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February 12, 2019

Mr. Ron Linton
U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Division of Decommissioning, Uranium Recovery, and Waste Programs
Reactor Decommissioning Branch
Mail Stop: T8F5, 11545 Rockville Pike
Rockville, MD 20852

SUBJECT: DOE Contract No. DE-SC0014664
INDEPENDENT CONFIRMATORY SURVEY OF LAND APPLICATION IRRIGATION AREAS AT THE HOMESTAKE MINING COMPANY OF CALIFORNIA GRANTS RECLAMATION PROJECT SITE, CIBOLA COUNTY, NEW MEXICO
RFTA No. 18-007; DCN 5328-SR-01-0

Dear Mr. Linton:

The Oak Ridge Institute for Science and Education (ORISE) is pleased to provide the subject final independent confirmatory survey report for the land application irrigation areas at the Homestake Mining Company of California Grants Reclamation Project Site in Cibola County, New Mexico. NRC's comments on the draft report have been incorporated into this final version.

Please feel free to contact me at 865.576.5073 or Erika Bailey at 865.576.6659 if there are any questions.

Sincerely,

Timothy J. Vitkus, CHP
Senior Scientist
ORISE

TJV:lw

Attachment

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INDEPENDENT CONFIRMATORY SURVEY REPORT OF LAND APPLICATION IRRIGATION AREAS AT THE HOMESTAKE MINING COMPANY OF CALIFORNIA GRANTS RECLAMATION PROJECT SITE, CIBOLA COUNTY, NEW MEXICO

T. J. Vitkus, CHP
and
S. T. Pittman, PhD
ORISE

FINAL REPORT

Prepared for the
U.S. Nuclear Regulatory Commission

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INDEPENDENT CONFIRMATORY SURVEY OF LAND APPLICATION IRRIGATION AREAS AT THE HOMESTAKE MINING COMPANY OF CALIFORNIA GRANTS RECLAMATION PROJECT SITE, CIBOLA COUNTY, NEW MEXICO

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FINAL REPORT

FEBRUARY 2019

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ACRONYMS

AA	alternate action
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
C	concentration
CO	Confirmatory Order
CP	Central Pivot
cpm	counts per minute
DOE	U.S. Department of Energy
dpm/100 cm^2	disintegrations per minute per 100 square centimeters
DQO	data quality objective
DS	decision statement
EPA	U.S. Environmental Protection Agency
FSS	final status survey
GPS	global positioning system
HMC	Homestake Mining Company
HMCGRP	Homestake Mining Company of California Grants Reclamation Project
ICPMS	Inductively Coupled Plasma Mass Spectrometry
LAI	land application irrigation
m^2	square meters
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
mg/kg	milligrams per kilogram
NaI	sodium iodide
NMED	New Mexico Environment Department
NMEID	New Mexico Environment Improvement Division
NRC	U.S. Nuclear Regulatory Commission
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocuries per gram
RPD	relative percent difference
PRC	proposed release criteria
PSQ	principal study question
Q	quantile
Q-Q	quantile-quantile
Ra-226	radium-226
ROC	radionuclide of concern
RPD	relative percent difference
SU	survey unit
Th-230	thorium-230
U	uranium
U-total	total natural uranium

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INDEPENDENT CONFIRMATORY SURVEY OF LAND APPLICATION IRRIGATION AREAS AT THE HOMESTAKE MINING COMPANY OF CALIFORNIA GRANTS RECLAMATION PROJECT SITE CIBOLA COUNTY, NEW MEXICO

EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission requested that the Oak Ridge Institute for Science and Education perform confirmatory survey activities of four former land application irrigation (LAI) areas at the Homestake Mining Company of California Grants Reclamation Project Site. The LAI areas were irrigated to grow alfalfa for livestock. The irrigation was via spray or flooding using groundwater that had been recovered and treated to reduce uranium, selenium, and thorium-230 contamination, which had resulted during uranium recovery operations. Confirmatory survey activities were conducted during the period of August 27–30, 2018 and consisted of gamma radiation surface soil scans, surface and subsurface soil sampling, and limited alpha-plus-beta scans and surface activity measurements on irrigation equipment.

The gamma radiation scans were performed over a systematic, randomly selected population of confirmatory investigation areas that consisted of 400-square-meters blocks. The scan objective was to determine if anomalous areas of elevated direct radiation indicative of residual contamination were present. If anomalies were identified, the areas were to be investigated via targeted soil sampling, in addition to a predetermined population of random soil sample locations that were collected from the center coordinate of each block. Samples were submitted for laboratory analysis to quantify radionuclide concentrations. Analytical results were compared to the licensee's final status survey (FSS) results, and the proposed release criteria (PRCs) for the LAIs. Irrigation equipment scans and measurements were performed to determine if there was evidence of residual contamination due to overspray from potentially contaminated groundwater.

Gamma radiation surface soil scans did not identify elevated direct radiation distinguishable from the local background in any of the confirmatory investigation areas or while traversing between these areas. Therefore, no locations were selected for targeted sampling. The static surface and subsurface gamma measurements collected pre- and post-sampling at all random locations were also consistent with typical detector background count rates for soils. Although background soil samples were not collected, the radionuclide concentrations in the LAI confirmatory soil samples were consistent with expected naturally occurring radioactive material background levels, were a fraction of the PRCs, and consistent with the FSS results. The maximum concentrations observed and

corresponding surface soil PRCs were 1.49 and 10.5 pCi/g for radium-226, 3.4 and 14 pCi/g for thorium-230, and 7.5 and 16 mg/kg for total uranium.

Alpha-plus-beta scans of the irrigation equipment identified uniform, elevated count rates commonly encountered on metal surfaces and indicative of natural radon long-lived progeny build-up. Although elevated, the total surface activity levels measured were less than the 5,000 dpm/100 cm^2 average limit specified in Table 2 of Regulatory Guide 8.30, *Health Physics Surveys in Uranium Recovery Facilities* (NRC 2002).

INDEPENDENT CONFIRMATORY SURVEY OF LAND APPLICATION IRRIGATION AREAS AT THE HOMESTAKE MINING COMPANY OF CALIFORNIA GRANTS RECLAMATION PROJECT SITE CIBOLA COUNTY, NEW MEXICO

1. INTRODUCTION

The Homestake Mining Company of California Grants Reclamation Project (HMCGRP) site is the location of a former uranium recovery mill that operated from 1958 to 1990 near Grants, New Mexico. Operations began in 1958 under a license issued by the Atomic Energy Commission and were conducted by the Homestake-Sapin Partners and the Homestake-New Mexico Partners. In 1961, after the dissolving of the Homestake-New Mexico Partnership, the Homestake-Sapin Partners assumed operations for the complete site. In 1968, the partnership merged with United Nuclear Corporation and formed United Nuclear-Homestake Partners. In 1981, Homestake purchased United Nuclear Corporation's interest, and the name changed to Homestake Mining Company (HMC) – Grants (EPA 2001, 2016).

In 1974, the State of New Mexico became an Agreement State and assumed authority to regulate uranium milling activities from the U.S. Nuclear Regulatory Commission (NRC). For two years, the New Mexico Environment Improvement Division (NMEID) and the U.S. Environmental Protection Agency (EPA) conducted a study to determine the impact of uranium mining and milling on local surface and groundwater quality, and it was discovered that private water wells in neighboring subdivisions were contaminated with selenium. In 1976, NMEID and HMC agreed to a groundwater protection plan, which was modified and approved in 1981 with a groundwater discharge plan (DP-200), also referred to as the groundwater restoration program. In September 1983, the site was designated as a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Superfund Site and placed on the National Priorities List, primarily due to the groundwater contamination discovered in residential wells. In 1986, the State of New Mexico returned regulatory authority to the NRC, and since then groundwater remediation has been regulated by three separate organizations: the New Mexico Environment Department (NMED) under DP-200, the NRC under Source Materials License No. SUA-1471, and the EPA through the CERCLA process. Milling operations ceased in 1990, and the mill was decommissioned and demolished between 1993 and 1995. Since that time, the NRC has directed activities associated with

decommissioning, surface reclamation and remediation, tailings impoundment stabilization, and site closure under License No. SUA-1471 (EPA 2001, 2016).

In 1977, HMC implemented its groundwater restoration program. It consisted of injecting freshwater into aquifer wells located near the south and southwest boundaries of the mill site in order to reverse the natural flow of groundwater away from residences and back toward the tailings impoundments. Collection wells near the impoundments then collected contaminated groundwater that was either treated at the reverse osmosis plant and re-injected into the aquifers or was routed to evaporation ponds (EPA 2001, 2016).

From 2000 through 2012, HMC implemented a second groundwater restoration system further south and southwest of the original and beyond the location of residential subdivisions. This secondary system was established on HMC land to remediate groundwater contaminant plumes that had migrated beyond the mill site and the primary collection system. This system consisted of collection wells that extracted contaminated water by pumping to reduce the contaminant levels (including uranium, selenium, and thorium-230) in the aquifer (EPA 2001, 2016). The treated water was used to irrigate four fields, referred to collectively as land application irrigation (LAI) areas using a spray irrigation system or a flood irrigation system in order to grow alfalfa for livestock. Each year, between 40.5 and 159 hectares (100 and 394 acres) were irrigated (EPA 2016; HMC 2017).

In 2017, the NRC issued a Confirmatory Order (CO) to HMC due to apparent violations, including the previous land application activities. This CO required, in part, that HMC develop an assessment of any impacts on future uses of LAI areas due to the use of the irrigation water containing byproduct material.

In 2017, as required by the CO, HMC submitted a final status survey (FSS) plan to the NRC for the release of these former LAI areas that were irrigated at the HMCGRP site, and an FSS Report on data collected was submitted to the NRC on July 2, 2018. Each of the four irrigated fields was classified as a Class 3 Survey Unit (SU) in accordance with the classification definitions provided in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000). The FSS consisted of gamma radiation surface scans and the collection of surface soil (0–15 centimeter [cm]) samples. Mean surface soil concentrations of radium-226 (Ra-226), natural uranium, and selenium were compared to the more restrictive soil screening levels issued by either the EPA or NMED.

Based on sample analytical results, the FSS conclusion was that each SU satisfied the proposed criteria for unrestricted release that were cited in the FSS plan and report (ERG 2017 and 2018).

The NRC requested that the Oak Ridge Institute for Science and Education (ORISE) perform confirmatory survey activities and provide independent data for the NRC's use in determining the adequacy of the FSS and confirmation that unrestricted release criteria have been satisfied. This report summarizes confirmatory survey activities associated with the HMC LAI areas.

2. SITE DESCRIPTION

The HMC site is located in Cibola County, New Mexico, approximately 9 kilometers (5.5 miles) north of the Village of Milan, at the intersection of Highway 605 and County Road 63. Currently, the site consists of two tailings impoundments, a groundwater extraction and injection system, a reverse osmosis water treatment facility, zeolite water treatment systems, two lined collection ponds, three lined evaporation ponds, and a groundwater collection system for areas outside the facility's licensed boundary. The only current operations at the site are related to the NRC-mandated Corrective Action Program for groundwater restoration (EPA 2001, 2016). Figure 2.1 provides an aerial view of the licensed site and the off-site fields that were irrigated with extracted groundwater (ERG 2017).

The yellow outlined areas in Figure 2.1 illustrate the four SUs associated with each of the fields that were irrigated outside the SUA-1471 licensed uranium mill site. HMC subdivided the combined area of approximately 160 hectares into four FSS SUs that were based on LAI sections. The field in Section 28 and the large field in Section 33 were irrigated with a center pivot irrigation system, and the small field in Section 33 and the field in Section 34 were irrigated by flooding. The irrigation area of Section 28 was originally 24 hectares and was expanded to 40 hectares prior to the 2005 growing season. The center pivot field of Section 33 is 61 hectares. The flood irrigation field of Section 33 is 9.7 hectares, and the flood irrigation field of Section 34 is 49 hectares (HMC 2017).

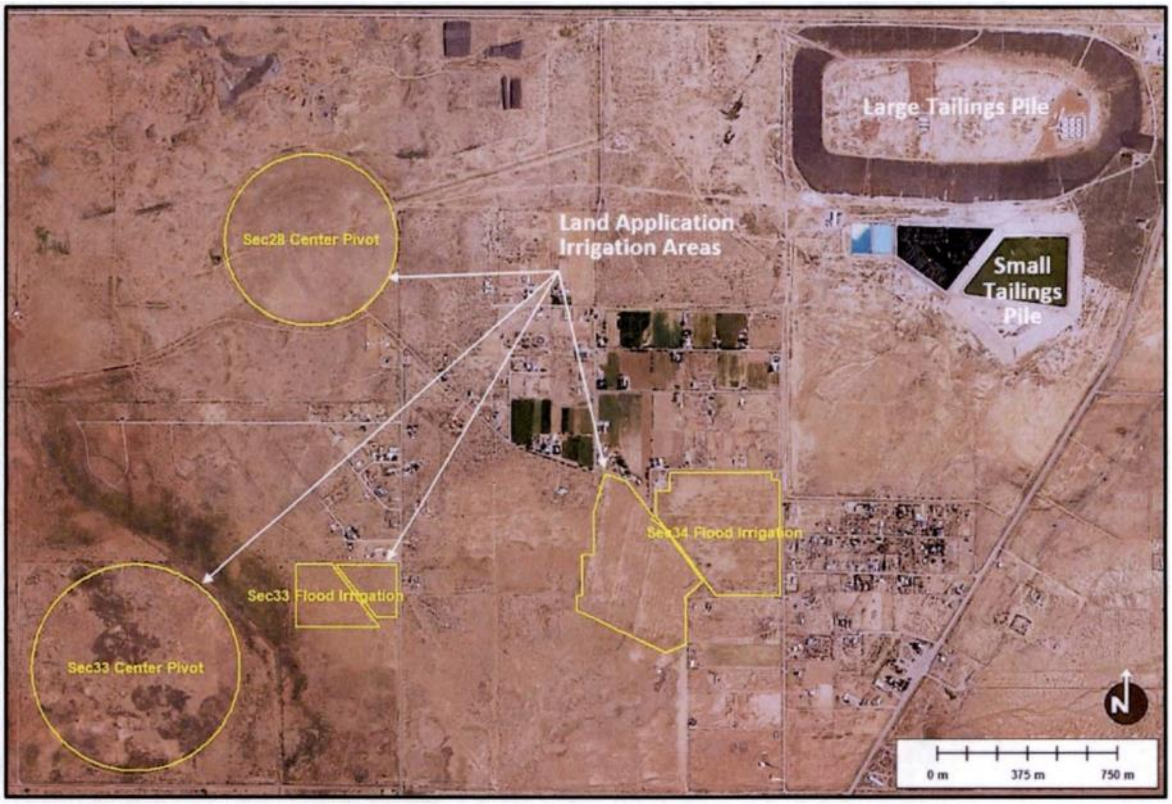

Figure 2.1. HMC Grants Reclamation Project Site (ERG 2017)

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 are 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

3.1 STATE THE PROBLEM

The first step in the DQO process defined the problem that necessitated the study, identified the planning team, and examined the project budget and schedule. The CO requires that HMC request the NRC's review and approval of the FSS for the former LAI areas. The NRC requested that ORISE perform confirmatory surveys at the HMCGRP site to provide independent documentation and radiological data for the NRC's consideration in their evaluation of the FSS. Therefore, the problem statement was as follows:

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

3.2 IDENTIFY THE DECISION

The second step in the DQO process identified the principal study questions (PSQs) and alternate actions (AAs); developed a decision statement (DS); 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. The PSQ, AAs, and combined DS are presented in Table 3.1.

Table 3.1. HMCGRP Confirmatory Survey Decision Process	
Principal Study Questions	**Alternative Actions**
PSQ: Do confirmatory survey results agree with the final radiological survey data for the HMC LAI areas.	Yes: Compile confirmatory data and report results to the NRC for their decision making. Provide independent verification that confirmatory field surveys did not identify anomalous areas of residual radioactivity, quantitative field and laboratory data satisfied the NRC-approved decommissioning criteria, and/or that statistical sample population examination/assessment conditions were met. No: Compile confirmatory data and report results to the NRC for their decision making. Provide independent verification of confirmatory survey results identifying any anomalous field or laboratory data and/or when statistical sample population examination/assessment conditions were not satisfied for the NRC's determination of the adequacy of the FSS data.
Decision Statements	
DS: Confirmatory survey results did/did not identify anomalous results or other conditions that preclude the FSS data from demonstrating compliance with the release criteria.	

3.3 IDENTIFY INPUTS TO THE DECISION

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:

- HMC characterization data
- HMC FSS data for LAI area soils
- HMC soil release criteria (discussed in Section 3.3.1)
- ORISE confirmatory survey results including: surface gamma radiation scans and static direct measurements
- ORISE volumetric sample analysis results for soil

3.3.1 Radionuclides of Concern

The primary radionuclides of concern (ROCs) identified for HMCGRP are alpha emitters resulting from uranium mining and milling. ROCs for HMCGRP are total uranium (U-total) in natural isotopic abundances (U-total: U-234, U-235, U-238), Ra-226, and thorium-230 (Th-230). Although HMC deemed it unnecessary to analyze soil samples for Th-230, as levels in irrigation water were not above background, the NRC requested the addition of this radionuclide to the list of confirmatory ROCs for surface soil. Additionally, although HMC did analyze soil samples for selenium due to elevated levels in irrigation water, the NRC did not require confirmatory sample analyses for selenium.

Sections 2.1 of both the HMC final status survey plan and final status survey report for the former LAI areas provided PRCs for U-total and Ra-226 in LAI surface (0–15 cm) soils, and per the documentation, the PRCs were also applied to subsurface (>15 cm) soil (ERG 2017 and 2018). These PRCs are reproduced in Table 3.2. The PRCs, which are in units of milligram/kilogram (mg/kg) or picocuries/gram of soil (pCi/g), as applicable, are based on the average concentration within any 100-square-meter (m^2) area. The Ra-226 PRC also includes contributions from naturally occurring background concentrations of Ra-226. Per the site's documentation, the NRC has approved an Ra-226 background concentration of 5.5 pCi/g. Th-230 PRCs or background concentrations were not provided in the HMC documentation. The Th-230 values given in Table 3.2 are from the NRC's NUREG-1620, *Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailing Radiation Control Act of 1978*. Appendix H states the following based on requirements for application of the radium benchmark dose modeling (NRC 2003):

> Section H2.0: "If a subject licensee can demonstrate that no contaminated buildings will remain, and that soil thorium-230 (Th-230) does not exceed 5 pCi/g (above background) in the surface and 15 pCi/g in subsurface soil in any 100-square-meter area that meets the radium standard, and the natural uranium (U-nat, that is, U-238, U-234, and U-235) level is less than 5 pCi/g above background, radium benchmark dose modeling is not required."
>
> Section H2.2.3: "The derived Th-230 soil limit will not cause any 100 square meters (m^2) area to exceed the Ra-226 limit at 1,000 years (i.e., current concentrations of Th-230 are less than 14 pCi/g surface and 43 pCi/g subsurface, if Ra-226 is at approximately background levels)."

ORISE soil sample Th-230 concentrations were compared to these values.

Table 3.2. Proposed Release Criteria for HMCGRP LAI Area Soils	
ROC	**Soil Release Criterion**
U-total (mg/kg)	16
Ra-226 (pCi/g)	10.5
Th-230 (pCi/g)[a]	5/14

[a]Taken from NUREG-1620 (NRC 2003)

In addition, as the individual PRCs for Ra-226 and Th-230 represent a separate radiological dose, the sum-of-fractions (SOF) approach—also referred to as the unity rule—is applied when multiple radionuclides are present to ensure compliance is demonstrated with the total dose limit. The SOF calculation for assessing soil concentration data is performed as follows:

$$SOF_{TOTAL} = \sum_{j=1}^{n} SOF_j = \sum_{j=1}^{n} \frac{C_j}{RC_j}$$

Where C_j is the gross concentration (i.e., background is not subtracted in this case) of ROC "j," and RC is the release criterion for ROC "j." The HMC FSS report did not include the SOF determination, as Th-230 was not included as an ROC and because the uranium release criterion was based on toxicity rather than dose.

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, volume, and time for which separate decisions must be made. Confirmatory surveys were conducted during four days, which constituted the temporal boundary of the study.

Confirmatory surveys were performed in each of the LAI SUs. However, for planning and assessments, the four SUs were combined into one confirmatory decision unit. Additionally, piping and center pivot equipment of the land application irrigation systems were investigated for residual radioactive surface contamination at the request of the NRC.

3.5 DEVELOP A DECISION RULE

The fifth step in the DQO process specified appropriate population parameters (e.g., mean, median); confirmed action levels were above detection limits; and developed an if…then… decision rule statement. For this survey effort, the confirmatory sampling plan was based on a presence/absence approach that accounted for both random and judgmental (targeted) sampling to provide a high level of confidence that the confirmatory decision area—the combined LAI area—was acceptable. That is, based on the Class 3 designation, radionuclide concentrations at any location, defined as a contiguous 100 m^2 area upon which the PRCs are based, should be at a small fraction of the PRCs. The input parameter assumptions included the following:

- The assumption that if the LAI areas were impacted by contaminated irrigation water via spray systems or flooding, ROCs were likely to have been distributed within the water and therefore uniformly deposited over the soils rather than heterogeneously deposited such as from spills.

- The FSS gamma radiation scans and soil sampling were adequate to provide at least a 90% probability that a given location investigated was acceptable (i.e., less than the PRCs). The gamma scans provided the mechanism to identify localized ROC deposits where the concentrations were potentially greater than the PRCs.

- A random sample confirmatory survey population that, if all results are less than the PRCs, would provide at least 95% confidence that 95% of any other selected random location would also be found to satisfy the PRCs. Random samples also provided the confidence for quantifying large areas of low-level distributed contamination where the ROC concentrations were less than the gamma scan minimum detectable concentration (MDC).

- Additionally, because the FSS identified a small area of elevated activity at the outer boundary of the SUs that may have been from a spill or some other non-uniform contaminant deposition mechanism, the random population could also be supplemented by targeted confirmatory areas from which judgmental samples would be collected. These targeted areas would be based on direct gamma radiation readings as the primary ROC, Ra-226, is readily detectable via gamma scanning at a fraction of the PRC. As such, it is more likely that samples collected from a targeted block exhibiting elevated direct gamma radiation

would be identified as unacceptable (i.e., greater than the PRCs) versus a sample from a random location where no elevated radiation levels are noted.

These planning inputs resulted in a sampling goal consisting of 30 or 35 total confirmatory blocks, dependent upon the targeted population size of either 10 targeted plus 20 random locations or 5 targeted plus 30 random locations distributed over the four LAI areas. For planning purposes, 5 targeted locations were assumed, requiring the larger population of at least 30 random locations.

The decision rule null and alternative hypotheses were stated as:

H_o: Should any single location exceed the PRCs, conclude that the combined LAI areas do not satisfy the PRCs.

H_A: Provided all investigation area results are a fraction of the PRCs, conclude that the combined LAI areas were properly classified and therefore satisfy the PRCs.

The decisions for the surveys of irrigation system equipment were restricted to determining if there was evidence of residual surface contamination and the corresponding as-found activity levels.

3.6 SPECIFY LIMITS ON DECISION ERRORS

The sixth step in the DQO process specified the decision maker's limits on decision errors, which were then used to establish performance goals for the survey. 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. A Type II error is incorrectly failing to reject the null hypothesis when the alternative hypothesis is true. This is also known as a false negative. Two orders of control were implemented to minimize decision errors regarding the decision statement introduced in Table 3.1.

The first order of control was to select decision error rates that were conservative yet still allowed for the project to be completed within the study boundaries. The Type I error rate, based on the planned 95% confidence of the decision, was therefore 5% (α=0.05) chance of incorrectly rejecting the null hypothesis. The power of the statistical test, denoted as the quantity 1-β, or the probability of the test to correctly reject the null hypothesis when it is false, is not specifically controllable for a

binomial decision. That is, a given location either does or does not exceed the PRCs in an area where contamination should not be identified. However, as the confirmatory survey study boundary encompassed the four SUs as a single decision unit, there was a probability that up to three of the individual SUs (based on a single confirmatory result in one SU exceeding the PRCs) could be incorrectly concluded to not satisfy the criteria. This investigation was not intended to control, or otherwise evaluate, the probability of the error.

The second order of control was to optimize the gamma scan MDC to ensure it was less than the primary ROC's (Ra-226) PRC and to ensure that analytical MDCs and uncertainties were a fraction of the individual PRCs. Scan and analytical MDCs are provided in Appendix D.

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. Survey design and laboratory analyses were optimized by implementing the procedures presented in Section 4 and Section 5, respectively.

4. PROCEDURES

The ORISE survey team performed visual inspections, measurements, and sampling activities within the four LAI SUs during the period of August 27 through August 30, 2018. Survey activities were conducted in accordance with the NRC-approved project-specific confirmatory survey plan, *ORAU Radiological and Environmental Survey Procedures Manual* and the *ORAU Environmental Services and Radiation Training Quality Program Manual* (ORISE 2018, ORAU 2016a, and ORAU 2018).

4.1 Reference System

ORISE referenced confirmatory measurement/sampling locations to global positioning system (GPS) coordinates, specifically in meters relative to NAD83, Zone New Mexico West. Measurement and sampling locations were documented on detailed survey maps.

4.2 GAMMA RADIATION SURFACE SCANS

The NRC requested that gamma radiation surface scans be performed within a 10-meter radius (~300 m^2) of planned soil sampling locations. Based on this parameter—which was increased to a planned individual confirmatory investigation unit area of 400 m^2 based on 20 meter × 20 meter blocks—the combined SUs were subdivided into a total population of 4,249 blocks from which the random confirmatory locations were selected. Visual Sample Plan version 7.10 was used to determine the required number of investigation areas and then generate the random-start/systematic locations for confirmatory survey blocks from the total population. The planning inputs defined in Section 3.5 were used to calculate the sample population size to achieve 95% confidence that at least 95% of any block within the LAI areas would satisfy the PRCs. Although the output was a minimum population size of 30 random locations, the random start point and systematic spacing resulted in the confirmatory area accommodating 41 locations as shown in Figure 4.1 and individually for each LAI area in Figures A-1 through A-4.[1]

[1] Note: The nomenclature for the sequential four digit identifiers in Figure 4.1 was expanded in Appendix A figures and tabulated data of Appendix B, where applicable, to 5328S####, which designates the ORISE-project tracking number (5328) and the investigated soil media (S).

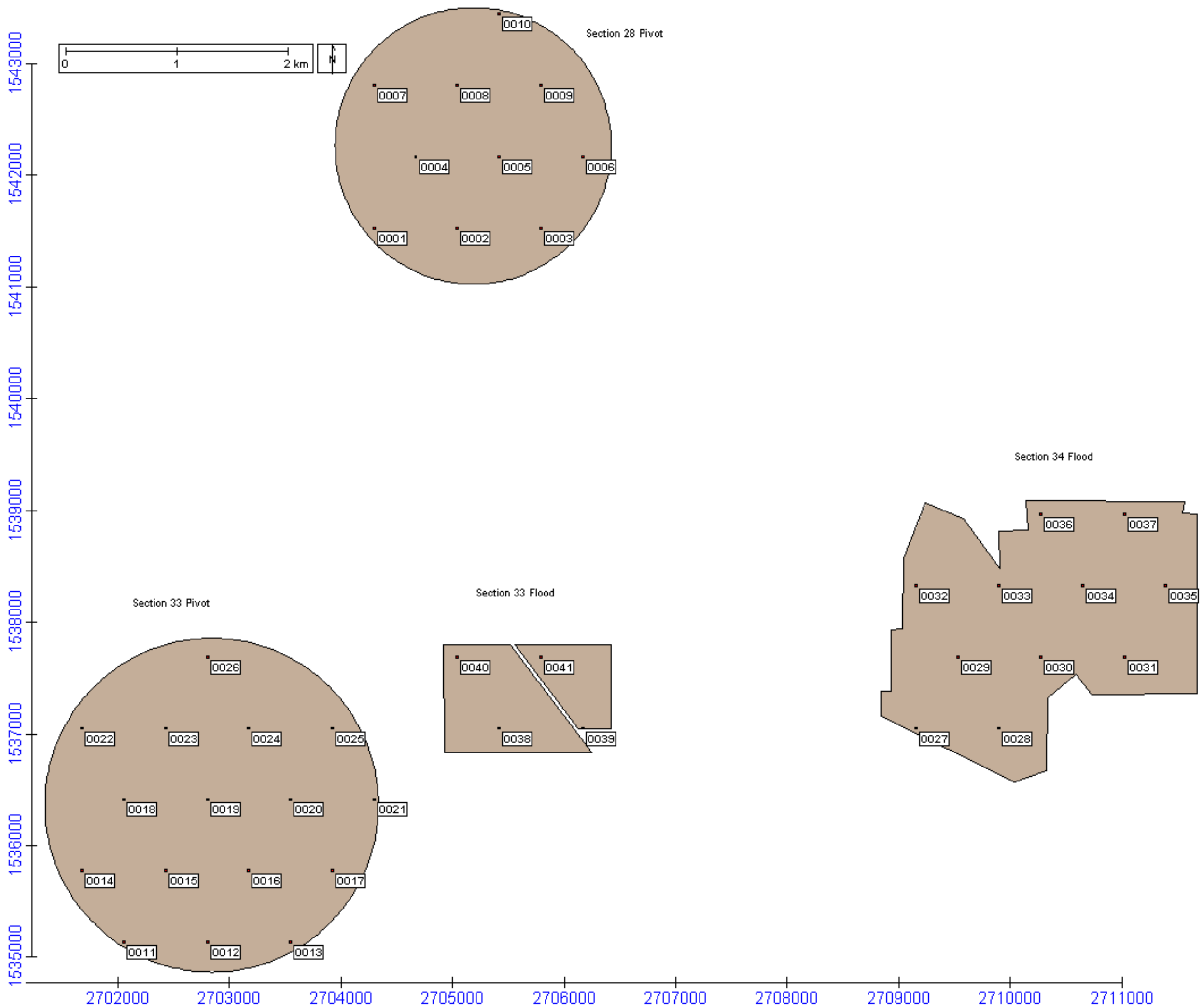

Figure 4.1. Confirmatory Random Start/Systematic Blocks

High density gamma radiation surface scans were performed within each block area and continuous scanning was performed while traversing between adjacent locations. Scans were performed using Ludlum Model 44-10 sodium iodide (NaI) scintillation detectors coupled to Ludlum Model 2221 ratemeter-scalers with audible indicators that the surveyor continuously monitored. The ratemeter-scalers were also coupled to GPS systems that enabled real-time gamma count rate and geo-referenced data capture for 38 of the 41 areas. The scan data for blocks 5328S0024, -0026, and -0028, were not electronically captured due to signal loss between the ratemeter-scaler and GPS unit. Additionally, two off-site areas were scanned (Figure A-6) to collect background gamma radiation data.

4.3 Gamma Radiation Static Measurements and Soil Sampling

Systematic static gamma radiation measurements were made, followed by soil sample collection at the central reference coordinate within each random 400 m^2 block. Surface soil samples were collected at each location using a 30-cm core sampler with polybutyrate sleeve followed by a static gamma radiation measurement at the 30-cm depth. Additional subsurface samples were also collected from the 30- to 60-cm interval at select locations. The number of subsurface locations sampled was dependent upon physical boundary limitations—specifically, the composition and density of the soil. Ultimately, 103 soil samples were collected from the 41 locations. The soil sample population consisted of 41 0–15 cm, 39 15–30 cm, and 23 30–60 cm samples. Figures A-1 through A-4 show sample locations. Sampling equipment was cleaned in the field and a new polybutyrate sleeve inserted into the core barrel between locations and the depth intervals to prevent cross-contamination.

4.4 Alpha and Beta Radiation Surface Scans and Measurements

The Section 33 center pivot equipment was scanned for alpha–plus-beta direct radiation. Static direct measurements were made at representative locations of elevated direct radiation identified during scans. Scans and direct measurements were performed using a Ludlum Model 44-142 beta scintillation detector coupled to a Ludlum Model 2221 ratemeter-scaler. Figure A-5 shows direct measurement locations.

5. SAMPLE ANALYSIS AND DATA INTERPRETATION

Samples were transferred to the Radiological and Environmental Analytical Laboratory in Oak Ridge, Tennessee for preparation and analysis. Sample analyses were performed in accordance with the *Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2017). For each sample location, soil cores collected from the top 30 cm of soil were subdivided into the 0–15 cm and 15–30 cm depth increments for individual analysis, and the ≥30 cm depth soil core from each location was analyzed as a single sample. Soil samples were analyzed by inductively coupled plasma mass spectroscopy (ICP/MS) for U-total and gamma spectroscopy for Ra-226 and Th-230. Analytical results are reported in units of mg/kg for U-total and pCi/g for Ra-226 and Th-230. Gamma radiation scan and static measurements are presented as gross counts per minutes.

Alpha-plus-beta measurements were converted to units of disintegrations per minute per 100 square centimeters (dpm/100 cm^2).

6. FINDINGS AND RESULTS

The results of the confirmatory survey activities are discussed in the subsections below.

6.1 SURFACE SCANS AND DIRECT MEASUREMENTS

Gamma radiation surface scan maps that show the data for the background areas and the LAI confirmatory investigation blocks are presented in Figures A-6 through A-44, with the exception of the data that were not electronically captured for areas 5328S0024, -0026 in the Section 33 Pivot and -0028 in the Section 33 Flood LAIs.

Each of the four LAI areas and the offsite background scans exhibited distinct background gamma radiation distributions when the data populations were compared, as shown in Figure 6.1 and summarized in Tables 6.1 and 6.2, whereby all LAI data could not be appropriately described by the off-site background reference areas. The LAI confirmatory scan data histograms were therefore further examined for skewness that may indicate isolated areas with elevated counts greater than background and also for multi-modal distributions indicative of large, potentially contaminated areas comingled with background data or, alternatively, more than one background population. The data from the two off-site background areas are shown together with the data from the four LAIs in the Figure 6.1 quad charts. The off-site backgrounds are clearly illustrated as a bi-modal distribution in Figure 6.1 (most notably in the SU 33 Flood chart which has the smallest Y-axis scale) as is a right skew of the SU 33 Central Pivot (CP) data and left skew of the SU 33 Flood data. Both of these skews were noted as spatially correlated variations in the detector background response as the surveyor traversed the respective LAI area. Figures A-45 through A-49 show the consolidated confirmatory scan results for each LAI area.

