

Final Report on the Radiological Clearance of Land in the Southern 600 Area of the Hanford Site

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-09RL14728



**P.O. Box 650
Richland, Washington 99352**

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Date Published
June 2015

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APPROVED
By Janis D. Aardal at 3:32 pm, Jun 24, 2015

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EXECUTIVE SUMMARY

Mission Support Alliance, LLC, was tasked by DOE-RL to determine if approximately 4,413 acres of land in the Southern 600 Area of the Hanford Site could be radiologically cleared for industrial use in accordance with the requirements of DOE O 458.1, *Radiation Protection of the Public and the Environment*. A large portion of this land, approximately 3,121 acres in the Southern 600 Area, was surveyed and determined to meet the requirements of DOE O 458.1 for radiological clearance. The soil concentrations of radionuclides are at about 1% of the authorized limits and are similar to concentrations found in background areas around the Hanford Site. No areas of elevated radioactivity were found in the areas scanned, and the levels were similar to those found in the background areas of the Hanford Site. No contaminated “land features” were found.

The main steps of the process followed to clear this land were those required by DOE O 458.1 and the *Multi-Agency Radiation Survey and Site Investigation Manual*.

HISTORICAL SITE ASSESSMENT

A historical site assessment was conducted and documented. It concluded that three higher-risk areas should be constrained from this clearance effort, and this reduced the land under consideration for clearance to approximately 3,121 acres. It further concluded that the radiological contamination on the remaining land was low, at or near background levels. The land was divided into three survey units for surveying for radiological clearance.

AUTHORIZED LIMITS

Authorized limits—allowed limits on the levels of radionuclides of Hanford origin in the surface soil—were calculated, documented, and approved. These authorized limits took into account dose limits on a resident farmer and on flora and fauna, as well as the dose limit on industrial workers.

Authorized Limits (pCi/g soil)	
Am-241	1,400
Co-60	11
Cs-137	21
Pu-239/240	1,600
Sr-90	23
U-234	690
U-235	200
U-238	690

SURVEY PLAN

A survey plan to determine if the authorized limits were met was written and approved. It described the number of soil samples to be taken, where and how they would be taken, and how they would be analyzed. It also described the areas to be scanned for small areas of elevated radioactivity in the soil and the scan method to be used. As a final precaution, it described the surveys to be completed on certain “land features,” such as an old gas cylinder and man-made holes in the ground, to ensure that they are not contaminated in excess of the DOE surface contamination guidelines.

SURVEYS

Soil samples were taken at 126 locations, 42 per survey unit, and analyzed by a qualified laboratory. Radiological scan surveys of the surface soil were conducted on six higher-risk areas. Radiological surveys were conducted on eleven higher-risk “land features.”

RESULTS OF SURVEYS

The results of the soil samples show that the concentrations of radionuclides in the surface soil of all three survey units are much less than the authorized limits—on the order of 1%. The soil concentrations are similar to concentrations measured in background areas around the Hanford Site. The scanning surveys did not find any areas of elevated soil concentration; the results were similar to those found in two background areas of the site. No contaminated “land features” were found.

PANEL REVIEW

The survey data as a whole was reviewed by a panel of health physicists, each of whom had some familiarity with different aspects of the radiological clearance of this land. Upon consideration, all members of the panel concluded that the land met the requirements of DOE O 458.1 for radiological clearance.

In conclusion, the approximately 3,121 acres of land in the Southern 600 Area that were surveyed meet the requirements of DOE O 458.1 for radiological clearance. The soil concentrations of radionuclides are at about 1% of the authorized limits and similar to concentrations found in background areas around the Hanford Site. No areas of elevated radioactivity were found in the areas scanned, and the levels found were similar to those found in background areas of the Hanford Site. No contaminated “land features” were found.

1.0 PURPOSE AND SCOPE

1.1 PURPOSE

The purpose of this report is to describe the radiological surveys used to determine if a portion of the land of the Southern 600 Area meets the approved authorized limits for removal from DOE's radiological control.

1.2 SCOPE

This report describes the following elements.

1. Background information concerning the radiological surveys
2. Surface soil sampling and analyses
3. Gamma scanning of land surfaces and analyses
4. Survey of land features noted during the site reconnaissance
5. Review and interpretation of data
6. ALARA assessment and MQOs
7. Review by panel of health physicists
8. Conclusion whether the authorized limits and other requirements have been met.

2.0 BACKGROUND DISCUSSION

2.1 INTENT OF THE LAND CONVEYANCE EFFORT

DOE-RL intends to convey some Hanford land, described as the Southern 600 Area, to other entities, probably commercial firms, to encourage business and industrial development in the area as Hanford completes its cleanup mission.

2.2 DESCRIPTION OF THE LAND TO BE CLEARED

The overall land to be assessed for radiological clearance at some time, called the Southern 600 Area, is shown in Figure 1, *Map of the Southern 600 Area*. As can be seen, the land comprises about 4,413 acres or about 6.9 square miles. However, as explained below, not all of this land is included in the initial conveyance. Figure 2, *Map of the Constrained Areas and Survey Units*, shows the land to be conveyed at this time, which comprises three survey units. The land marked as constrained areas will not be conveyed at this time, as described below. Only the land comprising the three survey units, 3,121 acres, is addressed in this final clearance report.

