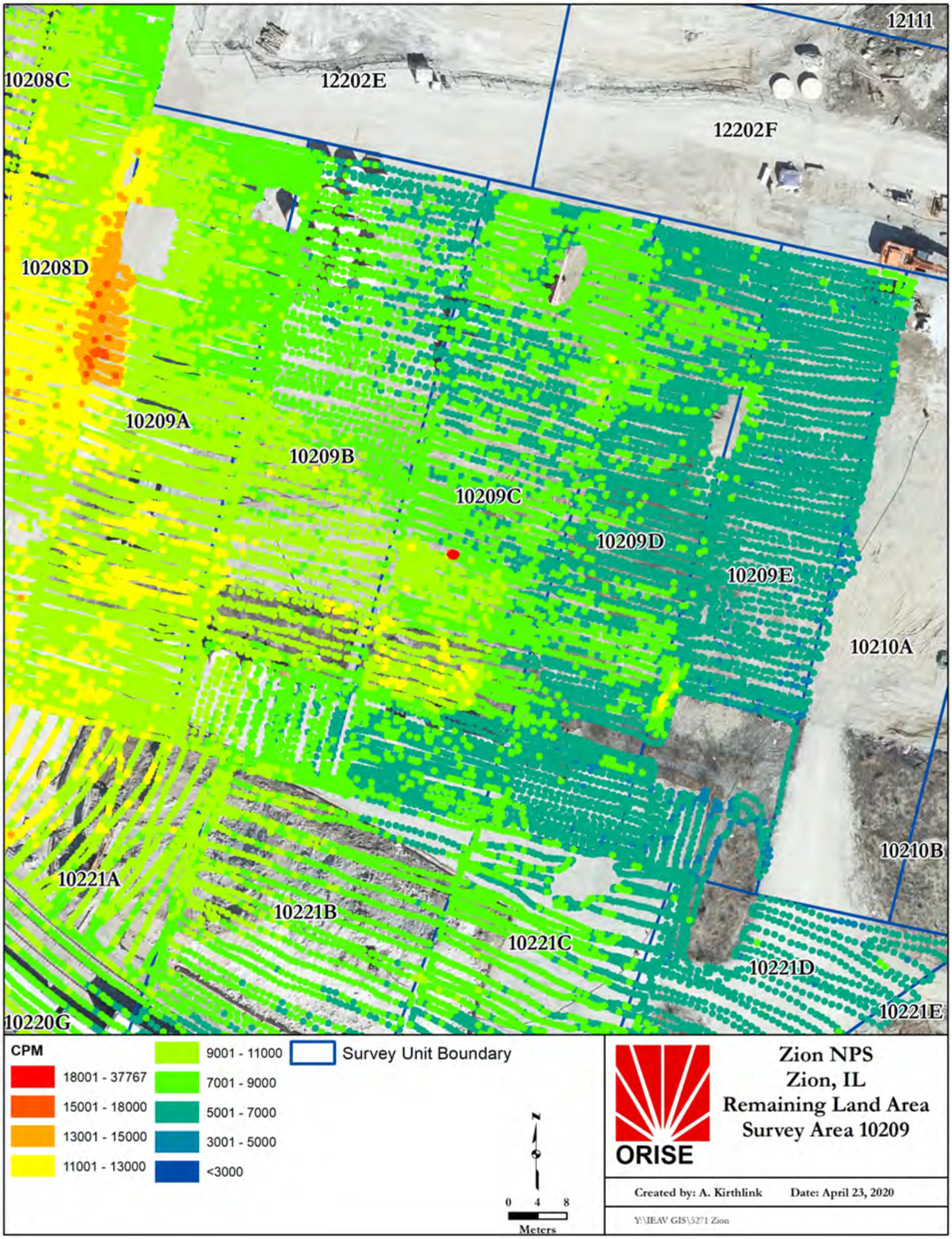

Figure A.8. Gamma Walkover Data for Survey Area 10209

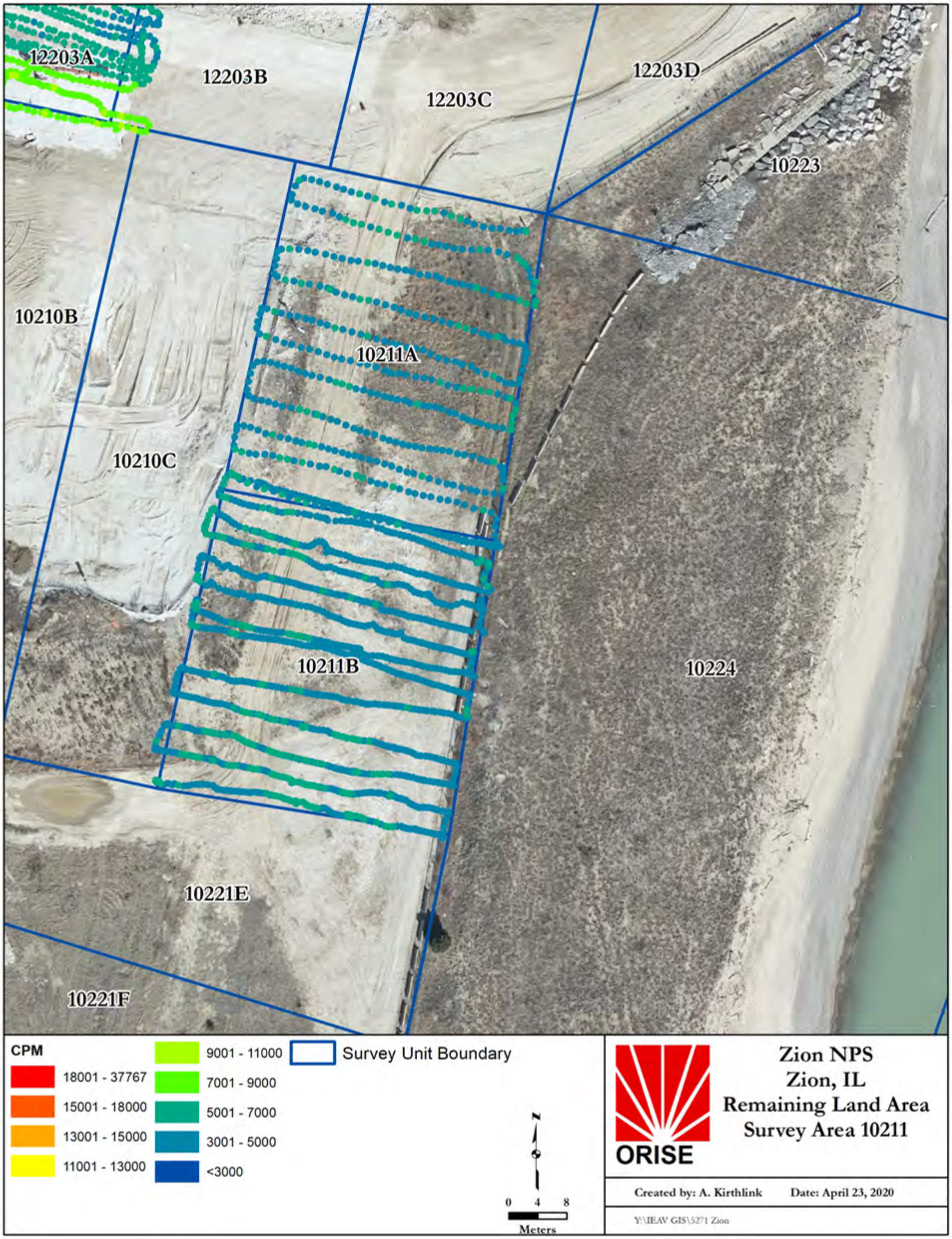

Figure A.9. Gamma Walkover Data for Survey Area 10211

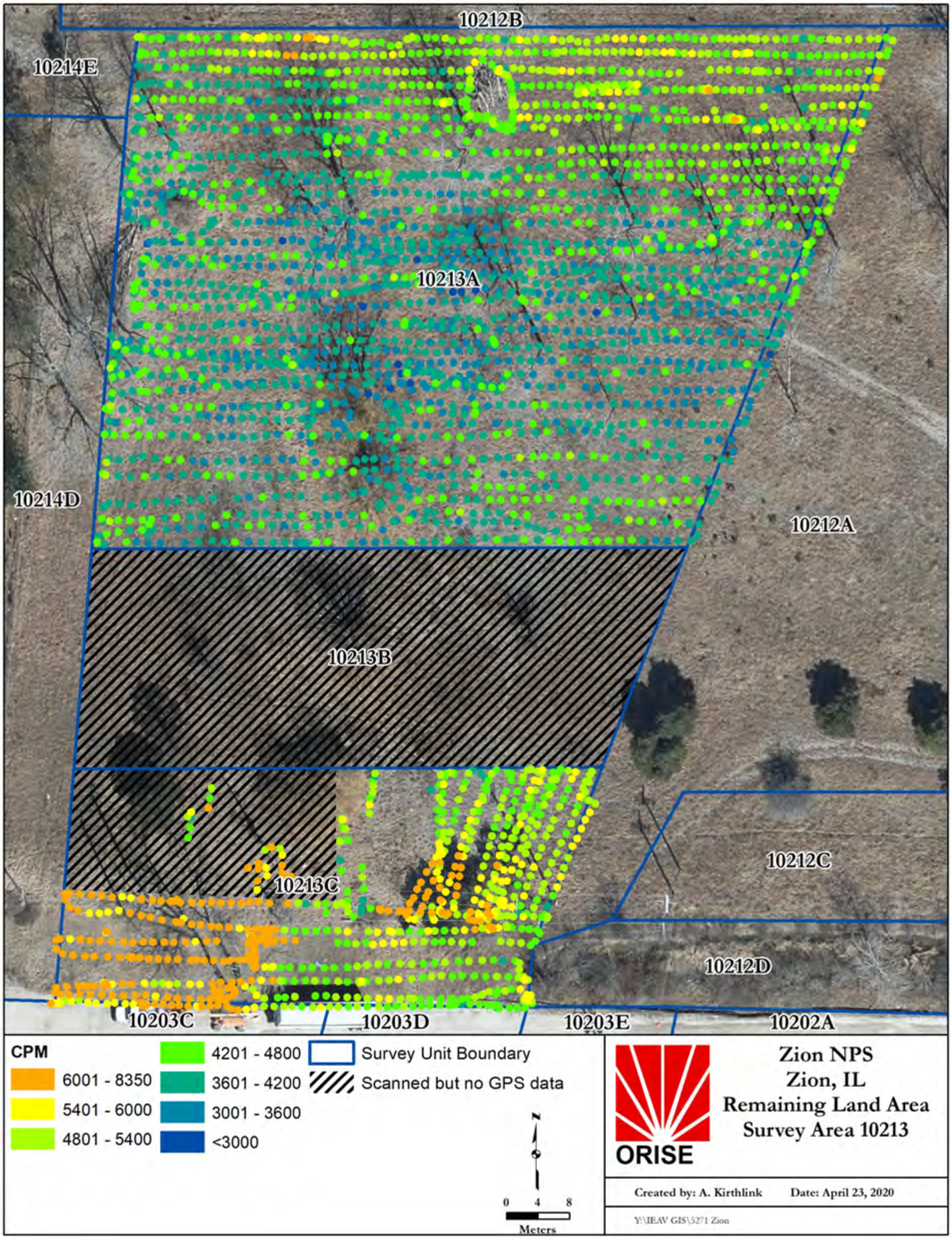

Figure A.10. Gamma Walkover Data for Survey Area 10213

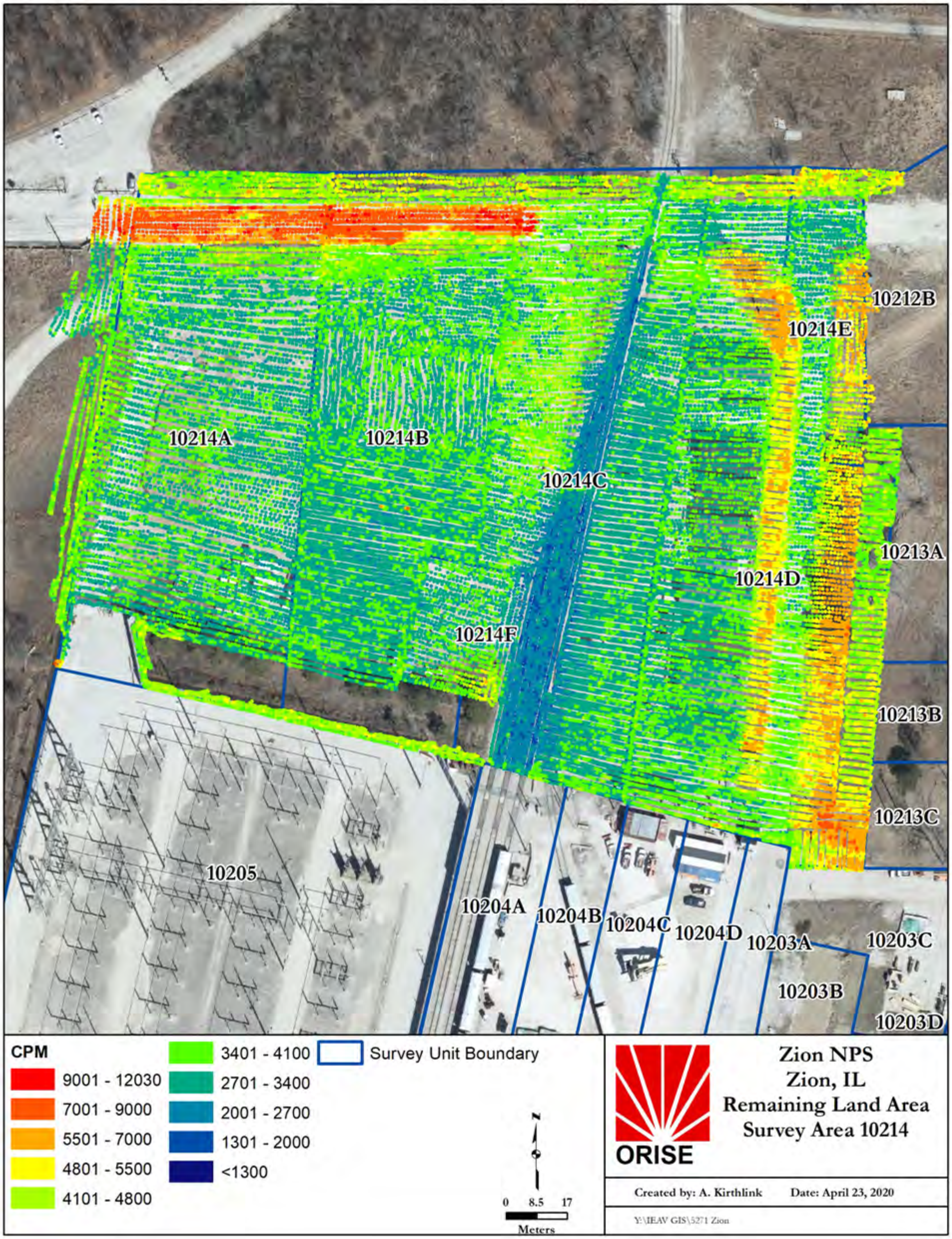

Figure A.11. Gamma Walkover Data for Survey Area 10214

Figure A.12. Gamma Walkover Data for Survey Area 10219

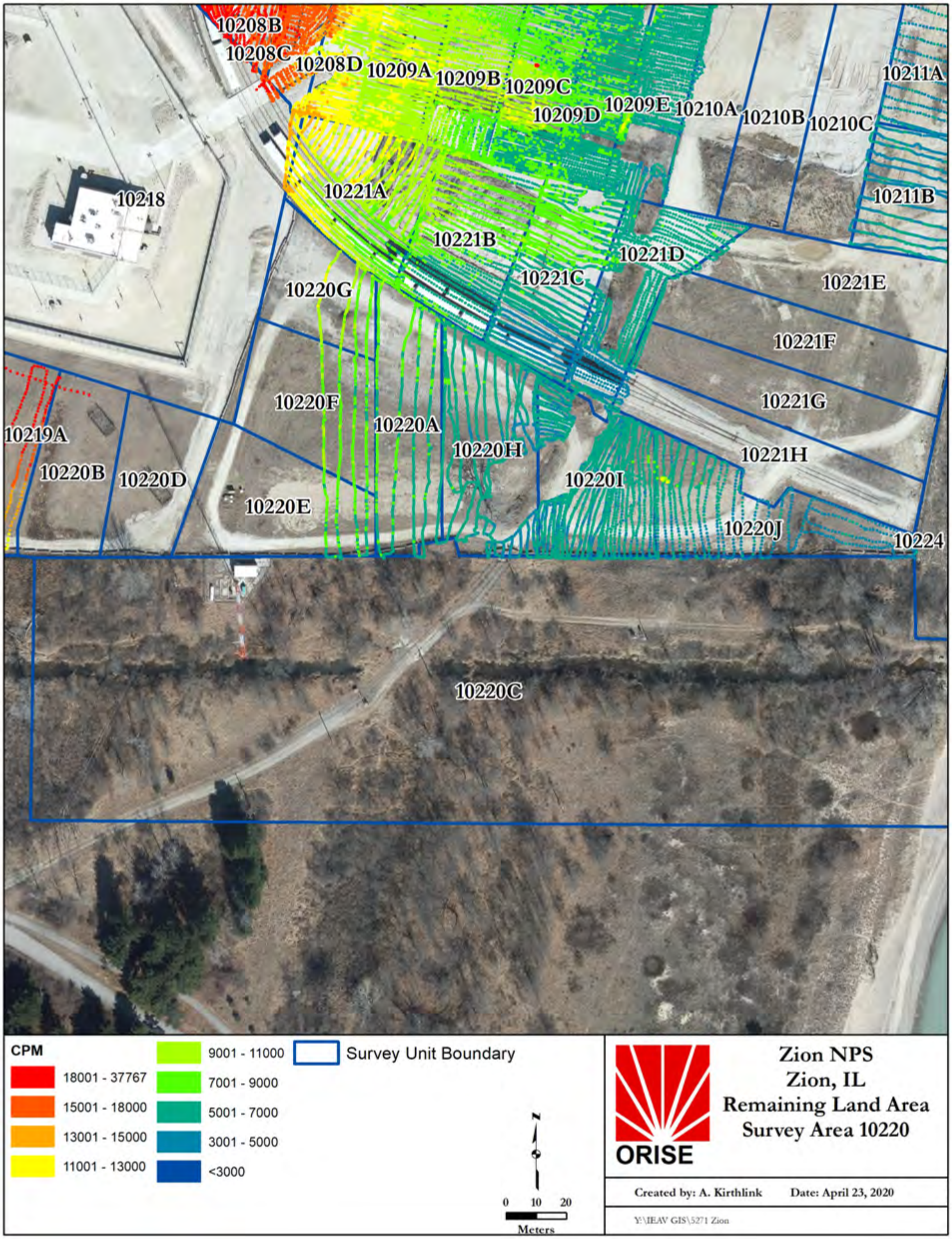

Figure A.13. Gamma Walkover Data for Survey Area 10220

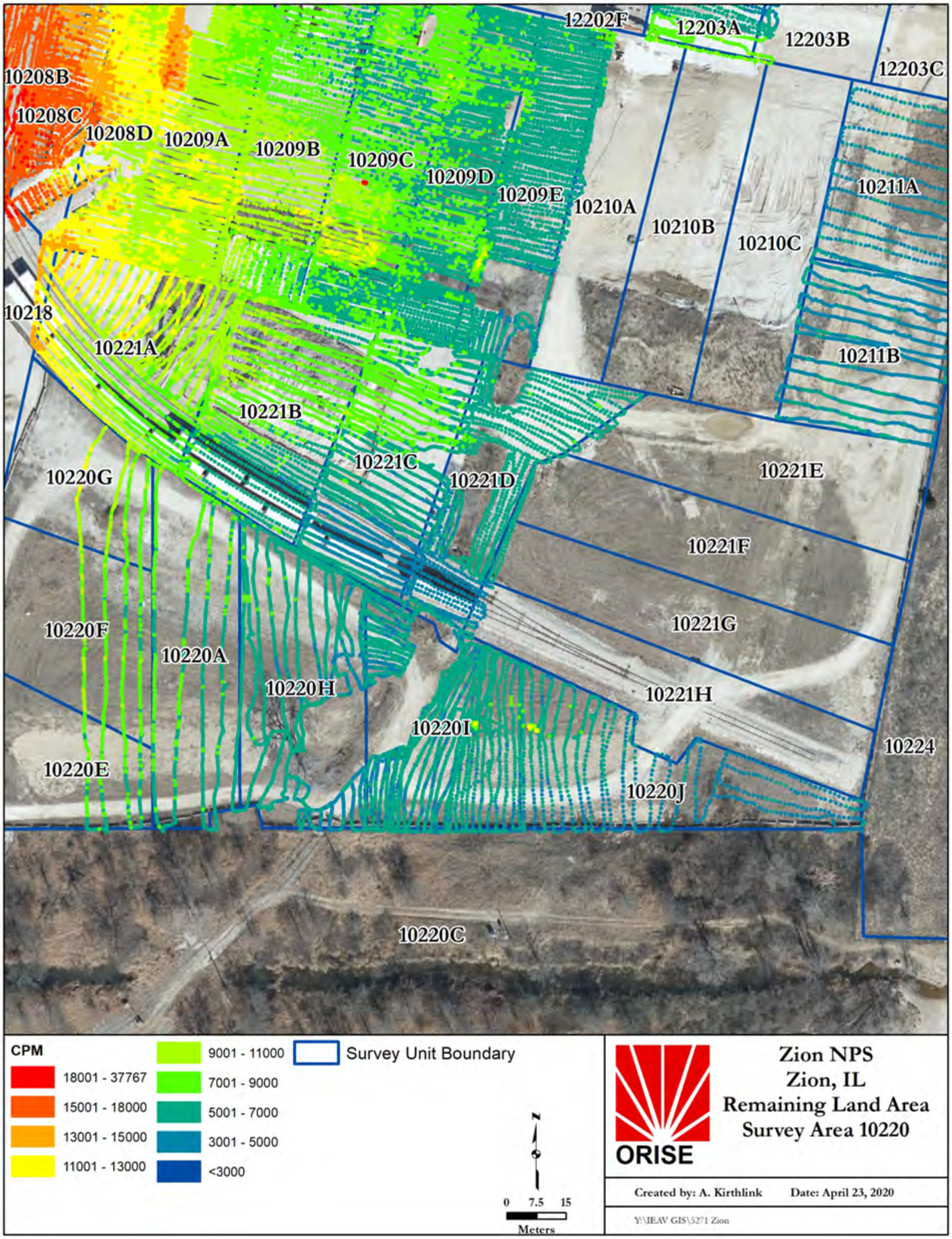

Figure A.14. Gamma Walkover Data for Survey Area 10221

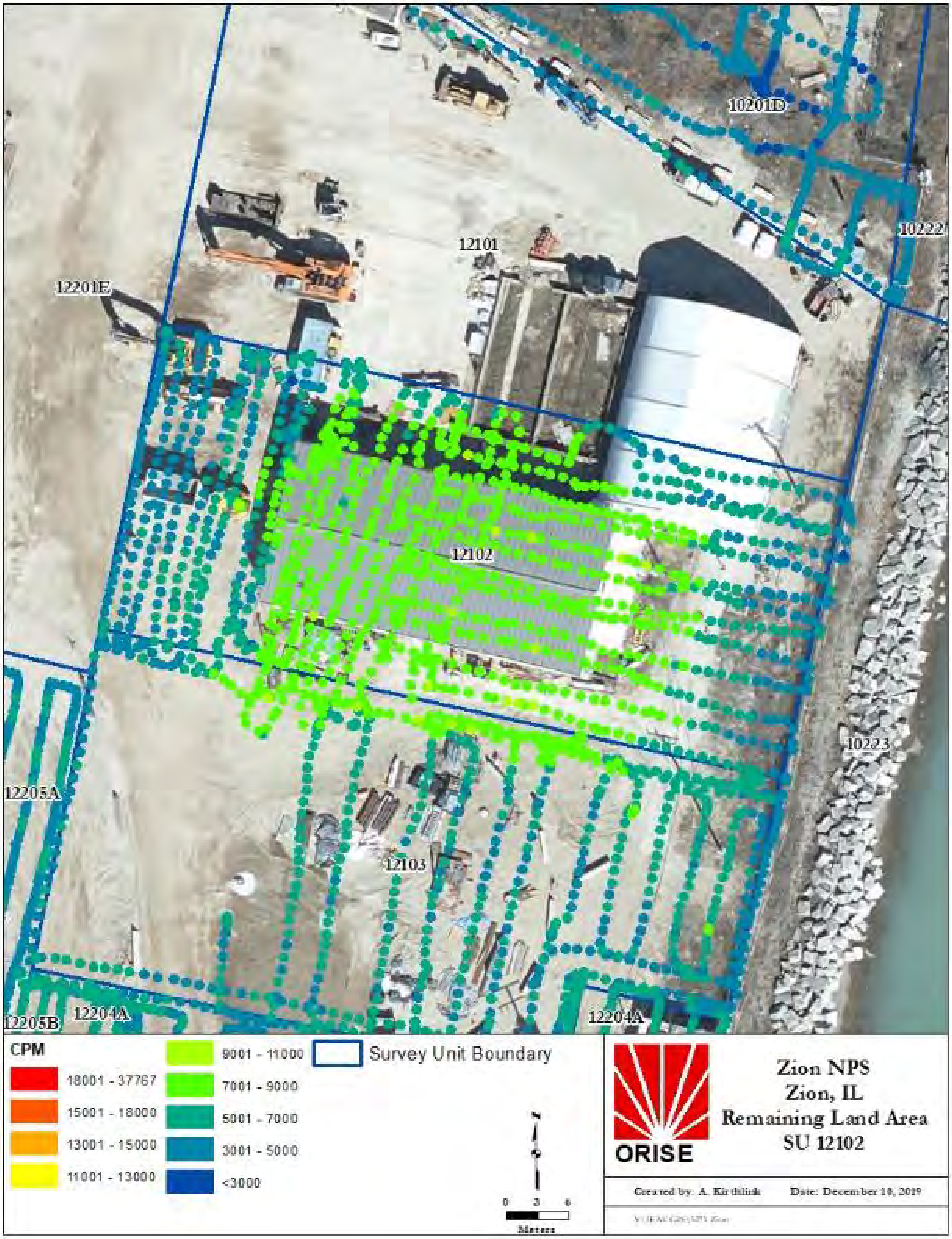

Figure A.15. Gamma Walkover Data for SU 12102

Figure A.16. Gamma Walkover Data for SU 12103

Figure A.17. Gamma Walkover Data for SU 12112

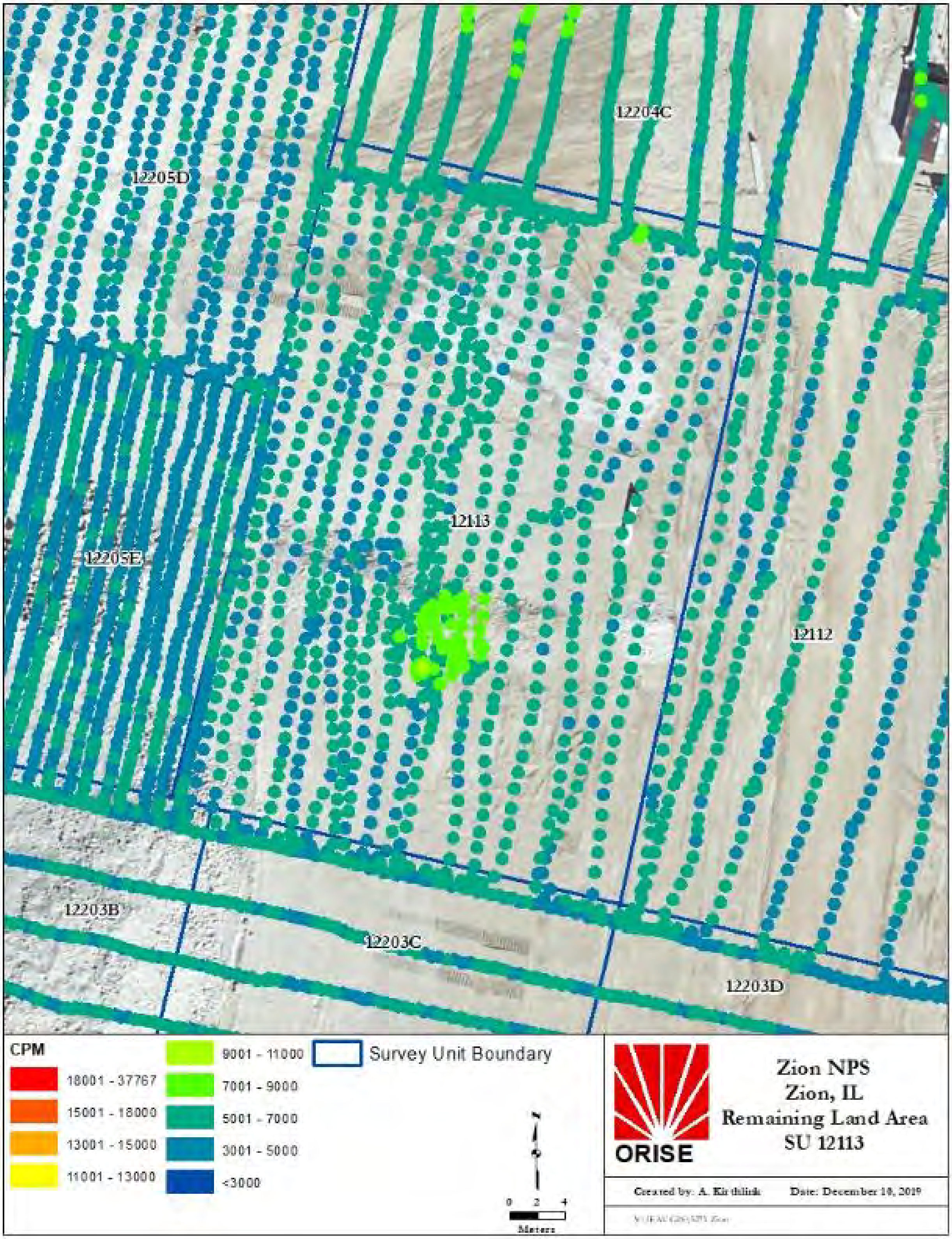