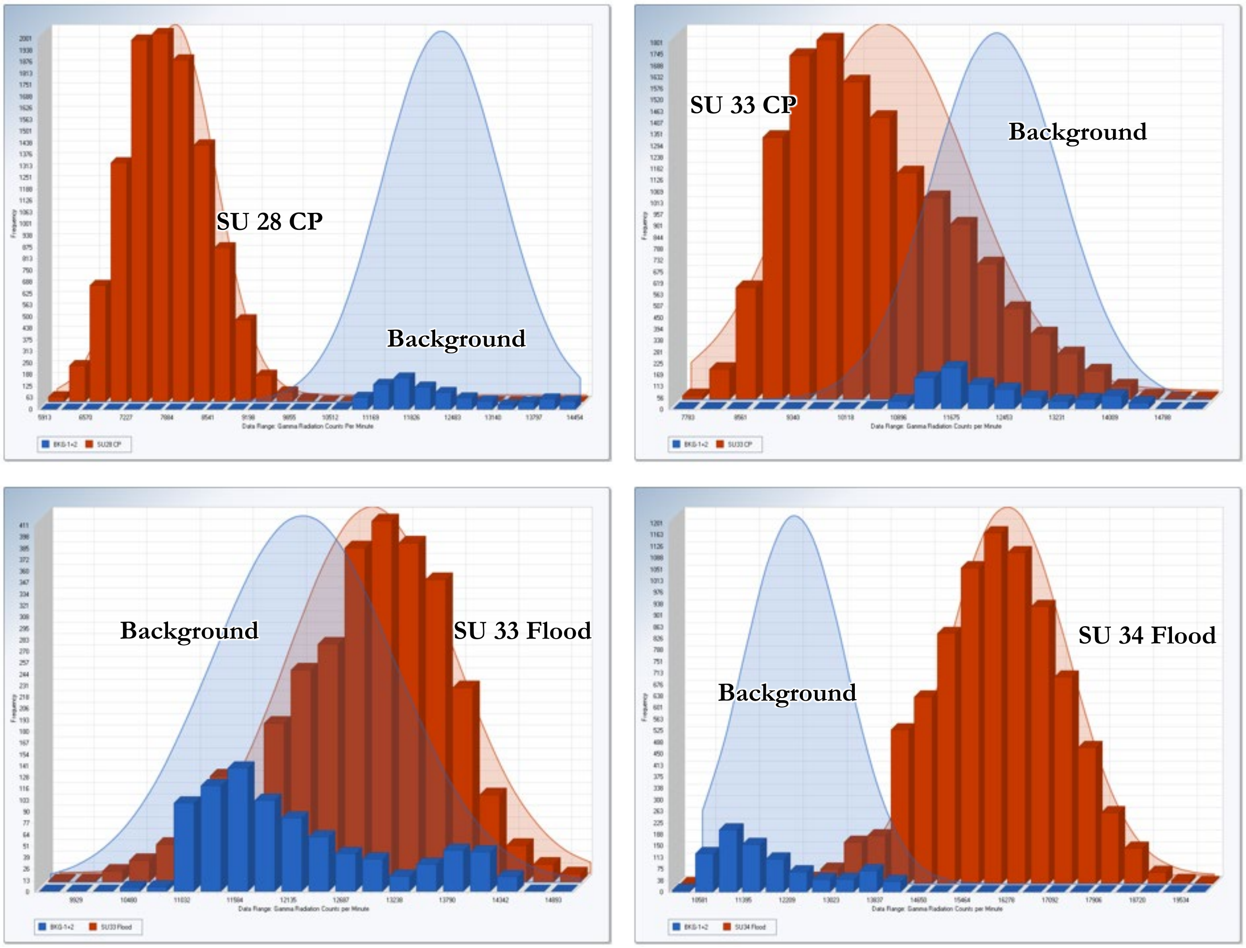

Figure 6.1. Comparative Background and LAI Gamma Radiation Scan Histograms

Table 6.1. General Gamma Radiation Count Rate Descriptive Statistics					
Area	**NumObs**	**Minimum**	**Maximum**	**Mean**	**SD**
BKG-1	463	10,472	14,409	12,667	981
BKG-2	484	9,453	13,063	11,376	561
BKG-1+2	840	10472	14409	12182	950
SU 28 CP	10790	5,868	10,612	7,759	658
SU 33 CP	13266	7,548	15,331	10,379	1,250
SU 33 Flood	2924	9,562	15,078	12,803	856
SU 34 Flood	7953	12,156	19,832	15,981	1,122

Table 6.2. Gamma Radiation Count Rate Percentiles										
Area	**NumObs**	**10%ile**	**20%ile**	**25%ile(Q1)**	**50%ile(Q2)**	**75%ile(Q3)**	**80%ile**	**90%ile**	**95%ile**	**99%ile**
BKG-1	463	11473	11718	11834	12536	13643	13776	14058	14197	14324
BKG-2	484	10669	10862	10969	11385	11812	11903	12083	12173	12666
BKG 1+2	840	11162	11382	11469	11893	12722	13033	13822	14082	14300
SU 28 CP	10790	6919	7188	7283	7730	8201	8328	8632	8892	9341
SU 33 CP	13266	8928	9262	9405	10173	11209	11481	12150	12744	13630
SU 33 Flood	2924	11528	12102	12261	12913	13419	13528	13799	14033	14518
SU 34 Flood	7953	14488	15010	15220	16001	16756	16949	17425	17798	18502

Because of the gamma radiation background variability—up to a factor of two within the four LAI areas—Figures A-7 through A-44 show the gamma radiation data binned and presented in two side-by-side formats: 1) data binned based on the mean and variability (standard deviations) of the individual LAI area population distribution general statistics presented in Table 6.1 to illustrate any anomalies, if present, relative to localized background; 2) data presented in common bins that are based on the combined background data populations (BKG 1+2 in Table 6.2) percentiles and calculated background threshold values to illustrate the relative variability between the LAI areas.

Surface scans of each LAI area did not identify any anomalous gamma radiation levels that were audibly distinguishable from the localized background within an LAI that would have warranted targeted sampling. The absence of elevated count rates is also evident in the Figure 6.2 Quantile-Quantile (Q-Q) plot, whereby there are no clustered outlier data in the right tail or step functions of the respective plots. Step functions result when more than one population is present—e.g., a combination of non-impacted areas characterized by only background counts and localized areas where the gamma radiation counts are from background plus contamination. Additionally, the relative ranking of the gamma count rate population distributions observed and shown in Figure 6.2—where SU 28 CP exhibited the lowest count rate ranges followed by, from lowest to highest, SU 33 CP, SU 33 Flood, and SU 34 Flood—correlated with the variable radium and uranium concentrations in the respective soil samples. The analytical results are discussed in Section 6.2. The variability in the gamma radiation levels and respective ROC concentrations are likely the result of different soil types noted within the LAIs during sampling, which ranged from unconsolidated, sandy to dense impenetrable, clay-like material.

The surface and subsurface static gamma radiation measurements that were collected at soil sampling locations are presented in Table B-1. The surface measurements were also consistent with the local scan data backgrounds as were the subsurface counts, where the observed increases were the result of detector geometry effects rather than indicative of subsurface contamination.

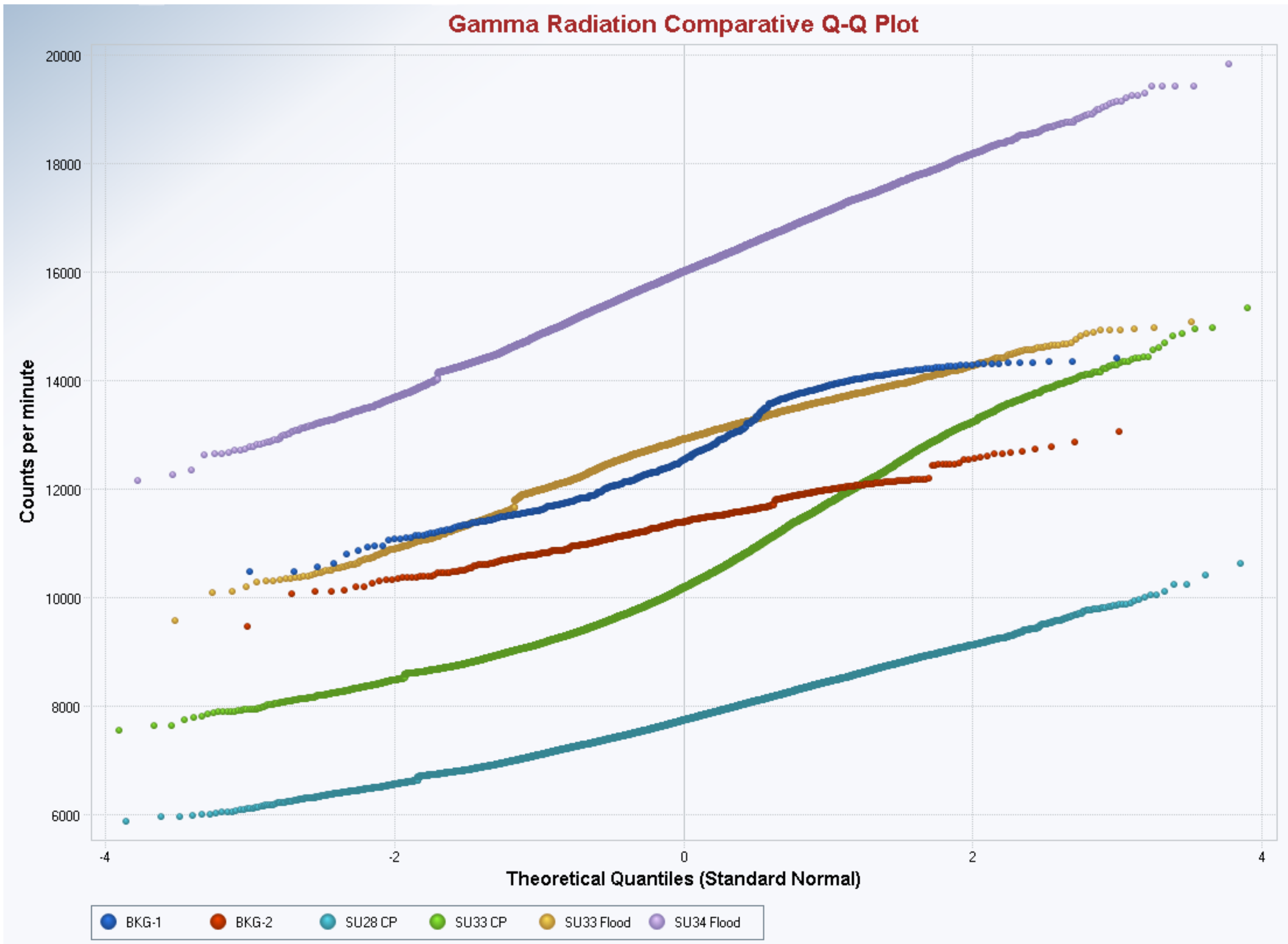

Figure 6.2. Gamma Radiation Q-Q Plots

Alpha-plus-beta surface scans of the Section 33 central pivot equipment identified count rates that were readily distinguishable from background on the metallic surfaces of the influent pipe and structural support pieces. The detector background was approximately 430 counts per minute (cpm) and scans ranged from 400 to 1200 cpm. Two direct measurements were performed and the locations are shown on Figure A-5. The corresponding surface activity levels for DM1 (1,061 cpm) and DM2 (898 cpm) shown on Figure A-5 were 570 and 420 dpm/100 cm^2, respectively, based on a detector total efficiency that assumes radium and associated decay progeny are present in equilibrium as described in Appendix D. The metal was rusted and this condition is commonly found to selectively accumulate the long-lived radon progeny, Pb-210. Scrape samples were not collected for laboratory analysis to determine whether the elevated count rates were the result of radium plus progeny or only from the long-lived radon progeny as this activity was not within the confirmatory survey scope. For comparison, the measurements were less than both the average total (5,000 dpm/100 cm^2) and the removable (1,000 dpm/100 cm^2) surface contamination limits provided in Table 2 of Regulatory Guide 8.30 for equipment release to unrestricted areas at uranium recovery facilities (NRC 2002).

6.2 RADIONUCLIDE CONCENTRATIONS IN SOIL

Table B-1 provides the analytical results for each soil sample. Table 6.3 presents a summary of the results for the combined LAI areas and sample depths.

Table 6.3. Radionuclide Concentration Summary

Radionuclide	Minimum	Maximum	Mean	SD
Ra-226 (pCi/g)	0.22	1.49	0.68	0.32
Th-230 (pCi/g)	-7.70	3.4	0.18	1.93
U-total (mg/kg)	1.42	7.47	3.33	1.59

Figures A-49 through A-51 present box plots for Ra-226, Th-230 and U-total for each LAI area. The box plots provide information on the median confidence interval, percentiles, minimum/maximum results, and potential outliers. As seen in the box plots comparison in Figure 6.3, there is relative correlation between the Ra-226 concentrations (U-total as well, although not shown here) and the observed variability and count rates of the gamma radiation scan results.

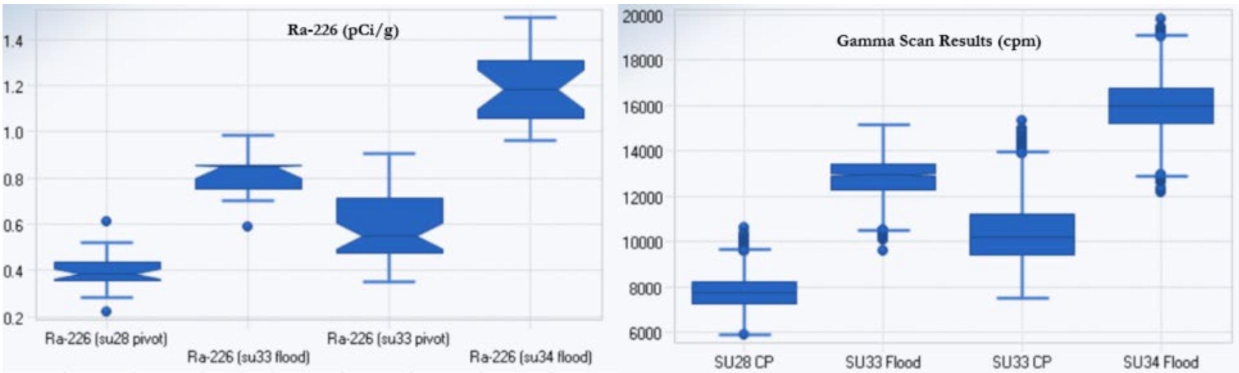

Figure 6.3. Comparative Box Plots of LAI Ra-226 Concentrations and Gamma Scan Results

The scan survey results for SU 34 Flood were elevated compared to the other survey units primarily because the Ra-226 concentrations were a factor of 1.5 to 3 times higher, on average, than the other survey units. Regardless, all Ra-226 and U-total concentrations in all surface and subsurface soil samples, including samples collected in survey unit SU34,were a fraction of the site's PRCs, with all Ra-226 results also being a fraction of the site reference background of 5.5 pCi/g. Although this confirmatory study was designed to assess the radiological status of the LAI soils relative to the PRCs rather than with background and consistent with natural background unaffected by mining operations. Although the FSS plan and report did not provide a site-specific Th-230 reference background or a PRC, the confirmatory sample Th-230 concentration ranges and averages were similar to the 0.7 to 5.2 pCi/g natural background results reported at another uranium recovery facility site located within the same geographic region (Table 3.1 of KOMEX 2006). For additional Th-230 data comparison, all results were less than the NUREG 1620 Section H2.2.3 14 pCi/g criteria and the more restrictive H2.0 value for Th-230 of 5 pCi/g value (NRC 2003).

The average Ra-226 and U-total concentrations for surface soil samples—HMC did not collect subsurface samples—was also compared to the licensee's results for each LAI area. Table 6.4 provides the comparison and relative percent differences (RPDs) of the means. By removing the absolute value operation from the RPD equation, the comparison indicates both negative (Ra-226) and positive (U-total) systematic biases in the comparative results. However, based on the low concentrations, the observed differences of the ORISE to HMC results would not affect the confirmatory survey decision and are likely the result of differences in analytical processes.

Table 6.4. Surface (0 to 15 cm) Soil Sample Mean Concentration Comparison						
	Ra-226 (pCi/g)		RPD[a]	U-total (mg/kg)		RPD
LAI	ORISE	HMC[b]		ORISE	HMC[b]	
SU 28 Pivot	0.4	0.9	-76.9	2.0	0.7	96.3
SU 33 Flood	0.8	1.7	-72.0	3.4	1.6	72.0
SU 33 Pivot	0.5	1.2	-82.4	2.6	1.3	66.7
SU 34 Flood	1.2	2.0	-50.0	6.2	4.1	40.8

[a]RPD = $\frac{C_{ORISE}-C_{HMC}}{\frac{C_{ORISE}+C_{HMC}}{2}} * 100$; where C = concentration, absolute value operation omitted from numerator to assess direction of systematic differences
[b]Mean data as reported in Tables 4, 6, 8, and 10 of ERG 2018

The data were also assessed for evidence of selective migration of potential contaminants during irrigation from the surface into the subsurface soil. Figures A-52 through A-54 show comparative Q-Q plots for each ROC plotted for the sample depth populations. For each ROC, the subsurface concentration distributions were similar to or less than, the surface concentration populations, providing evidence that had there been surface deposition of contaminated water, ROCs had not selectively migrated into the subsurface soils. The results were also representative of naturally occurring background ranges and were a fraction of the Table 3.2 PRCs and NUREG-1620, Appendix H limits.

7. SUMMARY

ORISE conducted confirmatory survey activities of the four land application irrigation areas at the HMCGRP Project Site during the period of August 27–30, 2018. Gamma radiation surface soil scans were performed, followed by surface and subsurface soil sampling. Limited alpha-plus-beta scans and surface activity measurements were performed on irrigation equipment to determine if there was evidence of residual contamination due to overspray from potentially contaminated groundwater.

Gamma radiation scans were conducted over 41 randomly selected 400 m^2 confirmatory investigation areas to determine if elevated direct gamma radiation levels were present. Soil samples were also collected at the center of each confirmatory area to a minimal depth of 15 cm and a maximum depth of 60 cm as conditions allowed. Samples were submitted for laboratory analysis to quantify radionuclide concentrations. Analytical results were compared with the site's FSS results and PRCs and other applicable limits.

Gamma radiation soil surface scans and static measurements did not identify any elevated direct radiation levels indicative of residual contamination. The observed variability in the gamma radiation count rate populations of the four LAI areas coincided with the respective variability of the Ra-226 and U-total concentrations. Although no confirmatory background soil samples were collected, the concentration ranges of Ra-226 in the LAI confirmatory surface and subsurface soil samples were less than the site's referenced 5.5 pCi/g background and were within the lower non-mining affected background concentration ranges reported for the region, as were Th-230 and U-total (KOMEX 2006). Additionally, the activity concentrations between the ROCs were consistent with the ratios expected within a natural background environment.

The maximum individual ROC concentrations in soil samples were 1.49 pCi/g for Ra-226 and 3.4 pCi/g for Th-230—with a maximum SOF of 0.35 using the NUREG-1620 Th-230 value of less than 14 pCi/g as the PRC—and 7.5 mg/kg (approximately 5 pCi/g) for U-total. Based on the combination of analytical results and gamma radiation scans not identifying any anomalies, the null hypothesis may be rejected in favor of the alternative hypothesis and conclude that the combined LAI areas were properly classified and are below the site PRCs for Ra-226 and U-total, and Th-230 concentrations were not elevated. Additionally, as the number of locations investigated (41) exceeded the required sample size to satisfy planning goals, the actual confirmatory decision confidence level achieved was greater than the planned 95% that at least 95% of any 100 m^2 block selected would be found to be less than the PRCs.

The limited scope alpha-plus-beta scans of the irrigation equipment identified uniform, elevated count rates commonly encountered on metal surfaces that could be the result natural radon long-lived progeny build-up. Samples were not collected to determine the radionuclides present, and no site data were available for confirmation. The two direct measurement results were less than equipment release criteria commonly used at uranium recovery facilities.