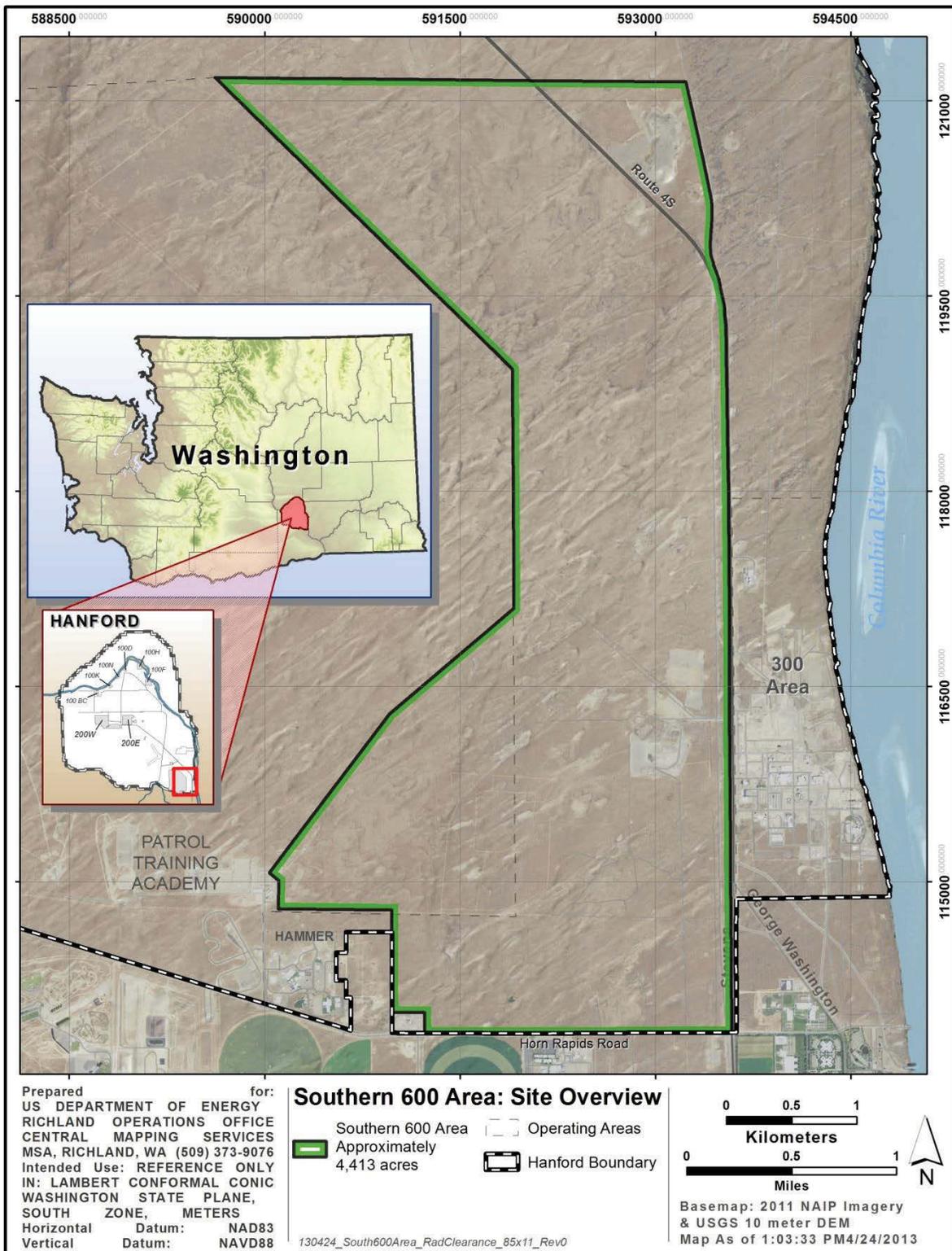


Figure 1. Map of the Southern 600 Area

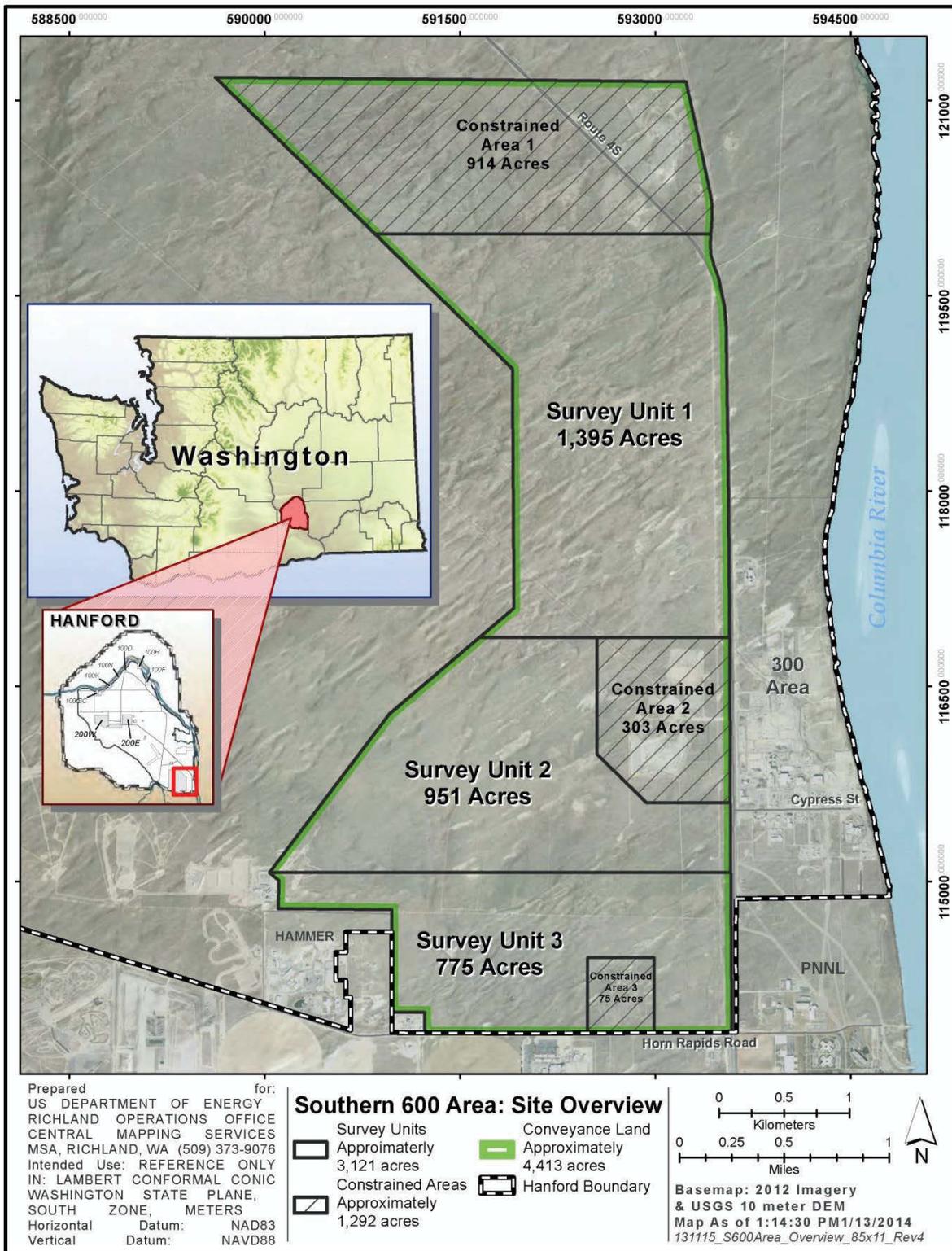


Figure 2. Map of the Constrained Areas and Survey Units

2.3 HISTORICAL SITE ASSESSMENT

As the first step in the land clearance process, a historical site assessment (HSA) of Southern 600 Area was completed in 2012 and revised in 2015 to allow it to be released to the public; see DOE/RL-2012-49, Rev.1, *Historical Site Assessment: Hanford Southern 600 Area* (2).

2.3.1 General Description

The HSA is a comprehensive review of the known radiological history of the Southern 600 Area and is the foundation of the clearance process. Its ultimate purpose is to develop a site conceptual model that specifies the type, extent and distribution of the controlled radioactive contamination on the site. It is from this information that the authorized limits and survey plan is derived.

In this case, the HSA investigated the sources of radioactivity and radiation, both Hanford and non-Hanford, that could possibly have affected the site, as well as the pathways by which that Southern 600 Area could have become contaminated. Specific data reviewed include the scoping surveys (discussed below), past aerial surveys, past radiological surveys, disposal and waste sites on the land. There were specific investigations of potential airborne, soil, biota and groundwater contamination. The potential for contamination along the railroad was also reviewed. As part of the historical site assessment, a team of health physicists did a detailed site reconnaissance, during which radiological scoping measurements were taken.

2.3.2 General Conclusions

The HSA drew some general conclusions that are important for the subsequent clearance process:

1. In order to facilitate the radiological clearance of useful areas of land, three areas, now called Constrained Areas, should be removed from the present clearance activities, due to a higher potential for contamination.
2. The remaining part of the Southern 600 Area should be divided into 3 separate survey units, each of which is MARSSIM Class 3. See Figure 2, *Map Showing Constrained Areas and Survey Units*.
3. The radionuclides of concern are Am-241, Co-60, Cs-137, Sr-90, Pu-239/240, Sr-90, U-234, U-235 and U-238.
4. A scoping survey, completed during the site reconnaissance, at 332 locations across the Southern 600 Area that measured low-energy photons, high-energy photons and surface beta radioactivity found no identifiable source of Hanford radioactivity. These measurements and their results are discussed in more detail below.

5. Historical aerial radiation surveys showed no elevated radiation areas attributable to Hanford radioactivity on the land to be cleared. This supports the classification of the survey units as MARSSIM class 3.
6. Overall, the Hanford radioactivity in the three survey units is likely to be very low, at or near background levels, and in the surface soil.

2.3.3 Scoping Surveys and Conclusions

During the site reconnaissance, radiation measurements were taken to look for any obvious elevated x-ray or gamma radiation level and/or unusual beta activity on the surface of the soil. These measurements are described in detail in HSA section 4.1, *Southern 600 Area Scoping Survey (2)*. Measurements were made at 332 locations for a total of 654 x-ray or gamma (photon) measurements and 321 beta radiation measurements. The photon measurements were made with a 2 inch x 2 inch NaI detector with two channels: 50-450 keV, and 500 keV and greater. The lower energy channel was set up for uranium and the higher energy channel for Cs-137, perhaps Co-60. One minute counts were taken with a scaler. The beta measurements were taken with a 600 cm² scintillator that was calibrated to measure beta energies above 200 keV; it was looking primarily for Pa-234m in the U-238 decay chain. One minute scaler counts were taken. All of these measurements were intended to be relative measurements.

The results of these measurements are displayed in Figure 3, *Map Showing Low Energy Photon Measurement Locations and Kriging*; Figure 4, *Map Showing High Energy Photon Measurement Locations and Kriging*; and Figure 5, *Map Showing Surface Beta Measurement Locations and Kriging*. The scoping survey points are noted as dots. The red shading is a kriging analysis carried out using ArcGIS (See *ArcGIS Help Reference*) (14). A statistical summary of the data from the scoping and background measurements is given in Table 1, *Statistical Summary of the Scoping Measurements*.