Figure A.18. Gamma Walkover Data for SU 12113

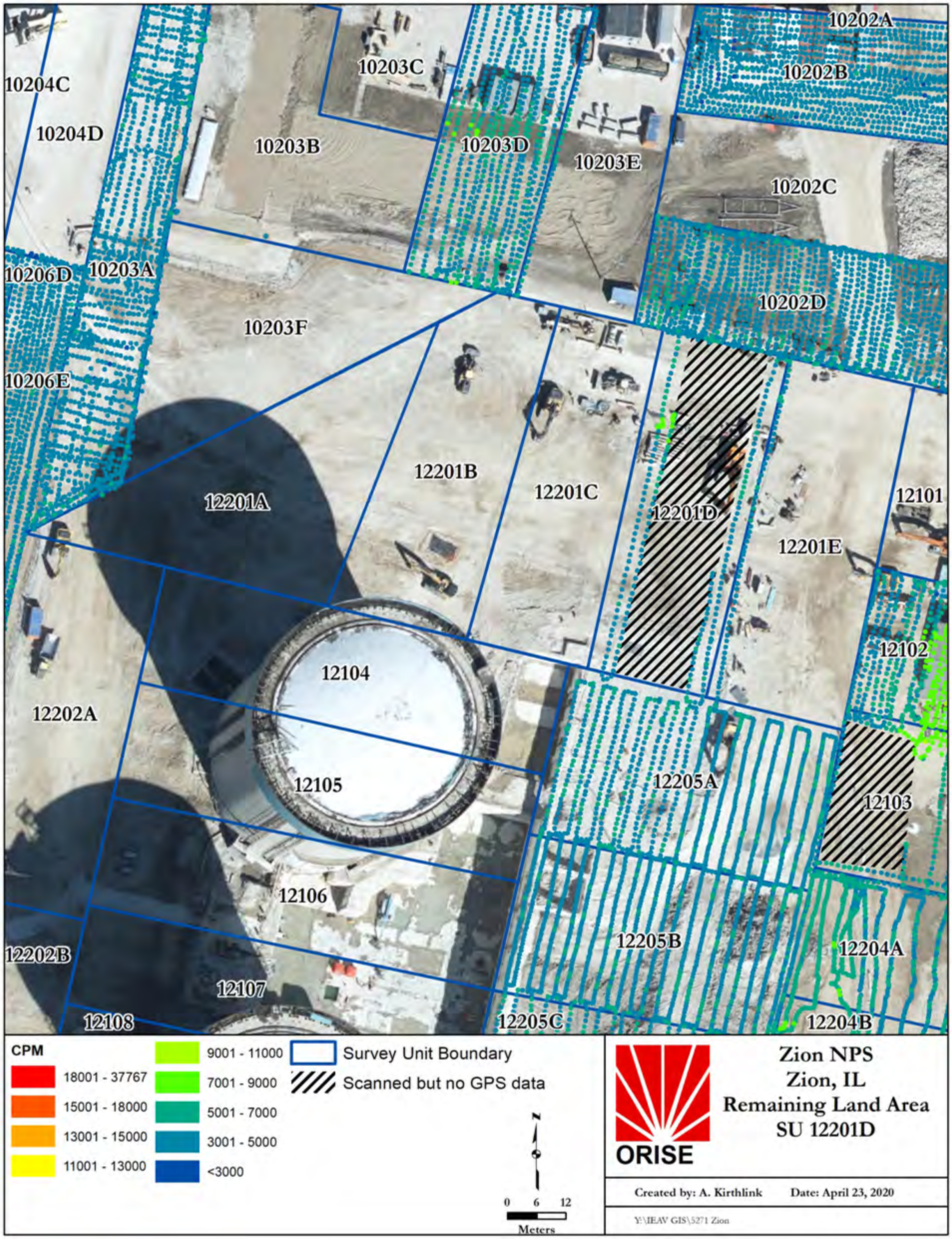

Figure A. 19. Gamma Walkover Data for Survey Area 12201

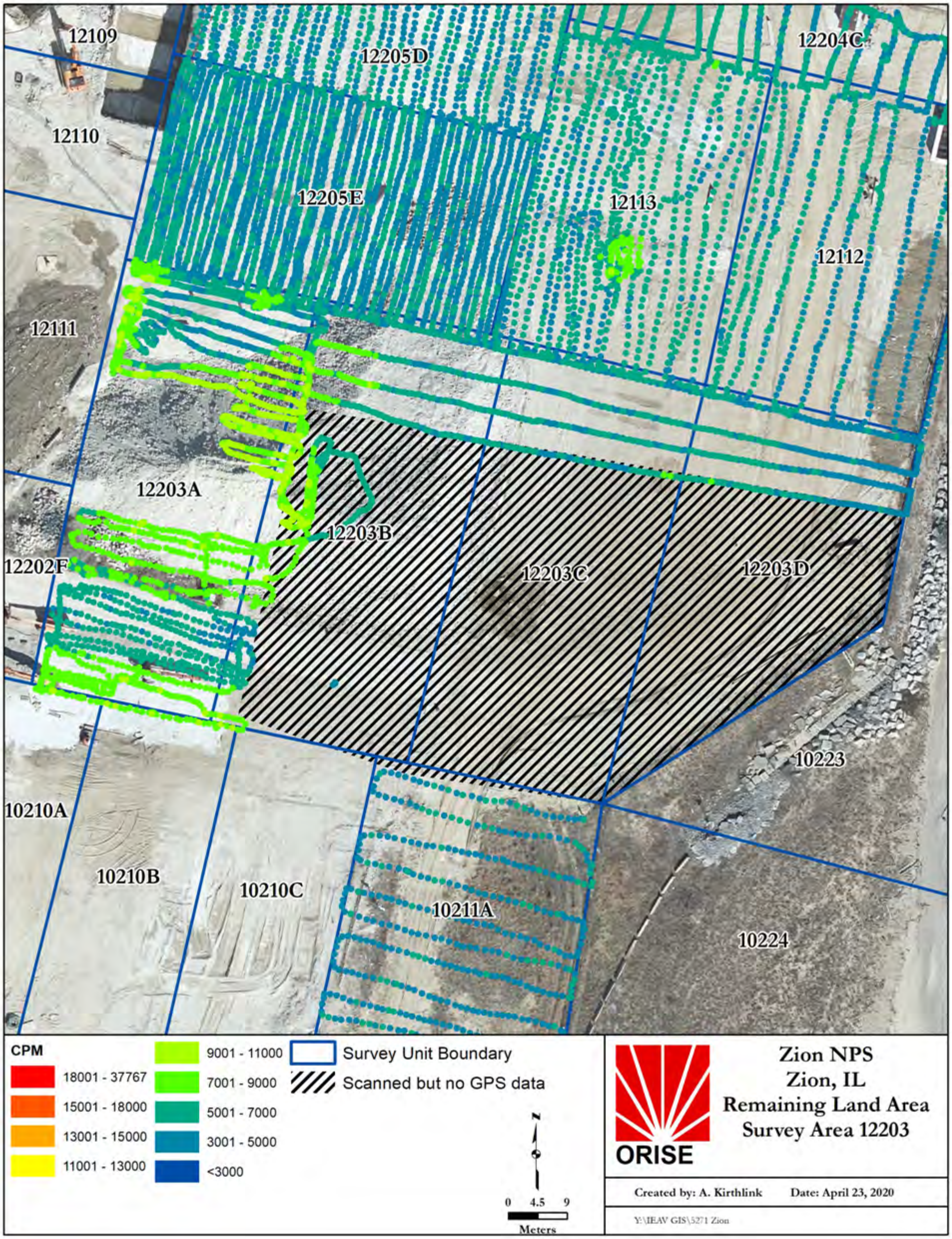

Figure A.20. Gamma Walkover Data for Survey Area 12203

Figure A.21. Gamma Walkover Data for Survey Area 12204

Figure A.22. Gamma Walkover Data for SU 12204A Post-Remediation

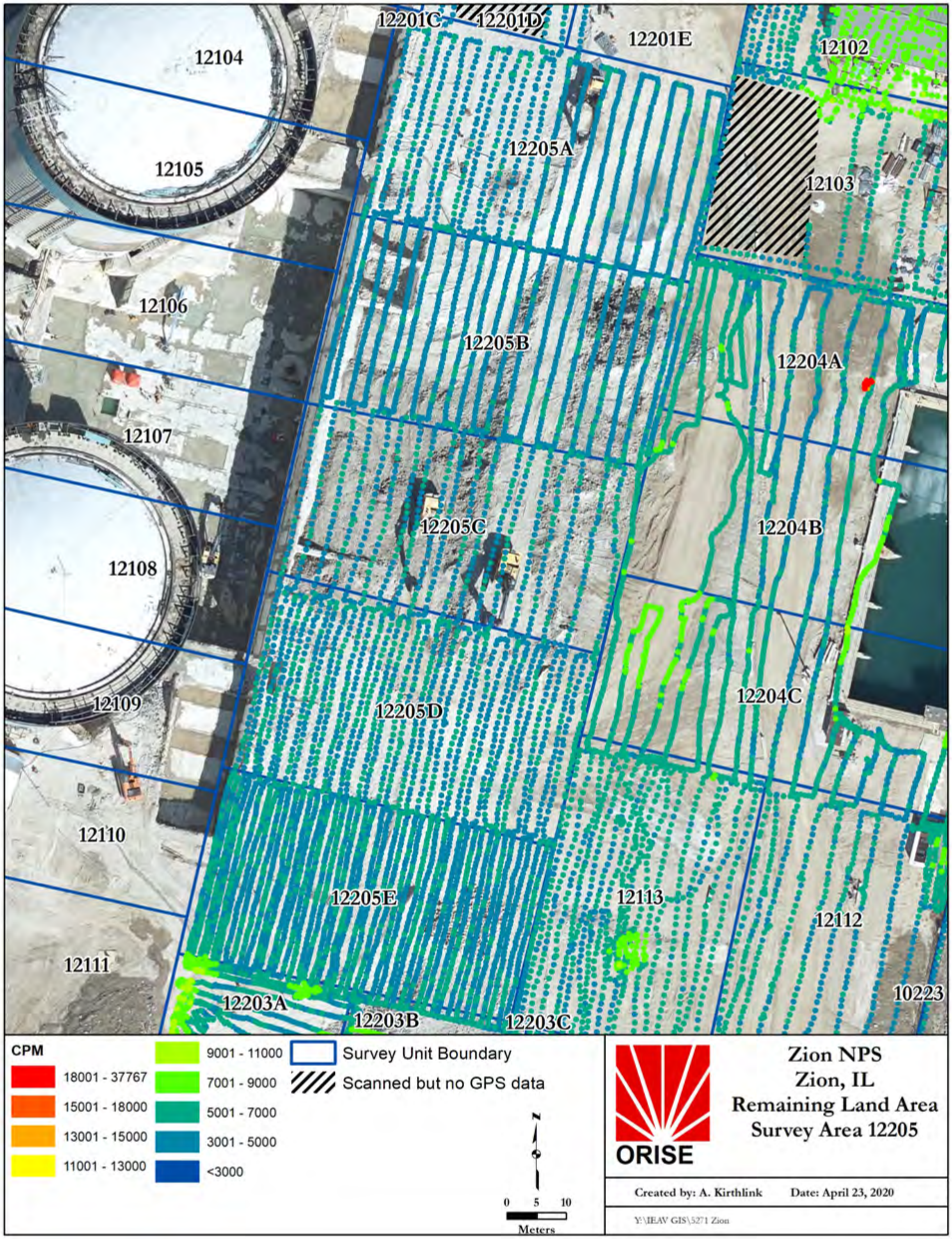

Figure A.23. Gamma Walkover Data for Survey Area 12205

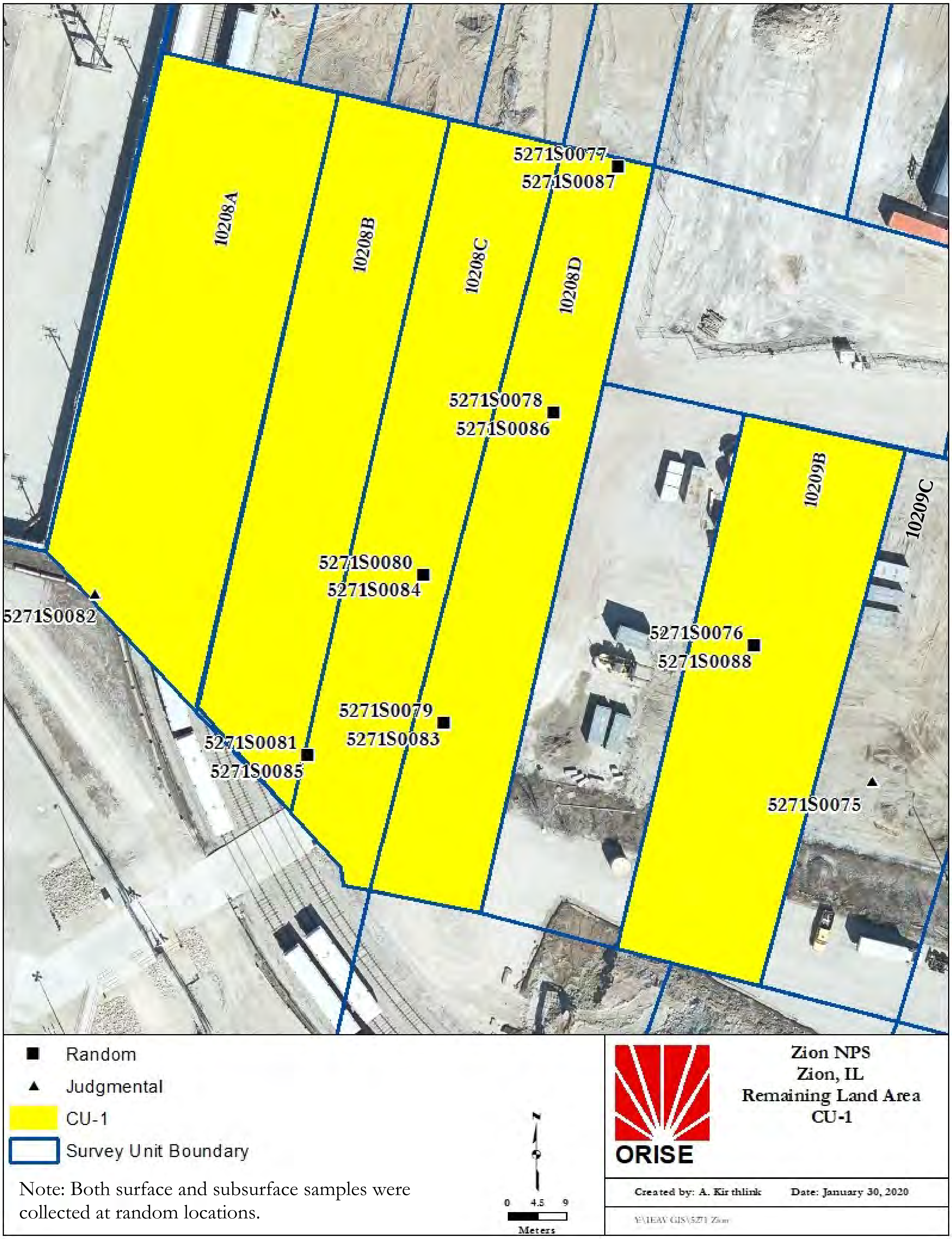

Figure A.24. CU-1 Sample Locations and SU 10209C Judgmental Sample Location

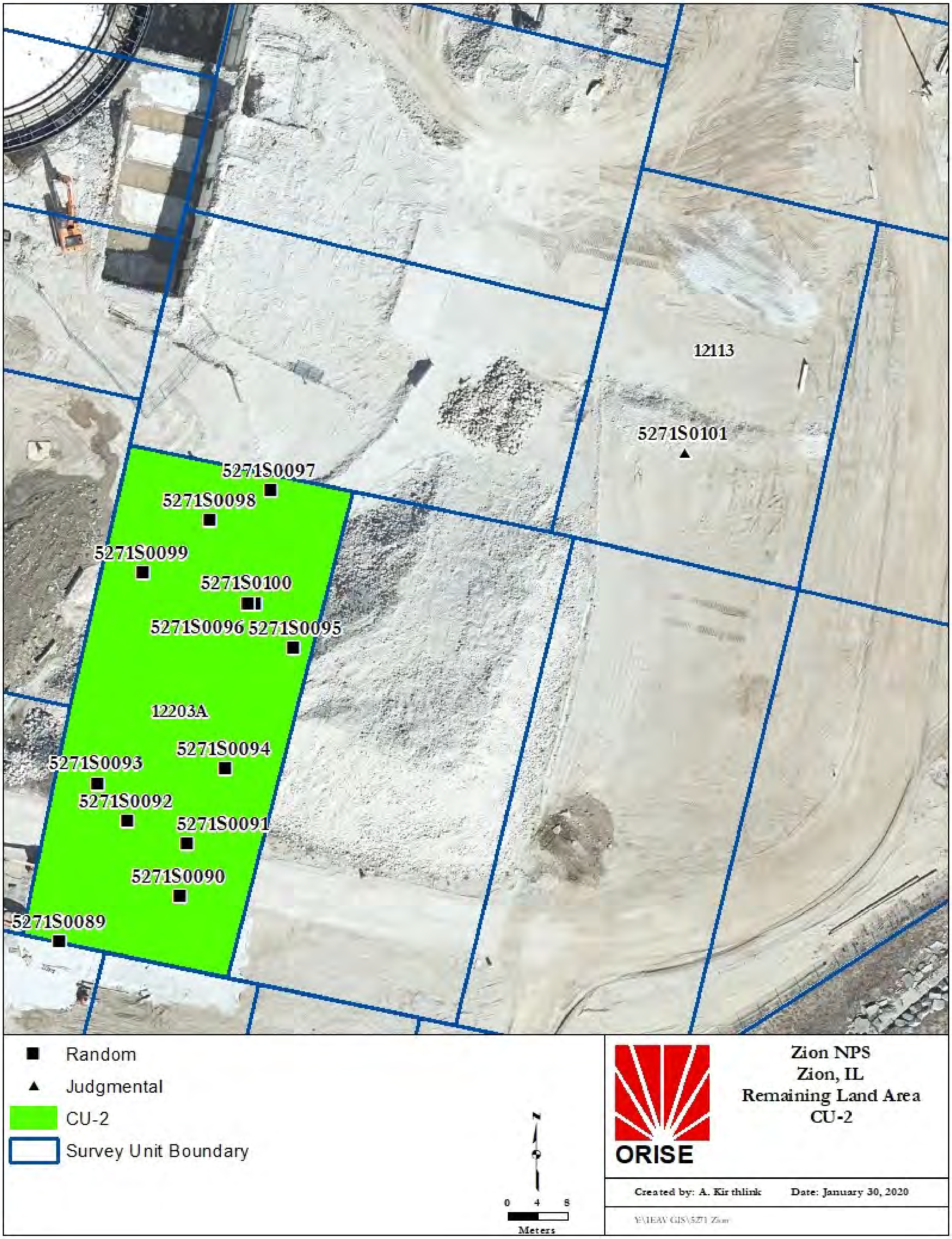

Figure A.25. CU-2 Sample Locations and SU 12113 Judgmental Sample Location

Figure A.26. CU-3 Sample Locations

Figure A.27. SU 00150 Sediment Sample Locations

APPENDIX B: DATA TABLES

Table B.1. Surface Soil Sample Locations and Gamma Measurements							