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APPENDIX A
FIGURES

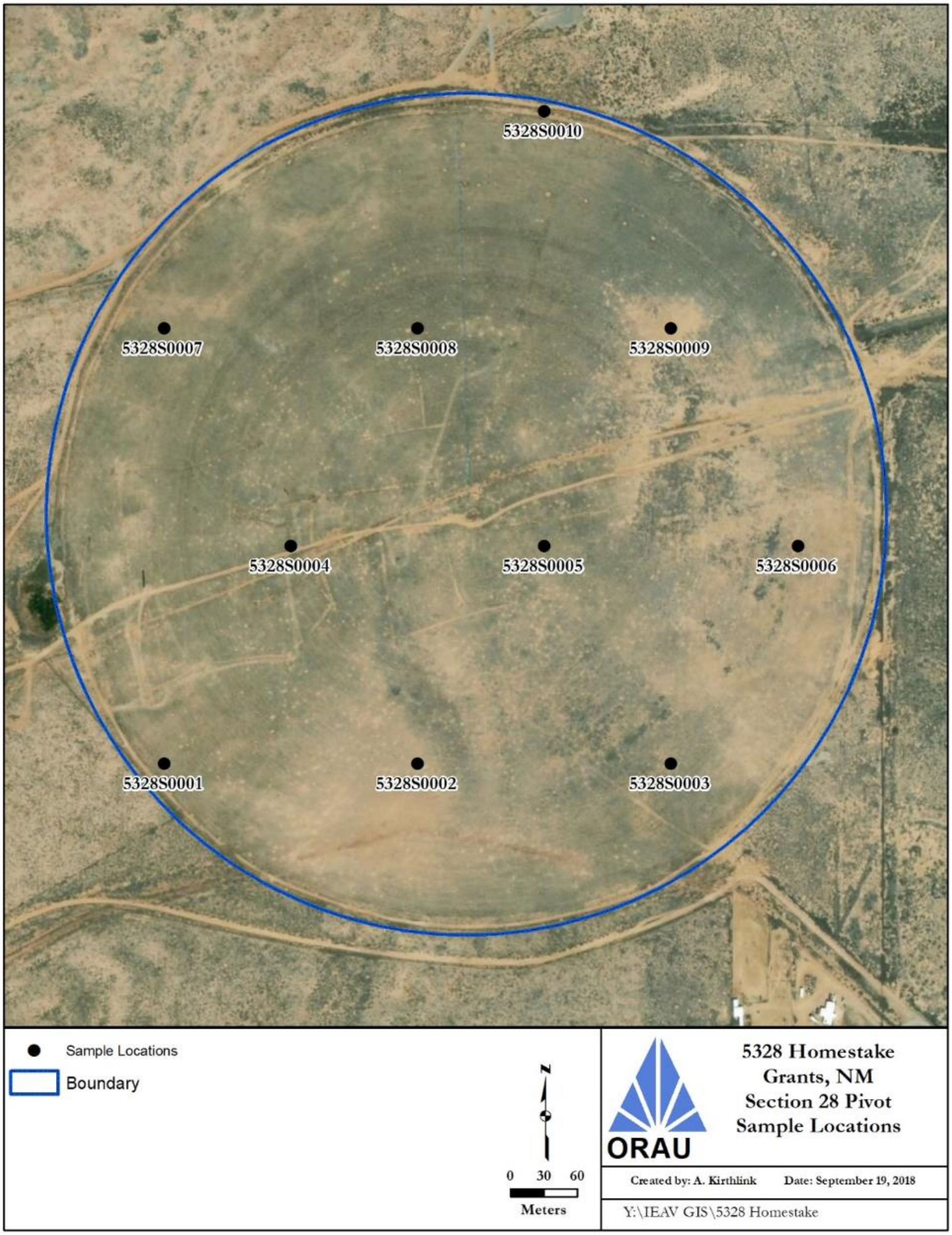


Figure A-1. SU 28 Confirmatory Areas and Sample Locations

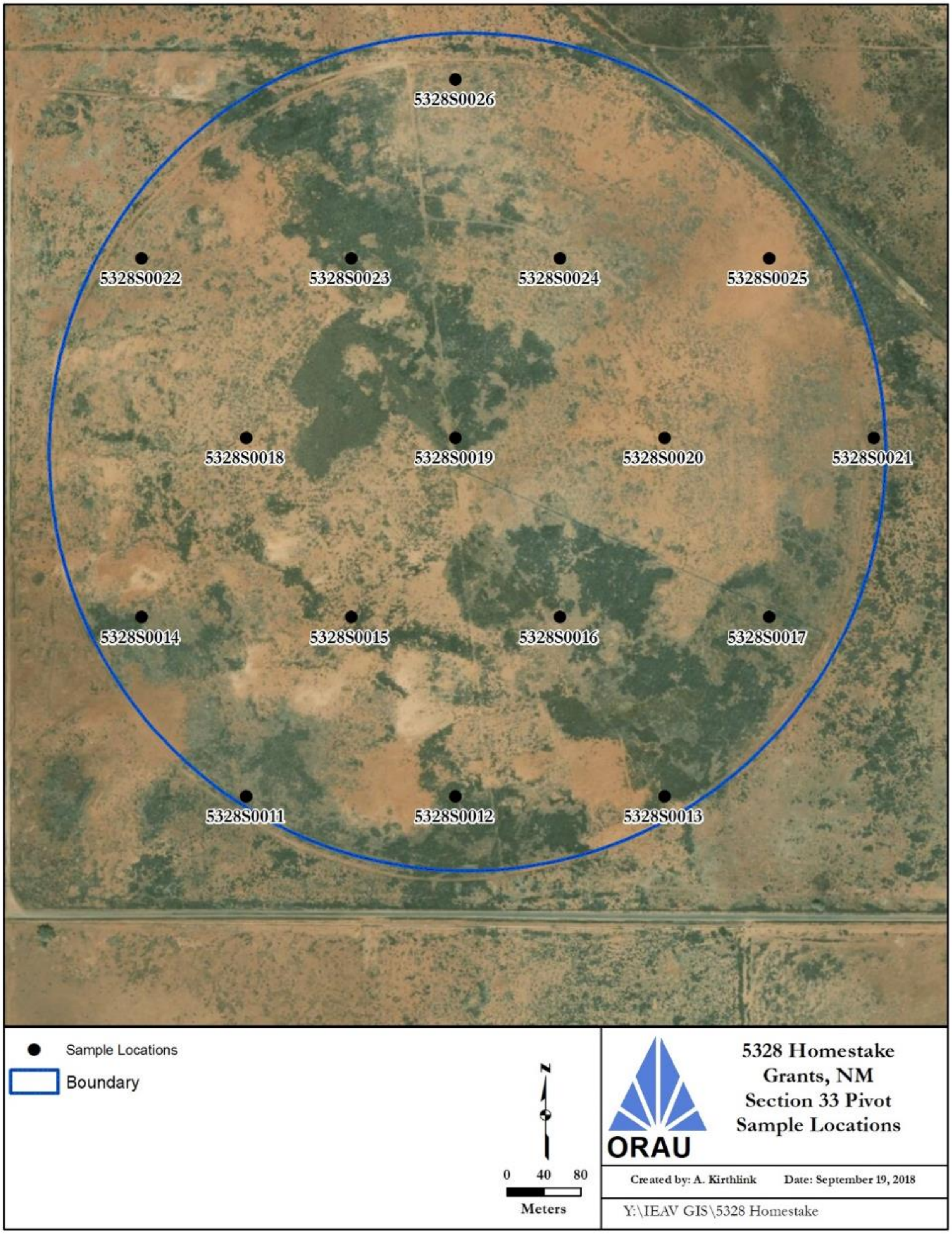


Figure A-2. SU 33 Pivot Confirmatory Areas and Sample Locations

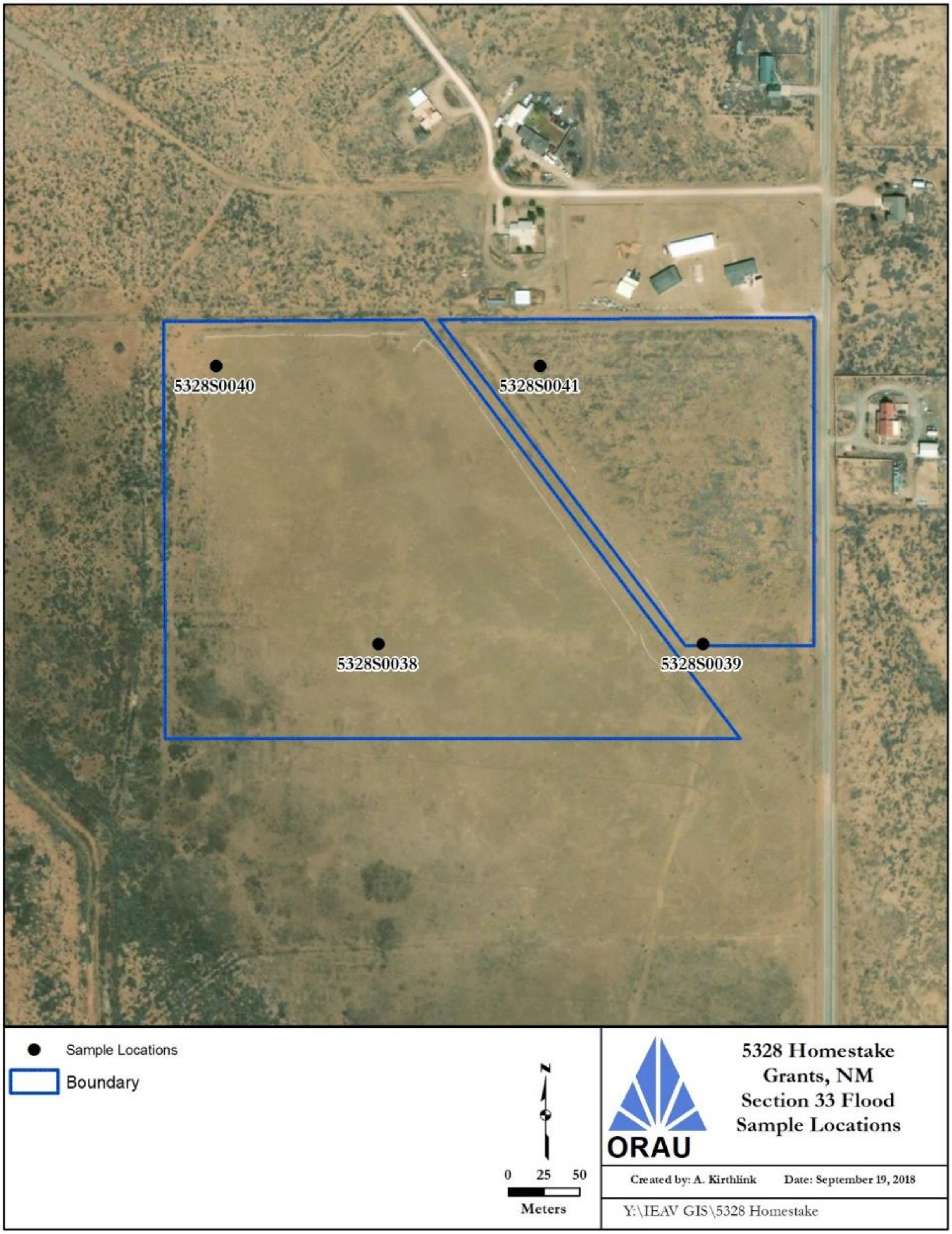


Figure A-3. SU 33 Flood Confirmatory Areas and Sample Locations

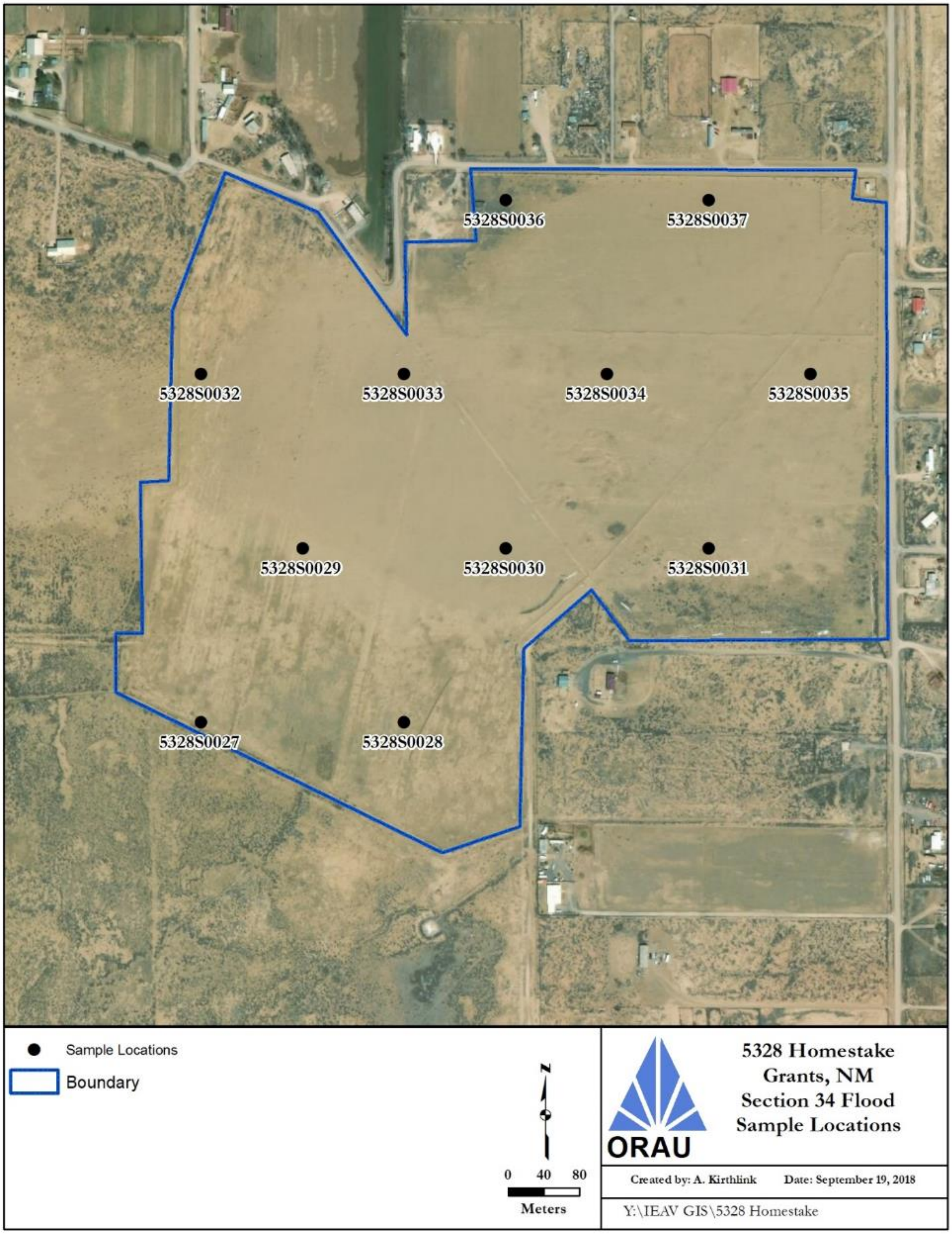


Figure A-4. SU 34 Flood Confirmatory Areas and Sample Locations

Section 33 Irrigation Equipment Central Pivot Looking West

Figure A-5. Section 33 Central Pivot Equipment, Direct Measurement Locations

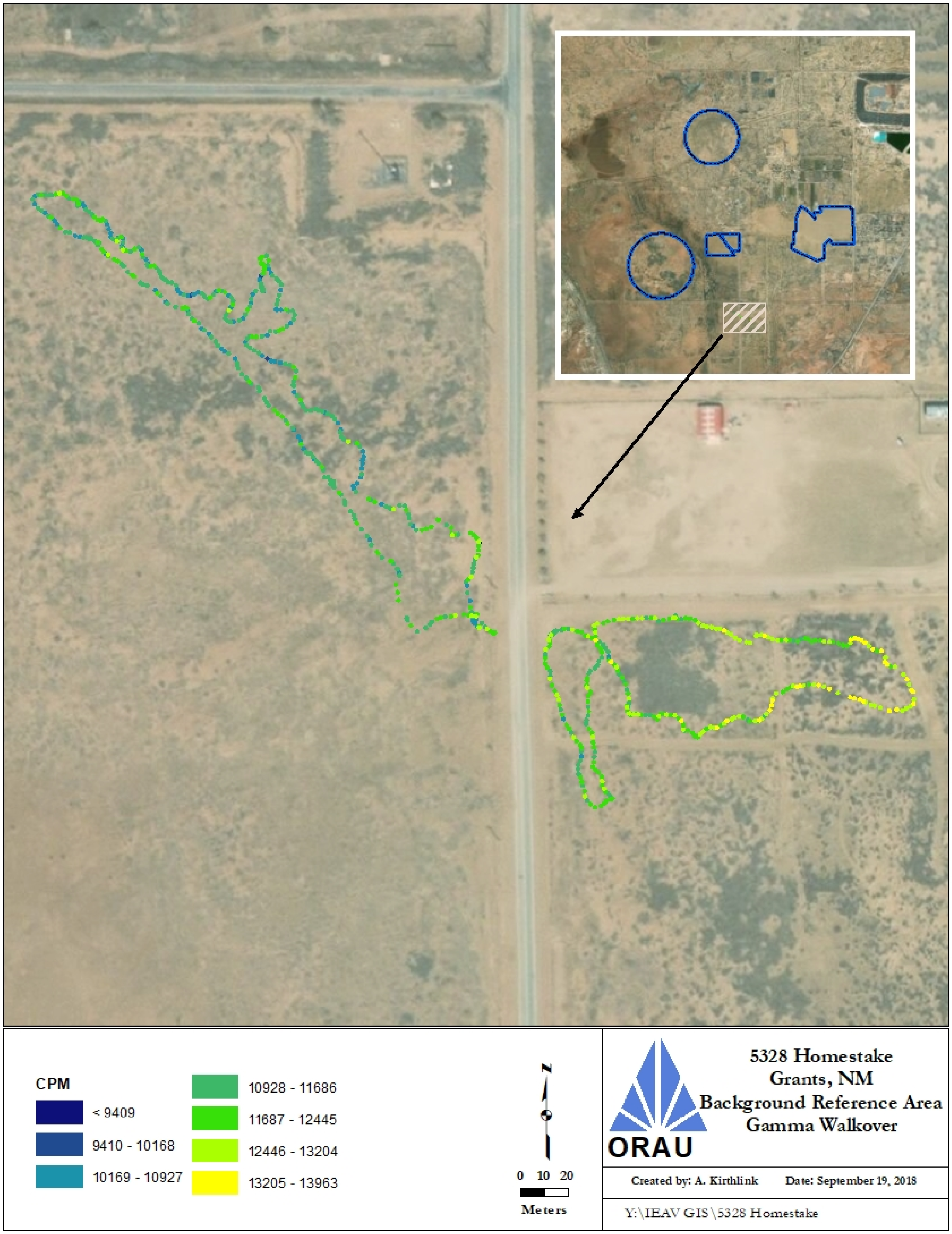


Figure A-6. Background Gamma Walkover Scans

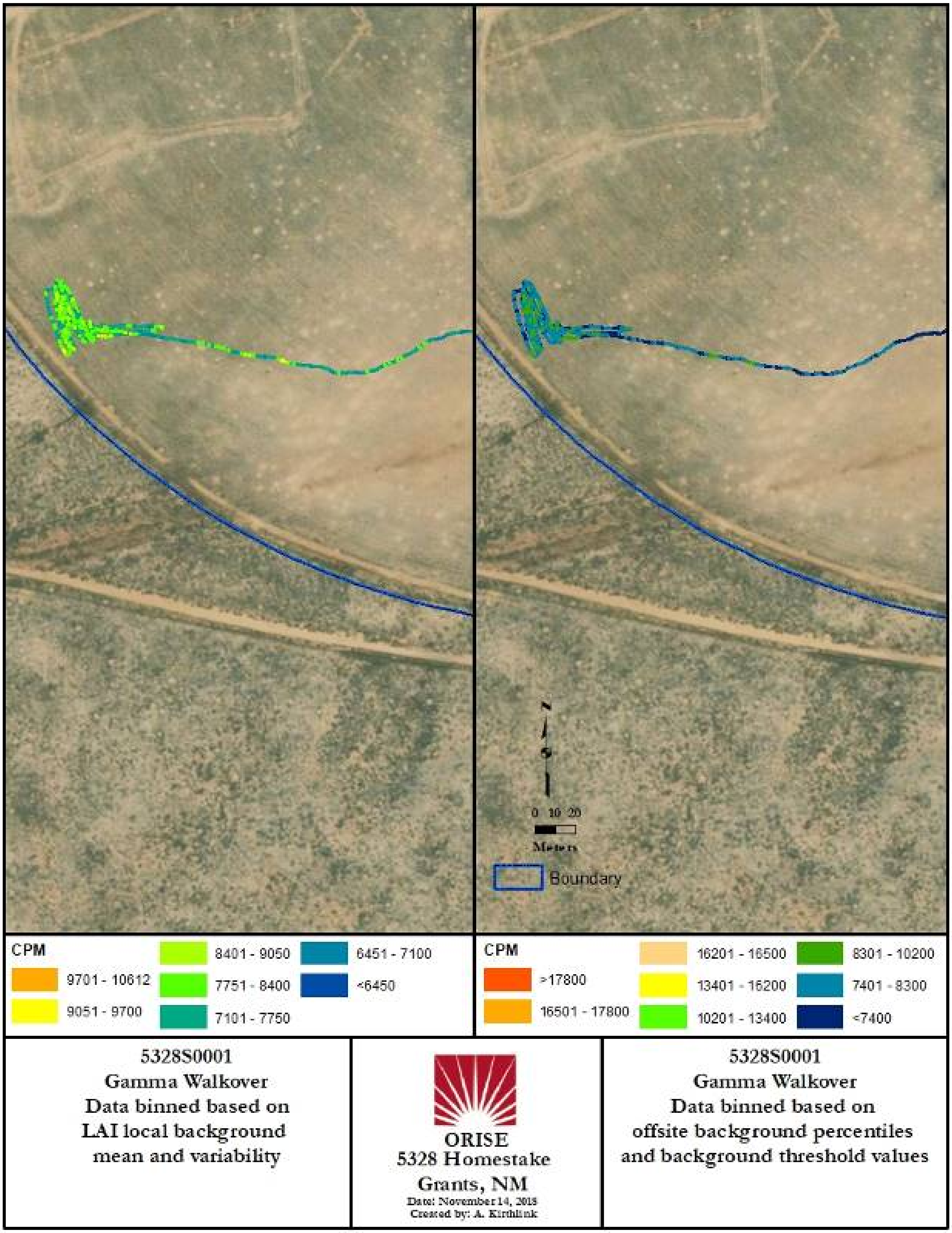


Figure A-7. Gamma Walkover Scan of 5328S0001 in SU 28 Central Pivot

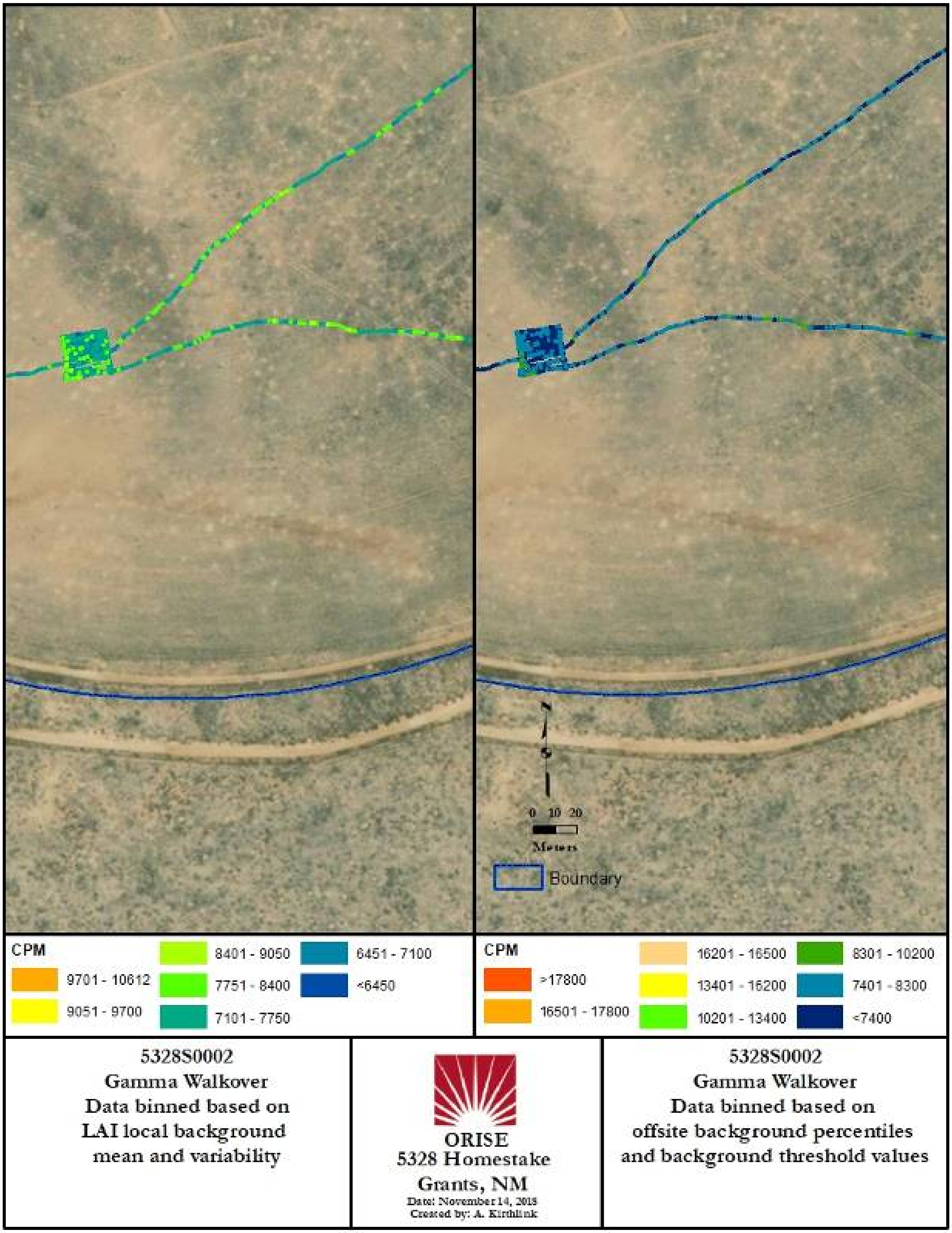


Figure A-8 Gamma Walkover Scan of 5328S0002 in SU 28 Central Pivot

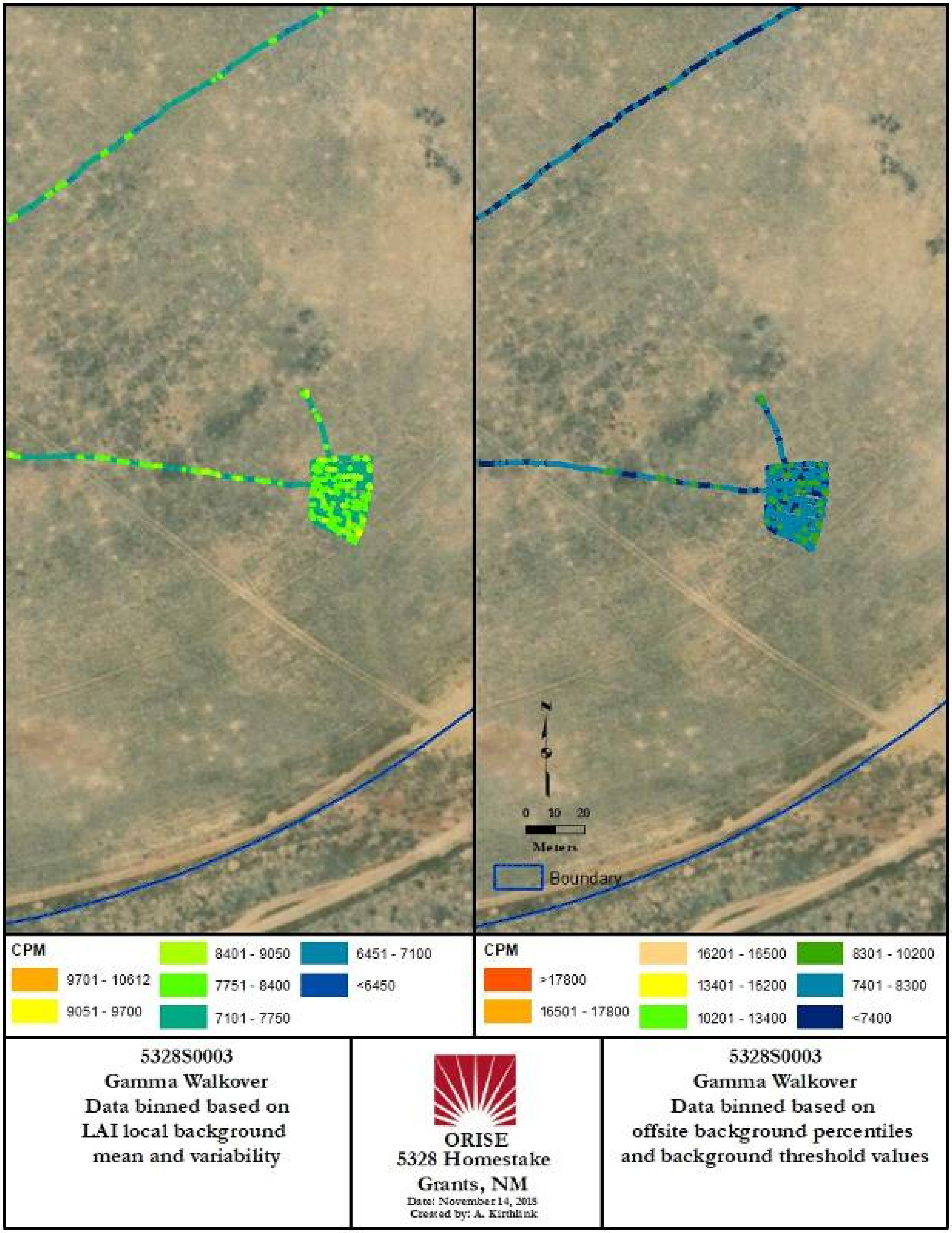


Figure A-9. Gamma Walkover Scan of 5328S0003 in SU 28 Central Pivot

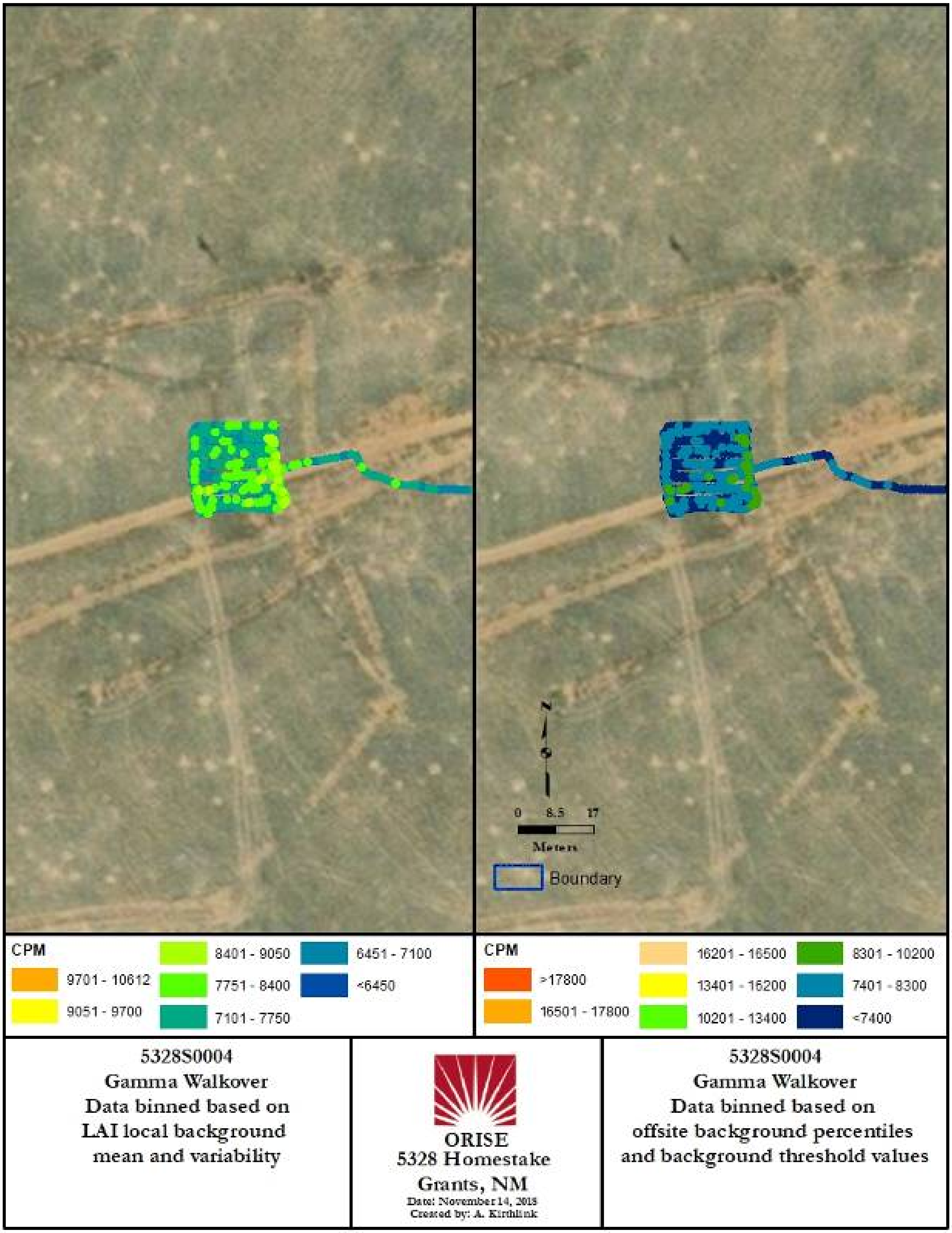


Figure A-10. Gamma Walkover Scan of 5328S0004 in SU 28 Central Pivot

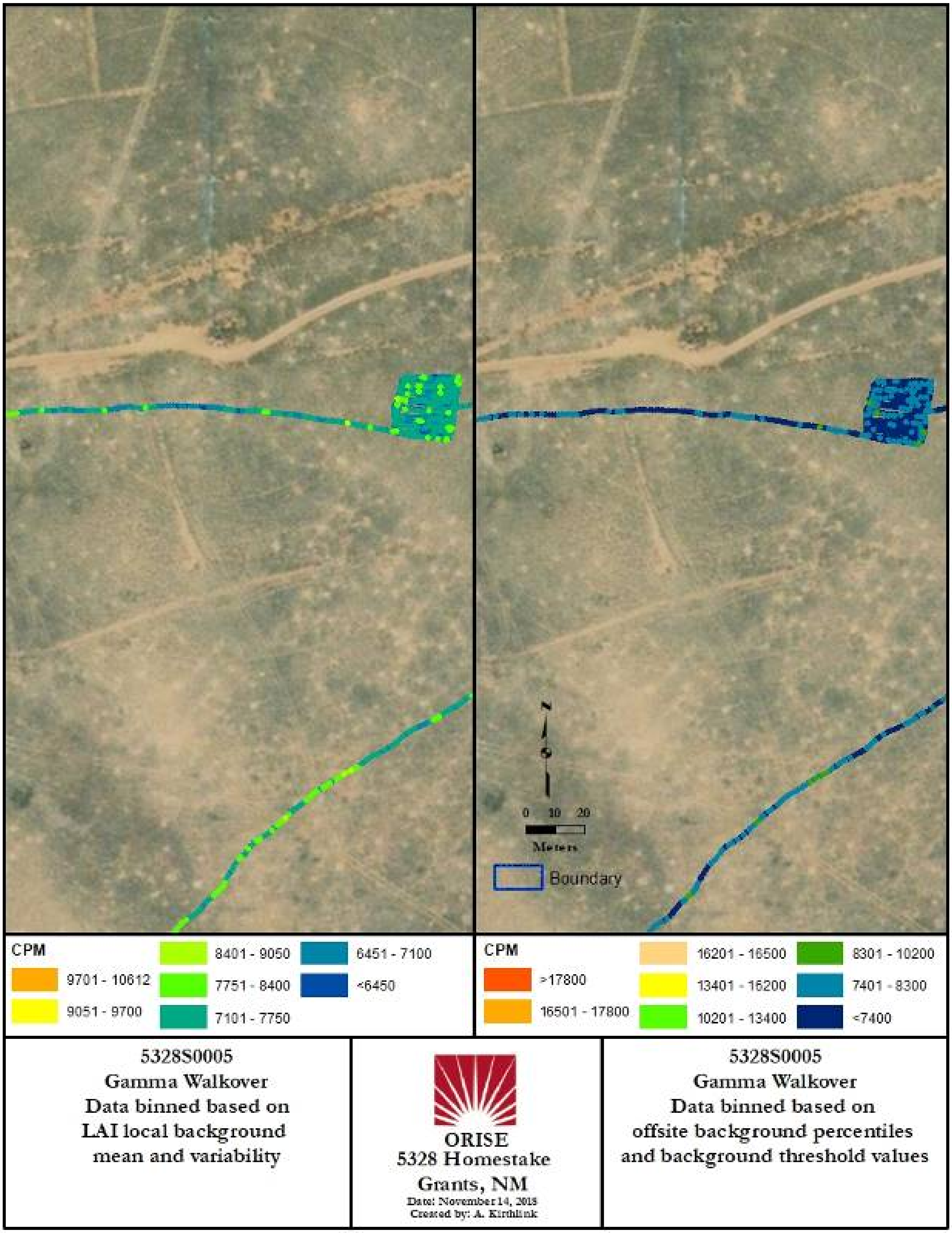


Figure A-11. Gamma Walkover Scan of 5328S0005 in SU 28 Central Pivot