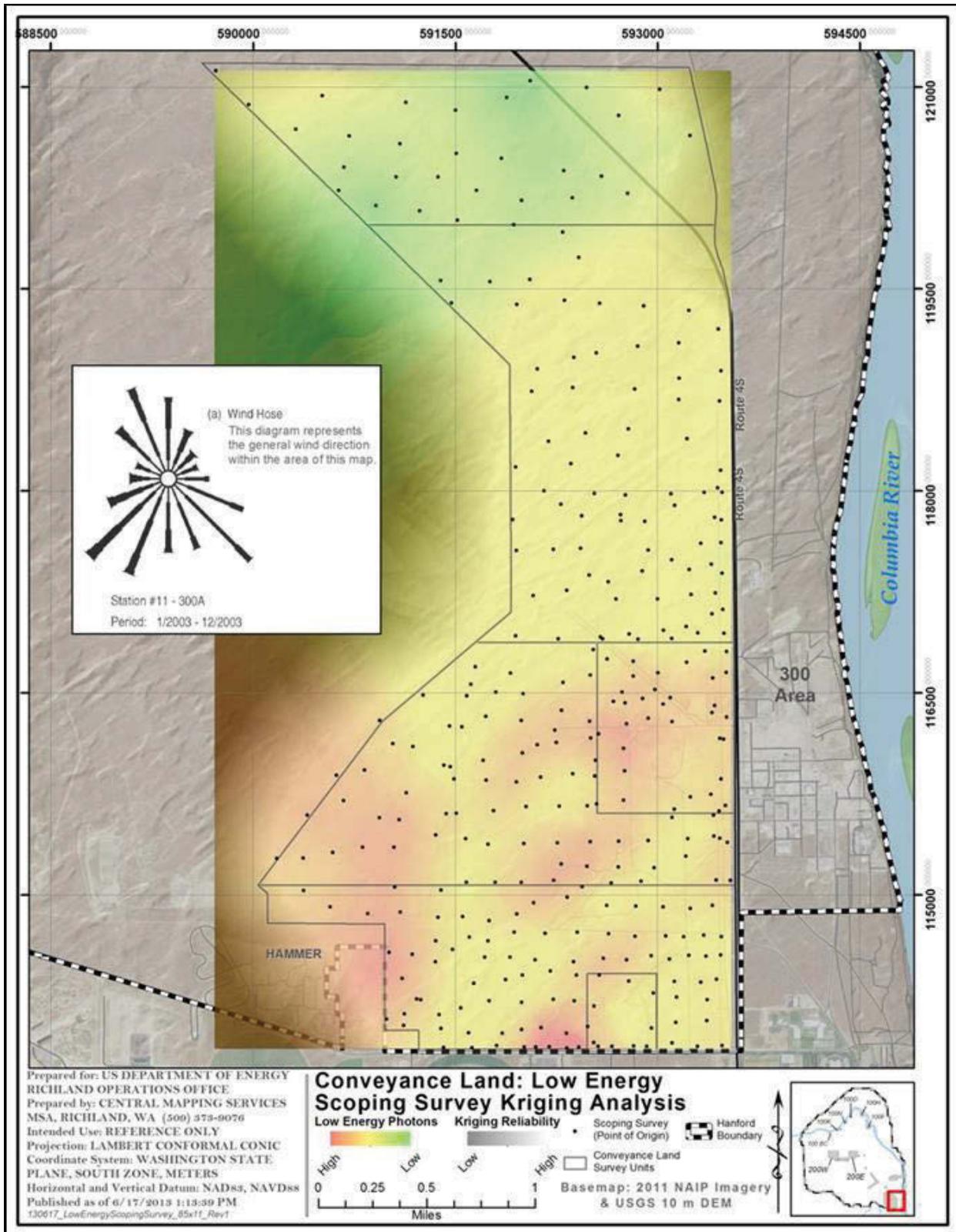


Figure 3. Map Showing Low Energy Photon Measurement Locations and Kriging

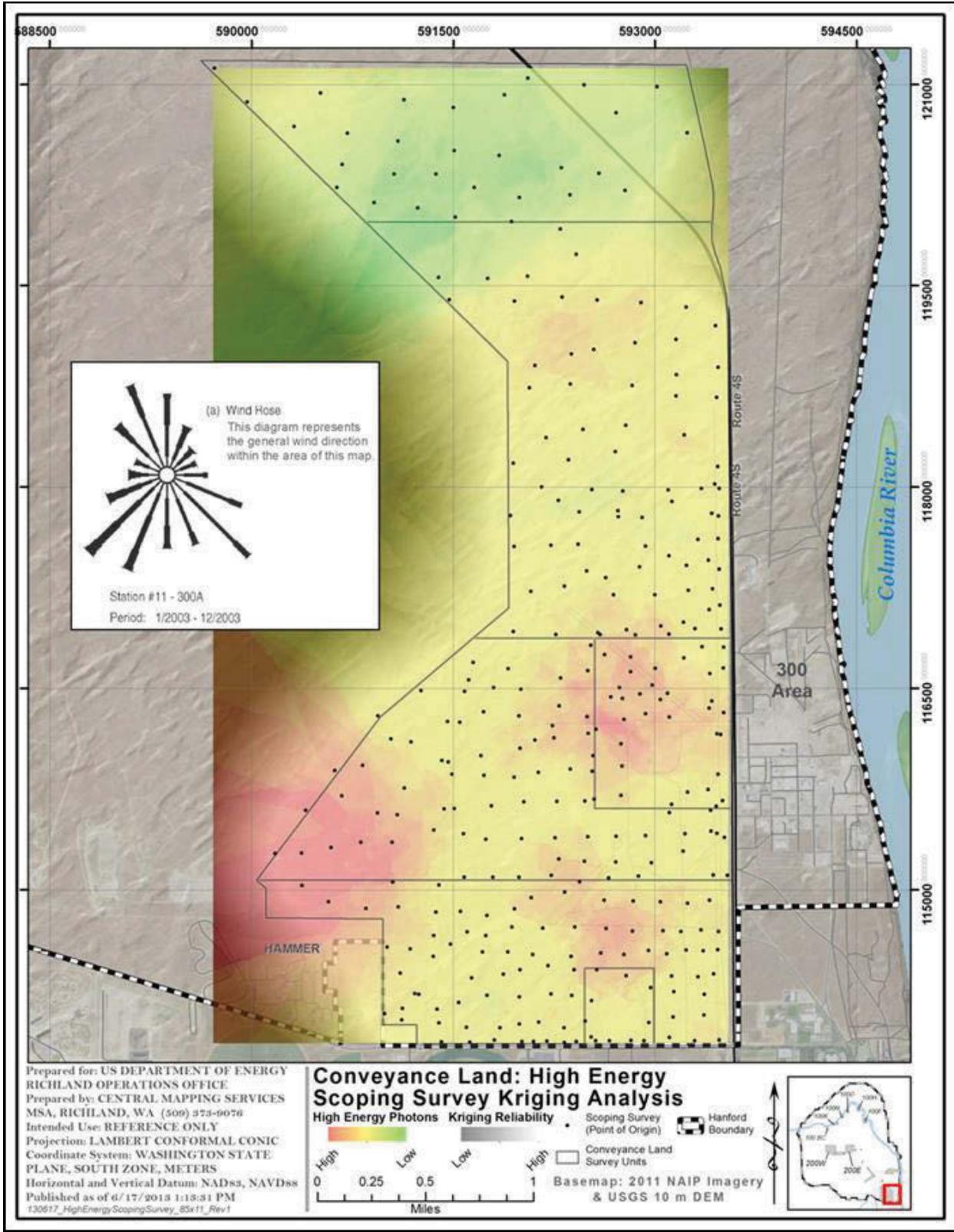


Figure 4. Map Showing High Energy Photon Measurement Locations and Kriging

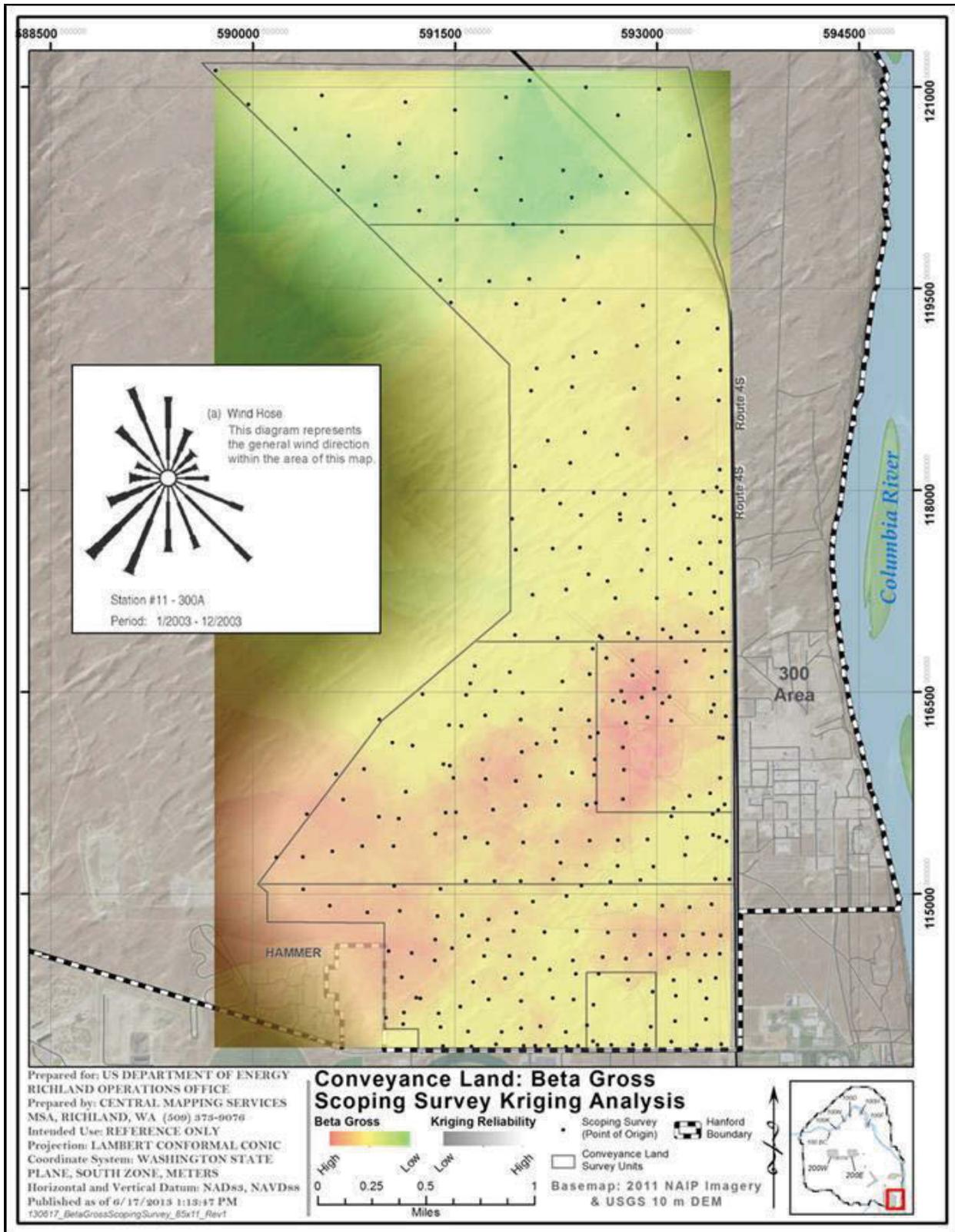


Figure 5. Map Showing Surface Beta Measurement Locations and Kriging

Table 1. Statistical Summary of the Scoping Measurements

Radiation Type	Location	Statistical Distribution	Mean (cpm)	Standard Deviation (SD) (cpm)	Standard Error of the Mean (cpm)	95% Confidence Interval (Mean)	N (Number of Data Points)	Skewness	Kurtosis	Coefficient of Variation [100(SD/Mean)]	Range (Maximum - Minimum Data Value) (cpm)	Interquartile Range (IQR) (cpm)	Maximum Data Value (cpm)	Comments
Gross Beta	Back ground	Normal	1885	88	14	1857-1913	41	-0.06	-0.15	4.67	408	125	2090	
Gross Beta	Entire South 600 Area	Johnson S1	1720	63	3.5	1712-1727	321	-0.28	0.32	3.67	401	85	1890	Normal is second best fit.
Gross Beta	SU1	Normal	1709	43	5.4	1698-1719	80	-0.25	0.45	2.81	273	66	1827	
Gross Beta	SU2	Normal	1734	58	7.2	1720-1749	65	-0.1	-0.72	3.35	252	95	1855	Very nearly the same as SU3 (statistically).
Gross Beta	SU3	Normal	1732	61	6.6	1719-1745	83	-0.1	0.37	3.49	315	74	1890	Very nearly the same as SU2 (statistically).
High Energy Photons	Back ground	Lognormal	1199	58	8.2	1183-1216	50	0.1	-0.39	4.81	238	69	1318	Normal very nearly as good a fit.
High Energy Photons	Entire South 600 Area	Gamma	1109	60	3.3	1102-1115	327	0.09	0.43	5.45	373	75	1292	Normal very nearly as good a fit.
High Energy Photons	SU1	Normal	1100	48	5.3	1089-1111	80	-0.19	-0.69	4.34	200	76	1192	
High Energy Photons	SU2	Lognormal	1117	60	7.4	1102-1131	65	0.53	0.34	5.33	271	68	1275	Normal is close. SU2 very nearly the same as SU3 except SU3 more kurtic.
High Energy Photons	SU3	Lognormal	1117	56	6.1	1105-1129	83	0.51	0.51	5.01	281	64	1292	Normal is close. SU3 very nearly the same as SU2 except SU3 more kurtic.

Radiation Type	Location	Statistical Distribution	Mean (cpm)	Standard Deviation (SD) (cpm)	Standard Error of the Mean (cpm)	95% Confidence Interval (Mean)	N (Number of Data Points)	Skewness	Kurtosis	Coefficient of Variation [100(SD/Mean)]	Range (Maximum - Minimum Data Value) (cpm)	Interquartile Range (IQR) (cpm)	Maximum Data Value (cpm)	Comments
Low Energy Photons	Back ground	Johnson SI	7621	256	36.2	7548-7693	50	0.64	0.34	3.36	1215	346	8298	Normal not too bad a fit, but high skewness.
Low Energy Photons	Entire South 600 Area	Johnson SU	7019	456	25.2	6970-7069	327	1.32	5.86	6.49	3982	487	9629	Apparent streaming from AREVA; high skewness & kurtosis; high maximum data value & range; high SD.
Low Energy Photons	Entire South 600 Area	Normal 2 Mixture	6985	381	21.3	6943-7027	320	0.06	0.54	5.46	2429	468	8076	Apparent AREVA values removed. "Normal 2 Mixture" fits a mixture of 2 normals.
Low Energy Photons	SU1	Normal	6788	196	21.9	6744-6832	80	-0.34	0.57	2.89	1059	250	7227	
Low Energy Photons	SU2	Lognormal	7157	356	44.2	7068-7245	65	0.45	0.1	4.98	1585	470	8076	Near normal.
Low Energy Photons	SU3	Johnson SI	7154	430	47.2	7061-7249	83	2.05	6.84	6.01	2653	445	9186	Includes high apparent AREVA values.
Low Energy Photons	SU3	Johnson SI	7094	308	34.7	7025-7163	79	0.63	0.19	4.35	1417	443	7950	Apparent AREVA values removed. Skewed some & off normal.