RSS ID	Survey Unit	Coordinates (m)		Sample ID	Gamma Measurement (cpm)		Sample Depth (cm)
		Easting	Northing		Pre-Sample	Post-Sample	
CU-1 (Survey Areas 10208 and 10209)							
1-1-1	10209B	343558	641580	--	9,872	--	--
1-1-2	10208D	343531	641680	5271S0077	7,041	6,194	0–15
1-1-3	10208B	343484	641656	--	11,077	--	--
1-2-1	10208A	343469	641676	--	8,065	--	--
1-2-2	10208D	343504	641594	5271S0079	8,897	8,768	0–15
1-2-3	10208D	343509	641611	--	10,617	--	--
1-3-1	10208C	343483	641589	5271S0081	13,223	13,801	0–15
1-3-2	10208D	343517	641625	--	9,139	--	--
1-3-3	10208D	343523	641677	--	7,812	--	--
2-1-1	10208B	343476	641640	--	12,369	--	--
2-1-2	10208C	343512	641673	--	8,368	--	--
2-1-3	10208D	343521	641642	5271S0078	7,998	7,198	0–15
2-2-1	10209B	343557	641615	--	6,984	--	--
2-2-2	10208A	343463	641610	--	15,301	--	--
2-2-3	10209B	343552	641606	5271S0076	7,288	6,612	0–15