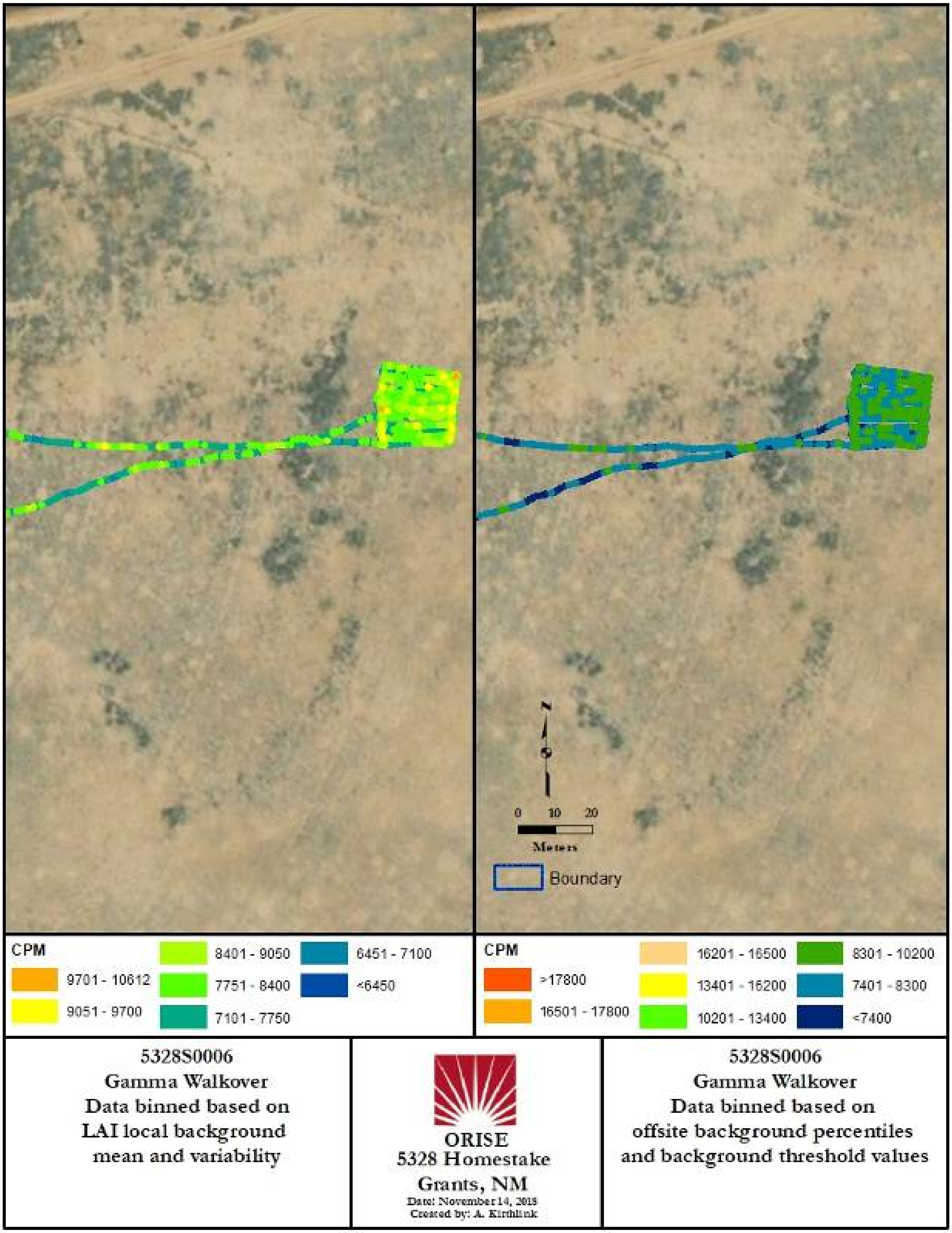


Figure A-12. Gamma Walkover Scan of 5328S0006 in SU 28 Central Pivot

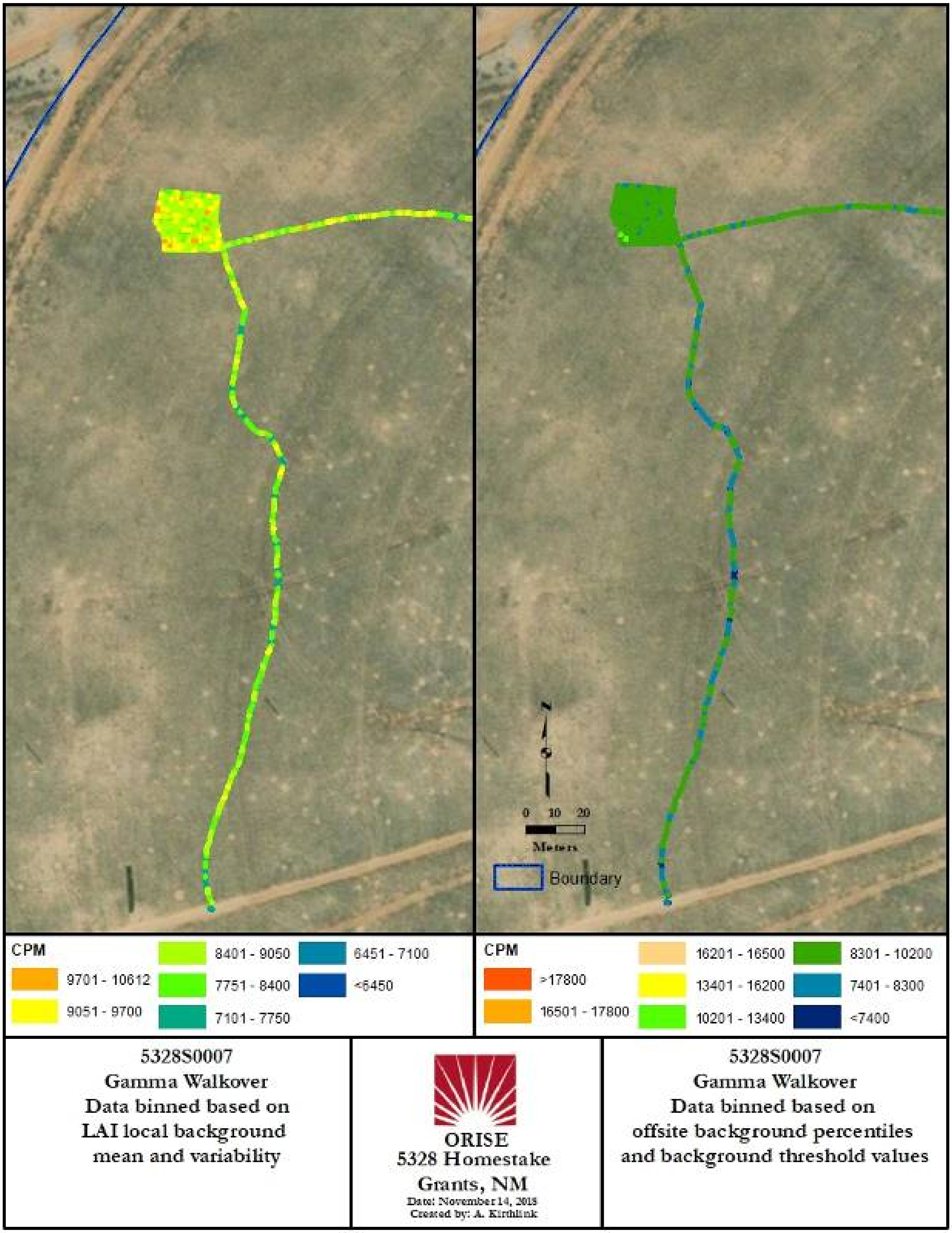


Figure A-13. Gamma Walkover Scan of 5328S0007 in SU 28 Central Pivot

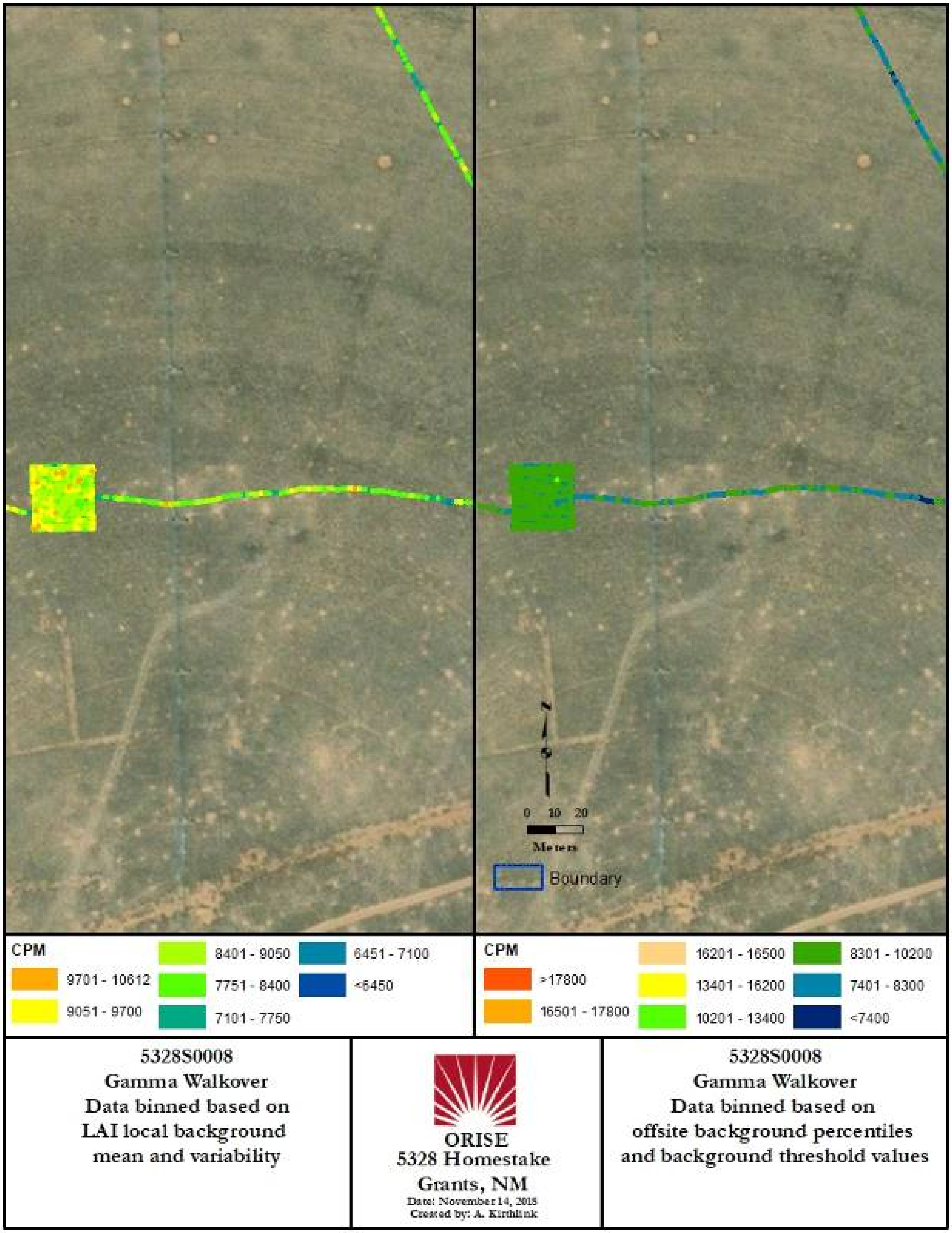


Figure A-14. Gamma Walkover Scan of 5328S0008 in SU 28 Central Pivot

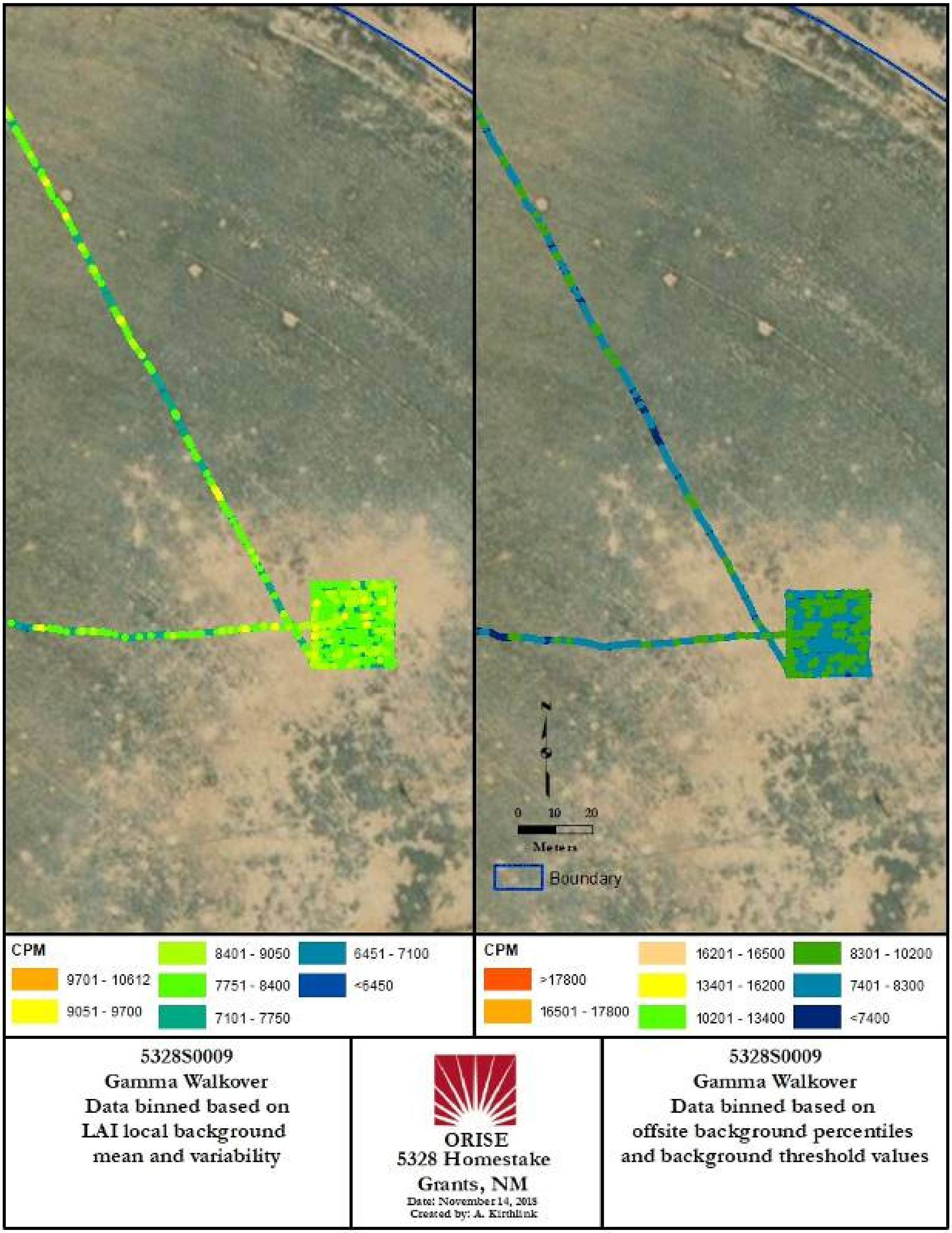


Figure A-15. Gamma Walkover Scan of 5328S0009 in SU 28 Central Pivot

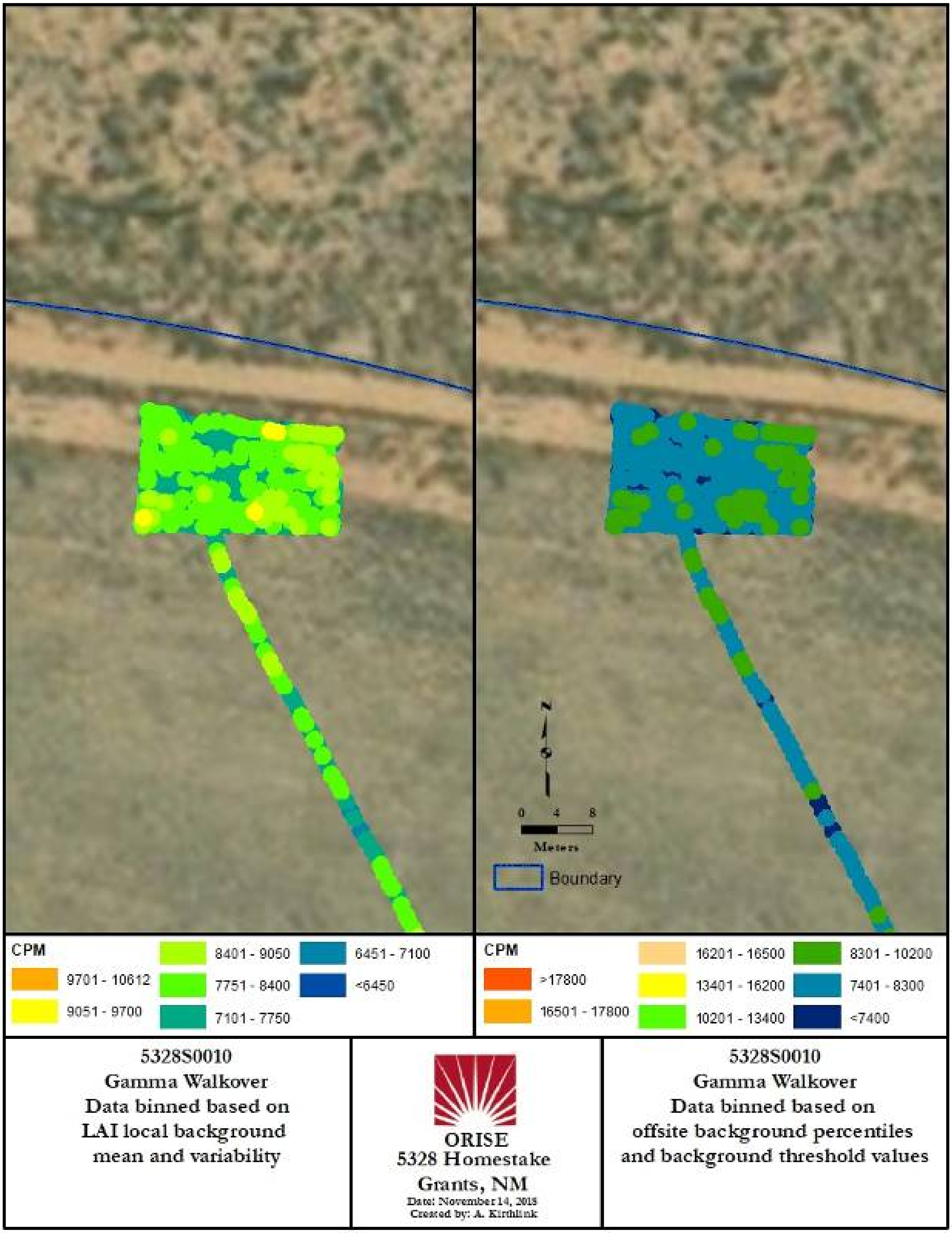


Figure A-16. Gamma Walkover Scan of 5328S0010 in SU 28 Central Pivot

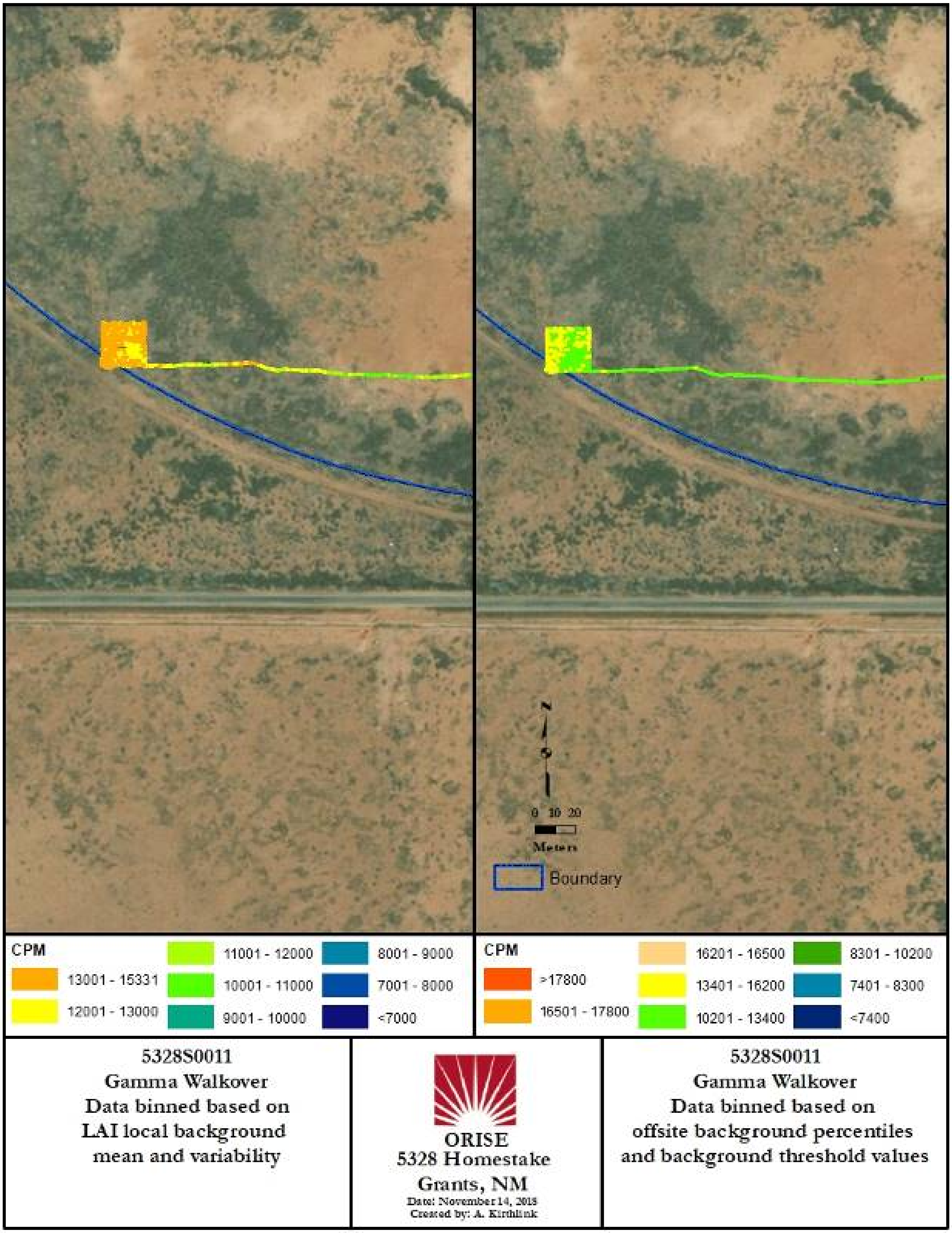


Figure A-17. Gamma Walkover Scan of 5328S0011 in SU 33 Central Pivot

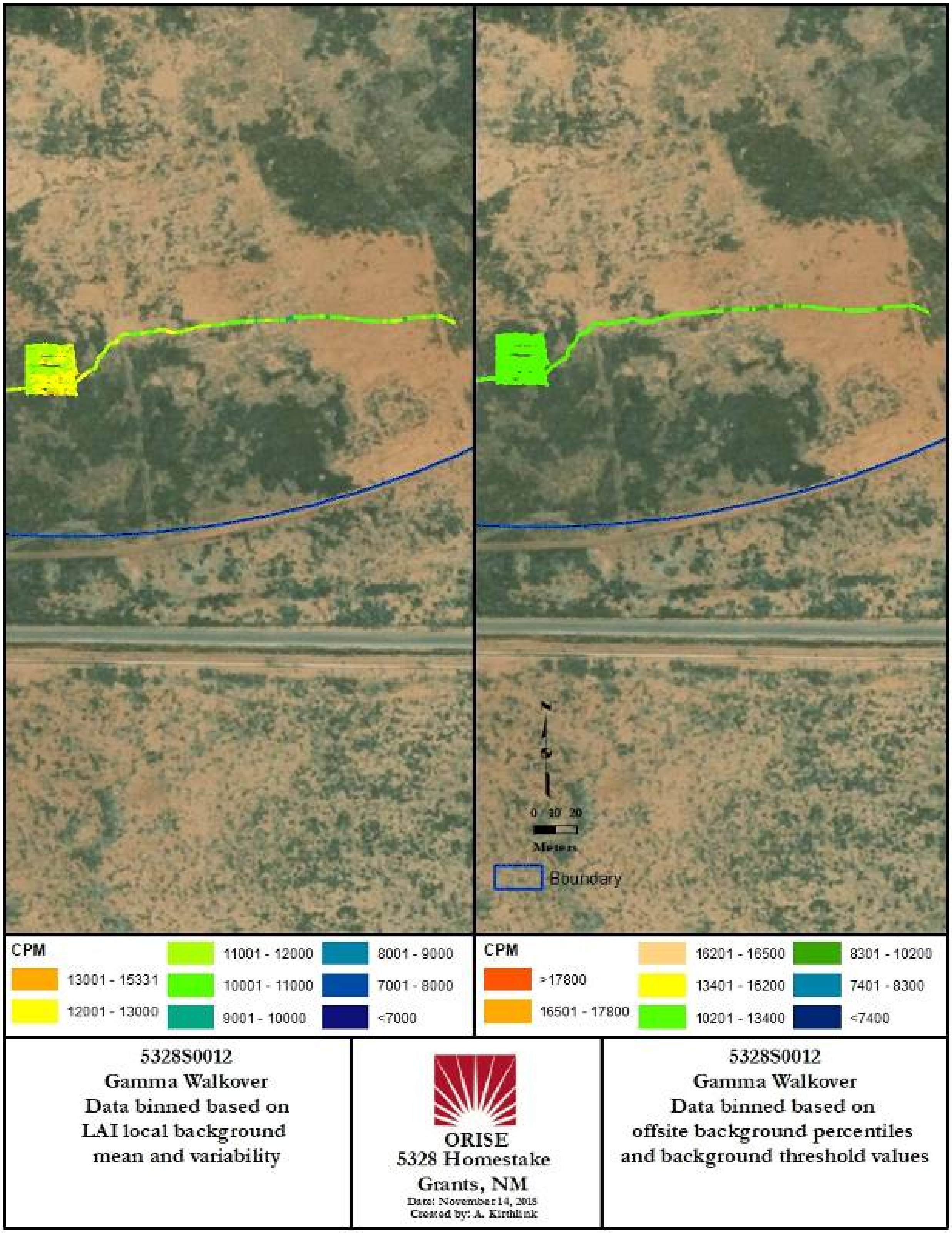


Figure A-18. Gamma Walkover Scan of 5328S0012 in SU 33 Central Pivot

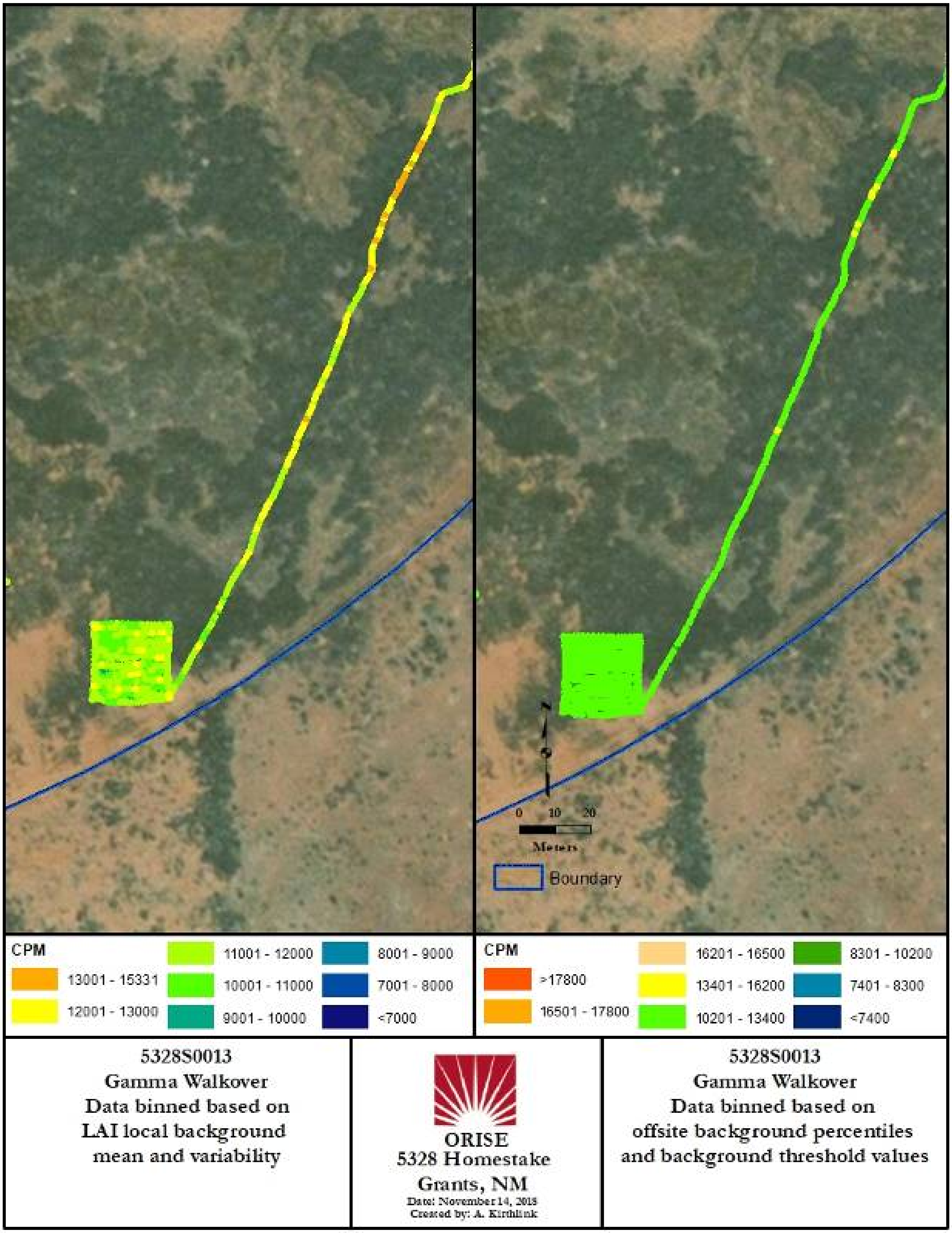
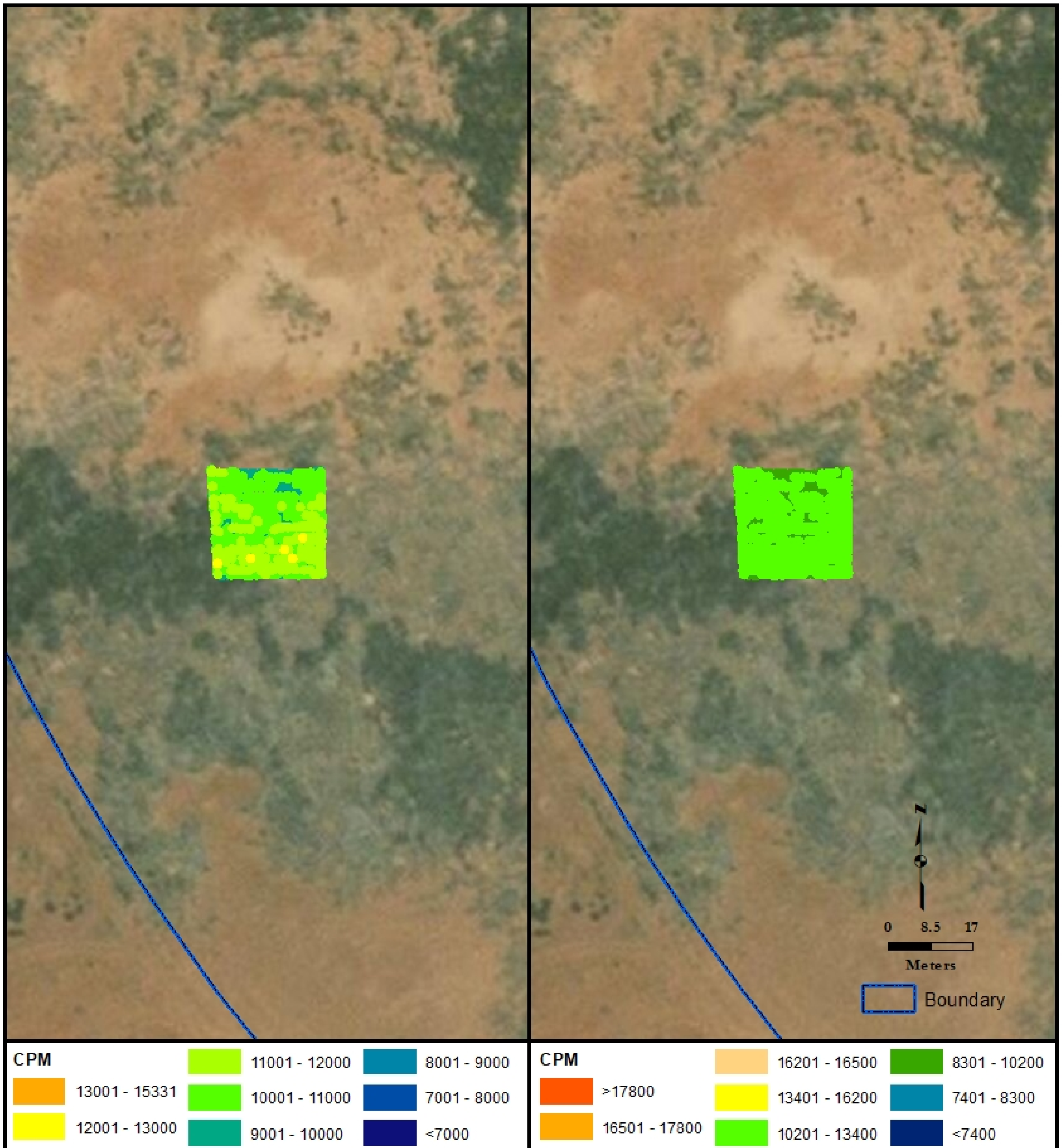


Figure A-19. Gamma Walkover Scan of 5328S0013 in SU 33 Central Pivot



5328S0014 Gamma Walkover Data binned based on LAI local background mean and variability	ORISE 5328 Homestake Grants, NM Date: November 14, 2018 Created by: A. Kirthlink	5328S0014 Gamma Walkover Data binned based on offsite background percentiles and background threshold values