In brief summary, the following can be taken from these values:

1. For all three types of measurements, the activity in Survey Unit 1 is lower and more uniform than the other two survey units, but the differences are quite small.
2. For all three measurements, Survey Units 2 and 3 are statistically virtually identical.
3. The variations for all three measurements across the survey units is small: The coefficient of variation ranges from about 2.8% to about 5.3%.
4. For all three radiations (low-energy photons, high-energy photons, and beta particles), it can be seen from the values in the table that the mean values for the radiation in each survey unit are actually less than the mean values from the background areas. The background areas are in an area of the Hanford Site believed to be largely unaffected by site operations. Although the background radiation measurements were taken at a different time and there are substantially fewer of them, nevertheless, this suggests that the man-made activity levels in the surveys units are small and near background levels.

In summary, within the limits of these scoping measurements, the soil radioactivity across the Southern 600 Area is fairly uniform and very likely at or near background levels.

2.4 AUTHORIZED LIMITS

The next step in the clearance process is the development and approval of authorized limits. The authorized limits were developed primarily for the intended industrial use of the site and are based upon the conclusions of the HSA.

2.4.1 Basis of the Authorized Limits

Although the intended use of the site is industrial, the authorized limits were developed from three considerations: the intended industrial use, the low-probability use of land by a resident farmer, and the dose to biota, as required by DOE O 458.1. The calculation were carried out primarily with RESRAD (7), a DOE sponsored and approved environmental modelling code from Argonne National Laboratory, for the radionuclides of concern for three cases: 25 mrem/y to an industrial worker; 100 mrem/y to a resident farmer; 1 rad/d to plants and 0.1 rad/d to animals. The approved authorized limit for each radionuclide is the smallest value derived from these four cases. See Table 2, *Authorized Limits*.

Table 2. Authorized Limits

Authorized Limits (pCi/g soil)	
Am-241	1,400
Co-60	11
Cs-137	21
Pu-239/240	1,600
Sr-90	23
U-234	690
U-235	200
U-238	690

2.4.2 Approval

The authorized limits were approved (5) by the Manager, DOE-RL, in consultation with DOE-HQ (6).

2.5 MAIN SURVEY PLAN

The next step in the clearance process is to develop and describe the means by which the land will be tested to see if it meets the authorized limits and is free of any small areas of concentrated radioactivity that might be missed by a relatively low-density class 3 soil sampling campaign. This was done by way of the main survey plan, HNF-57979, Rev.0, *Survey Plan for the Radiological Clearance of a Portion of the Southern 600 Area of the Hanford Site* (8).

The main survey plan describes the radiological surveys and other activities that need to be done in order to determine if the land can be radiologically cleared. The descriptions in the survey plan concentrate on the primary technical and radiological requirements and cannot, as a practical matter, call out the details of the processes to be used for surveys. These processes are described in lower-level or sub-tier survey plans described below.

In general, the main survey plan describes the bases and requirements of the following.

1. Soil Sampling Points
2. Location and Extent of Gamma Scanning Areas
3. "Land Features" to be Surveyed
4. Three Sub-tier Survey Plans to Guide Field Surveys
5. Measurement Quality Objectives
6. Operating Instructions
7. Training
8. ALARA Assessment

2.6 LOWER-LEVEL SURVEY PLANS

As discussed above, the main survey plan calls out three lower-level survey plans to guide actual field implementation.

2.6.1 Soil Sampling

The details of soil sampling are described in LTS Test Plan, *Radiological Soil Sampling Plan for Survey Units 1, 2, & 3 in the Southern 600 Area* (10), which was reviewed and approved by the Lead Health Physicist before it was implemented.

2.6.2 Gamma Scan Surveys

The details of gamma scanning surveys are described in LTS Test Plan, *Mobile Gamma Spectrometer Scan Surveys of the Southern 600 Area* (11), which was reviewed and approved by the Lead Health Physicist before it was implemented.

2.6.3 Land Features Surveys

The details of the land features surveys are described in LTS Test Plan, *Land Features Survey Plan for the Southern 600 Area* (12), which was reviewed and approved by the Lead Health Physicist before it was implemented.

2.7 OTHER IMPLEMENTING DOCUMENTS AND ACTIVITIES

The surveys and operating instructions used to perform these land clearance activities were constituted under MSA's Long-Term Stewardship (LTS) program and are primarily intended for radiological monitoring under the LTS program and for land clearance activities, although it is available for use for other company requirements.

2.7.1 Other Implementing Documents

Operating instructions, in the form of LTS Desk Instructions, have been written to control such things as the operation of specialized LTS radiation detection instruments, soil sampling, data analysis and presentation, technical basis documents, technical notes, test plans, training and other required functions. All desk instructions are approved by the Lead Health Physicist before they are used. See Table 3, *List of Desk Instructions Used*.

Table 3. List of Desk Instructions Used

List of Desk Instructions Used
Assignments and Responsibilities of the LTS Radiological Monitoring Staff
Data Representation and Data Analysis
Logistical Aspects of Radiological Surveys
LTS Radiological Monitoring and Real Property Radiological Clearance Desk Instructions
Maintaining Formal and Informal Records
Operation of the Polaris Ranger Diesel
Operation of the RS-700 Mobile Gamma Spectrometer
Operation of the Berkeley Nucleonics SAM 940 Gamma Spectrometer
Operation of the ORTEC Detective DX-100 for Radionuclide Identification
Soil Sampling
Technical Basis Documents
Technical Notes
Test Plans
Training and Qualification on Specialized Long-Term Stewardship Radiological Monitoring Equipment
Use & Control of LTS Radiological Monitoring Equipment

2.7.2 Training

All radiological control technicians are trained on the special aspects of LTS radiological surveys before they undertake these activities. For instance, they are trained on the use of the Mobile Gamma Spectrometer, the ORTEC Detective intrinsic germanium spectrometer and the Berkeley Nucleonics SAM-940 spectrometer before they can do surveys for record. Training is carried out under LTS Desk Instruction *Training and Qualification on Specialized Long-Term Stewardship Radiological Monitoring Equipment* and records of the training are kept. Training on soil sampling was also given to the Radiological Control Technicians who took soil samples. All training is approved by the Lead Health Physicist.

3.0 SOIL SAMPLING

3.1 LOCATIONS OF SOIL SAMPLES

3.1.1 How Sample Locations Were Chosen

The number of soil sampling locations was chosen using *Visual Sample Plan* (9), which was sponsored by DOE and developed by the Pacific Northwest National Laboratory. The inputs to the calculation were chosen and agreed to by the Lead Health Physicist, a DOE health physicist and an independent health physicist from Dade Moeller, Inc. *Visual Sample Plan* calculated that 35 locations in each survey unit would be needed to meet the sampling requirements. Additional sample points are recommended to account for any loss of data, such as a failed sample analysis, and *Visual Sample Plan's* recommended default of 20% was accepted (large numbers of failures were not anticipated) for a total of 42 samples per survey unit. This selection process is

documented in the main sample plan, HNF-57979, Rev.0, *Survey Plan for the Radiological Clearance of a Portion of the Southern 600 Area of the Hanford Site* (8).

The exact location of the samples was also calculated by *Visual Sample Plan*, but under circumstances needed to meet DOE-HQ's request that there be evidence that the sample locations were fairly chosen and that there was no cherry-picking of sample locations. The determination of these points was witnessed by a DOE representative, Mr. Frank M. Roddy, then of DOE-RL and an independent observer, Dr. James D. Hoover, former Dean of Environmental Engineering, Washington State University. See Figure 6, *Map Showing Soil Sampling Locations*.

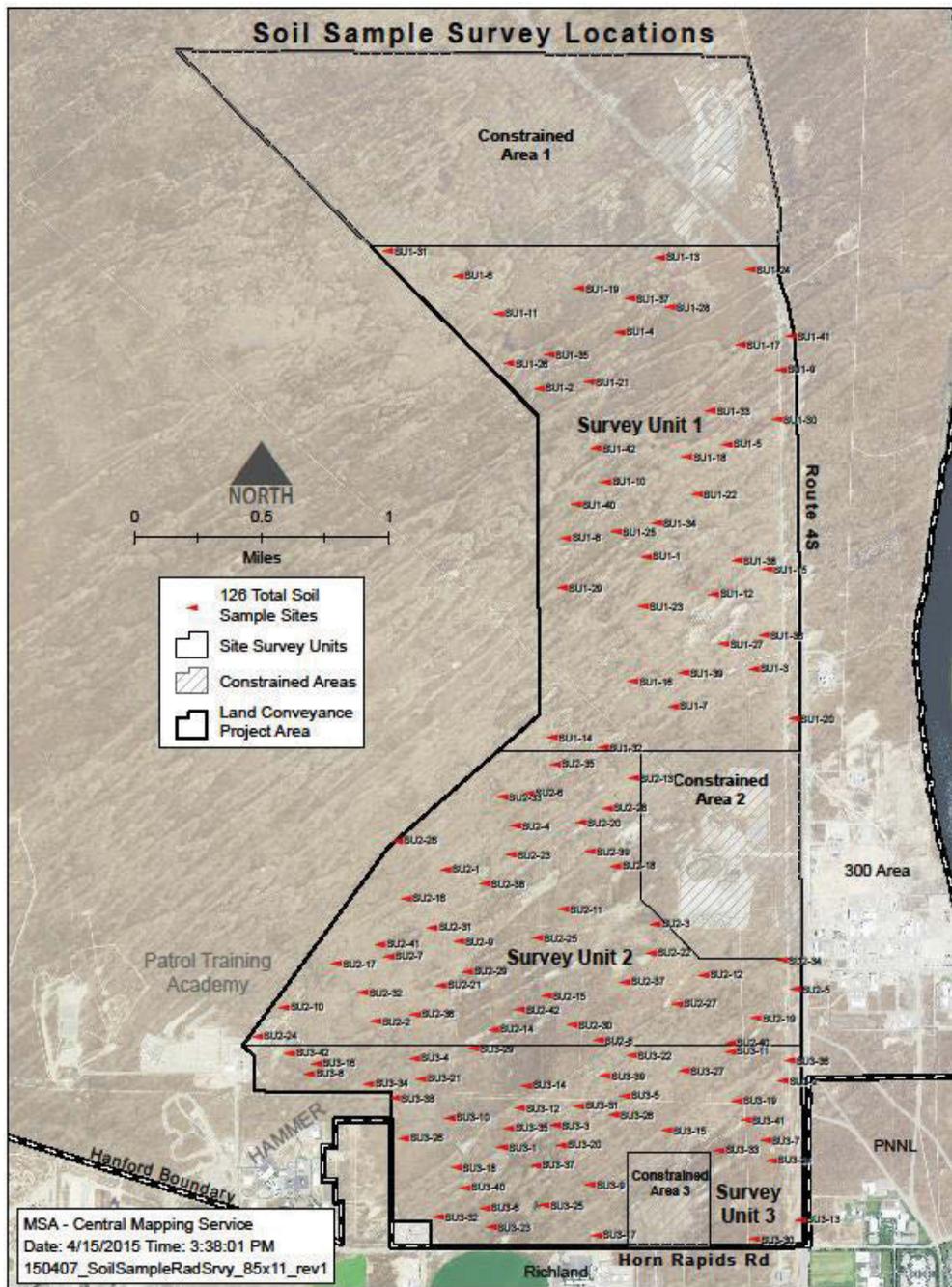


Figure 6. Map Showing Soil Sampling Locations

3.1.2 How Samples Were Taken and Controlled

Samples were taken in accordance with LTS Test Plan, *Radiological Soil Sampling Plan for Survey Units 1, 2, & 3 in the Southern 600 Area (10)* and LTS Desk Instruction *Soil Sampling*.