2-3-1	10208C	343501	641617	5271S0080	11,419	10,224	0–15
2-3-2	10208A	343474	641681	--	9,664	--	--
2-3-3	10208A	343464	641625	--	9,771	--	--
CU-3 (Survey Areas 10214)							
1-1-1	10214	343443	642083	5271S0106	2,955	3,728	0-15
1-1-2	10214	343561	642148	--	3,410	--	--
1-1-3	10214	343620	642104	--	4,456	--	--
1-2-1	10214	343472	642170	--	3,028	--	--

Table B.1. Surface Soil Sample Locations and Gamma Measurements							
RSS ID	Survey Unit	Coordinates (m)		Sample ID	Gamma Measurement (cpm)		Sample Depth (cm)
		Easting	Northing		Pre-Sample	Post-Sample	
1-2-2	10214	343590	642061	5271S0103	2,971	3,164	0–15
1-2-3	10214	343531	642126	--	2,669	--	--
1-3-1	10214	343542	642090	5271S0104	3,500	3,290	0–8
1-3-2	10214	343483	642155	--	2,884	--	--
1-3-3	10214	343601	642047	--	2,945	--	--
2-1-1	10214	343454	642112	--	3,085	--	--
2-1-2	10214	343572	642177	--	3,795	--	--
2-1-3	10214	343513	642068	5271S0105	3,023	3,156	0–8
2-2-1	10214	343631	642133	--	2,878	--	--
2-2-2	10214	343498	642071	5271S0107	2,992	3,010	
2-2-3	10214	343616	642137	--	3,132	--	--
2-3-1	10214	343587	642093	--	2,617	--	--
2-3-2	10214	343528	642158	--	2,871	--	--
2-3-3	10214	343646	642050	5271S0102	3,957	6,332	0–15
CU-2 (SU 12203A)							
--	12203A	343646	641621	5271S0089	7,704	10,927	0–15
--	12203A	343662	641627	5271S0090	5,258	5,570	0–15
--	12203A	343663	641634	5271S0091	6,519	7,215	0–15
--	12203A	343655	641637	5271S0092	6,290	6,616	0–15
--	12203A	343651	641642	5271S0093	7,694	8,288	0–15
--	12203A	343668	641644	5271S0094	8,410	10,137	0–15
--	12203A	343677	641660	5271S0095	8,802	12,070	0–15
--	12203A	343672	641666	5271S0096	9,200	11,914	0–15
--	12203A	343674	641681	5271S0097	7,669	11,272	0–15
--	12203A	343666	641677	5271S0098	4,164	3,530	0–15
--	12203A	343657	641670	5271S0099	8,748	11,515	0–15

Table B.1. Surface Soil Sample Locations and Gamma Measurements							
RSS ID	Survey Unit	Coordinates (m)		Sample ID	Gamma Measurement (cpm)		Sample Depth (cm)
		Easting	Northing		Pre-Sample	Post-Sample	
--	12203A	343671	641666	5271S0100	9,192	11,350	0–15

Table B.2. CU-1 Subsurface Soil Sample Locations and Gamma Measurements							
RSS ID	Survey Unit	Coordinates (m)		Sample ID	Gamma Measurement (cpm)		Sample Depth (cm)
		Easting	Northing		Pre-Sample	Post-Sample	
1-2-2	10208D	343504	641594	5271S0083	8,768	3,251	15–50
2-3-1	10208C	343501	641617	5271S0084	11,325	15,583	15–50
1-3-1	10208C	343483	641589	5271S0085	11,144	5,092	15–50
2-1-3	10208D	343521	641642	5271S0086	8,084	7,806	15–50
1-1-2	10208D	343531	641680	5271S0087	6,150	7,239	15–50
2-2-3	10209B	343552	641606	5271S0088	7,686	7,757	15–50