Figure A-20. Gamma Walkover Scan of 5328S0014 in SU 33 Central Pivot

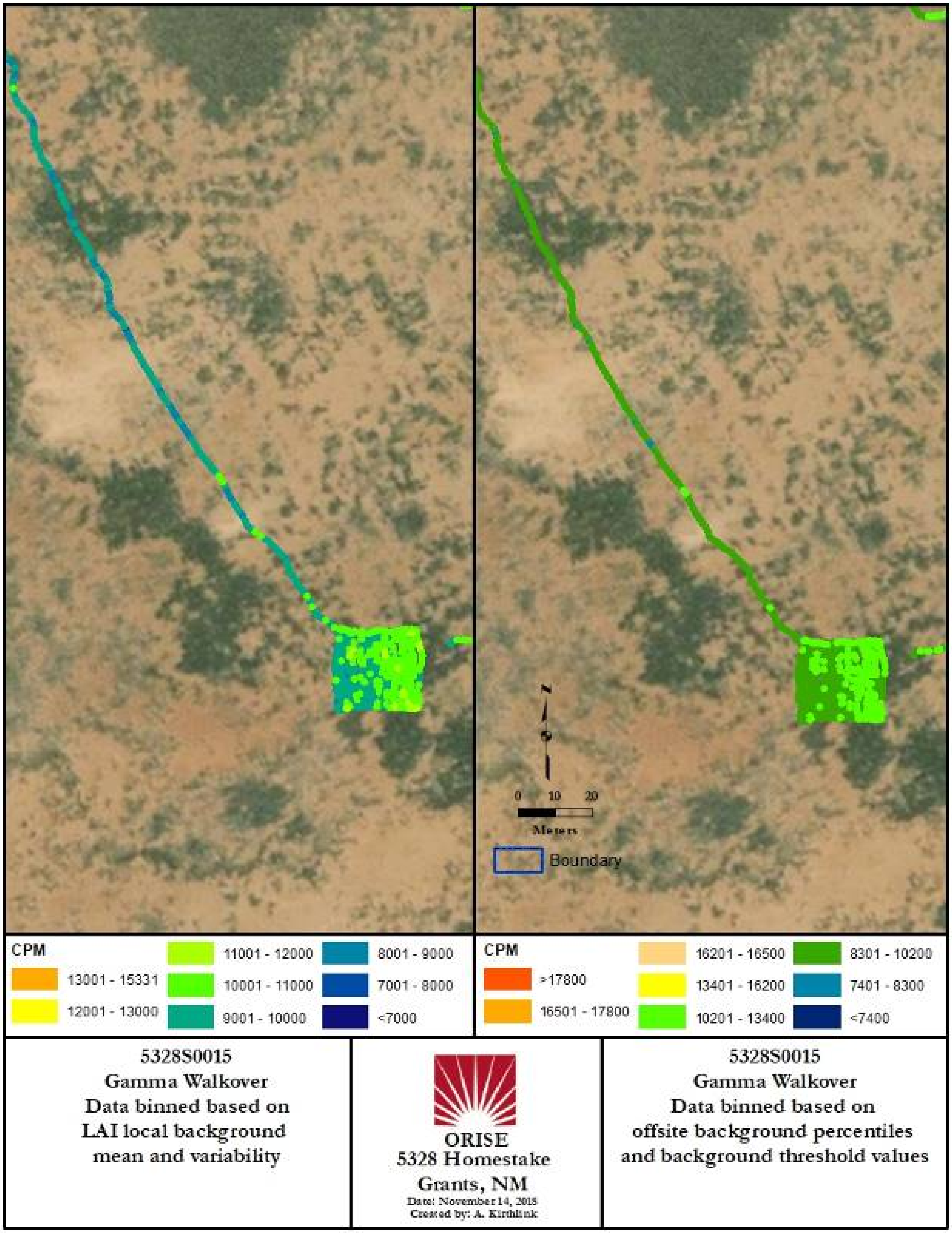


Figure A-21. Gamma Walkover Scan of 5328S0015 in SU 33 Central Pivot

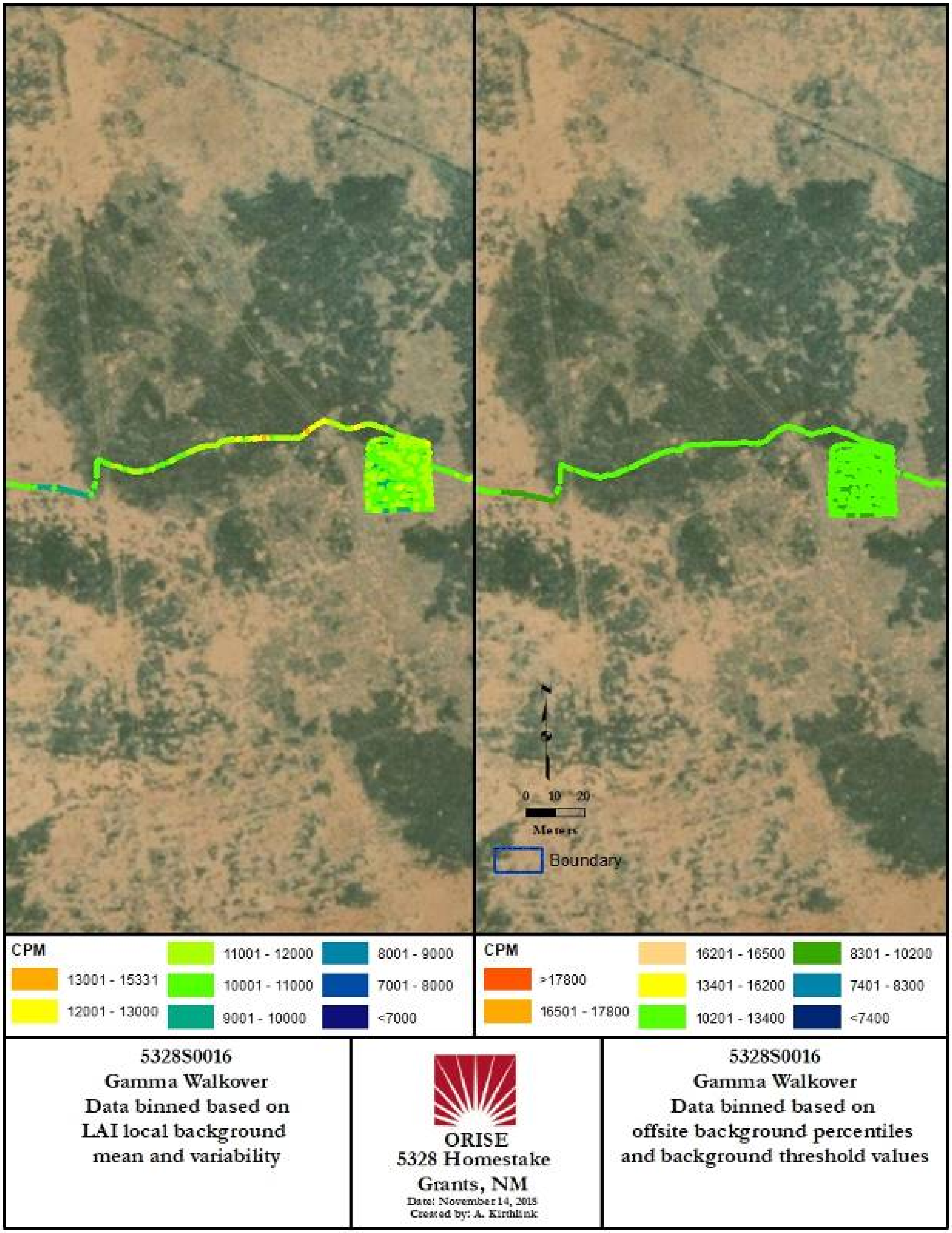


Figure A-22. Gamma Walkover Scan of 5328S0016 in SU 33 Central Pivot

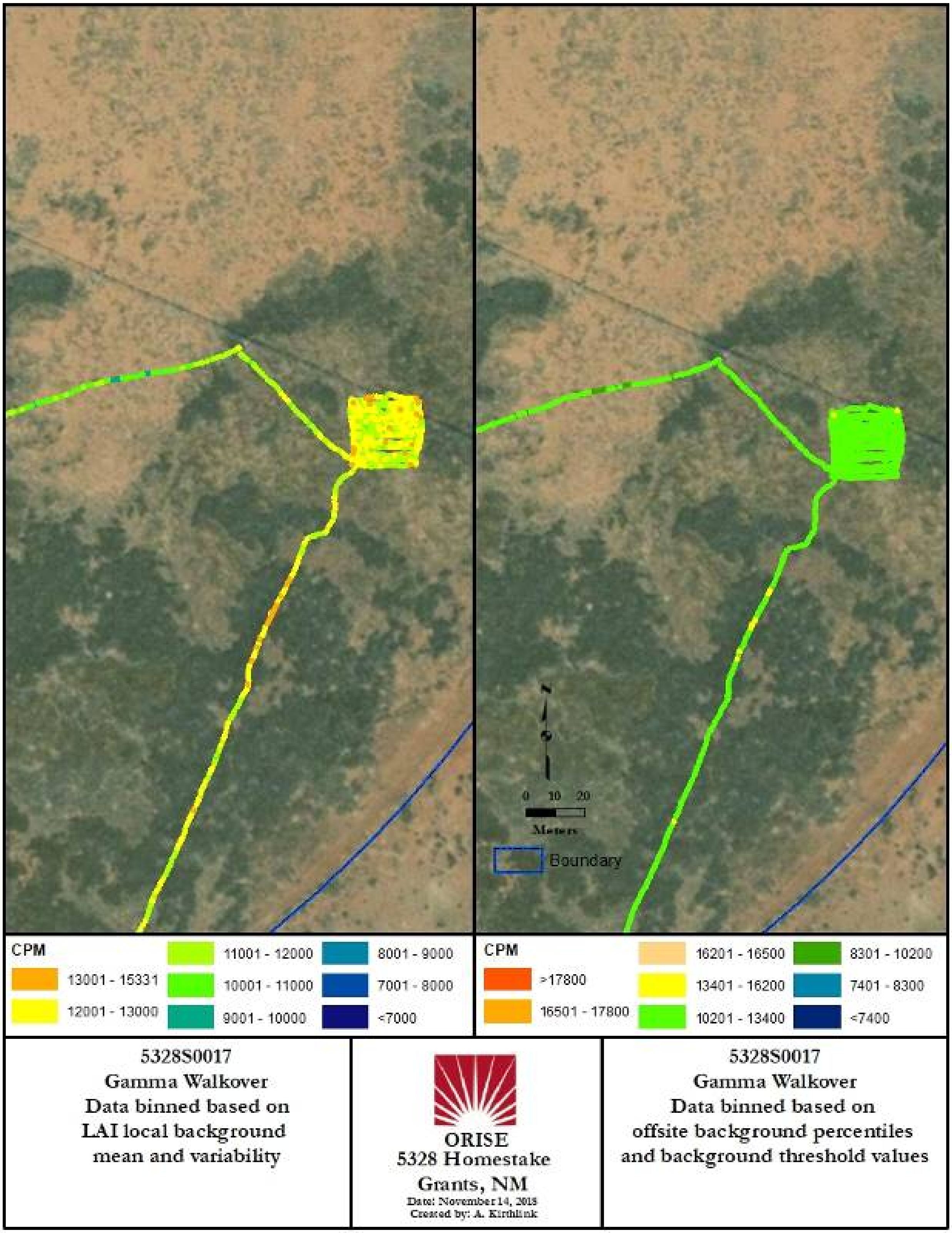


Figure A-23. Gamma Walkover Scan of 5328S0017 in SU 33 Central Pivot

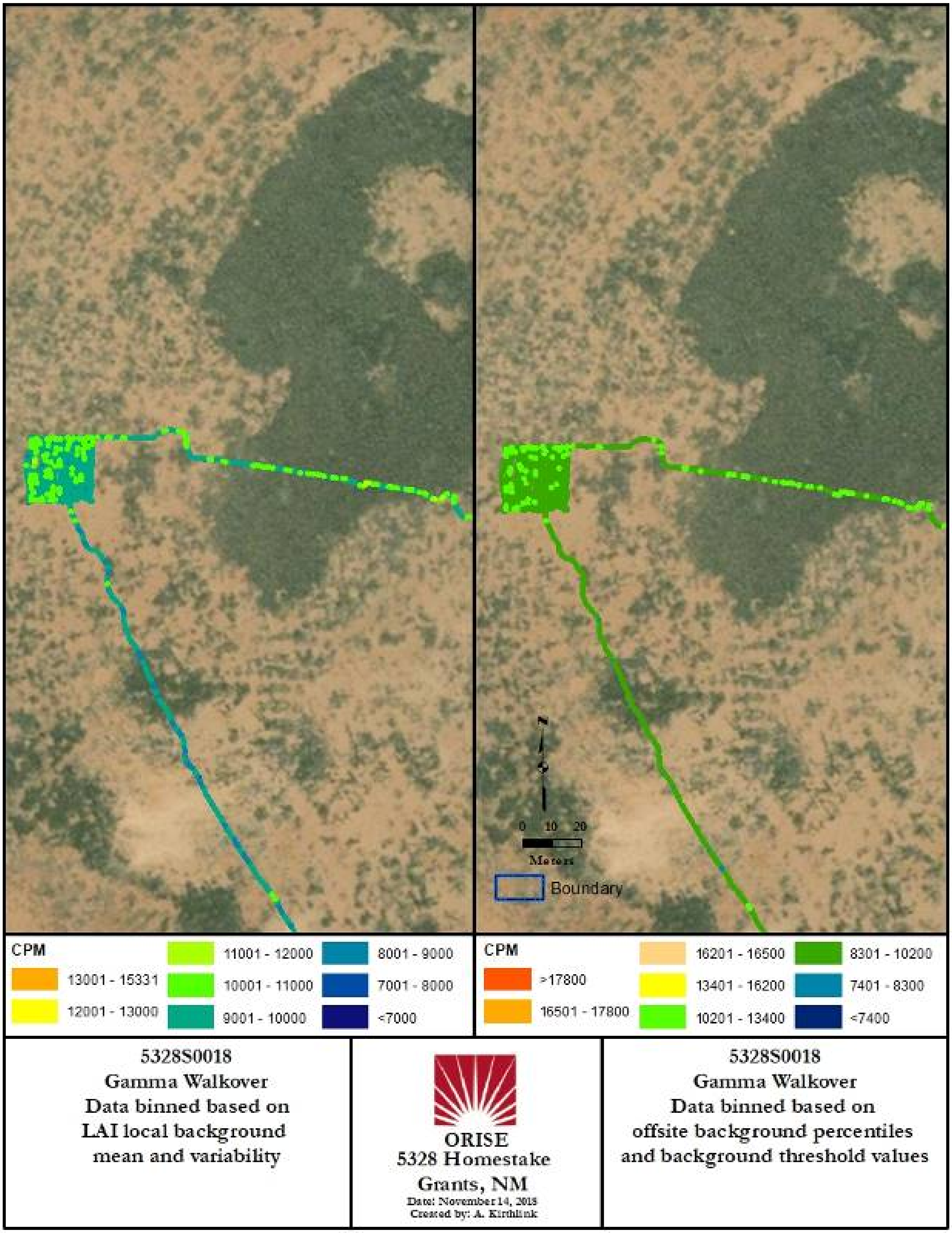


Figure A-24. Gamma Walkover Scan of 5328S0018 in SU 33 Central Pivot

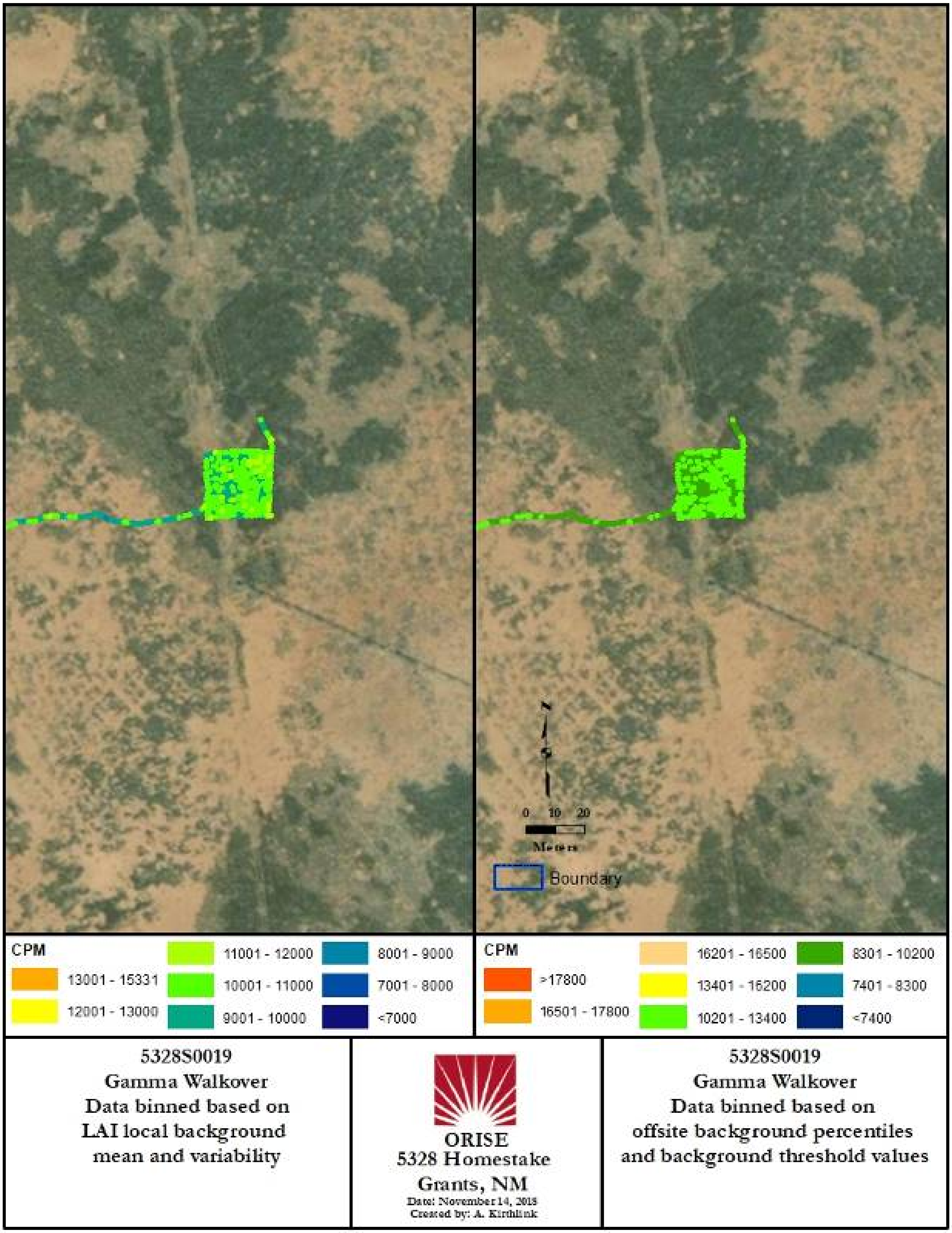


Figure A-25. Gamma Walkover Scan of 5328S0019 in SU 33 Central Pivot

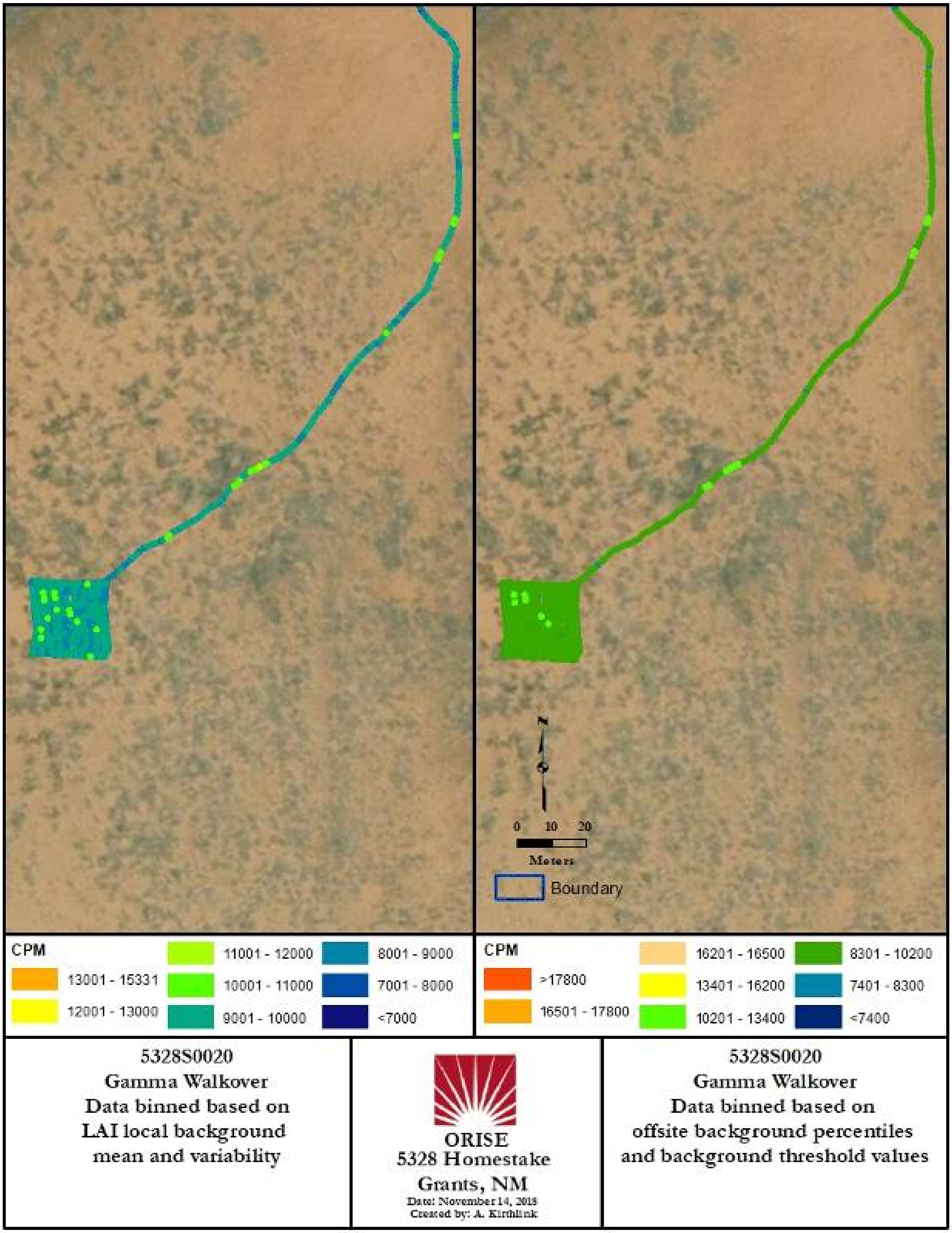


Figure A-26. Gamma Walkover Scan of 5328S0020 in SU 33 Central Pivot

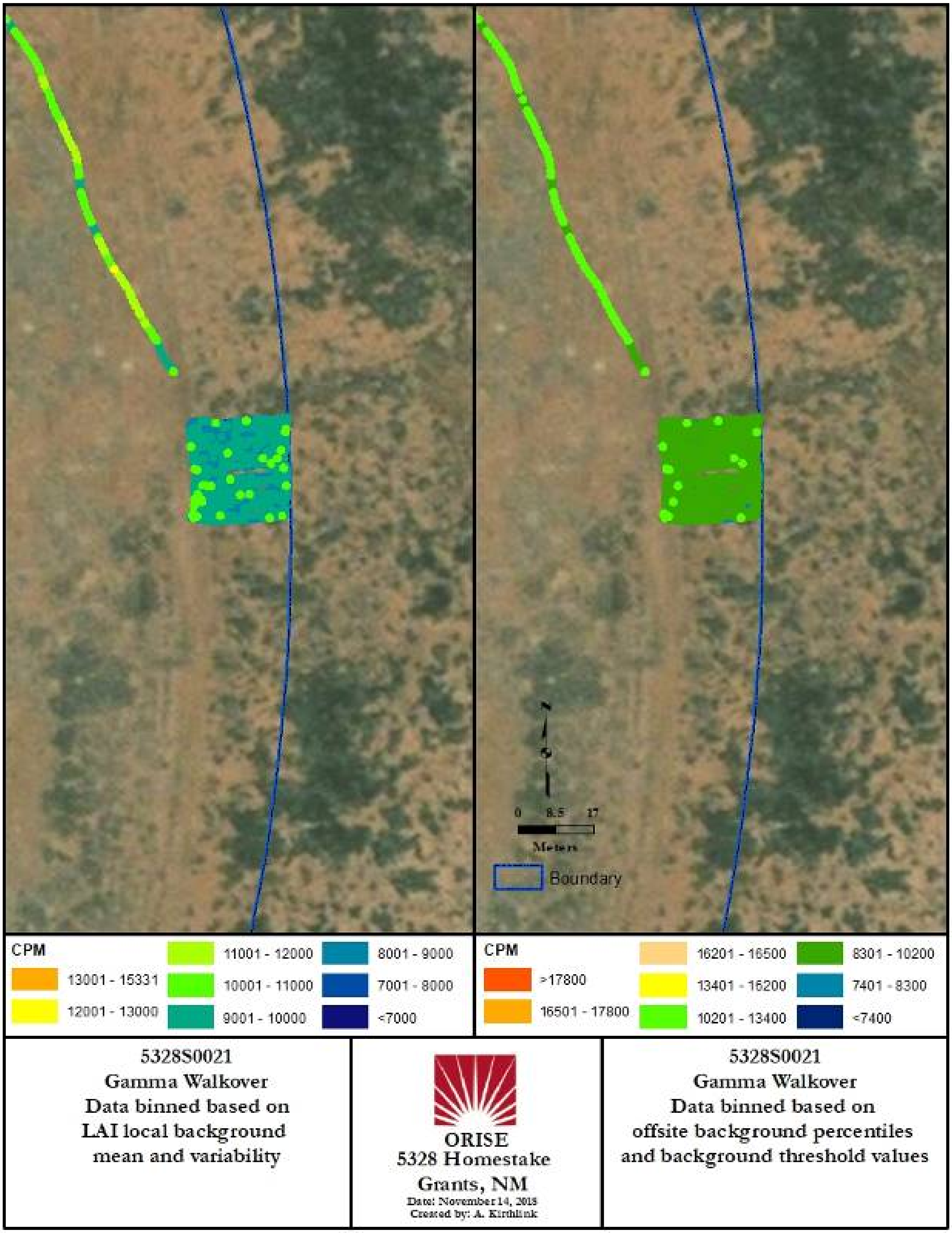


Figure A-27. Gamma Walkover Scan of 5328S0021 in SU 33 Central Pivot

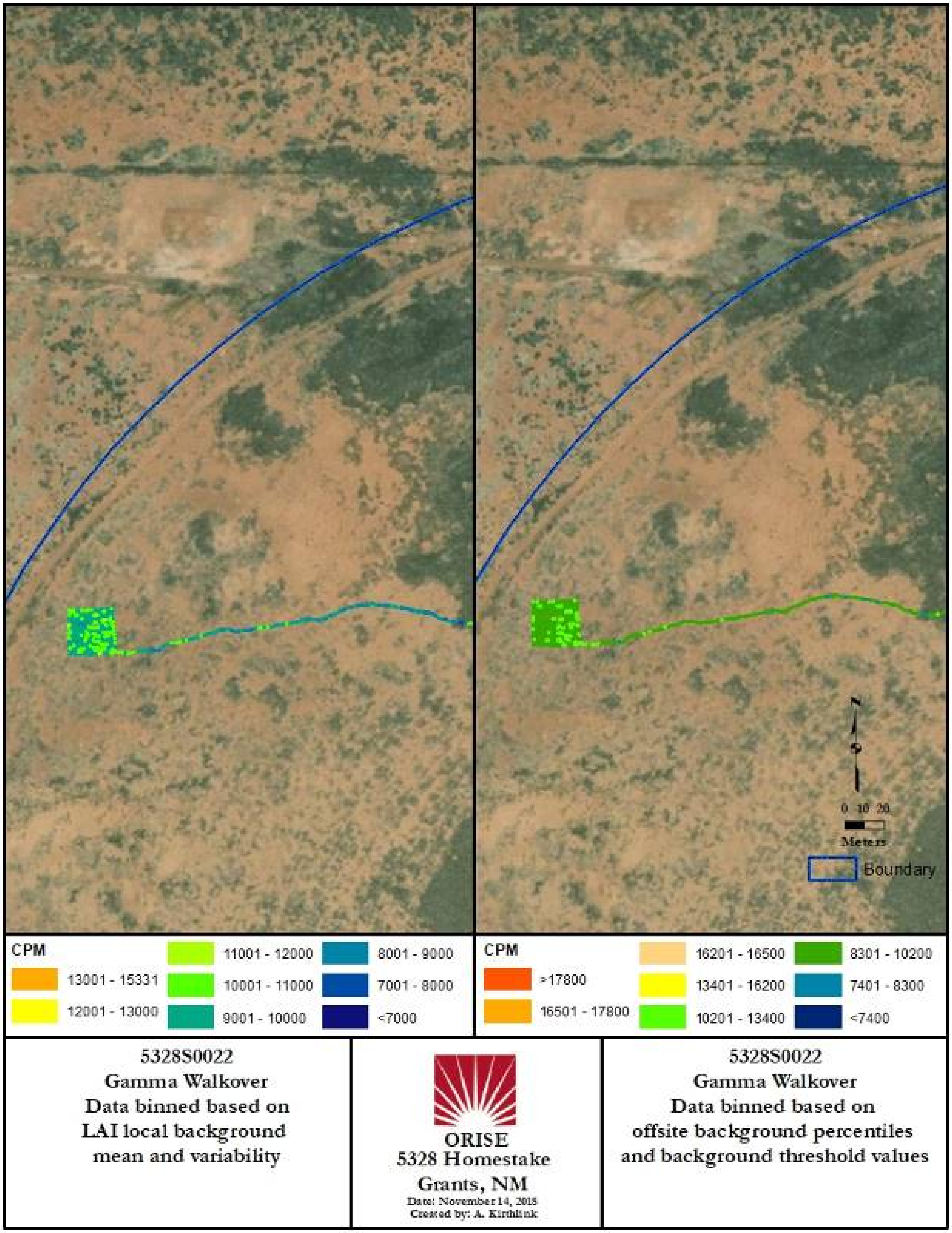


Figure A-28. Gamma Walkover Scan of 5328S0022 in SU 33 Central Pivot

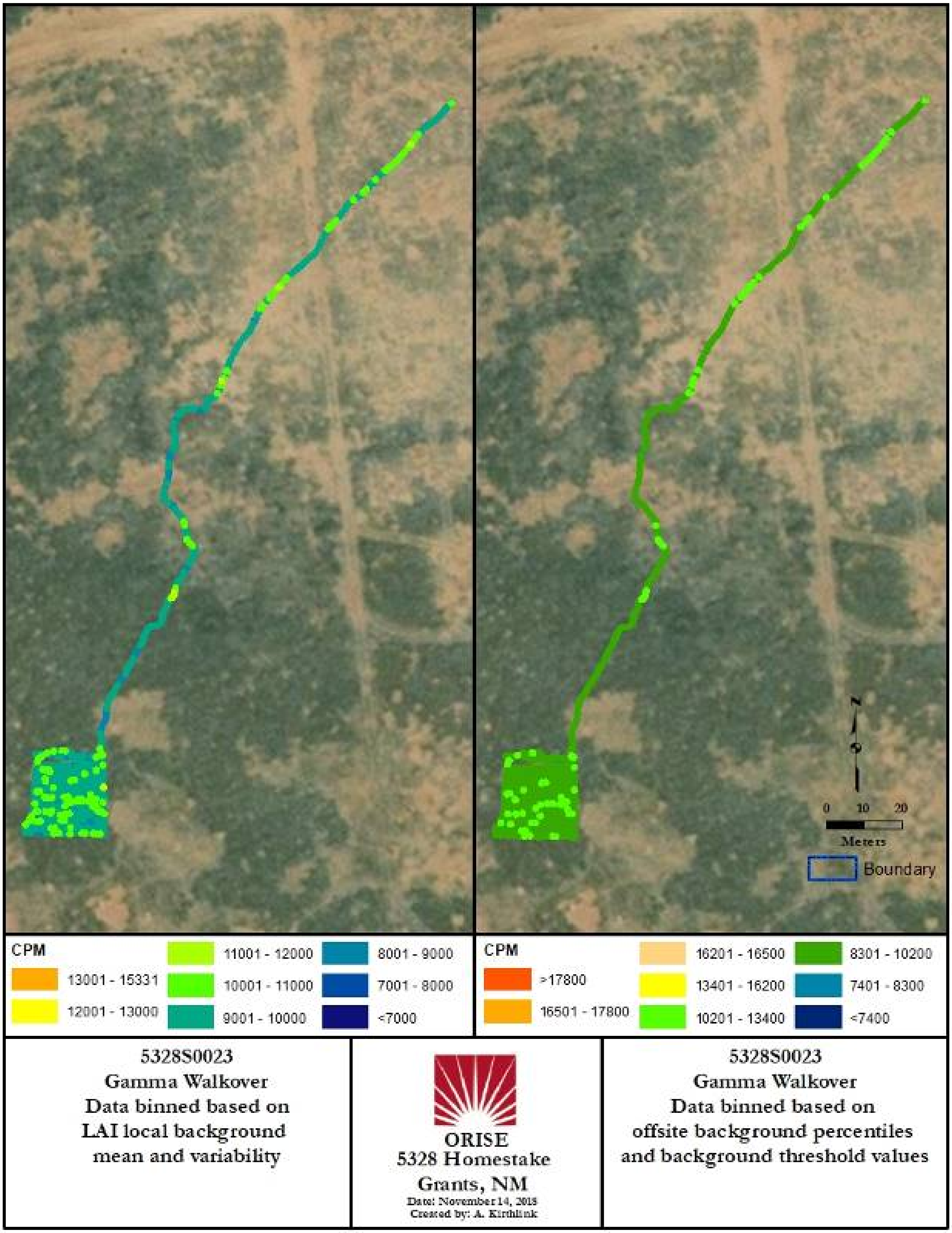


Figure A-29. Gamma Walkover Scan of 5328S0023 in SU 33 Central Pivot

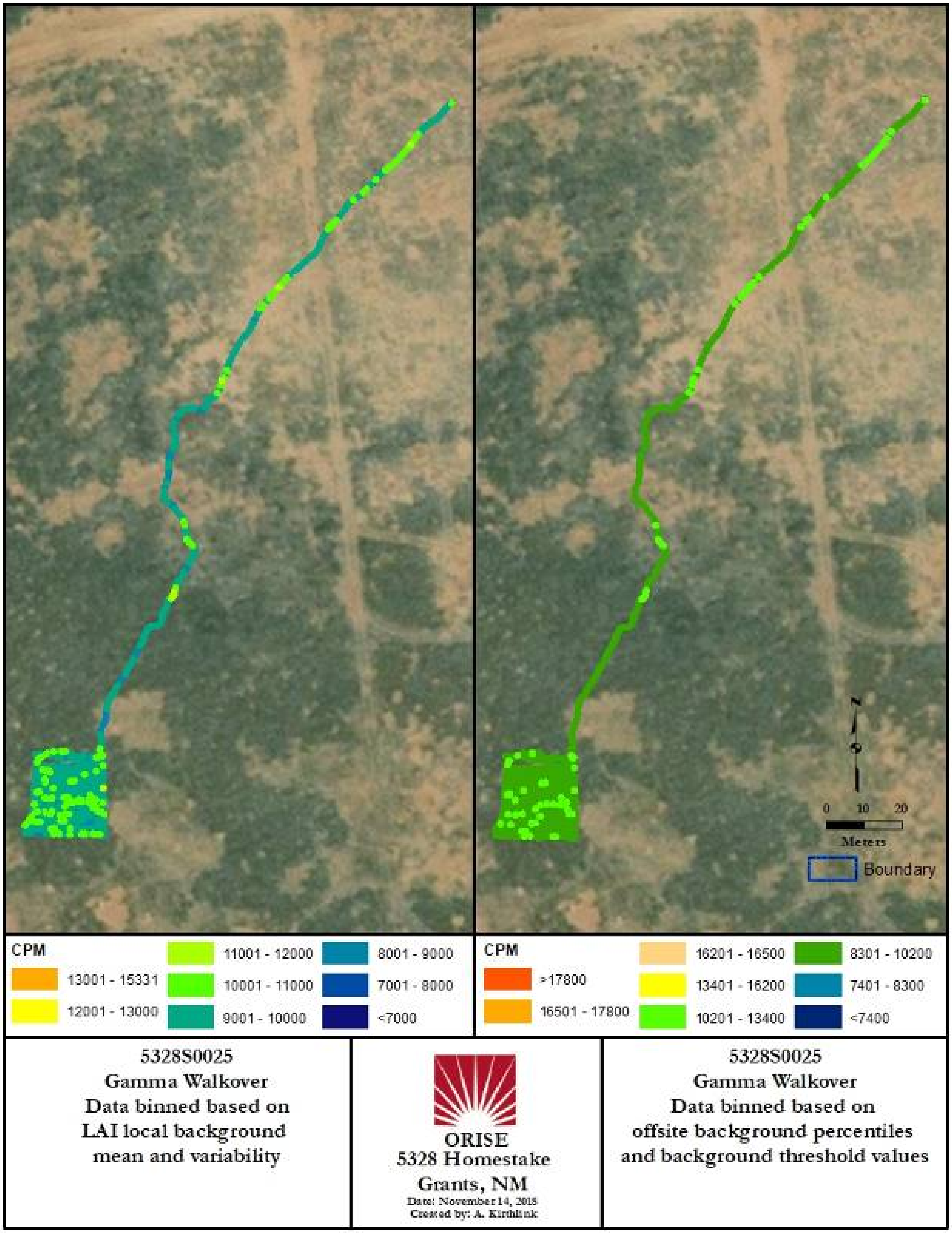


Figure A-30. Gamma Walkover Scan of 5328S0025 in SU 33 Central Pivot

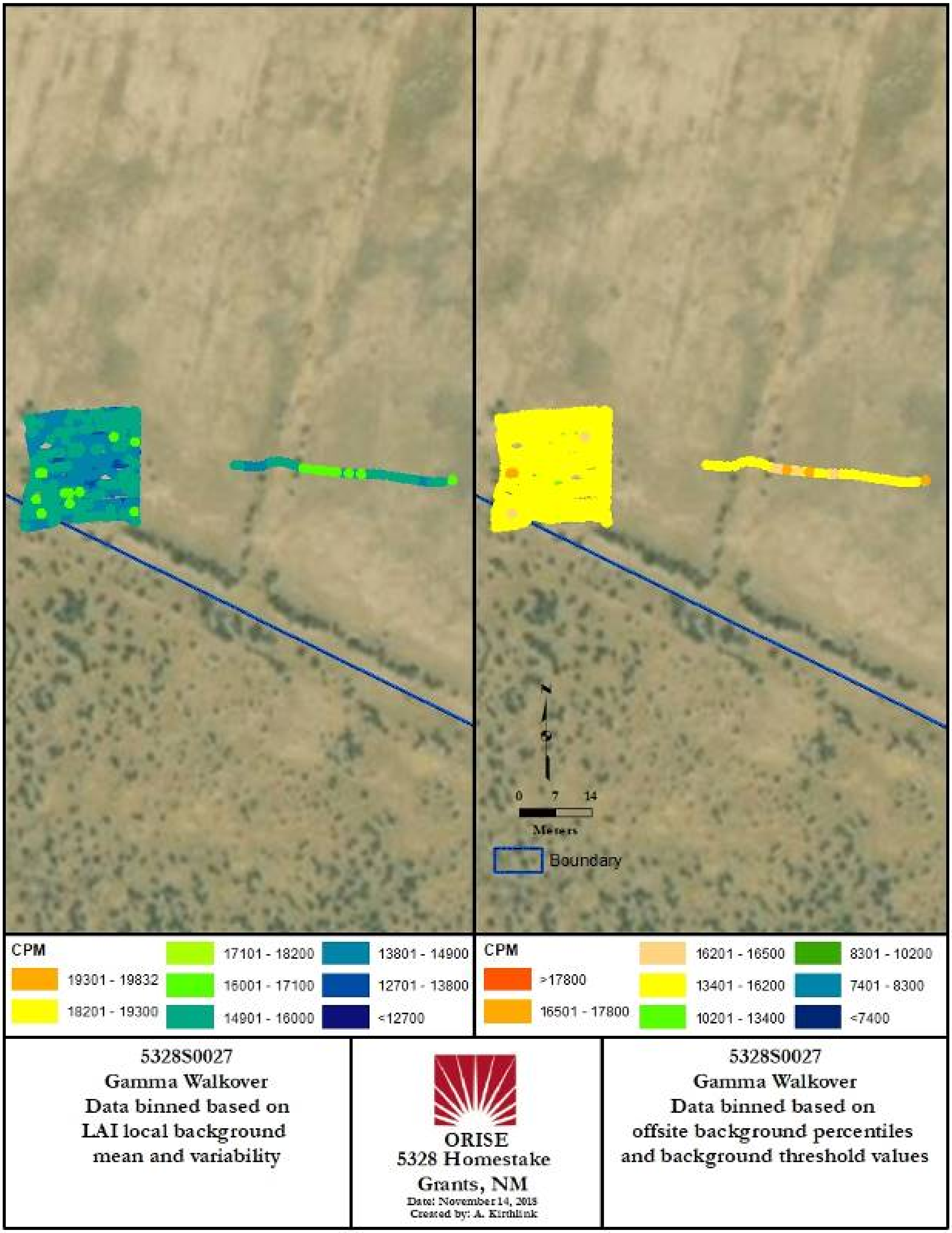


Figure A-31. Gamma Walkover Scan of 5328S0027 in SU 34 Flood

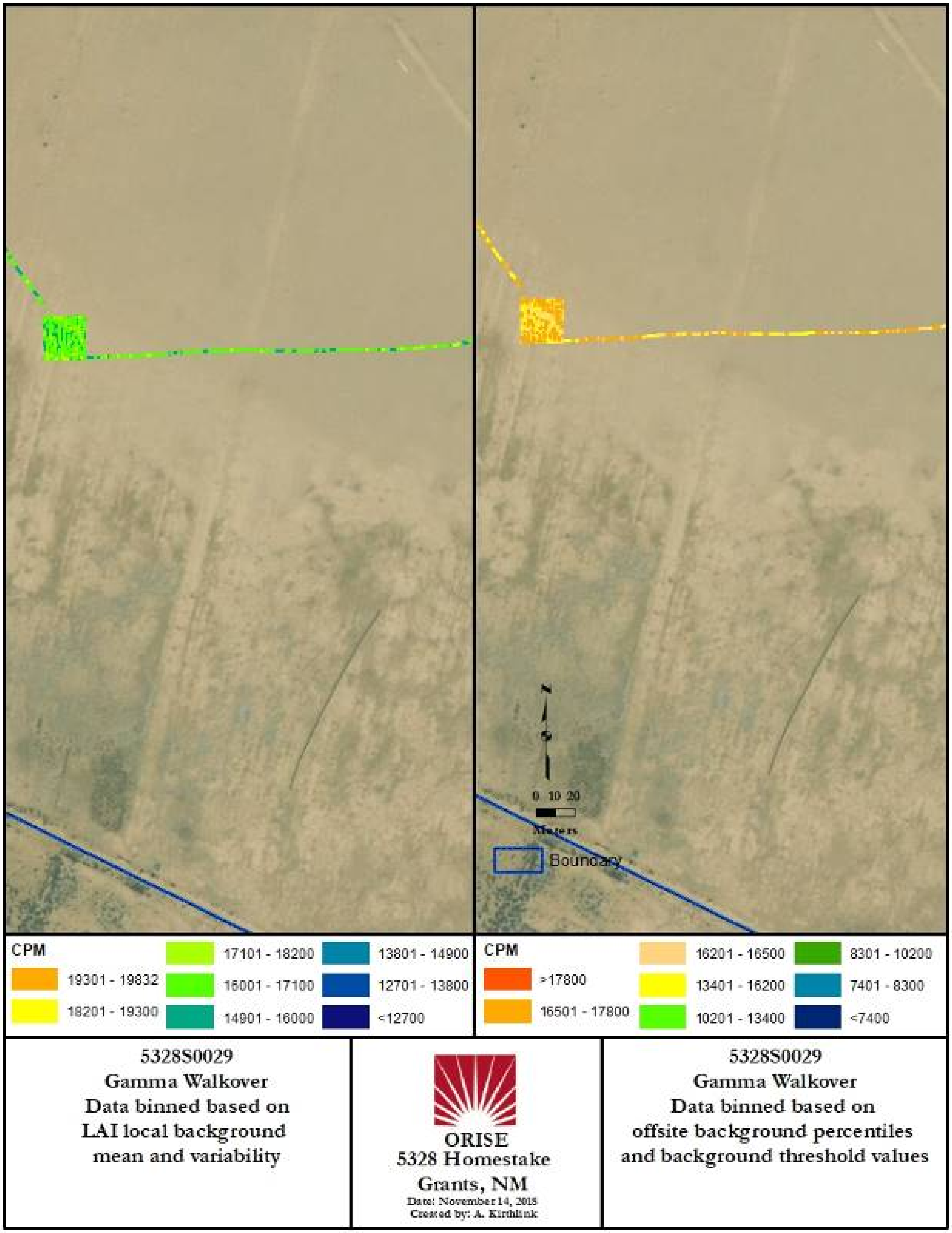


Figure A-32. Gamma Walkover Scan of 5328S0029 in SU 34 Flood

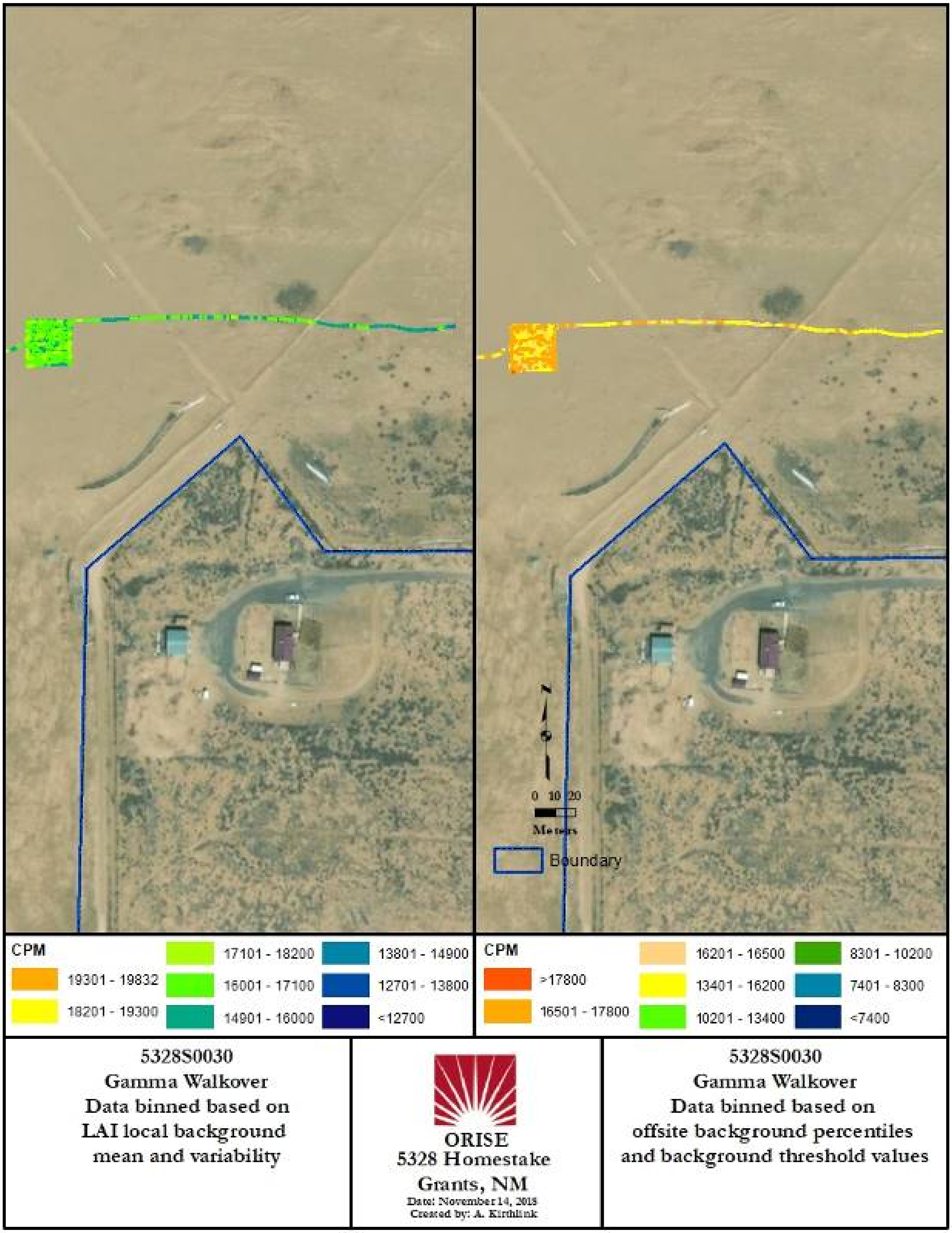


Figure A-33. Gamma Walkover Scan of 5328S0030 in SU 34 Flood

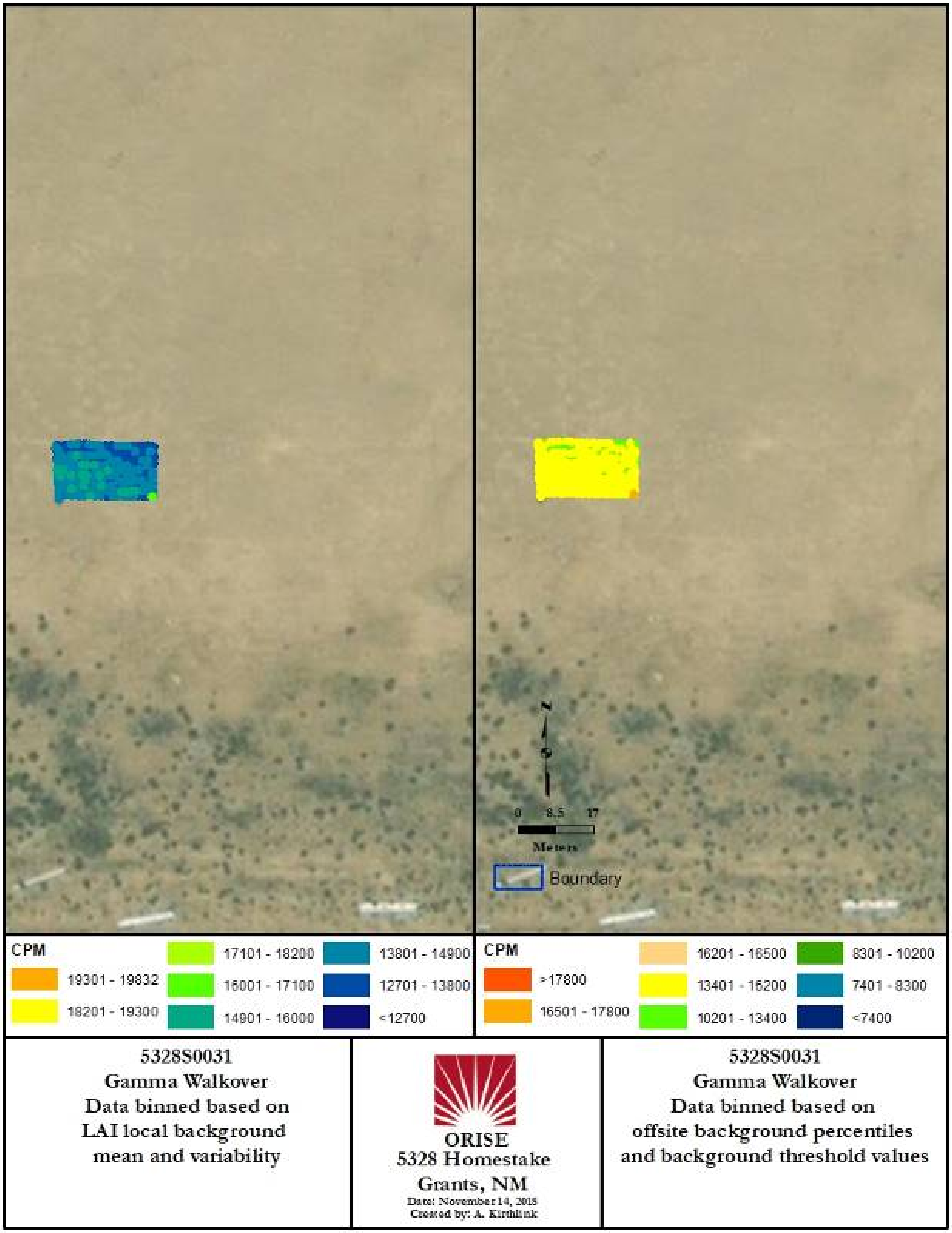


Figure A-34. Gamma Walkover Scan of 5328S0031 in SU 34 Flood

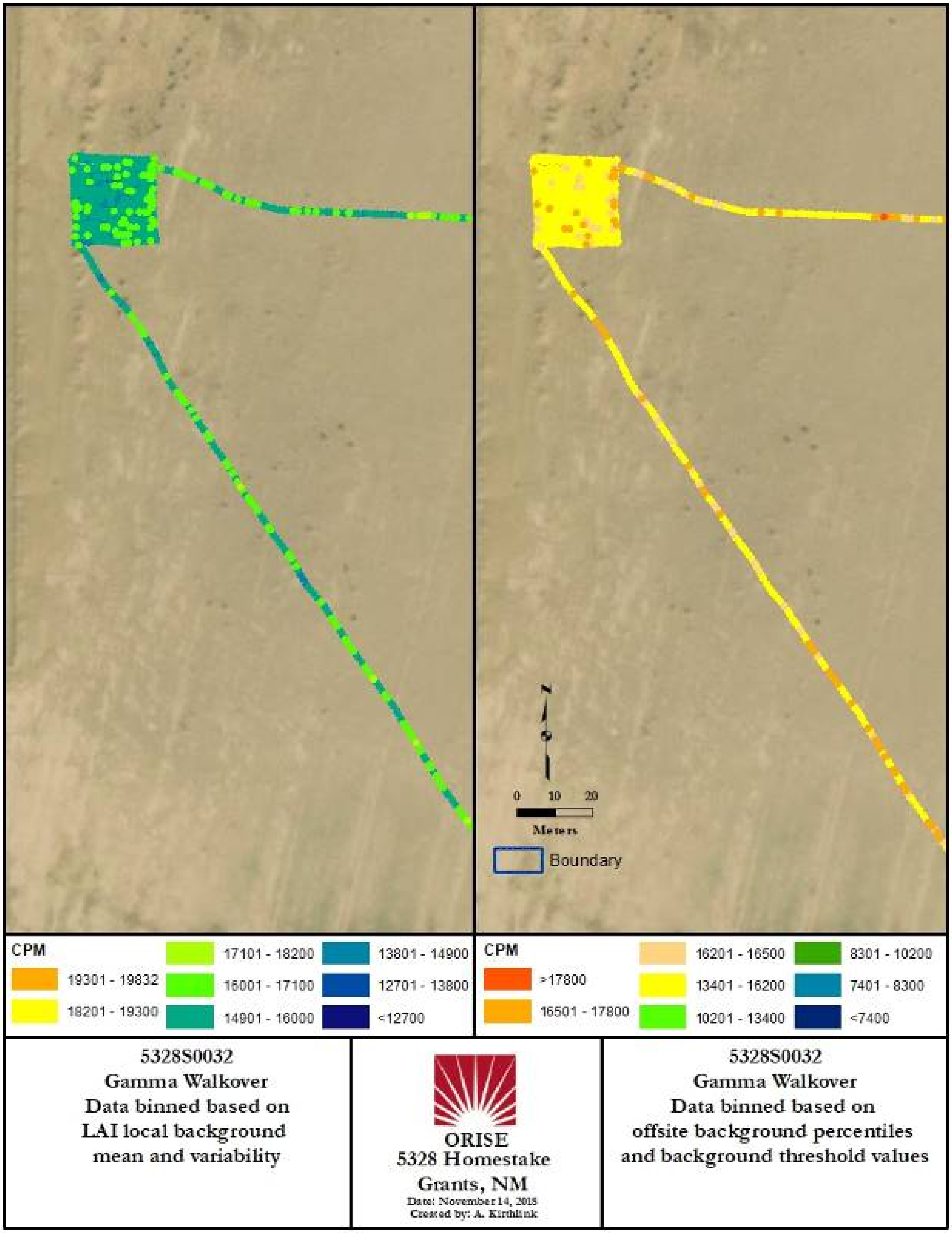


Figure A-35. Gamma Walkover Scan of 5328S0032 in SU 34 Flood

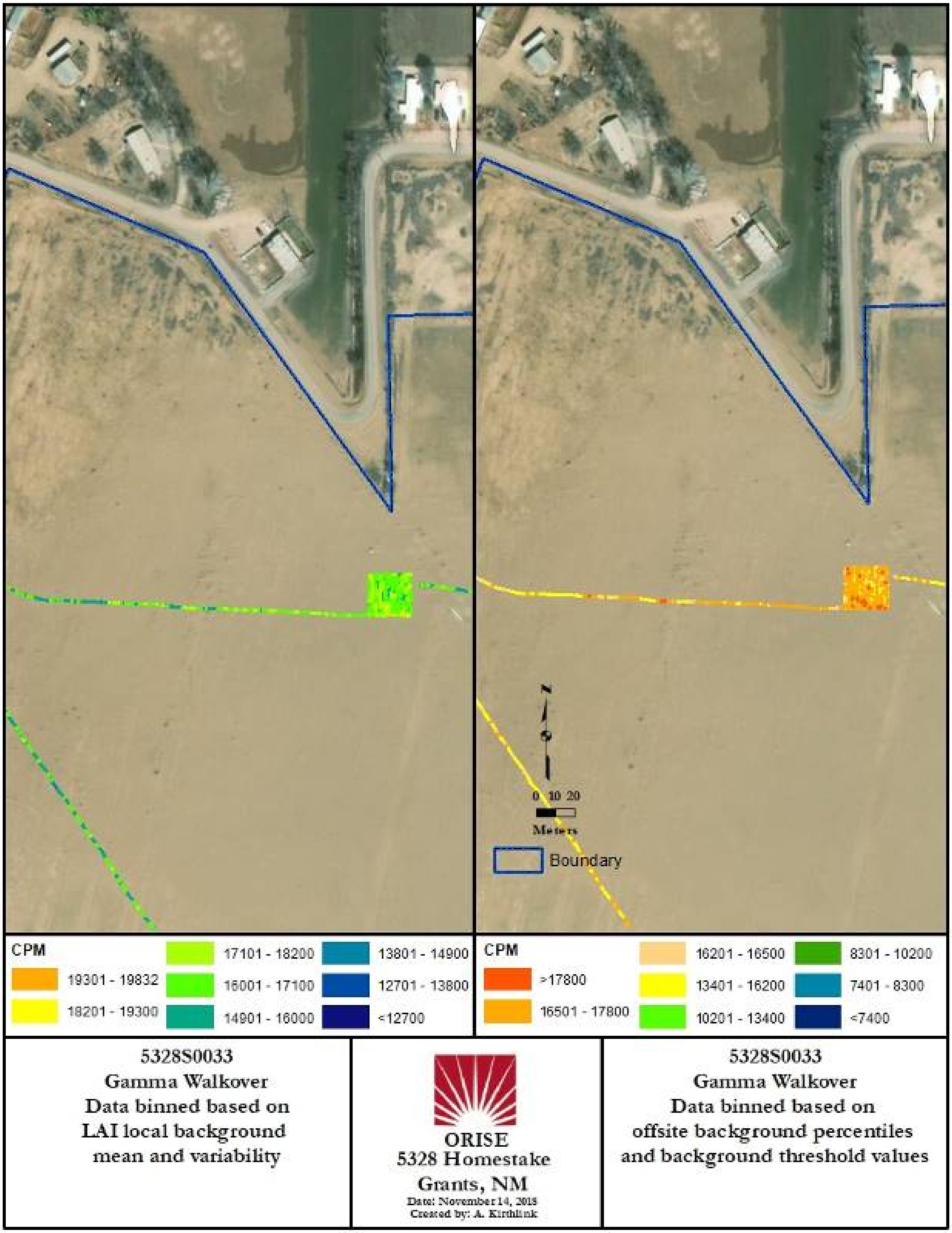


Figure A-36. Gamma Walkover Scan of 5328S0033 in SU 34 Flood

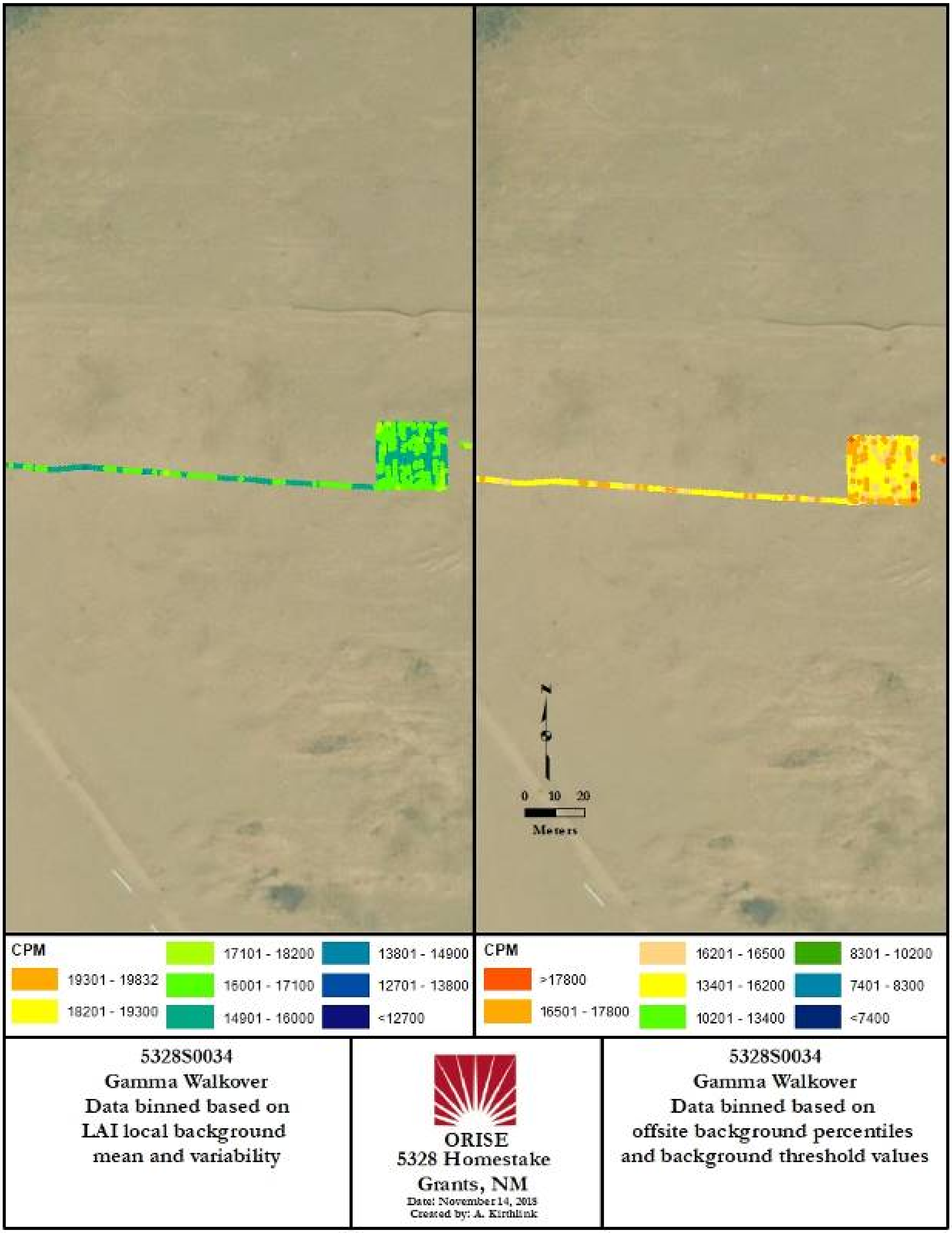


Figure A-37. Gamma Walkover Scan of 5328S0034 in SU 34 Flood

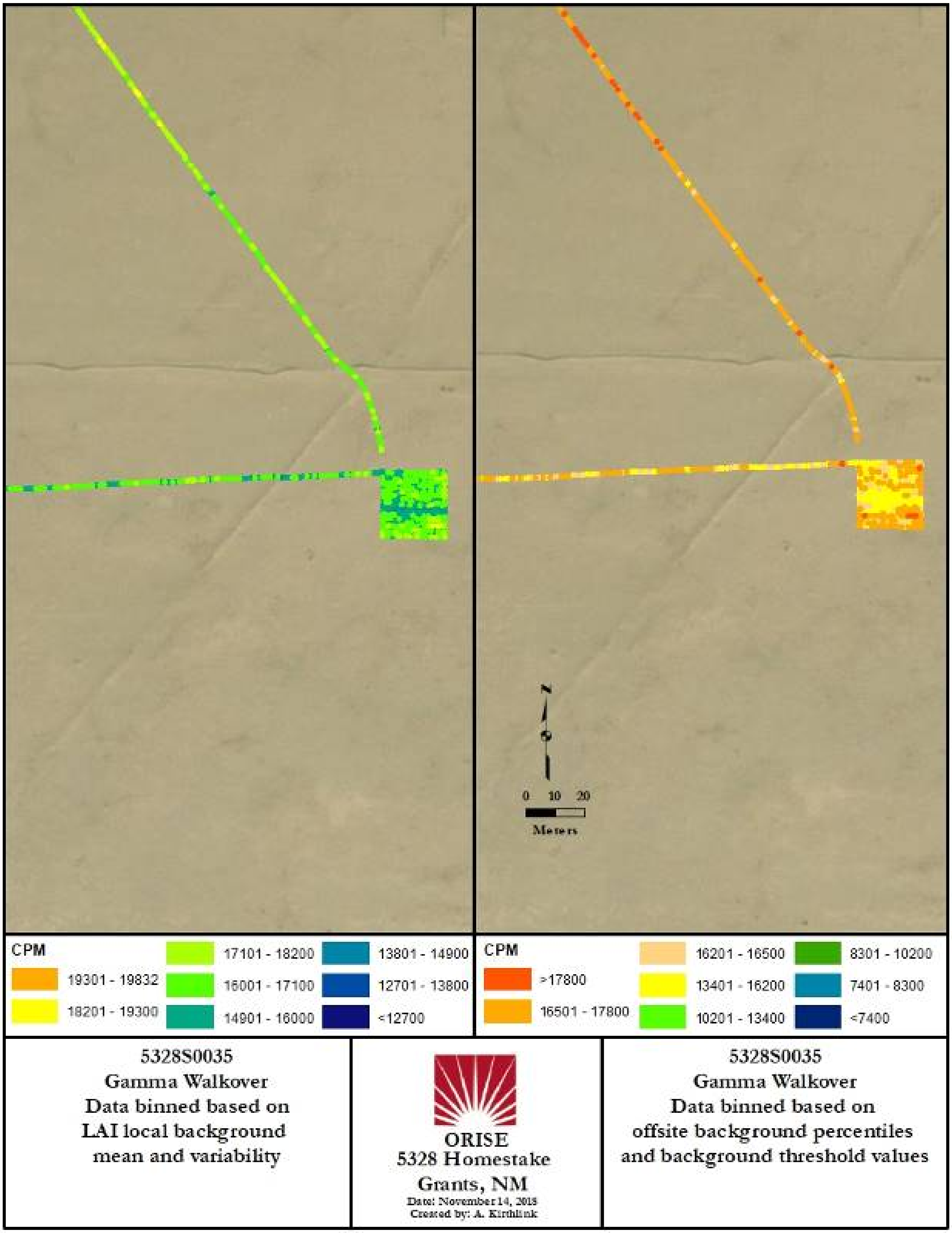


Figure A-38. Gamma Walkover Scan of 5328S0035 in SU 34 Flood

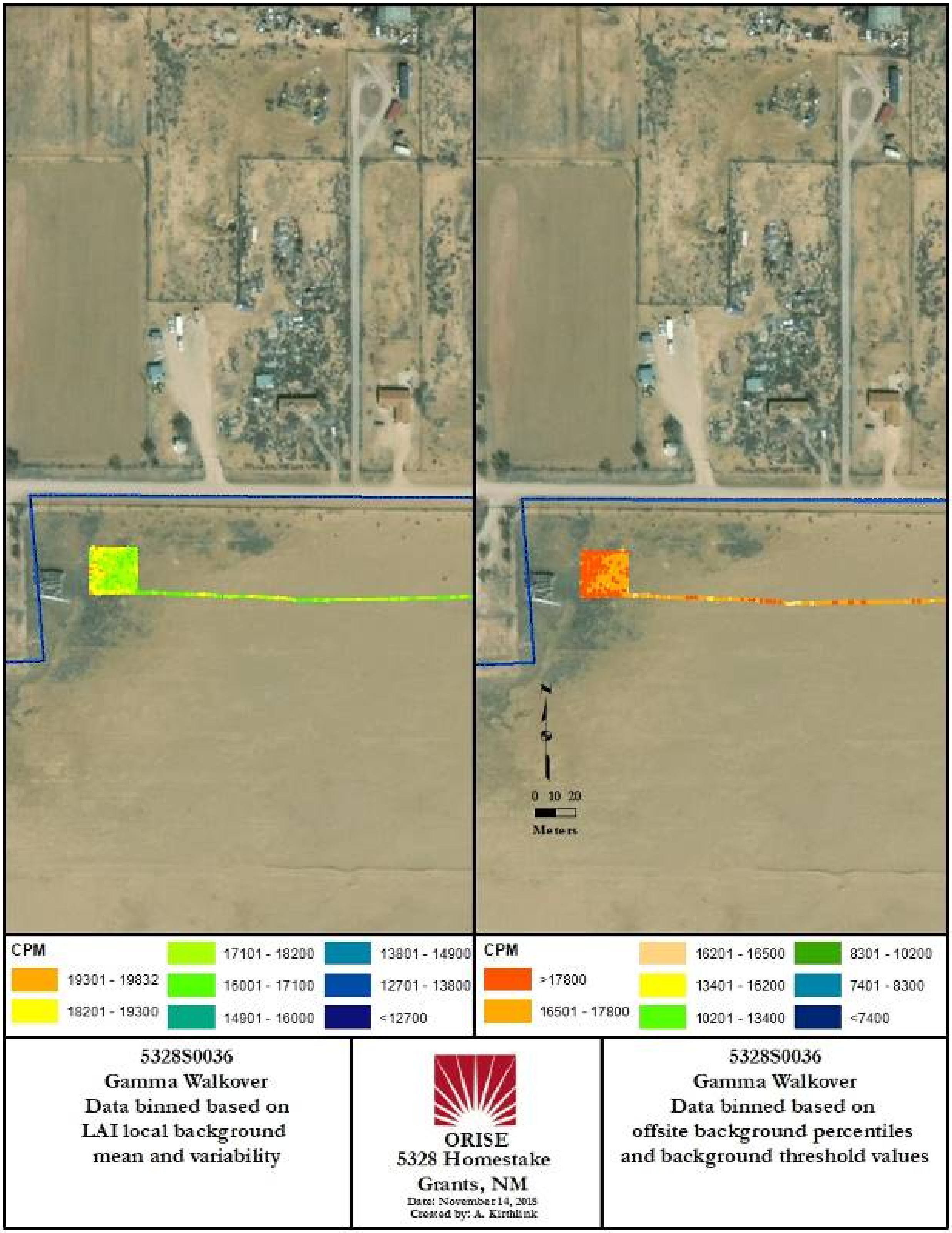


Figure A-39. Gamma Walkover Scan of 5328S0036 in SU 34 Flood

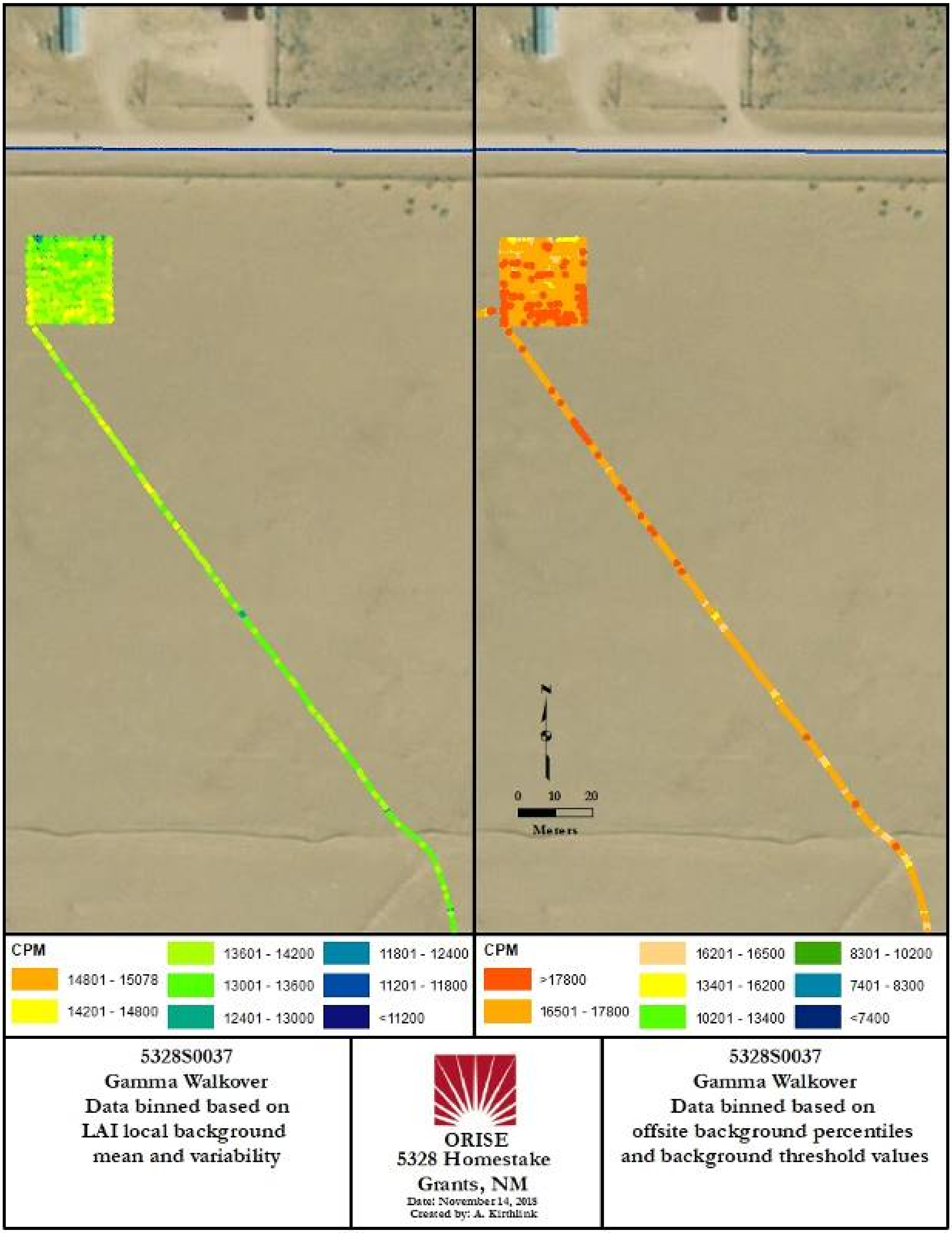


Figure A-40. Gamma Walkover Scan of 5328S0037 in SU 34 Flood

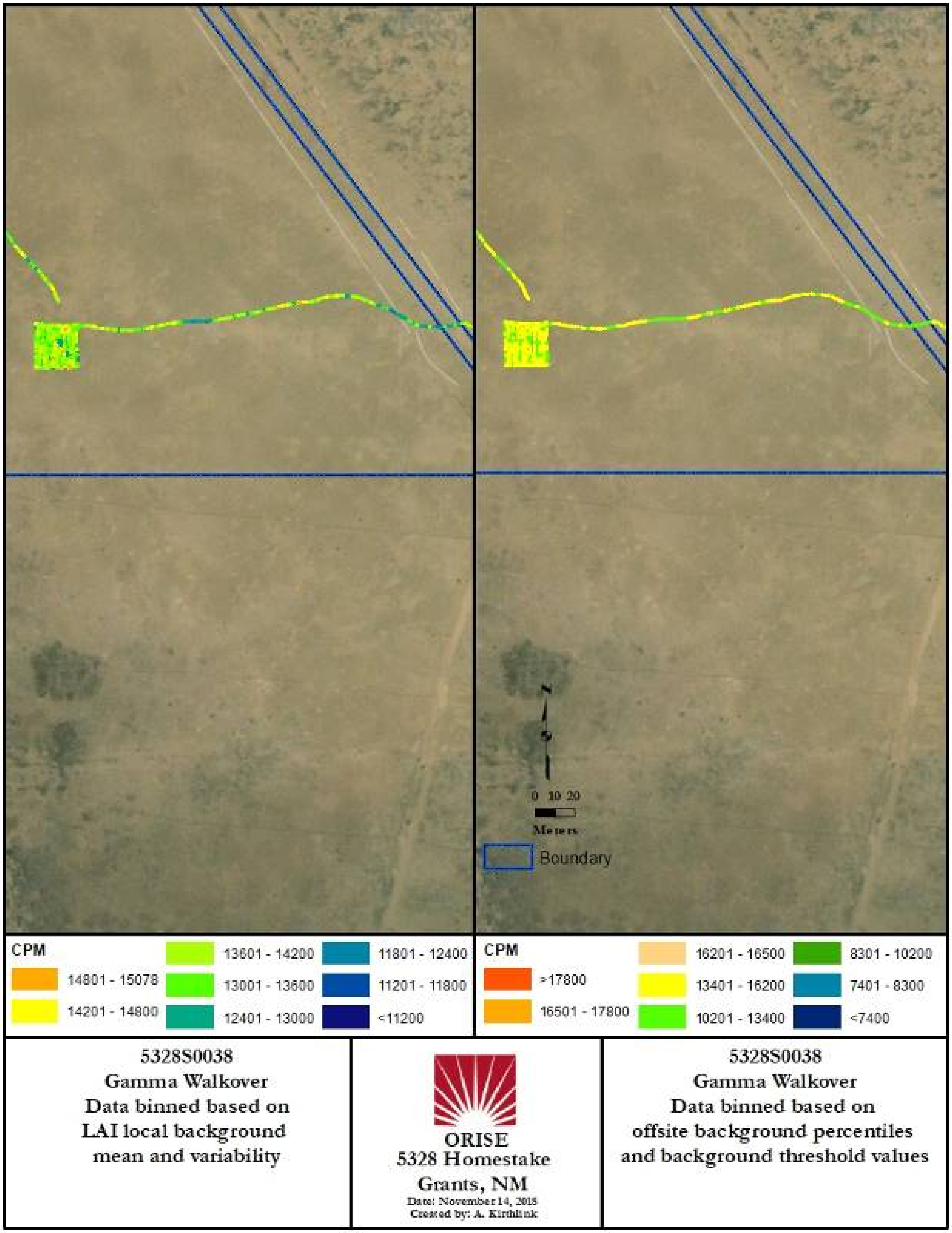


Figure A-41. Gamma Walkover Scan of 5328S0038 in SU 33 Flood

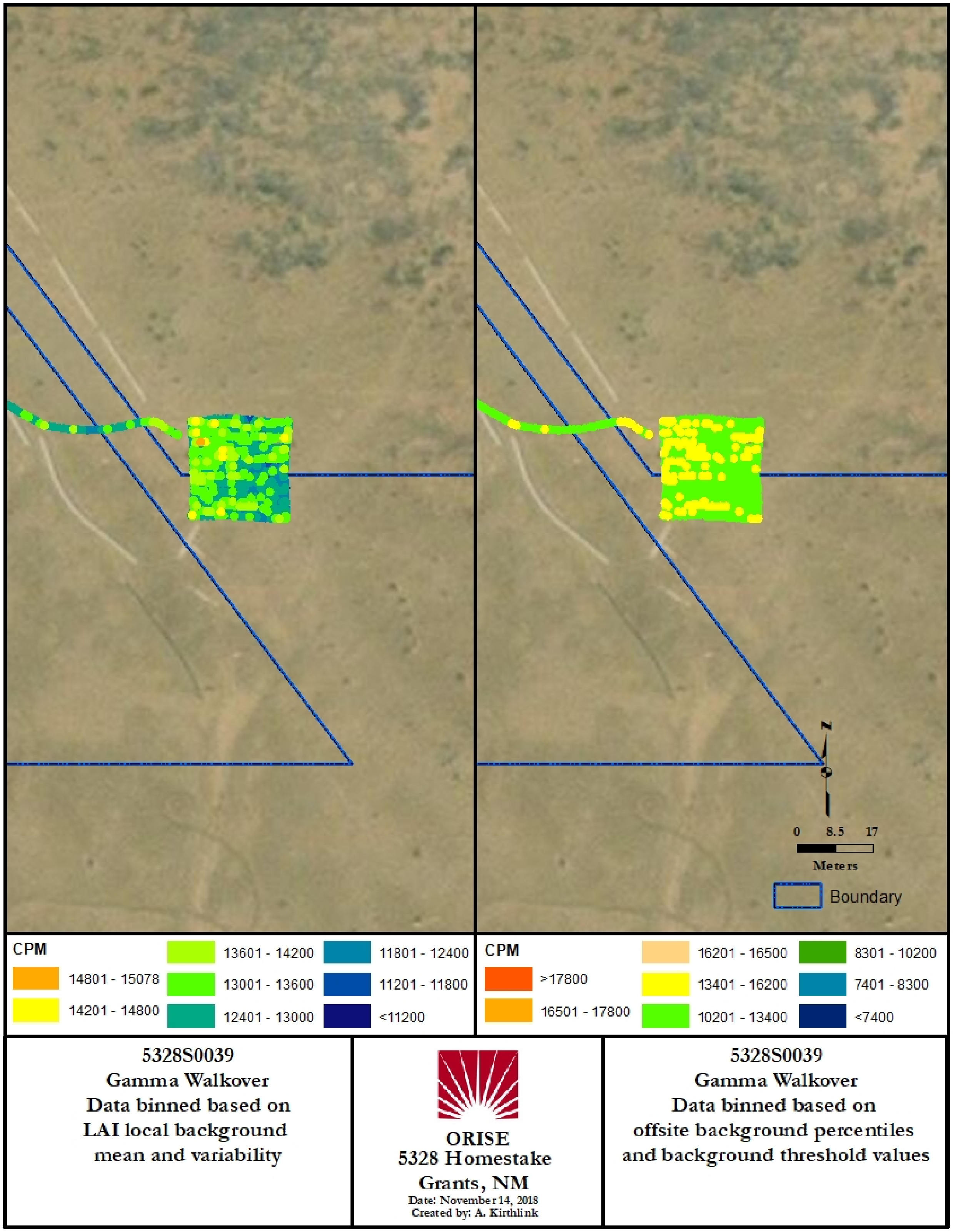


Figure A-42. Gamma Walkover Scan of 5328S0039 in SU 33 Flood

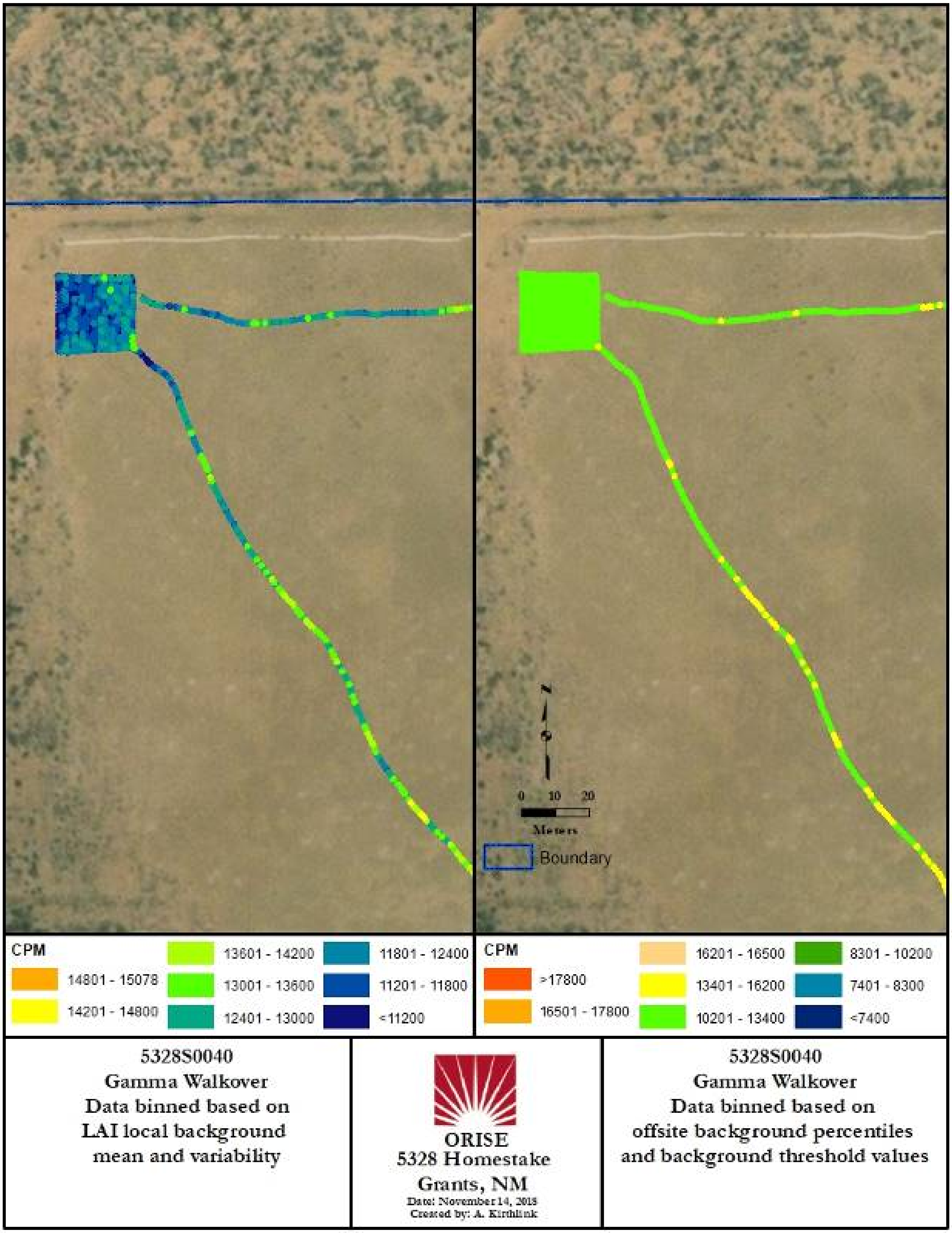


Figure A-43. Gamma Walkover Scan of 5328S0040 in SU 33 Flood

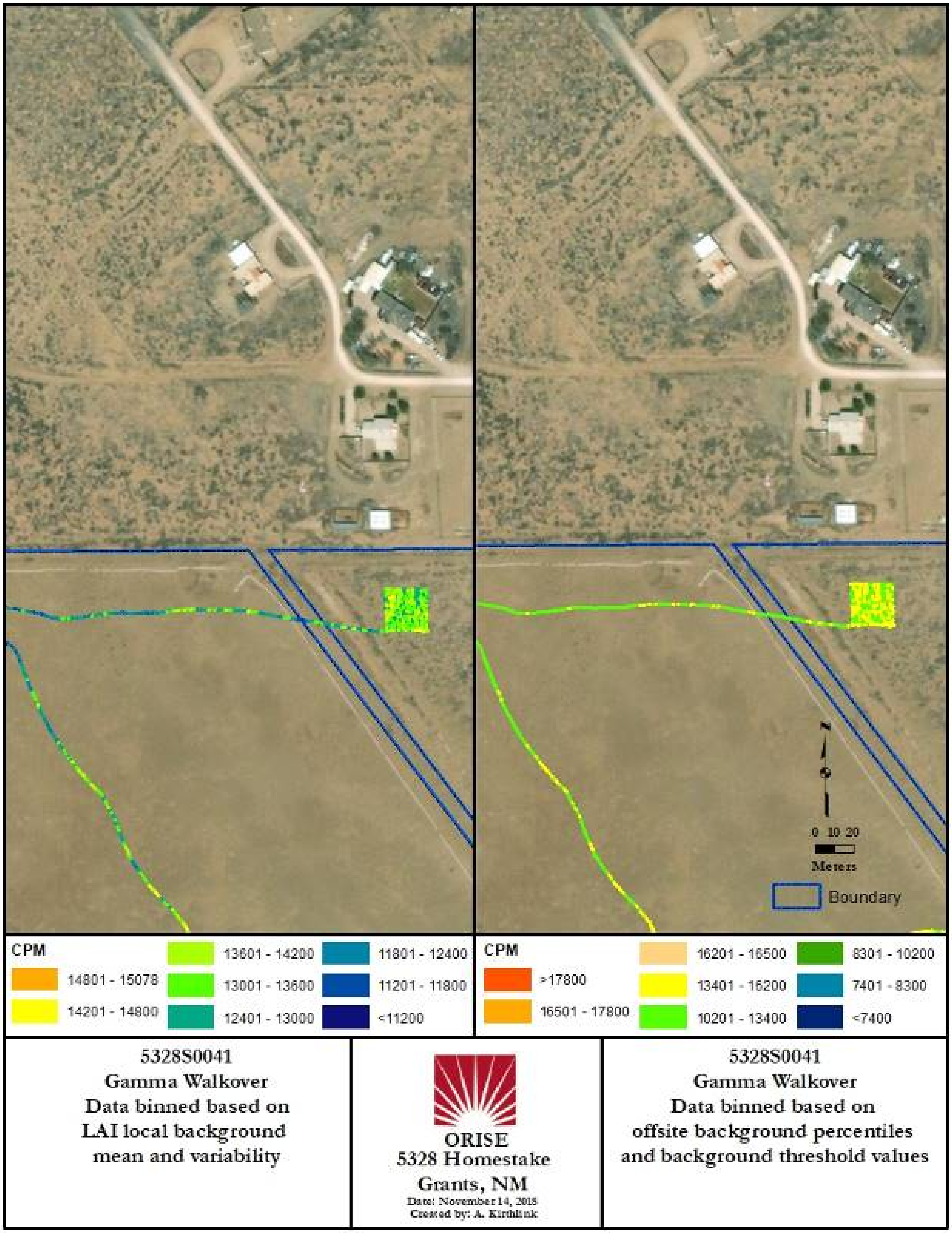


Figure A-44. Gamma Walkover Scan of 5328S0041 in SU 33 Flood

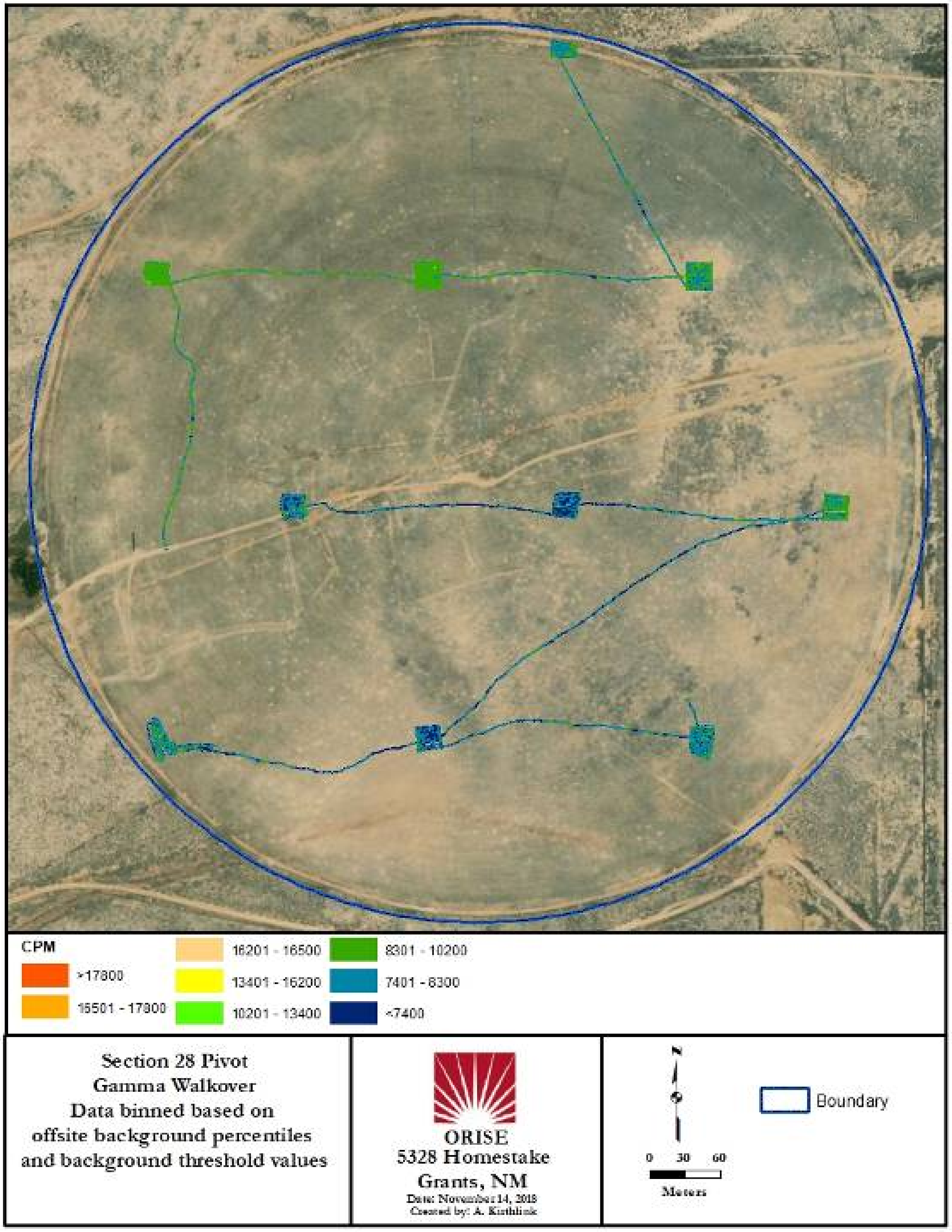


Figure A-45. Gamma Walkover Scan Overview of SU 28 Central Pivot

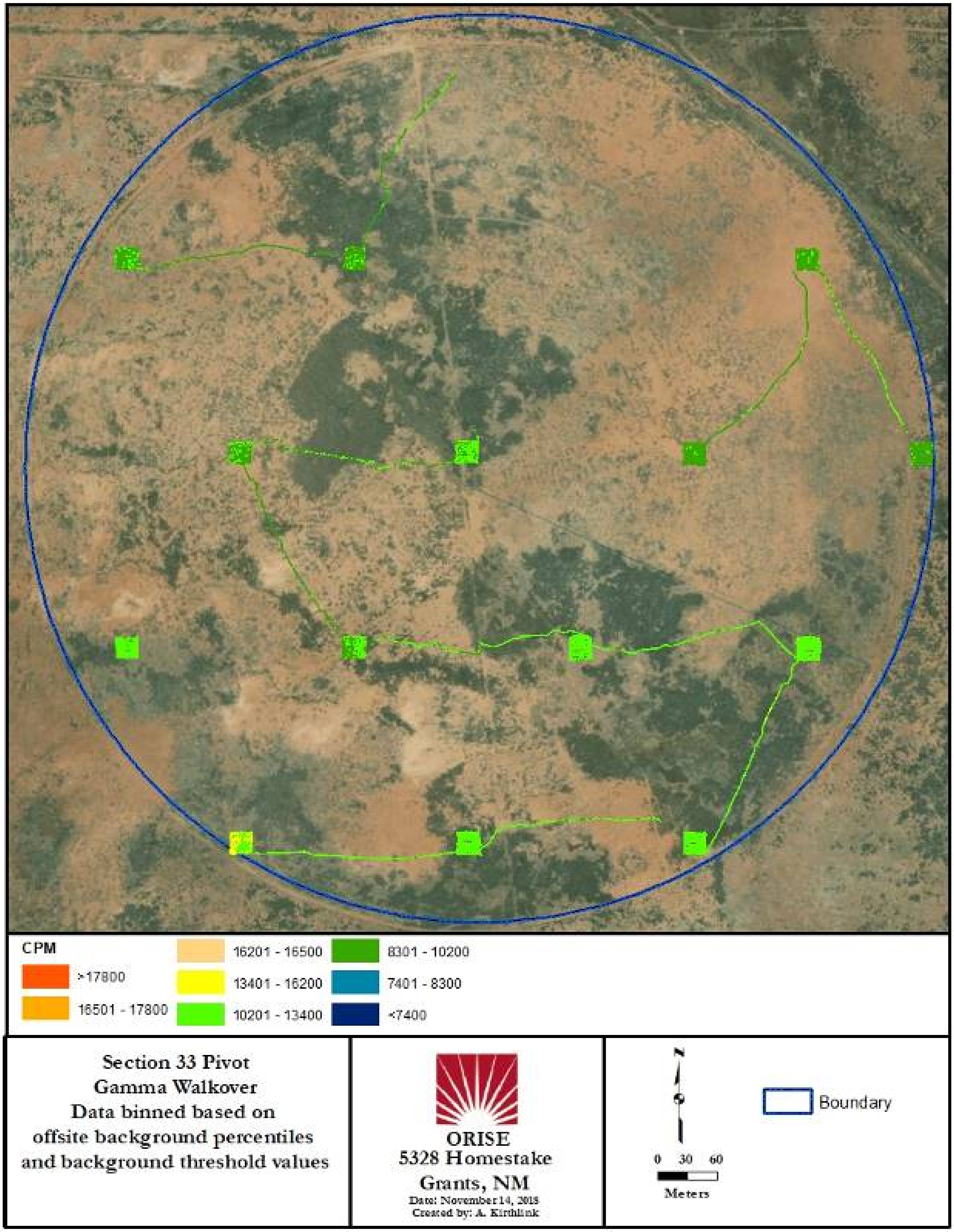


Figure A-46. Gamma Walkover Scan of SU 33 Overview Central Pivot

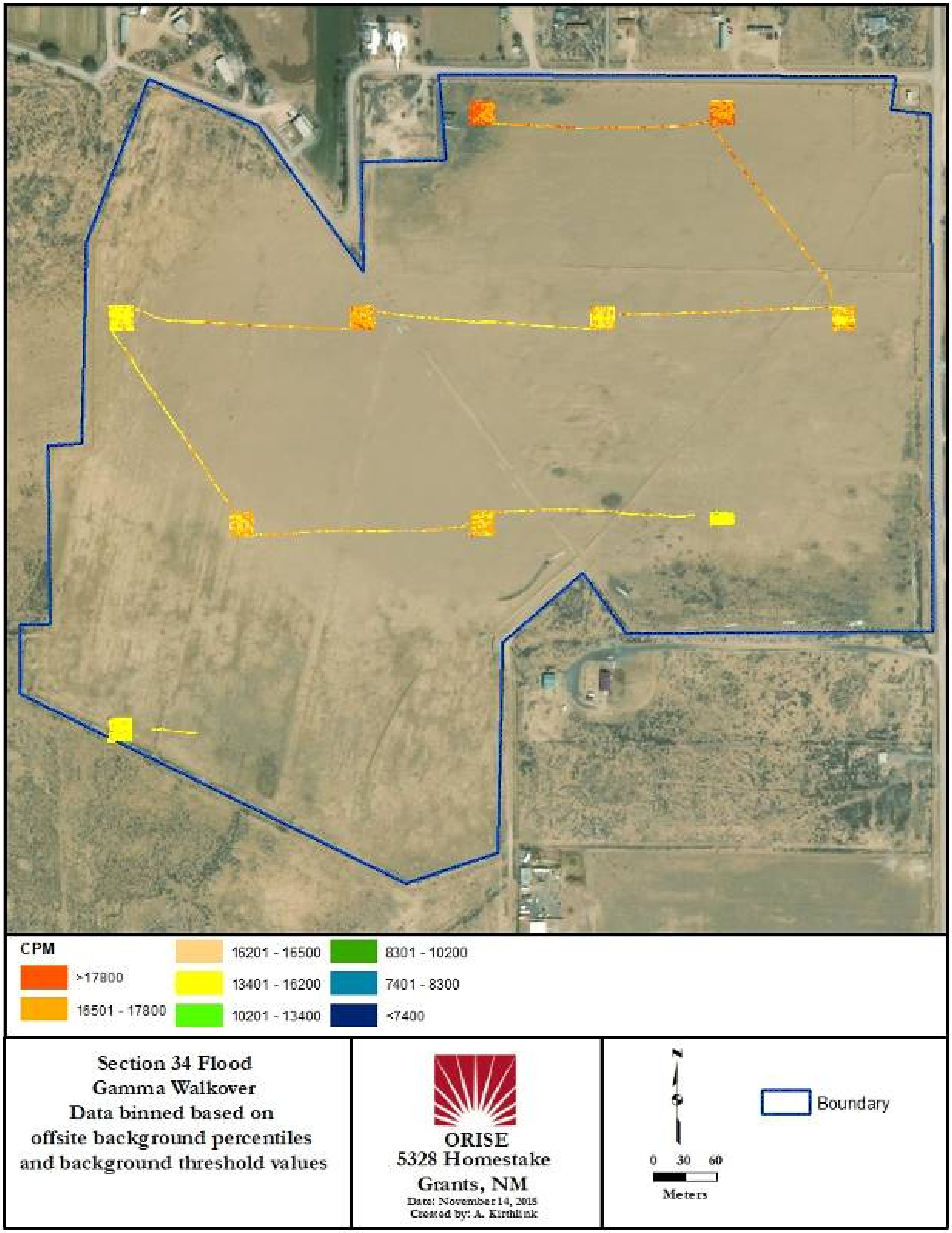


Figure A-47. Gamma Walkover Scan Overview of SU 34 Flood

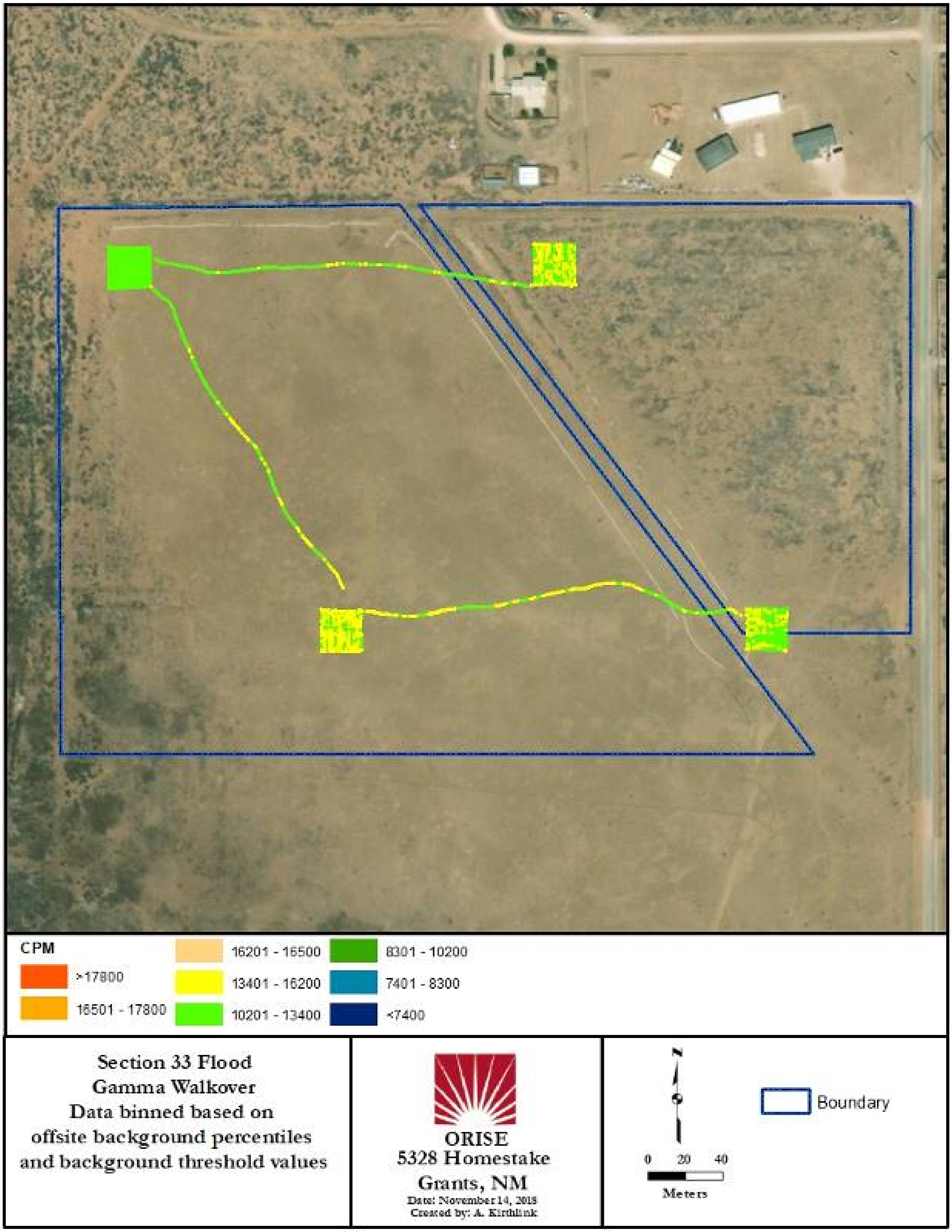


Figure A-48. Gamma Walkover Scan Overview of SU 33 Flood

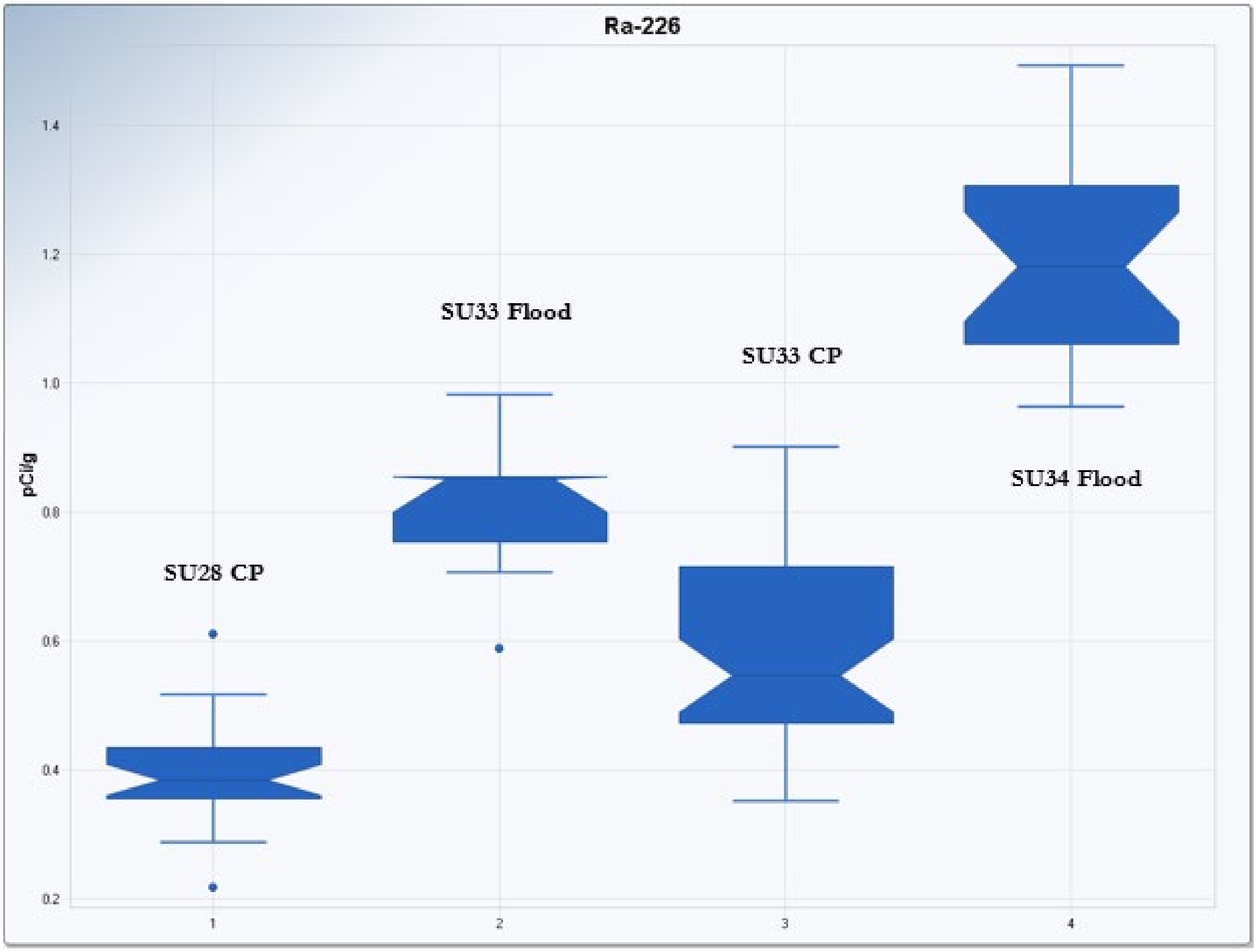


Figure A-49. LAI Ra-226 Concentration Summary Box Plots

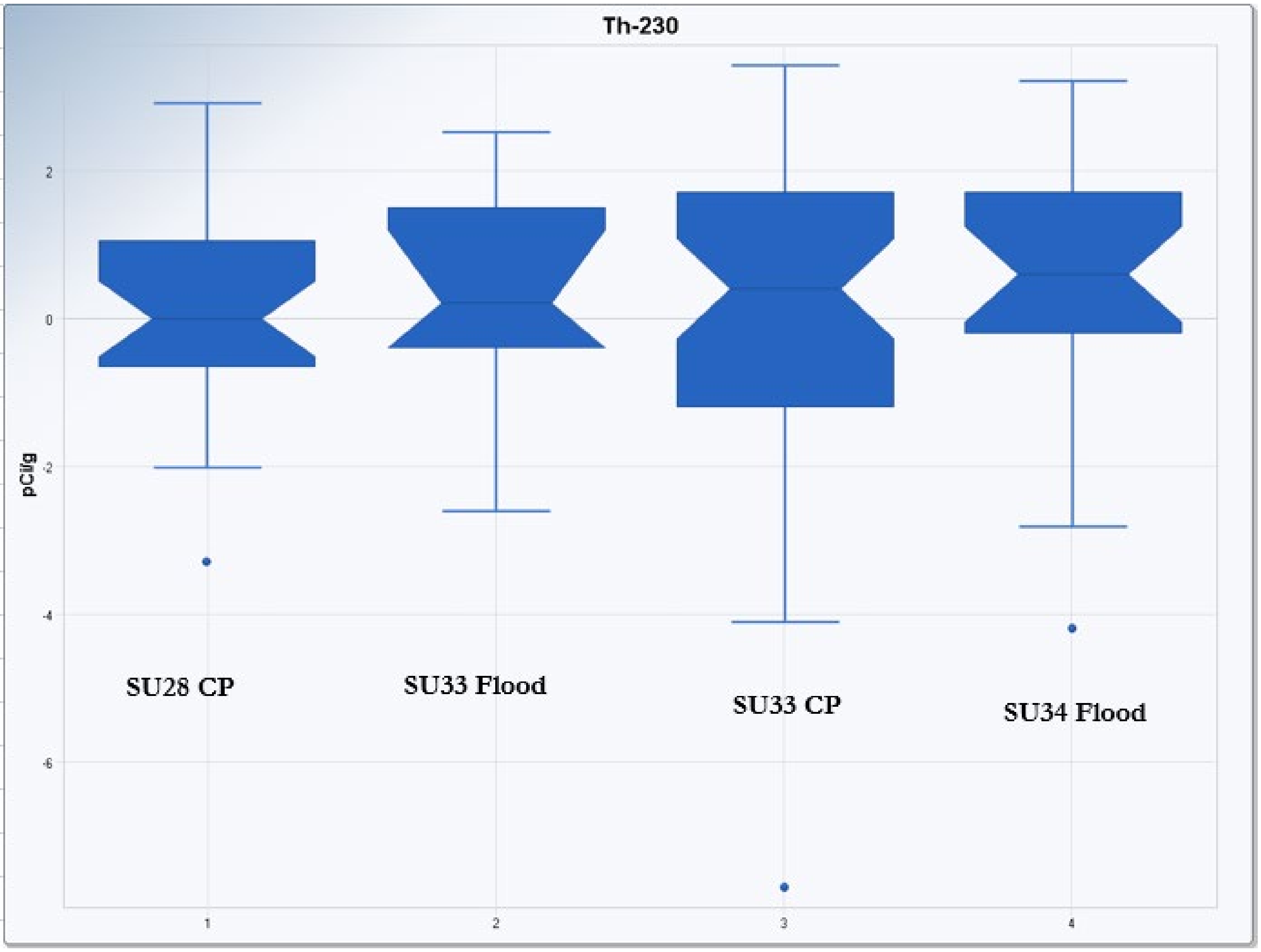


Figure A-50. LAI Th-230 Concentration Summary Box Plots

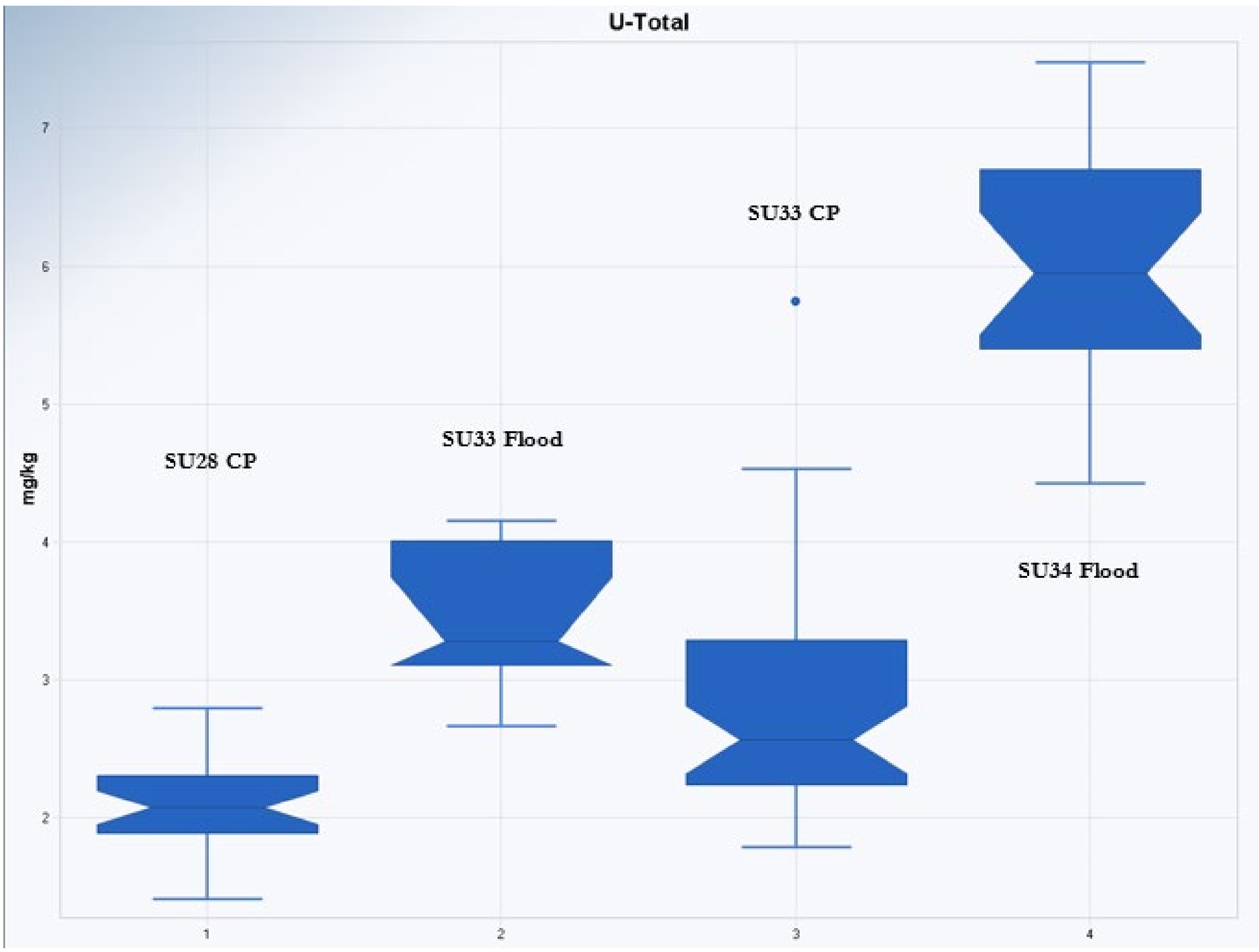


Figure A-51. LAI U-Total Concentration Summary Box Plots

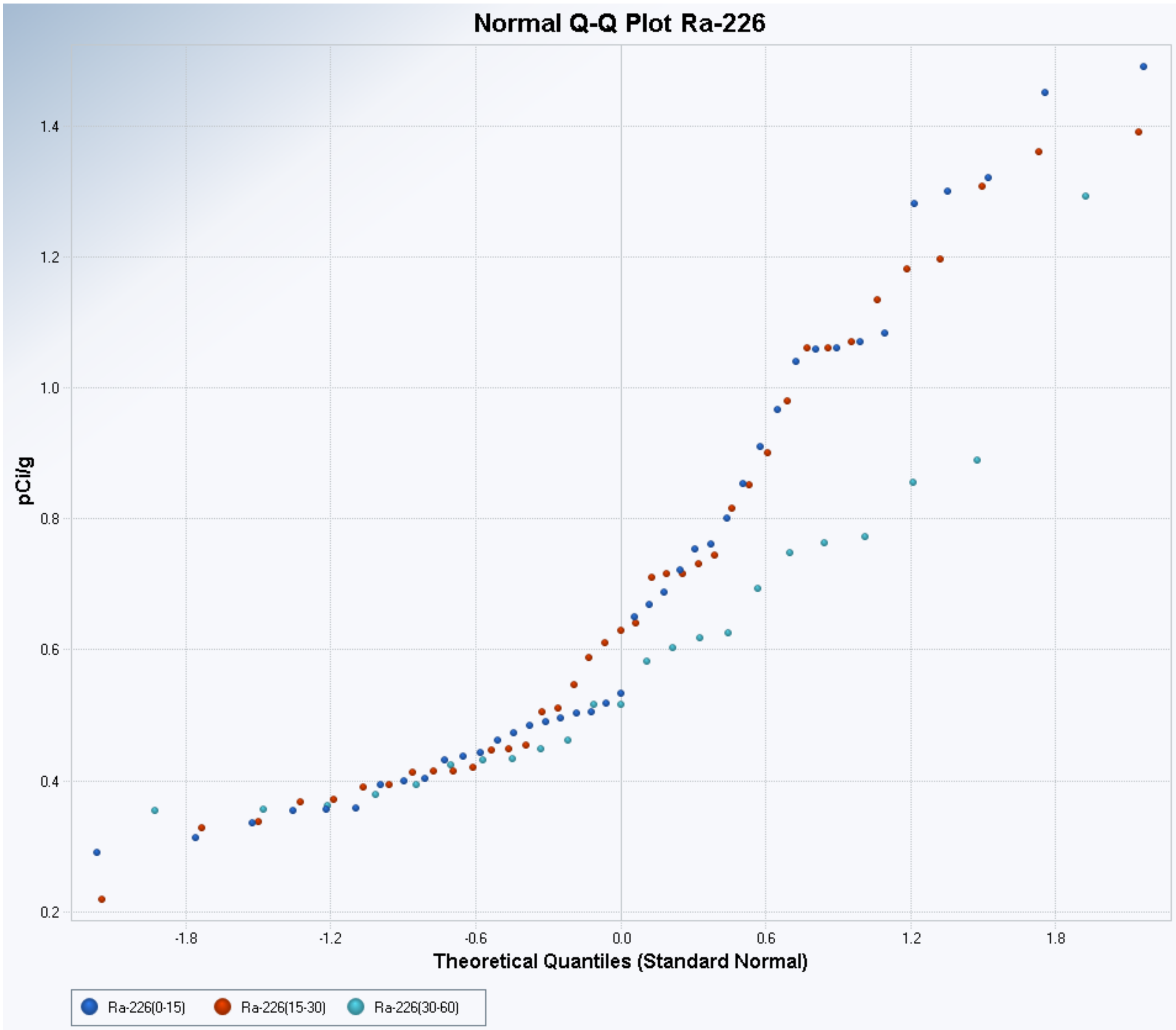


Figure A-52. Ra-226 Concentration Depth Plots

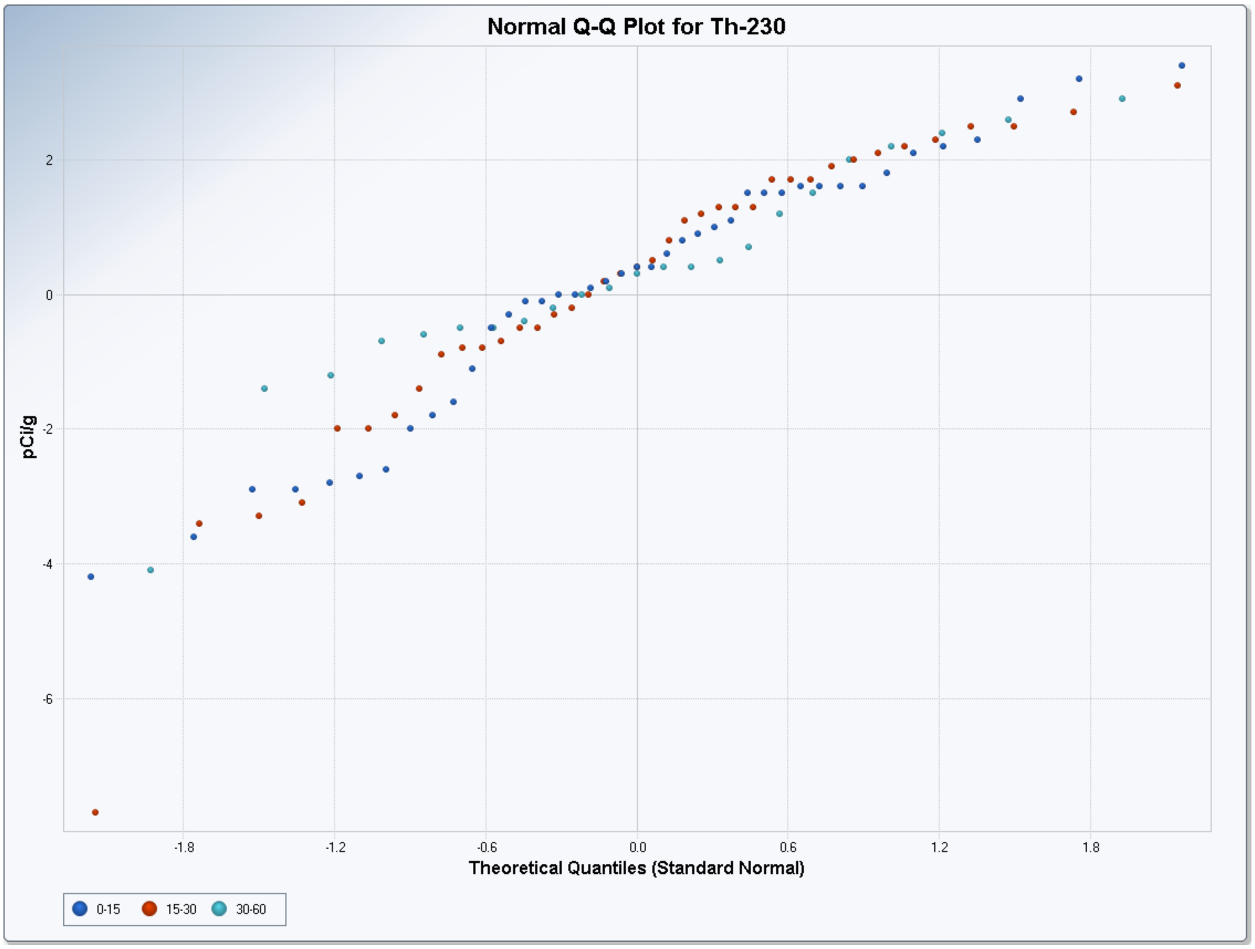


Figure A-53. Th-230 Concentration Depth Plots

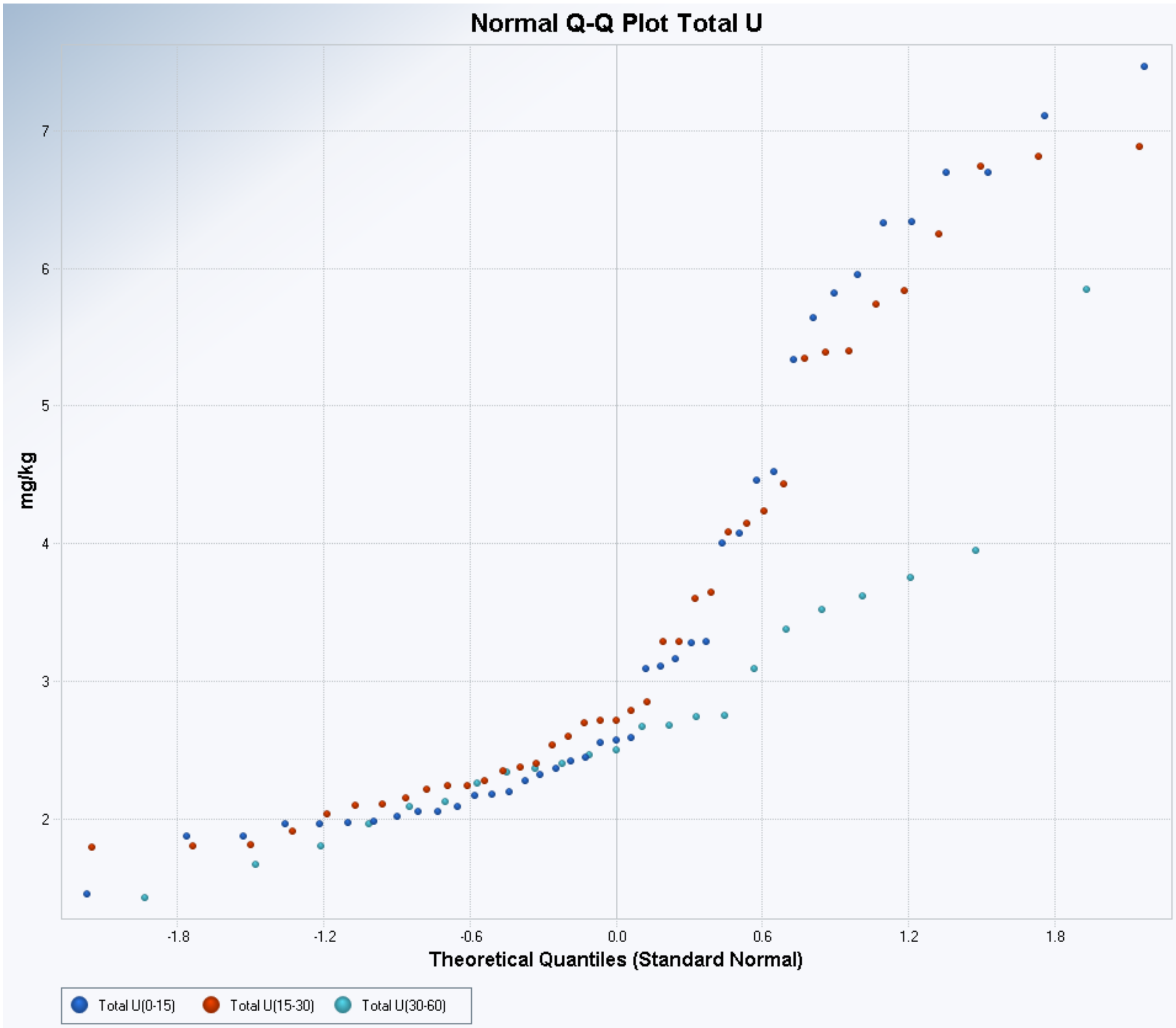


Figure A-54. U-Total Concentration Depth Plots

APPENDIX B
SOIL SAMPLE ANALYTICAL RESULTS

Table B-1. ROC Concentrations and Static Gamma Measurements for Soil Samples						
Sample ID[a]	γ pre (cpm)	γ post (cpm)	Ra-226 (pCi/g)	Th-230 (pCi/g)	SOF	Total U (mg/kg)
SU 28 Pivot						
5328S0001A	7,191	--	0.400 ± 0.061	-1.8 ± 3.0	-0.09	1.96
5328S0001B	--	10,507	0.328 ± 0.036	-0.5 ± 2.3	0.00	1.80
5328S0001C[b]	--	10,656	0.355 ± 0.063	-0.7 ± 3.1	0.00	1.67
5328S0002A	6,742	--	0.357 ± 0.054	0.0 ± 2.3	0.03	1.97
5328S0002B	--	8,962	0.218 ± 0.066	0.0 ± 4.1	0.01	1.81
5328S0002C[b]	--	8,950	0.448 ± 0.045	0.0 ± 2.1	0.02	1.80
5328S0003A	7,198	--	0.355 ± 0.056	0.8 ± 2.6	0.09	1.96
5328S0003B	--	10,721	0.367 ± 0.062	1.3 ± 3.1	0.05	2.35
5328S0003C[b]	--	11,349	0.361 ± 0.069	-0.5 ± 3.2	0.01	2.12
5328S0004A	7,578	--	0.432 ± 0.071	2.1 ± 2.4	0.19	2.06
5328S0004B	--	10,877	0.610 ± 0.076	2.1 ± 2.3	0.08	2.54
5328S0004C	--	--[c]	0.516 ± 0.050	-0.6 ± 2.5	0.01	2.34
5328S0005A	7,081	--	0.313 ± 0.055	0.9 ± 1.9	0.09	1.87