The precise locations were found by an MSA cartographer using a GPS instrument. At each location, five 6-inch deep soil samples were taken within about 20 feet of the central location and sieved and composited in a mixing bowl. After mixing, a 500 ml sample was taken and placed into a 500 ml Nalgene bottle. The bottle was sealed and labeled with an ABCASH identification label. ABCASH (Automated Bar Coding of Air Samples at Hanford) is an existing electronic bar-code sample control system used at Hanford to control environmental and other samples for analysis. At the end of the day, the samples were either stored or delivered to the analytical laboratory under strict chain-of-custody requirements. Some photos of the soil sampling follow.









At 12 locations, 4 in each survey unit, MSA took duplicate samples from the mixing bowl to use as blind samples for TestAmerica to analyze to check the repeatability of their analyses. See Figure 7, *Map Showing Soil Sample Duplicate Locations*.

At 18 of MSA's locations in each survey unit, DOE's independent verification contractor, ORISE, took a single 6-inch soil sample as part of their verification program. ORISE used rank-set sampling to select 6 samples from each survey unit for independent analysis at their laboratory in Oak Ridge, Tennessee. See Figure 8, *Map Showing Soil Sample Locations Common with ORISE*.

3.2 LABORATORY ANALYSES

3.2.1 Laboratory Used

Soil sample analysis was done at TestAmerica Richland, which is approved by DOE for the analyses of radionuclides in soil.

3.2.2 Analyses Done and QA

TestAmerica analyzed each soil sample for the 8 radionuclides for which there are authorized limits (Am-241, Co-60, Cs-137, Sr-90, Pu-239/240, U-234, U-235 and U-238), the two that were requested by DOE-HQ (Th-232 and Ra-226), and 4 others requested by the Lead Health Physicist for analytical purposes (Pa-234m, K-40, Bi-214 and Tl-208). TestAmerica also provided results for Pu-238. Only the results for the 8 radionuclides for which there are

authorized limits and the two requested by DOE-HQ are discussed here. TestAmerica used approved methods for their analyses.

The 12 blind samples were sent to TestAmerica with no information about the location from which they were taken. The same analyses were done on this samples as on the other samples.

The Lead Health Physicist requested one element of analytical data that TestAmerica does not normally report for soil sample, the decision level (Currie's critical level, L_c). TestAmerica normally reports the minimum detectable concentration for such samples, but the decision level—in accordance with Currie's method—was used in the analyses reported here to determine whether activity has been detected in the samples or not.

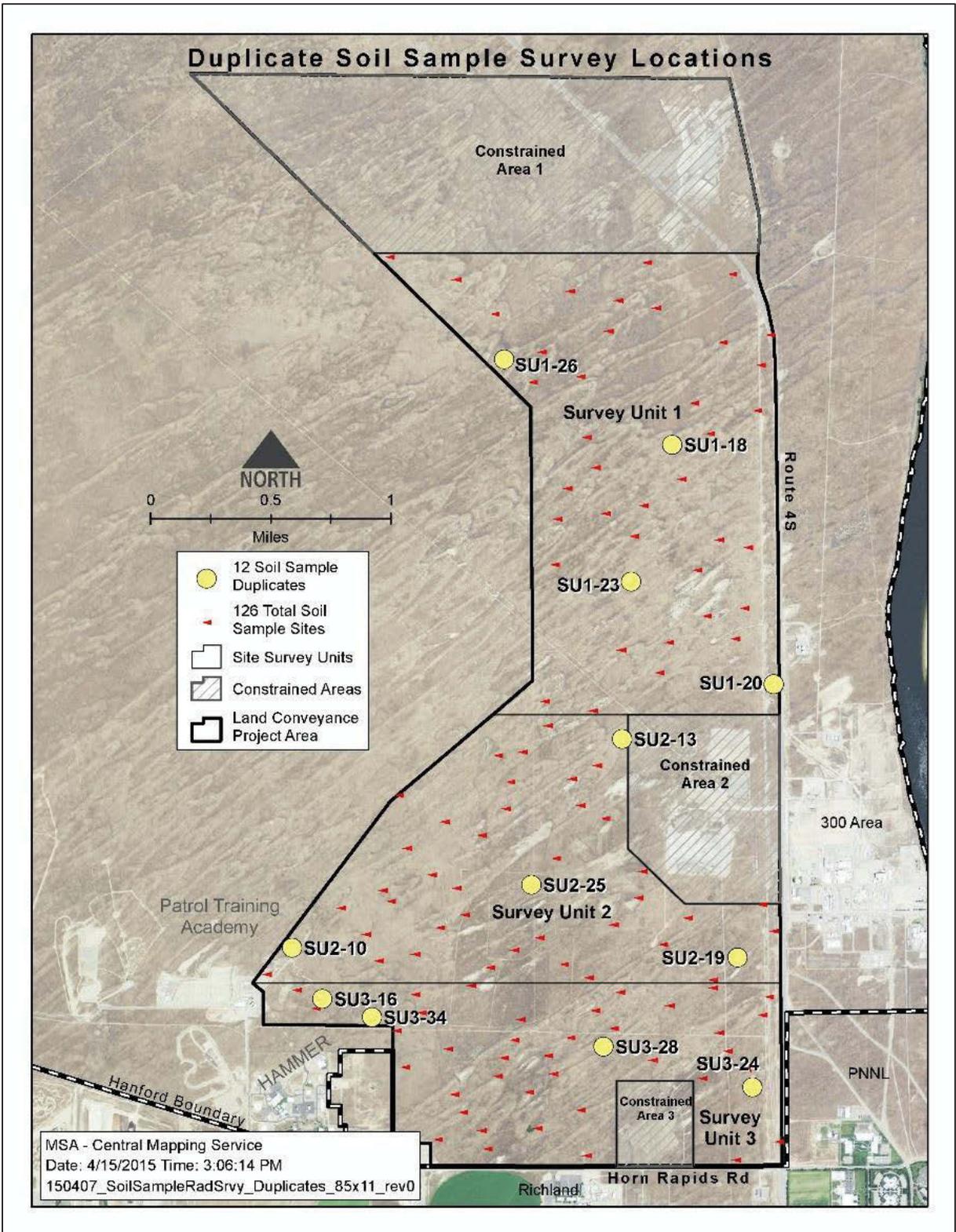


Figure 7. Map Showing Soil Sampling Duplicate Locations

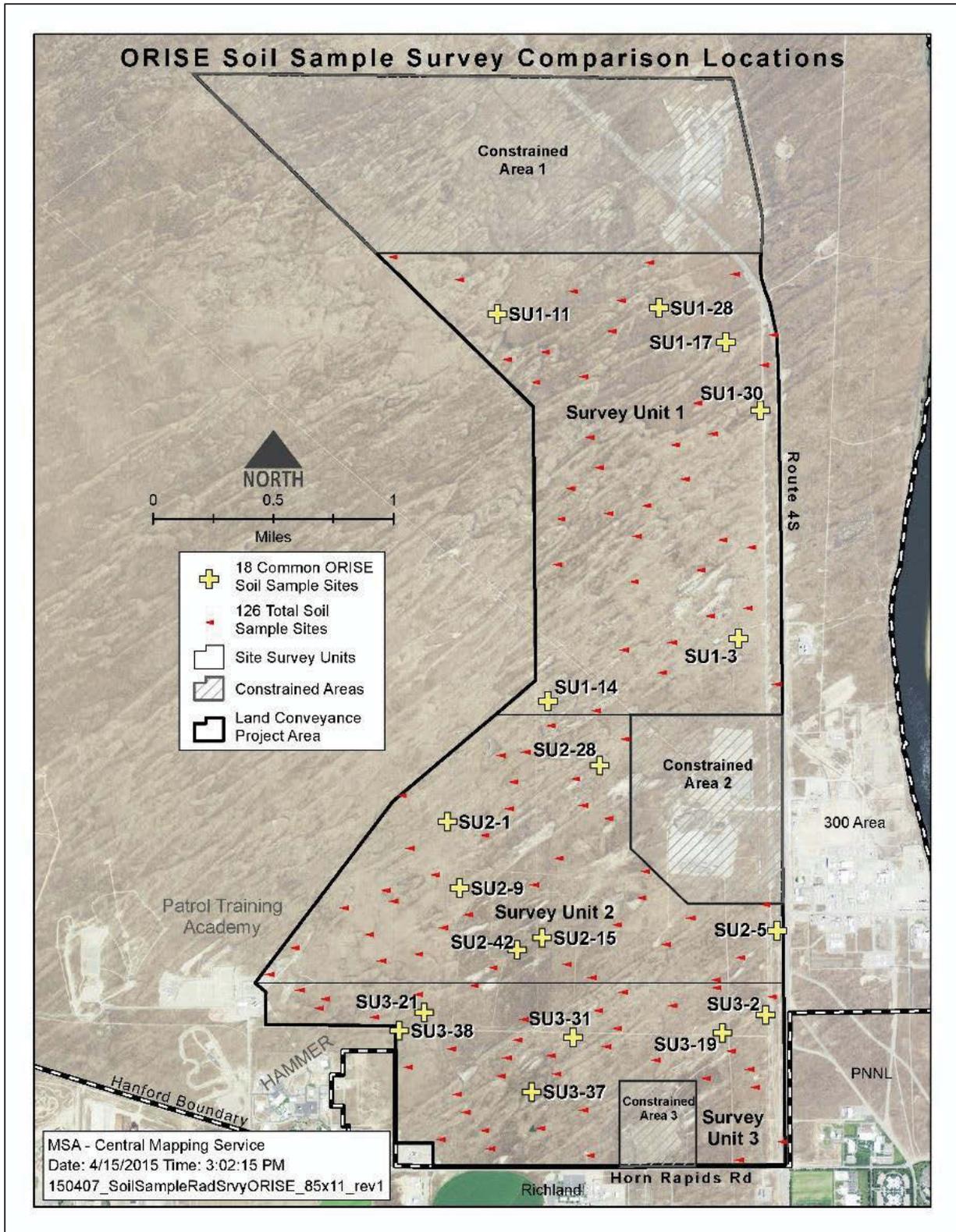


Figure 8. Map Showing the Soil Sample Locations Common with ORISE

3.2.3 Outcome of Data Review

During the data review, two small reporting anomalies—not problems with the data itself, just the reporting—were found. These were reported to TestAmerica, who promptly corrected them. Once the reviewed spreadsheet of data was completed, it was archived onto a MSA share drive that is backed-up nightly. A second spreadsheet was developed with some additional columns that explicitly stated the survey unit and sample number for each result. This spreadsheet of data was provided to ORISE for their review. A third, considerably simplified, spreadsheet was developed by removing columns of data—such as the specific instrument used for a given analysis—that would not be used in the analysis of the data. This third spreadsheet was used for all data analyses.