Table B.3. Judgmental Surface Soil Sample Locations and Gamma Measurements						
Survey Unit	Coordinates (m)		Sample ID	Gamma Measurement (cpm)		Sample Depth (cm)
	Easting	Northing		Pre-Sample	Post-Sample	
10209C	343570	641585	5271S0075	26,247	7,643	0–15
10208A	343450	641614	5271S0082	24,393	17,763	0–15
12113	343729	641686	5271S0101	7,492	9,972	0–15

Table B.4. ROC Concentrations in CU-1 and CU-3																					
Sample ID	Co-60 (pCi/g)			Cs-134 (pCi/g)			Cs-137 (pCi/g)			Ni-63 (pCi/g)			Sr-90 (pCi/g)			H-3(pCi/g)			SOF[a]	
	Conc. [b]	TPU[c]	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU
CU-1 (Survey Areas 10208 and 10209)																					
5271S0076	0.016	0.017	0.039	0.013	0.018	0.039	0.017	0.013	0.029	--	--	--	--	--	--	--		--	0.03	0.01
5271S0077	0.004	0.014	0.030	0.000	0.013	0.028	0.005	0.011	0.026	--	--	--	--	--	--	--	--	--	0.01	<0.01
5271S0078	-0.004	0.020	0.040	0.016	0.015	0.038	0.009	0.014	0.034	--	--	--	--	--	--	--	--	--	0.01	<0.01
5271S0079	0.022	0.013	0.035	0.000	0.004	0.028	**0.040**	0.010	0.020	--	--	--	--	--	--	--	--	--	0.03	0.01
5271S0080	-0.003	0.012	0.024	-0.003	0.006	0.029	0.016	0.013	0.028	--	--	--	--	--	--	--	--	--	<0.01	<0.01
5271S0081	-0.006	0.020	0.039	0.001	0.005	0.042	0.007	0.012	0.039	--	--	--	--	--	--	--	--	--	<0.01	<0.01
CU-3 (Survey Areas 10214)																					
5271S0102	0.009	0.022	0.044	0.019	0.022	0.046	**0.072**	0.018	0.030	--	--	--	--	--	--	--	--	--	0.04	0.01
5271S0103	0.013	0.013	0.030	0.007	0.015	0.030	0.017	0.015	0.032	0.37	0.41	0.68	0.37	0.27	0.44	0.6	1.7	2.9	0.14	0.04
5271S0104	0.011	0.043	0.085	0.003	0.011	0.087	0.023	0.042	0.084	--	--	--	--	--	--	--	--	--	0.02	0.01
5271S0105	-0.008	0.014	0.027	-0.009	0.009	0.035	0.000	0.013	0.032	--	--	--	--	--	--	--	--	--	<0.01	<0.01
5271S0106	0.012	0.020	0.045	-0.006	0.009	0.043	**0.051**	0.022	0.045	--	--	--	--	--	--	--	--	--	0.03	0.01
5271S0107	-0.003	0.011	0.023	0.009	0.012	0.029	0.006	0.010	0.023	--	--	--	--	--	--	--	--	--	0.01	<0.01

[a]The SOF calculation does not include the fractional contributions from HTD ROC, unless sample analysis was completed for these radionuclides
[b]Results greater than MDC are bolded
[c]Uncertainties are based on total propagated uncertainties at the 95% confidence level
Conc. = concentration
TPU = total unpropagated uncertainty
MDC = minimum detectable concentration
pCi/g = picocuries per gram

Table B.5. Radionuclide Concentration in CU-2 (SU 12203A) Soil Samples																				
Sample ID	Co-60 (pCi/g)			Cs-134 (pCi/g)			Cs-137 (pCi/g)			Ni-63 (pCi/g)			Sr-90 (pCi/g)			H-3(pCi/g)			SOF[a]	
	Conc.	TPU[b]	MDC	Conc.	TPU	MDC	Conc.[c]	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU
5271S0089	-0.002	0.027	0.054	-0.002	0.009	0.063	0.008	0.022	0.026	--	--	--	--	--	--	--	--	--	<0.01	<0.01
5271S0090	0.007	0.006	0.022	0.026	0.022	0.047	**0.040**	0.017	0.036	--	--	--	--	--	--	--	--	--	0.03	0.01
5271S0091	0.010	0.018	0.038	0.000	0.006	0.041	0.038	0.018	0.039	--	--	--	--	--	--	--	--	--	0.02	0.01
5271S0092	0.034	0.016	0.034	-0.004	0.009	0.041	**0.086**	0.020	0.037	--	--	--	--	--	--	--	--	--	0.06	0.01
5271S0093	0.010	0.021	0.046	0.026	0.022	0.049	0.009	0.008	0.029	0.26	0.41	0.69	-0.04	0.13	0.25	1.5	1.7	2.9	0.03	0.01
5271S0094	-0.015	0.029	0.055	-0.005	0.008	0.062	-0.028	0.026	0.051	--	--	--	--	--	--	--	--	--	<0.01	<0.01
5271S0095	-0.010	0.024	0.048	-0.005	0.013	0.062	-0.029	0.021	0.045	--	--	--	--	--	--	--	--	--	<0.01	<0.01
5271S0096	0.000	0.032	0.059	0.045	0.031	0.066	-0.001	0.021	0.058	--	--	--	--	--	--	--	--	--	0.03	0.01
5271S0097	-0.001	0.035	0.065	0.043	0.020	0.041	**0.043**	0.020	0.041	**0.70**	0.40	0.66	0.17	0.15	0.25	0.3	1.5	2.6	0.10	0.02
5271S0098	0.002	0.014	0.029	-0.003	0.006	0.030	0.016	0.013	0.029	--	--	--	--	--	--	--	--	--	0.01	0.00
5271S0099	-0.013	0.030	0.058	0.000	0.012	0.071	0.007	0.018	0.052	--	--	--	--	--	--	--	--	--	<0.01	<0.01
5271S0100	-0.012	0.032	0.063	-0.008	0.009	0.071	-0.015	0.030	0.061	--	--	--	--	--	--	--	--	--	<0.01	<0.01

[a]The SOF calculation does not include the fractional contributions from HTD ROC, unless sample analysis was completed for these radionuclides
[b]Uncertainties are based on total propagated uncertainties at the 95% confidence level
[c]Results greater than MDC are bolded
Conc. = concentration
TPU = total propagated uncertainty
MDC = minimum detectable concentration
pCi/g = picocuries per gram

Table B.6. ROC Concentrations in CU-1 (Survey Areas 10208 and 10209) Subsurface Soil Samples																				
Sample ID	Co-60 (pCi/g)			Cs-134 (pCi/g)			Cs-137 (pCi/g)			Ni-63 (pCi/g)			Sr-90 (pCi/g)			H-3(pCi/g)			SOF[a]	
	Conc.	TPU[b]	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Op	BC
5271S0083	0.004	0.015	0.032	-0.002	0.006	0.029	0.003	0.010	0.024	--	--	--	--	--	--	--	--	--	0.01	<0.01
5271S0084	-0.010	0.026	0.051	0.023	0.025	0.057	-0.003	0.022	0.045	--	--	--	--	--	--	--	--	--	0.02	0.01
5271S0085	0.006	0.014	0.040	-0.003	0.021	0.039	0.018	0.013	0.028	--	--	--	--	--	--	--	--	--	0.02	<0.01
5271S0086	0.002	0.014	0.030	0.000	0.006	0.035	0.012	0.008	0.027	--	--	--	--	--	--	--	--	--	0.01	<0.01
5271S0087	0.003	0.018	0.039	0.028	0.018	0.046	0.004	0.014	0.035	--	--	--	--	--	--	--	--	--	0.03	0.01
5271S0088	-0.002	0.005	0.038	0.013	0.021	0.042	0.012	0.013	0.037	0.23	0.41	0.69	0.03	0.15	0.27	0.6	1.7	2.9	0.09	0.02

[a]The SOF calculation does not include the fractional contributions from HTD ROC; unless sample analysis was completed for these radionuclides
[b]Uncertainties are based on total propagated uncertainties at the 95% confidence level.
Conc. = concentration
TPU = total propagated uncertainty
MDC = minimum detectable concentration

Table B.7. ROC Concentrations in Judgmental Soil Samples																				
Sample ID	Co-60 (pCi/g)			Cs-134 (pCi/g)			Cs-137 (pCi/g)			Ni-63 (pCi/g)			Sr-90 (pCi/g)			H-3(pCi/g)			SOF[a]	
	Conc.	TPU[b]	MDC	Conc.	TPU	MDC	Conc.[c]	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Conc.	TPU	MDC	Op	BC
5271S0075	0.007	0.021	0.033	0.050	0.023	0.060	**7.25**	0.79	0.06	0.63	0.42	0.69	0.00	0.26	0.47	**9.3**	1.8	2.5	2.03	0.52
5271S0082	0.024	0.006	0.035	-0.006	0.007	0.050	**0.088**	0.021	0.035	0.67	0.41	0.68	-0.07	0.26	0.48	2.3	2.1	3.5	0.05	0.01
5271S0101	0.014	0.029	0.057	0.027	0.033	0.067	0.024	0.011	0.037	--	--	--	--	--	--	--	--	--	0.04	0.01

[a]The SOF calculation does not include the fractional contributions from HTD ROC, unless sample analysis was completed for these radionuclides
[b]Uncertainties are based on total propagated uncertainties at the 95% confidence level
[c]Results greater than MDC are bolded
Conc. = concentration
TPU = total propagated uncertainty
MDC = minimum detectable concentration