5328S0005B	--	9,085	0.390 ± 0.029	1.3 ± 2.3	0.05	2.10
5328S0005C	--	9,302	0.354 ± 0.036	0.7 ± 1.6	0.03	2.46
5328S0006A	7,876	--	0.443 ± 0.047	-0.1 ± 2.9	0.04	2.18
5328S0006B[b]	--	11,269	0.394 ± 0.087	-0.5 ± 3.7	0.01	2.03
5328S0007A	7,378	--	0.437 ± 0.074	-1.6 ± 3.7	-0.07	2.59
5328S0007B	--	9,129	0.454 ± 0.072	1.2 ± 3.5	0.05	2.28
5328S0008A	7,233	--	0.394 ± 0.066	0.0 ± 2.1	0.04	2.17
5328S0008B	--	10,471	0.415 ± 0.082	-3.3 ± 5.1	-0.06	2.10
5328S0008C	--	--[c]	0.379 ± 0.071	2.0 ± 3.4	0.06	2.36
5328S0009A	7,128	--	0.335 ± 0.065	2.9 ± 2.8	0.24	2.02
5328S0009B	--	10,304	0.371 ± 0.069	-2.0 ± 2.6	-0.03	2.78
5328S0009C[b]	--	--[c]	0.462 ± 0.071	0.5 ± 2.3	0.03	2.26
5328S0010A	6,772	--	0.290 ± 0.062	-1.1 ± 3.3	-0.05	1.45
5328S0010B	--	9,915	0.336 ± 0.061	-1.8 ± 5.0	-0.03	1.91
5328S0010C[b]	--	--[c]	0.393 ± 0.064	0.4 ± 2.1	0.03	1.42
SU 33 Pivot						
5328S0011A	10,244	--	0.721 ± 0.081	-2.0 ± 3.3	-0.07	4.52
5328S0011B	--	14,304	0.744 ± 0.093	2.3 ± 2.8	0.09	4.23
5328S0011C[b]	--	--[c]	0.772 ± 0.095	0.4 ± 4.2	0.05	3.95
5328S0012A	7,989	--	0.473 ± 0.068	-2.9 ± 2.9	-0.16	2.36

Table B-1. ROC Concentrations and Static Gamma Measurements for Soil Samples

Sample ID[a]	γ pre (cpm)	γ post (cpm)	Ra-226 (pCi/g)	Th-230 (pCi/g)	SOF	Total U (mg/kg)
5328S0012B	--	12,372	0.511 ± 0.071	1.1 ± 3.2	0.05	2.22
5328S0012C[b]	--	--[c]	0.431 ± 0.070	-4.1 ± 5.1	-0.07	2.74
5328S0013A	7,998	--	0.354 ± 0.064	3.4 ± 3.2	0.28	1.87
5328S0013B	--	12,664	0.413 ± 0.061	-0.8 ± 2.8	0.00	2.40
5328S0013C[b]	--	--[c]	0.515 ± 0.075	-0.5 ± 2.8	0.01	2.50
5328S0014A	9,762	--	0.669 ± 0.078	1.5 ± 3.4	0.17	3.09
5328S0014B[b]	--	--	0.90 ± 0.11	-7.7 ± 4.4	-0.14	5.74
5328S0015A	8,044		0.505 ± 0.066	1.1 ± 2.8	0.13	1.98
5328S0015B	--	11,641	0.419 ± 0.064	1.7 ± 2.3	0.06	2.24
5328S0015C[b]	--	--[c]	0.424 ± 0.059	0.1 ± 2.7	0.02	1.96
5328S0016A	7,971	--	0.490 ± 0.070	0.1 ± 3.3	0.05	2.42
5328S0016B	--	11,142	0.448 ± 0.062	1.3 ± 2.4	0.05	2.60
5328S0017A	9,366	--	0.687 ± 0.072	-3.6 ± 3.3	-0.19	3.29
5328S0017B	--	14,347	0.716 ± 0.093	2.5 ± 4.0	0.09	3.65
5328S0017C[b]	--	--[c]	0.692 ± 0.077	1.5 ± 3.3	0.07	3.75
5328S0018A	10,386	--	0.496 ± 0.066	1.6 ± 2.3	0.16	2.32
5328S0018B	--	12,494	0.447 ± 0.061	-0.8 ± 2.7	0.00	2.15
5328S0018C	--	--[c]	0.433 ± 0.071	-0.2 ± 3.5	0.02	2.40
5328S0019A	11,151	--	0.483 ± 0.075	-2.9 ± 3.6	-0.16	2.09
5328S0019B	--	14,710	0.546 ± 0.075	3.1 ± 3.6	0.10	2.84
5328S0019C	--	--[c]	0.762 ± 0.090	1.2 ± 4.0	0.07	3.62
5328S0020A	10,110	--	0.517 ± 0.065	-0.3 ± 2.8	0.03	2.57
5328S0020B	--	12,754	0.504 ± 0.077	-3.1 ± 5.2	-0.05	2.37
5328S0020C	--	--[c]	0.617 ± 0.059	-1.2 ± 2.6	0.00	2.68
328S0021A	9,906	--	0.403 ± 0.058	0.3 ± 2.7	0.06	2.19
5328S0021B	--	13,514	0.415 ± 0.062	-3.4 ± 3.4	-0.06	1.80
5328S0021C	--	--[c]	0.603 ± 0.072	0.3 ± 3.1	0.04	2.09
5328S0022A	9,998	--	0.533 ± 0.073	1.6 ± 2.6	0.17	2.05
5328S0022B	--	13,858	0.640 ± 0.077	2.0 ± 3.2	0.08	2.72
5328S0023A	9,804	--	0.503 ± 0.068	-2.7 ± 3.6	-0.14	2.28
5328S0023B	--	14,926	0.715 ± 0.085	1.9 ± 3.9	0.08	2.24
5328S0023C	--	--[c]	0.889 ± 0.089	2.9 ± 3.1	0.11	3.52
5328S0024A	11,578	--	0.761 ± 0.090	2.2 ± 4.1	0.23	4.08
5328S0024B	--	15,500	0.816 ± 0.093	-1.4 ± 4.1	0.01	3.57
5328S0024C	--	--[c]	0.748 ± 0.053	2.4 ± 1.9	0.09	3.08
5328S0025A	9,941	--	0.461 ± 0.061	0.2 ± 2.4	0.06	2.56

Table B-1. ROC Concentrations and Static Gamma Measurements for Soil Samples						
Sample ID[a]	γ pre (cpm)	γ post (cpm)	Ra-226 (pCi/g)	Th-230 (pCi/g)	SOF	Total U (mg/kg)
5328S0025B	--	13,877	0.629 ± 0.045	1.7 ± 3.0	0.07	2.71
5328S0025C	--	--[c]	0.625 ± 0.073	2.2 ± 3.8	0.08	2.74
5328S0026A	9,483	--	0.650 ± 0.078	0.4 ± 3.8	0.09	2.47
5328S0026B	--	13,687	0.731 ± 0.078	2.2 ± 3.2	0.09	3.32
5328S0026C	--	--[c]	0.582 ± 0.055	-1.4 ± 3.2	0.00	3.37
SU 34 Flood						
5328S0027A	14,003	--	0.966 ± 0.075	-0.5 ± 3.8	0.06	4.46
5328S0027B	--	19,453	1.195 ± 0.059	0.3 ± 2.7	0.07	5.83
5328S0028A	14,673	--	1.49 ± 0.11	-2.8 ± 5.3	-0.06	6.34
5328S0028B	--	19,809	1.39 ± 0.10	-0.7 ± 4.6	0.05	6.89
5328S0029A	14,510	18,439	1.28 ± 0.11	3.2 ± 4	0.35	6.70
5328S0030A	15,743	--	1.450 ± 0.093	1.0 ± 3.4	0.21	7.11
5328S0030B	--	19,867	1.307 ± 0.063	0.8 ± 2.8	0.08	6.81
5328S0031A	13,580	15,838	1.082 ± 0.056	0.6 ± 2.6	0.15	5.82
5328S0032A	14,679	--	1.06 ± 0.11	1.8 ± 5.0	0.23	5.34
5328S0032B	--	18,813	1.133 ± 0.097	1.7 ± 4.5	0.09	4.44
5328S0033A	15,774	--	1.30 ± 0.11	1.64 ± 0.86	0.24	7.47
5328S0033B	--	19,320	1.36 ± 0.13	0.5 ± 5.4	0.08	6.74
5328S0034A	15,321	--	1.04 ± 0.10	1.5 ± 4.2	0.21	6.33
5328S0034B	--	17,371	1.06 ± 0.11	0.4 ± 4.7	0.06	5.35
5328S0035A	15,464	--	1.07 ± 0.10	-4.2 ± 3.6	-0.20	5.64
5328S0035B	--	17,480	1.06 ± 0.11	2.7 ± 4.8	0.11	5.39
5328S0036A	15,763	--	1.059 ± 0.095	-0.1 ± 4.5	0.09	5.95