3.3 DATA ANALYSES FOR SOIL SAMPLING

3.3.1 Methods of Analyses

All analyses of soil sampling data, as well as gamma scanning data, were carried out by the Lead Health Physicist using *Mathematica*¹ 10 (13). *Mathematica* was chosen for this work for a number of reasons. *Mathematica* is a widely-used, well-developed and strongly-supported technical programming package. In addition to extensive mathematical functions, it has strong list processing and graphical capabilities, which are particularly useful for these applications. It uses a functional programming language—as opposed to procedural—and it is thus much quicker to program; it has over 5,000 built-in functions and supports user-defined functions. *Mathematica* uses a notebook format that allows the user to add text and graphics directly in the notebook, as well as the mathematical programming. This allows the user to add needed explanation directly at the point of the programming, and it shows the step-by-step development of the calculations. The notebooks can be saved as pdf files.

Mathematica also contains facilities that assist the user in making sure that the calculations are valid. As presently practiced, each *Mathematica* notebook used in this work has a section called “Checks on Commands” that contains small problems with known answers for each main function used that are run each time the notebook is evaluated to ensure that the main functions are evaluating properly. It also contains facilities that allow the user to see the data actually being used by a given function in tabular form, so that he can check to see that it is as expected.

3.3.2 Results of Analyses

The analytical data from the soil analyses were analyzed for three cases. First, for each survey unit, the data was analyzed to determine if the authorized limits have been met. This is supported by a comparison of the measured values of soil concentrations to published site background values. Second, the duplicate samples were analyzed to determine if the repeatability of TestAmerica’s analyses are adequate. Third, the results of ORISE’s soil analyses were compared to TestAmerica’s analyses to determine if the results provided by TestAmerica are of sufficient accuracy to determine if the authorized limits have been met.

¹ Mathematica is a trademark of Wolfram Group, LLC

All calculations for these analyses were carried out in LTS Technical Note *Southern 600 Area Soil Sample Analyses*, Rev.0 (15). The data was saved as a Common Separate Variable file and read into *Mathematica 10* as a nested list.

3.3.2.1 Authorized Limits Tests

For each radionuclide with an authorized limit in each survey unit, the concentration of the radionuclide in pCi/g soil was evaluated against the decision level, Lc. If it was equal to or greater than the decision level, the value was used as reported; if it was less than the decision level, half the decision level was reported for its value in the calculation of authorized limit. Once this was done, the mean of these values for each radionuclide (for a given survey unit) was divided by its authorized limit and the values for each radionuclide so calculated were summed.

The values in pCi/g soil for each radionuclide in each survey unit and across all three survey units are shown in the following distribution charts. See Figures 9–16. Note: These distribution charts illustrate fitted distributions of data and in some case drop slightly below zero. No values used were actually negative, and the negative values are artifacts of the fitting. Nevertheless, these charts give a good sense of the magnitudes and distributions of the data.

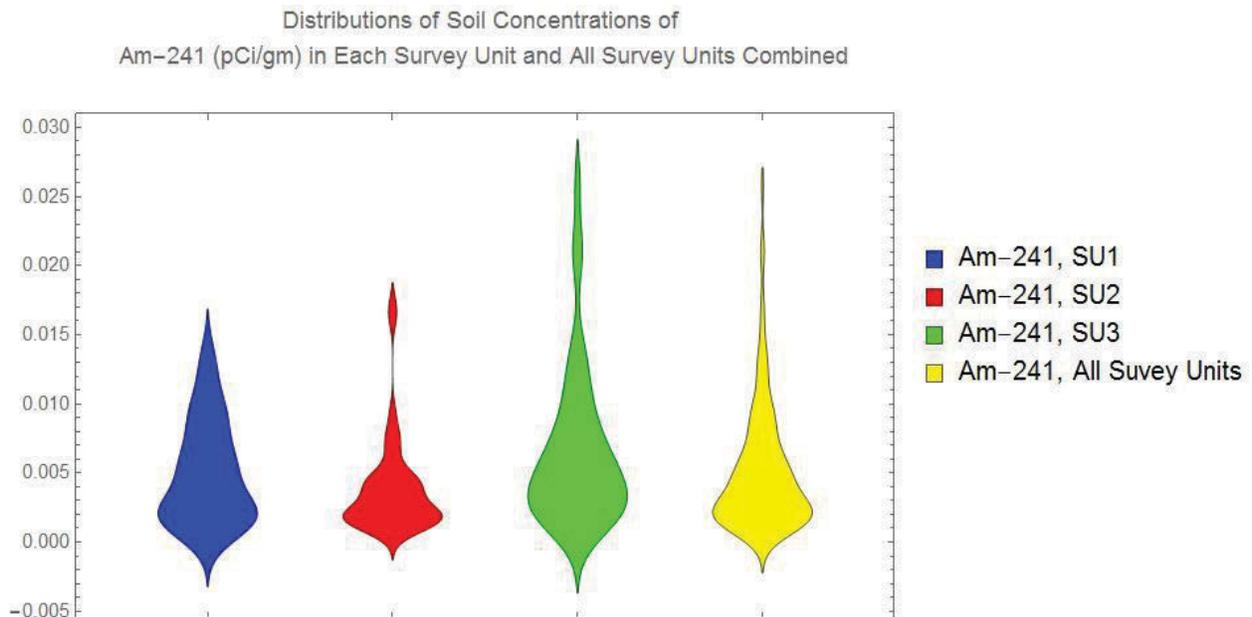


Figure 9. Distribution of Soil Concentrations of Am-241 (pCi/g) in Each Survey Unit and All Survey Units Combined

Distributions of Soil Concentrations of
Co-60 (pCi/gm) in Each Survey Unit and All Survey Units Combined

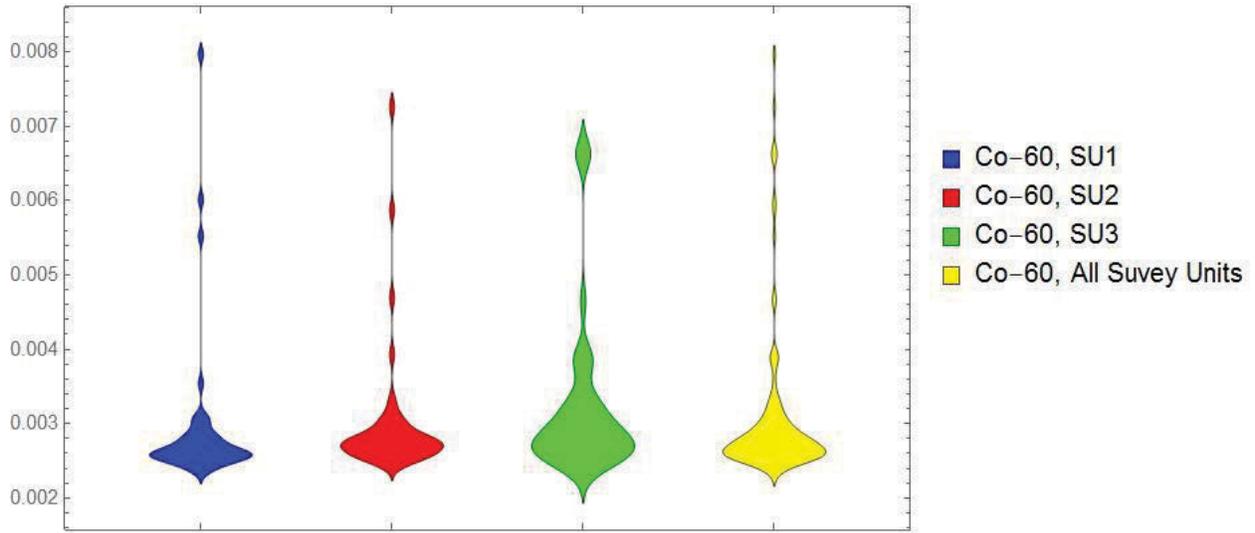


Figure 10. Distribution of Soil Concentrations of Co-60 (pCi/g) in Each Survey Unit and All Survey Units Combined

Distributions of Soil Concentrations of
Cs-137 (pCi/gm) in Each Survey Unit and All Survey Units Combined

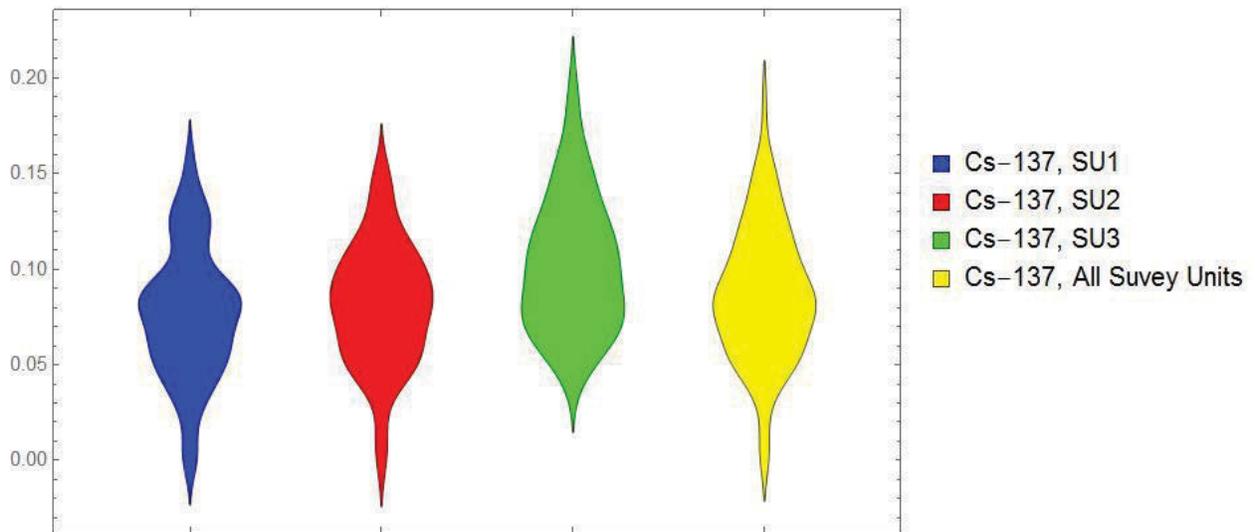


Figure 11. Distribution of Soil Concentrations of Cs-137 (pCi/g) in Each Survey Unit and All Survey Units Combined