Table B.8. ROC Concentrations in Sediment Samples										
Sample ID	**Location**	**Co-60 (pCi/g)**			**Cs-134 (pCi/g)**			**Cs-137 (pCi/g)**		
		Conc.[a]	**TPU[b]**	**MDC**	**Conc.**	**TPU**	**MDC**	**Conc.**	**TPU**	**MDC**
5271S0108	CB-7	0.009	0.012	0.026	0.010	0.015	0.031	0.017	0.009	0.020
5271S0109	CB-6	0.007	0.013	0.029	0.013	0.013	0.031	**0.053**	0.016	0.029
5271S0110	CB-5	0.038	0.050	0.117	0.051	0.044	0.108	**0.320**	0.061	0.097
5271S0111	CB-9	**0.053**	0.021	0.040	-0.005	0.006	0.052	**0.145**	0.028	0.043

[a]Results greater than MDC are bolded.
[b]Uncertainties are based on total propagated uncertainties at the 95% confidence level.
CB = catch basin
Conc. = concentration
TPU = total propagated uncertainty
MDC = minimum detectable concentration

APPENDIX C: MAJOR INSTRUMENTATION

C.1. SCANNING AND MEASUREMENT INSTRUMENT/ DETECTOR COMBINATIONS

The display of a specific product is not to be construed as an endorsement of the product or its manufacturer by the author or his employer.

C.1.1 GAMMA

Ludlum NaI[Tl] Scintillation Detector Model 44-10, Crystal: 5.1 cm × 5.1 cm
(Ludlum Measurements, Inc., Sweetwater, Texas)
Coupled to: Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, Texas)
Coupled to: Trimble Geo 7X
(Trimble Navigation Limited, Sunnyvale, CA)

C.2. LABORATORY ANALYTICAL INSTRUMENTATION

Low-Background Gas Proportional Counter
Series 5 XLB
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Eclipse Software
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Extended Range Intrinsic Detector
CANBERRA/Tennelec Model No: ERVDS30-25195
Canberra Lynx ® Multichannel Analyzer
Canberra Gamma-Apex Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
EG&G ORTEC Model No. GMX-45200-5
Canberra Lynx ® Multichannel Analyzer
Canberra Gamma-Apex Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
EG&G ORTEC Model No. GMX-30P4
Canberra Lynx ® Multichannel Analyzer
Canberra Gamma-Apex Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Dell Workstation
(Canberra, Meriden, Connecticut)

High-Purity, Intrinsic Detector
EG&G ORTEC Model No. CDG-SV-76/GEM-MX5970-S
Canberra Lynx ® Multichannel Analyzer
Canberra Gamma-Apex Software
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, Tennessee) and
Dell Workstation
(Canberra, Meriden, Connecticut)

Liquid Scintillation Counter
Perkin Elmer Tricarb 5110TR
(Perkin Elmer, Waltham, Massachusetts)

APPENDIX D: SURVEY AND ANALYTICAL PROCEDURES

D.1. PROJECT HEALTH AND SAFETY

The Oak Ridge Institute of Science and Education (ORISE) performed all survey activities in accordance with the *Oak Ridge Associated Universities (ORAU) Radiation Protection Manual*, the *ORAU Radiological and Environmental Survey Procedures Manual,* and the *ORAU Health and Safety Manual* (ORAU 2014, ORAU 2016a, and ORAU 2016b). Prior to on-site activities, a Work-Specific Hazard Checklist was completed for the project and discussed with field personnel. The planned activities were thoroughly discussed with site personnel prior to implementation to identify hazards present. Additionally, prior to performing work, a pre-job briefing and walk down of the survey areas were completed with field personnel to identify hazards present and discuss safety concerns. Should ORISE have identified a hazard not covered in ORAU 2016a or the project's Work-Specific Hazard Checklist for the planned survey and sampling procedures, work would not have been initiated or continued until the hazard was addressed by an appropriate job hazard analysis and hazard controls.

D.2. CALIBRATION AND QUALITY ASSURANCE

Calibration of all field instrumentation was based on standards/sources traceable to National Institute of Standards and Technology (NIST).

Field survey activities were conducted in accordance with procedures from the following documents:

- *ORAU Radiological and Environmental Survey Procedures Manual* (ORAU 2016a)
- *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORAU 2019a)
- *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2019b)

The procedures contained in these manuals were developed to meet the requirements of U.S. Department of Energy (DOE) Order 414.1D and NRC's *Quality Assurance Manual for the Office of Nuclear Material Safety and Safeguards*, and contain measures to assess processes during their performance.

Quality control procedures include

- Daily instrument background and check-source measurements to confirm that equipment operation is within acceptable statistical fluctuations.

- Participation in Mixed-Analyte Performance Evaluation Program and Intercomparison Testing Program laboratory quality assurance programs.
- Training and certification of all individuals performing procedures.
- Periodic internal and external audits.

D.3. SURVEY PROCEDURES

D.3.1 SURFACE SCANS

Scans for elevated gamma radiation were performed by passing the detector slowly over the surface. The distance between the detector and surface was maintained at a minimum. The thallium-doped sodium iodide (NaI[Tl]) scintillation detectors were used solely as a qualitative means to identify elevated radiation levels in excess of background. Identification of elevated radiation levels that could exceed the localized background were determined based on an increase in the audible signal from the indicating instrument or were identified after post-processing the scan data while the team was still at the site.

D.3.2 SOIL SAMPLING

Surface soil samples (approximately 0.5 kilogram each) were collected by ORISE personnel using a clean garden trowel to transfer soil into a new sample container. Subsurface soil samples were collected using a manual soil auger. The entire 15-centimeter (cm) to 50-cm depth interval was collected in 2-gallon plastic bags and homogenized in the field and then a portion was given to Zion*Solutions*. The remaining soil was retained by ORISE. All containers were labeled and security sealed in accordance with ORISE procedures. Zion*Solutions* shipped the samples under chain-of-custody to the ORISE laboratory for analysis.

D.4. RADIOLOGICAL ANALYSIS

D.4.1 GAMMA SPECTROSCOPY

Samples were analyzed as received and homogenized or crushed, as necessary, and a dry portion sealed in a size-appropriate Marinelli beaker or container. The quantity placed in the beaker was chosen to reproduce the calibrated counting geometry. Net material weights were determined, and the samples were counted using intrinsic, high-purity, germanium detectors coupled to a pulseheight analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using computer capabilities inherent in the analyzer system. All total absorption peaks (TAPs) associated with the radionuclides of concern (ROCs) were reviewed for consistency of activity. Spectra also were reviewed for other identifiable TAPs. TAPs used for determining the activities of the radionuclides and the typical associated minimum detectable concentrations (MDCs) for a 1-hour count time are presented in Table D.1.

Table D.1. Typical MDCs and TAPs for ROCs

Radionuclide[a]	TAP (MeV)[b]	MDC (pCi/g)[c]
Co-60	1.332	0.06
Cs-134	0.795	0.06
Cs-137	0.662	0.05

[a]Spectra also were reviewed for other identifiable TAPs.
[b]MeV = mega electron volt
[c]picocurie per gram

D.4.2 RADIOACTIVE STRONTIUM ANALYSIS

Strontium-90 (Sr-90) concentrations were quantified by total sample dissolution followed by radiochemical separation, and were counted on a low-background gas proportional counter. Samples were homogenized and dissolved by a combination of potassium hydrogen fluoride and pyrosulfate fusions. The fusion cakes were dissolved, and strontium was co-precipitated on lead sulfate. The sulfate-salt complex was dissolved in ethylenediaminetetraacetic acid (EDTA) at a pH of 8.0. The strontium was separated from residual calcium and lead by re-precipitating strontium sulfate from EDTA at a pH of 4.0. Strontium was separated from barium by complexing the strontium in diethylenetriaminepentaacetic acid (DTPA) while precipitating barium as barium chromate. The strontium was ultimately converted to strontium carbonate and counted on a low-background gas proportional counter. The typical MDC for a 60-minute count time using this procedure is 0.4–0.6 pCi/g for a 1-gram sample.

D.4.3 H-3 ANALYSIS

Tritium (H-3) analysis for the soil samples was performed using a material oxidizer, and counted by liquid scintillation. The material oxidizer combusts samples in a stream of oxygen gas and passes the products (including carbon dioxide and water vapor), through a series of catalysts. H-3 is carried by water and is captured in a trapping scintillation cocktail specific to water. The typical MDC for H-3 for a 60-minute count time using this procedure is 3–5 pCi/g.

D.4.4 Ni-63 Analysis

Soil samples were spiked with a nickel (Ni) and cobalt carrier and digested with a mixture of nitric and hydrochloric acids. Unwanted elements, such as iron and cobalt, then were removed by running the slurry via anion exchange chromatography. Nickel was then separated from the slurry using a nickel selective resin cartridge. The purified nickel then was eluted off of the column with a dilute nitric acid solution. Ni-63 activity then was determined via liquid scintillation counting. The typical MDC for a 1-gram sample and 60-minute count time using this procedure is 1.8 pCi/g.

D.4.5 Detection Limits

Detection limits, referred to as MDCs, were based on a 95% confidence level. Because of variations in background levels, measurement efficiencies, and contributions from other radionuclides in samples, the detection limits differed from sample to sample and instrument to instrument.