5328S0036B	--	19,205	1.07 ± 0.11	-2.0 ± 4.4	0.01	5.40
5328S0036C	--	--[c]	1.292 ± 0.078	2.6 ± 5.0	0.12	5.84
5328S0037A	16,667	--	1.32 ± 0.11	2.3 ± 3.9	0.29	6.69
5328S0037B	--	17,789	1.18 ± 0.11	-0.2 ± 3.7	0.05	6.25
SU 33 Flood						
5328S0038A	12,826	--	0.91 ± 0.11	1.6 ± 4.0	0.20	4.00
5328S0038B	--	16,535	0.98 ± 0.10	2.5 ± 4.7	0.11	4.18
5328S0039A	12,130	--	0.754 ± 0.080	-2.6 ± 4.1	-0.11	3.13
5328S0039B	--	14,590	0.709 ± 0.088	-0.3 ± 3.6	0.03	2.73
5328S0040A	10,531	--	0.800 ± 0.094	0.4 ± 4.5	0.10	3.17
5328S0040B	--	15,640	0.587 ± 0.069	0.2 ± 3.0	0.03	3.28
5328S0040C	--	--[c]	0.854 ± 0.048	-0.4 ± 2.3	0.03	2.67
5328S0041A	12,682	--	0.853 ± 0.093	1.5 ± 4.4	0.19	3.28

Table B-1. ROC Concentrations and Static Gamma Measurements for Soil Samples						
Sample ID[a]	**γ pre (cpm)**	**γ post (cpm)**	**Ra-226 (pCi/g)**	**Th-230 (pCi/g)**	**SOF**	**Total U (mg/kg)**
5328S0041B	--	15,965	0.851 ± 0.079	-0.9 ± 3.9	0.02	4.08

[a]Sample A collected from 0-15 cm depth; B from 15-30 cm; C from 30-60 cm when possible
[b]Refusal before depth achieved
[c]Borehole diameter was not sufficient to place the detector at the base of the location

APPENDIX C
MAJOR INSTRUMENTATION

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 SCANNING AND MEASUREMENT INSTRUMENT/DETECTOR COMBINATIONS

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 Data Logger (Trimble Navigation Limited, Sunnyvale, California)

C.1.2 Alpha-plus-Beta

Ludlum Scintillation Detector Model 44-142, 100 cm^2 physical area, 1.2 mg/cm^2 Mylar window
(Ludlum Measurements, Inc., Sweetwater, Texas)
coupled to:
Ludlum Ratemeter-scaler Model 2221
(Ludlum Measurements, Inc., Sweetwater, Texas

C.2 LABORATORY ANALYTICAL INSTRUMENTATION

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)

Inductively Coupled Plasma Mass Spectrometer
Perkin Elmer Model: Nexion 300X
(Shelton, Connecticut)
Used in conjunction with:
Nexion 300X ICPMS Software
Dell Workstation
(Perkin Elmer, Shelton, Connecticut)

Alpha Spectrometry System
Canberra Alpha Analyst
(Canberra, Meriden, Connecticut)
Used in conjunction with:
Ion Implanted Detectors Model 7200
Canberra Apex Alpha Software
Dell Workstation
(Canberra, Meriden, Connecticut)

APPENDIX D
SURVEY PROCEDURES

D.1 PROJECT HEALTH AND SAFETY

ORISE performed all survey activities in accordance with the *ORAU Radiation Protection Manual*, the *ORAU Health and Safety Manual*, and the *ORAU Radiological and Environmental Survey Procedures Manual* (ORAU 2014, ORAU 2016b, and ORAU 2016a). 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 the *ORAU Radiological and Environmental Survey Procedures Manual* (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 it 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.

Calibration of field instrumentation and laboratory equipment was performed in accordance with procedures from the following documents:

- *ORAU Radiological and Environmental Survey Procedures Manual* (ORAU 2016a)
- *ORAU Radiological and Environmental Analytical Laboratory Procedures Manual* (ORAU 2017)

Quality control procedures included:

- 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

Gamma scans were performed using a Ludlum 44-10 NaI scintillation detector with a 2-inch × 2-inch crystal. The distance between the detector and surface was maintained at a minimum. The Ra-226 scan minimum detectable concentration (MDC) for the NaI detectors of 4.3 pCi/g was determined in accordance with NUREG-1507 and the following equations:

$$MDCR = d' \times \sqrt{b_i} \times {}^{60}/_{i}$$

Where:

MDCR = minimum detectable count rate

d' = index of sensitivity, assigned value of 2.32

b_i = background counts (~10,000 counts on site) in the observation interval (1 second)

$$Scan\ MDC = \frac{MDCR}{\sqrt{p} \times DEC \times ERC}$$

Where:

p = surveyor efficiency = 0.5

DEC = 2 × 2-in NaI detector efficiency coefficient in cpm/μR/hr for Ra-226 = 821

ERC = exposure rate to concentration ratio for Ra-226 = 0.71

Identifications of elevated radiation levels that could exceed the guidelines were determined based on an increase in the audible signal from the indicating instrument.

D.3.2 Surface Activity Measurements

Measurements of alpha-plus-beta surface activity levels were performed using a Ludlum 44-142 detector coupled to a Ludlum 2221 portable ratemeter-scaler. Count rates (cpm) were integrated over one minute with the detector held in a static position.

The alpha-plus-beta static measurements in cpm were converted to total surface activity units of dpm/100 cm^2 using the equation below:

$$dpm/100\ cm^2 = \frac{C - B}{\varepsilon_{tot} \times G}$$