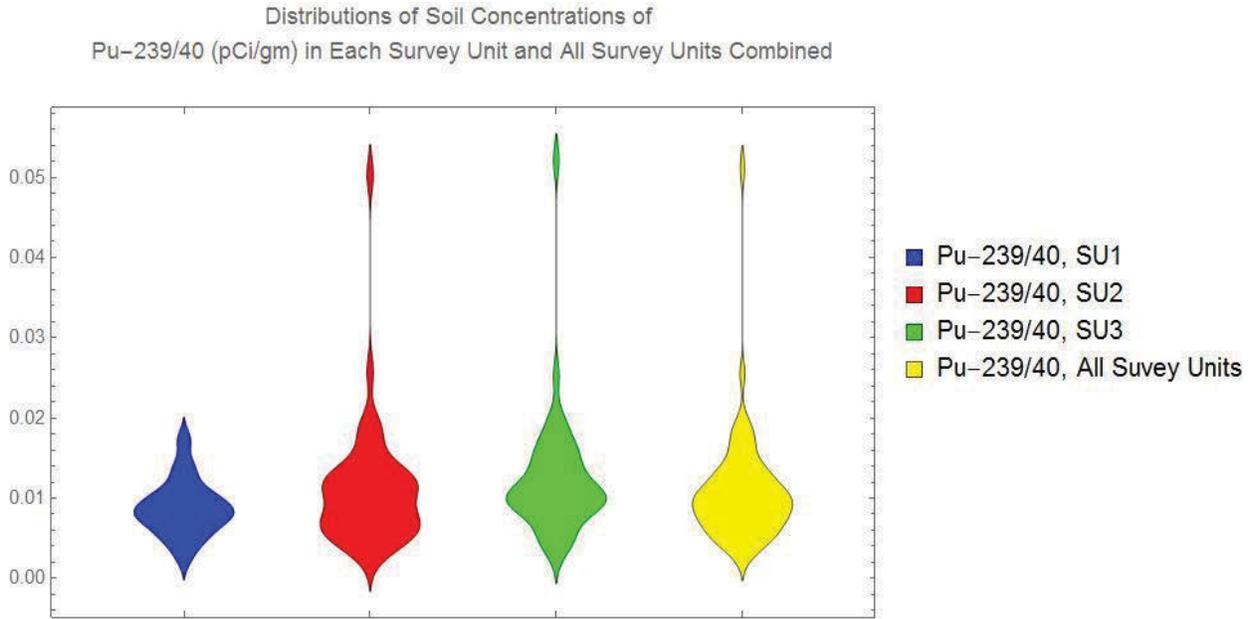


Figure 12. Distribution of Soil Concentrations of Pu-239/40 (pCi/g) in Each Survey Unit and All Survey Units Combined

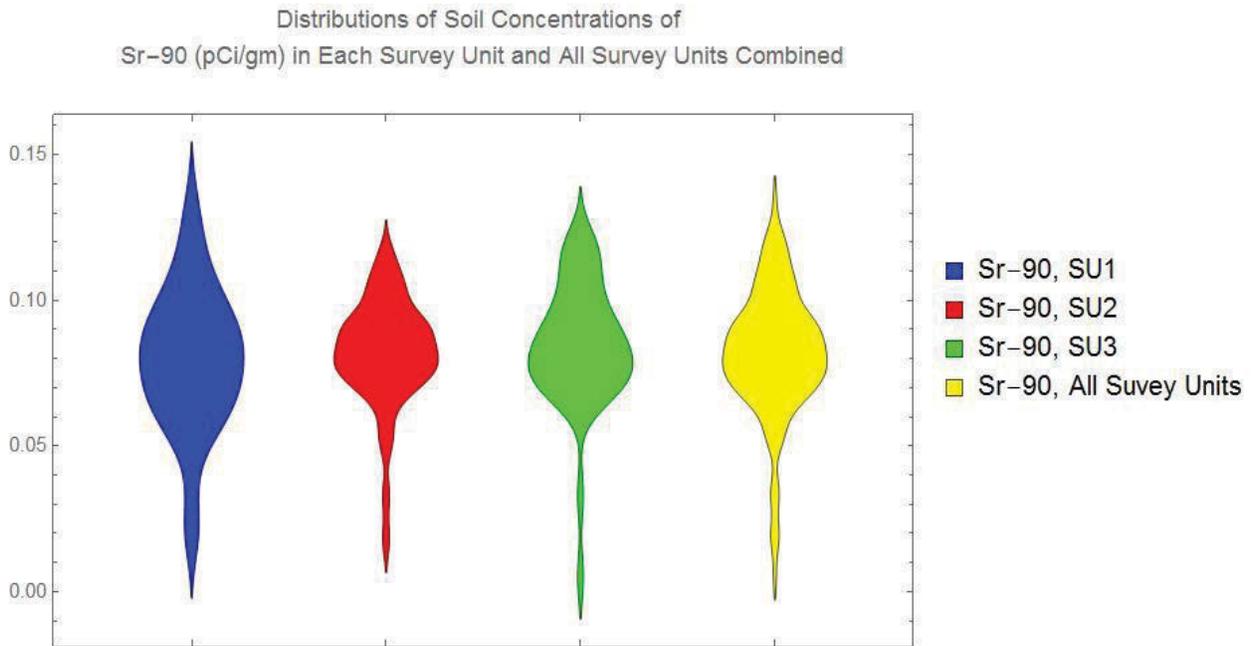


Figure 13. Distribution of Soil Concentrations of Sr-90 (pCi/g) in Each Survey Unit and All Survey Units Combined

Distributions of Soil Concentrations of
U-234(pCi/gm) in Each Survey Unit and All Survey Units Combined

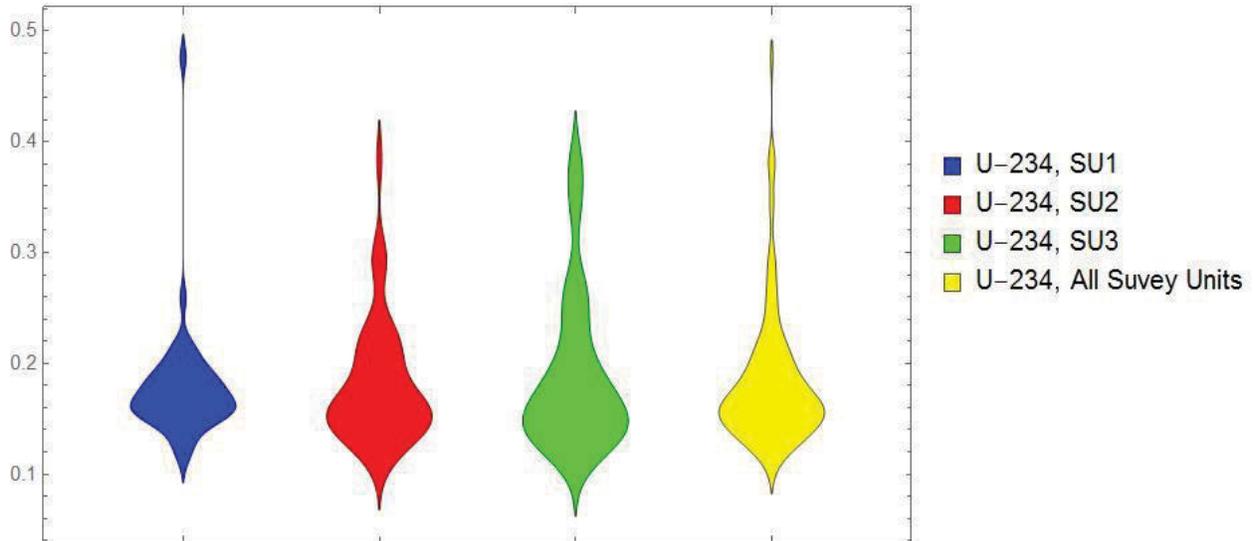


Figure 14. Distribution of Soil Concentrations of U-234 (pCi/g) in Each Survey Unit and All Survey Units Combined

Distributions of Soil Concentrations of
U-235 (pCi/gm) in Each Survey Unit and All Survey Units Combined

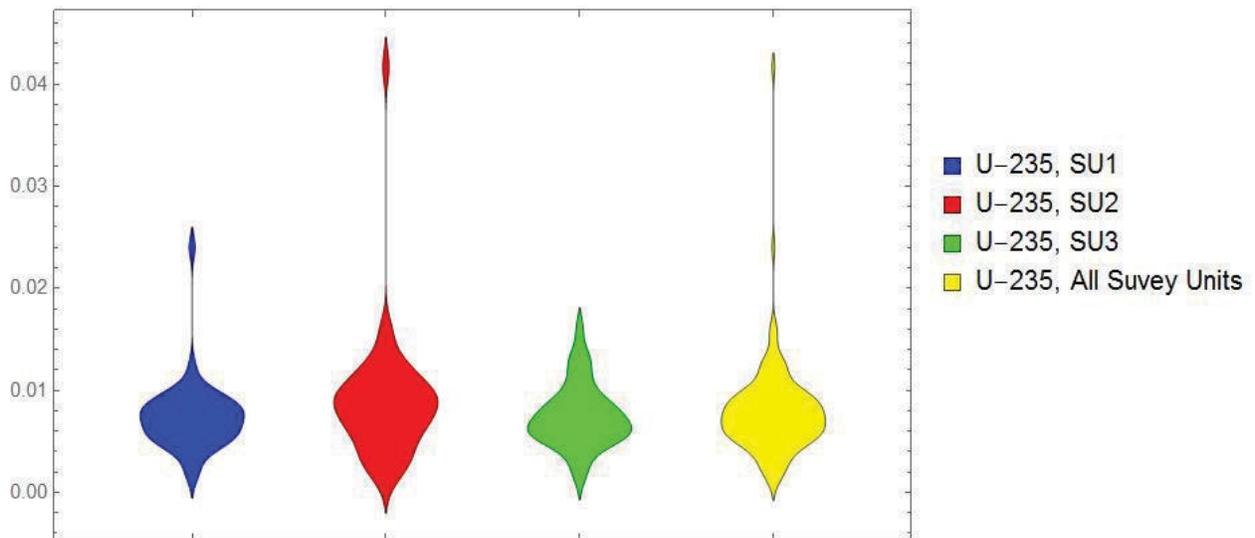


Figure 15. Distribution of Soil Concentrations of U-235 (pCi/g) in Each Survey Unit and All Survey Units Combined