Where:

C = measured count rate (cpm)

B = background count rate (cpm)

G = geometry factor (unitless) = $\frac{Physical\ Detector\ Area\ (cm^2)}{100\ cm^2} = 1.0$

ε_{tot} = total weighted efficiency (unitless) = 1.1

Due to the number of emissions from Ra-226 and its associated progeny, multiple radiation particles are counted during the surface activity measurement. Therefore, a total weighted efficiency for Ra-226 and its associated progeny was calculated by:

$$\varepsilon_{tot} = \sum_n F_n \times \varepsilon_{i,n} \times \varepsilon_{s,n}$$

Where:

F_n = fractional abundance of n^{th} emission

$\varepsilon_{i,n}$ = instrument efficiency for n^{th} emission

$\varepsilon_{s,n}$ = surface efficiency (0.25 for alpha and low-energy beta particles, 0.5 for high-energy beta particles) for n^{th} emission

The efficiency determination worksheet results are shown in the following:

Weighted Efficiency Input/Output Table								
Nuclide	Half-Life (yrs)	Total Intensity	Mean E (keV)	Max. E (keV)	Relative Fraction	ε_i	ε_s	ε_t
Ra-226 Decay Series Beta Emitters								
Pb-214	5.10E-05	1.00	225	719	0.75	0.56	0.50	0.21
Bi-214	3.79E-05	1.00	639	1,770	0.75	0.62	0.50	0.23
Pb-210	2.22E+01	1.00	6.1	24.4	0.75	0.00	0.25	0.00
Bi-210	1.37E-02	1.00	389	1,160	0.75	0.60	0.50	0.23
							$\sum \beta\varepsilon_t$	0.67
Ra-226 Decay Series Alpha Emitters								
Ra-226	1.60E+03	1.00	4,773	N/A	1.00	0.40	0.25	0.10
Rn-222	1.05E-02	1.00	5,485	N/A	0.75	0.40	0.25	0.08
Po-218	5.89E-06	1.00	6,001	N/A	0.75	0.40	0.25	0.07
Po-214	5.19E-12	1.00	7,686	N/A	0.75	0.40	0.25	0.08
Po-210	3.79E-01	1.00	5,304	N/A	0.75	0.40	0.25	0.08
							$\sum \alpha\varepsilon_t$	0.41
		Worksheet Results in terms of dpm/100 cm^2 Ra-226						
		Total Efficiency ($\sum \alpha\varepsilon_t$, $\beta\varepsilon_t$)						1.1

The MDC for static surface activity measurements was calculated using the following equation:

$$MDC = \frac{3 + (4.65\sqrt{B})}{TG\varepsilon_{tot}}$$

Where:

B = background in time interval, T (1 min)

T = count time (min) used for field instruments

ε_{tot} = total efficiency = $\varepsilon_i \times \varepsilon_s$

G = geometry correction factor (1.00)

The static MDC for an instrument background of 400 cpm was 90 dpm/100 cm^2.

D.3.3 Soil Sampling

Surface soil samples (approximately 0.5 kilogram each) were collected, using a 30-cm core sampler with polybutyrate sleeve or a clean garden trowel. ORISE personnel labeled each sample in accordance with ORISE survey procedures and completed the required custody documentation.

D.4 RADIOLOGICAL ANALYSIS

D.4.1 Gamma Spectroscopy

Samples were analyzed as received, mixed, crushed, and/or homogenized as necessary, and a portion sealed in a 0.1 or 0.25-liter Marinelli beaker. The quantity placed in the beaker was chosen to reproduce the calibrated counting geometry. Net material weights were determined and the samples counted using intrinsic, high purity, germanium detectors coupled to a pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using the computer capabilities inherent in the analyzer system. Sample counts were performed after 27 days to allow the Ra-226 progeny, Pb-214, to ingrow at 99%. All total absorption peaks (TAPs) associated with the ROCs were reviewed for consistency of activity. TAPs used for determining the activities of ROCs and the typical associated MDCs for a one-hour count time were:

Table D-1. Typical MDCs and TAPs for ROCs		
Radionuclide	**TAP (keV)**	**MDC (pCi/g)**
U-238 by Th-234	63.3	0.5
U-235	143.8	0.1
Th-230	67.7	5
Ra-226 (by Pb-214)	351.9	0.1

Typical MDC's are based on 95% confidence level. Because of variations in background levels, sample quantities, measurement efficiencies, and contributions from other radionuclides in samples, the detection limits differ from sample to sample and instrument to instrument.

D.4.2 Mass Spectroscopy

Soil samples were analyzed for total uranium (U-total) by Inductively Coupled Plasma Mass Spectrometry (ICPMS). The ORISE method is similar to ASTM C1345-08 with minor modifications. The samples were prepared and spiked with a known amount of U-232 tracer to determine the chemical yield. The uranium was separated from the matrix using extraction chromatography and the eluted uranium from the columns was split into two fractions. The first fraction was used to measure the U-232 recovery by alpha spectrometry and the second fraction was used to measure the requested uranium isotopes by ICPMS. The U-232 recovery was then applied to the data generated from the ICPMS.

D.4.3 Detection Limits

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