Distributions of Soil Concentrations of
U-238 (pCi/gm) in Each Survey Unit and All Survey Units Combined

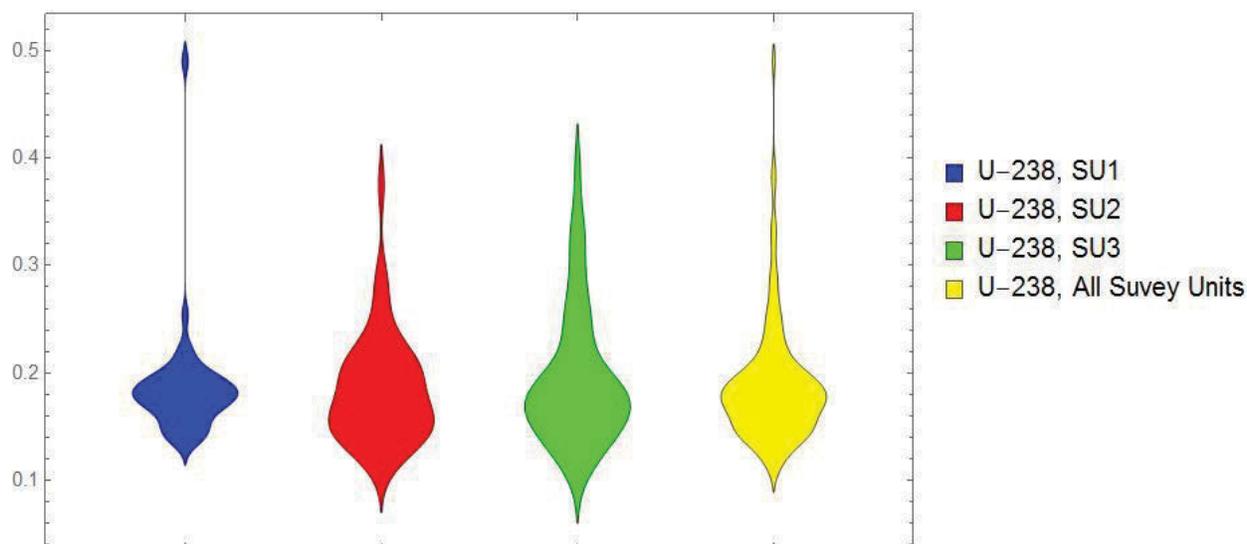


Figure 16. Distribution of Soil Concentrations of U-238 (pCi/g) in Each Survey Unit and All Survey Units Combined

An understanding of the actual magnitudes of the ratios in the sum-of-fractions calculations for the authorized limits can be gained for each radionuclide by calculating the sum-of-fractions using the mean and maximum values of the concentrations. See Table 4, *Magnitude of Measured Values of Soil Concentrations for All Survey Units Combined*.

Table 4. Magnitude of Measured Values of Soil Concentrations for All Survey Units Combined

	Mean Value (pCi/g)	Maximum Value (pCi/g)	Ratio Mean to AL	Ratio Maximum to AL	Authorized Limit (pCi/g)
Am-241	0.0051	0.0258	3.70×10^{-6}	1.84×10^{-5}	1400
Co-60	0.0031	0.008	2.78×10^{-4}	7.25×10^{-6}	11
Cs-137	0.0867	0.193	4.13×10^{-3}	9.19×10^{-3}	21
Pu-239/240	0.0108	0.0521	6.73×10^{-6}	3.26×10^{-5}	1600
Sr-90	0.082	0.135	3.56×10^{-3}	5.87×10^{-3}	23
U-234	0.1829	0.476	2.65×10^{-4}	6.90×10^{-4}	690
U-235	0.0079	0.0417	3.94×10^{-5}	2.09×10^{-4}	200
U-238	0.1886	0.49	2.73×10^{-4}	7.10×10^{-4}	690

It is seen from these figures and the table that the values reported for each radionuclide are quite small compared to the authorized limits.

The final calculation of the sum-of-fractions value by survey unit is given in Table 5, *Results of the Sum-of-Fractions for Soil Samples*.

Table 5. Results of the Sum-of-Fractions for Soil Samples

Survey Unit	Sum-of-Fractions Value
1	0.008
2	0.008
3	0.009

As can be seen, the sum-of-fractions are less than 0.01 in all three cases. These values correspond to an estimated dose of 0.25 mrem/y. These values as compared to the sum-of-fractions limit of 1 are shown graphically in Figure 17, *Pie Charts Illustrating the Sum-of-Fractions for Soil Samples by Survey Unit*.

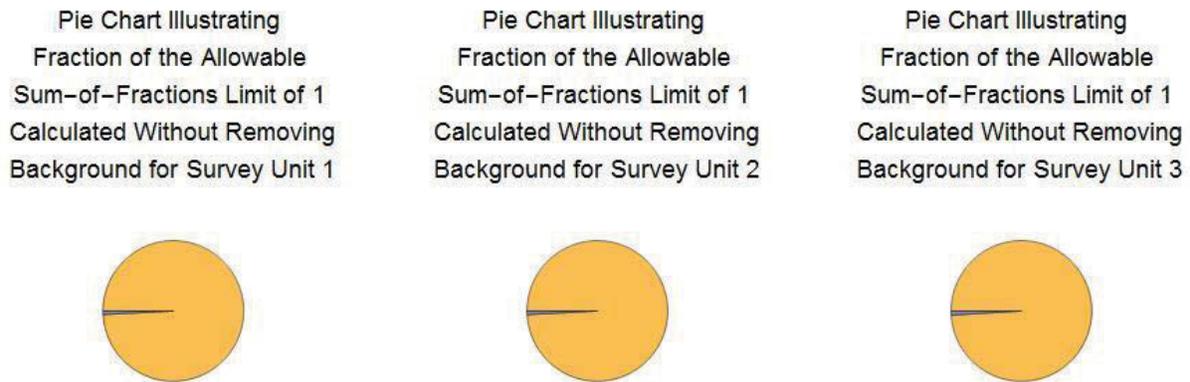


Figure 17. Pie Charts Illustrating the Sum-of-Fractions for Soil Samples by Survey Unit

It is useful to compare the mean values reported across all three survey units to the site background values. The best available background values are given in DOE/RL-96-12, Rev.0, *Hanford Site Background: Part 2, Soil Background for Radionuclides* (16). Table 6, *Comparison of Southern 600 Area Soil Concentrations to Background Soil Concentrations*, shows the mean concentrations, standard deviations, and maximum concentrations for both MSA’s values and the background values.

Table 6. Comparison of Southern 600 Area Soil Concentrations to Background Soil Concentrations

		Mean (pCi/g)	Standard Deviation (pCi/g)	Maximum (pCi/g)
Co-60	MSA Concentrations	0.003	0.001	0.008
	Background Concentrations	0.001	0.006	0.039
Cs-137	MSA Concentrations	0.087	0.035	0.193
	Background Concentrations	0.417	0.338	1.64
Pu-239/240	MSA Concentrations	0.011	0.007	0.052
	Background Concentrations	0.009	0.008	0.033
Sr-90	MSA Concentrations	0.082	0.022	0.135
	Background Concentrations	0.081	0.069	0.366
U-234	MSA Concentrations	0.183	0.061	0.476
	Background Concentrations	0.793	0.233	1.51
U-235	MSA Concentrations	0.008	0.005	0.042
	Background Concentrations	0.052	0.037	0.386
U-238	MSA Concentrations	0.189	0.056	0.49
	Background Concentrations	0.763	0.216	1.21

As can be seen from these values, the statistical values of the concentrations measured by MSA are either less than or comparable to reported background values for the Hanford Site. Although the values are not perfectly comparable, since MSA used 6-inch soil samples and the reported background values are 1-inch samples and MSA's sample are from one area and the background values are taken from a much larger area, this comparison does demonstrate that the measured values of radionuclide concentrations in the soil in the Southern 600 Area are at or near background levels.

It is worth noting that Co-60 showed detectable activity in only 7 of 126 measurements, and this provides further support that it is either not present or at very low levels. Americium-241 was present in 77 of 126 measurements, and this provides further support that it is likely at low levels.

3.3.2.2 Duplicates Tests

In order to test the repeatability of TestAmerica's analyses, 12 soil sample locations—4 from each survey unit—were chosen for blind duplicates. See Figure 18, *Map Showing Soil Sampling Duplicate Locations*. They were sent to TestAmerica with no indication that they were

duplicates. The results of TestAmerica's analyses were tested for consistency using a value called the "duplicate error ratio," which tests to see if the two values lie within 3 times their combined standard deviation of each other. A value of 3 or less is considered acceptable. Since there were 10 analytes per sample, there were 120 duplicate error ratios determined. See Table 7, *Duplicate Error Ratios (DER) between MSA Primary Soil Samples and QA Soil Samples*.

Table 7. Duplicate Error Ratios (DER) between MSA Primary Soil Samples and QA Soil Samples

	Cs-137	Sr-90	Co-60	Am-241	Pu-239/ 240	U-234	U-235	U-238	Th-232	Ra-226
QA001 & SU1-18	0.57	0.02	1.77	0.88	0.81	0.05	0.22	1.15	0.09	0
QA002 & SU1-20	1.87	0.44	1.62	0.17	0.51	0.95	1.07	0.28	1.15	0.38
QA003 & SU1-23	0.09	0.99	0.86	2.41	0.15	0.42	0.15	0.28	0.85	0.43
QA004 & SU1-26	1.5	0.75	1.44	0.1	0.25	0.79	0.22	1.77	0.67	0.81
QA005 & SU2-10	0.08	1.72	1.31	0.7	0.05	0.87	0.72	0.96	0.8	0.08
QA006 & SU2-13	0.51	1.48	0.38	0.98	1.24	3.05	2.46	2.38	0.17	0.87
QA007 & SU2-19	4.62	0.08	2.72	0.82	0.98	0.16	1.14	1.5	0.86	1.04
QA008 & SU2-25	0.15	1.73	0.65	1.81	1.79	0.28	0.97	1.1	0.78	0.59
QA009 & SU3-16	0.22	1.36	1.22	0.25	0.47	1.47	0.6	0.76	0.97	0.08
QA010 & SU3-24	0.74	0.83	0.04	0.4	0.05	1.22	0.61	1.78	1.98	0.98
QA011 & SU3-28	1.03	6.26	0.09	0.77	0.42	1.61	0.83	2.8	1.03	0.16
QA012 & SU3-34	0.61	1.5	0.92	2.17	0	1.29	1.84	1.39	0.93	0.13

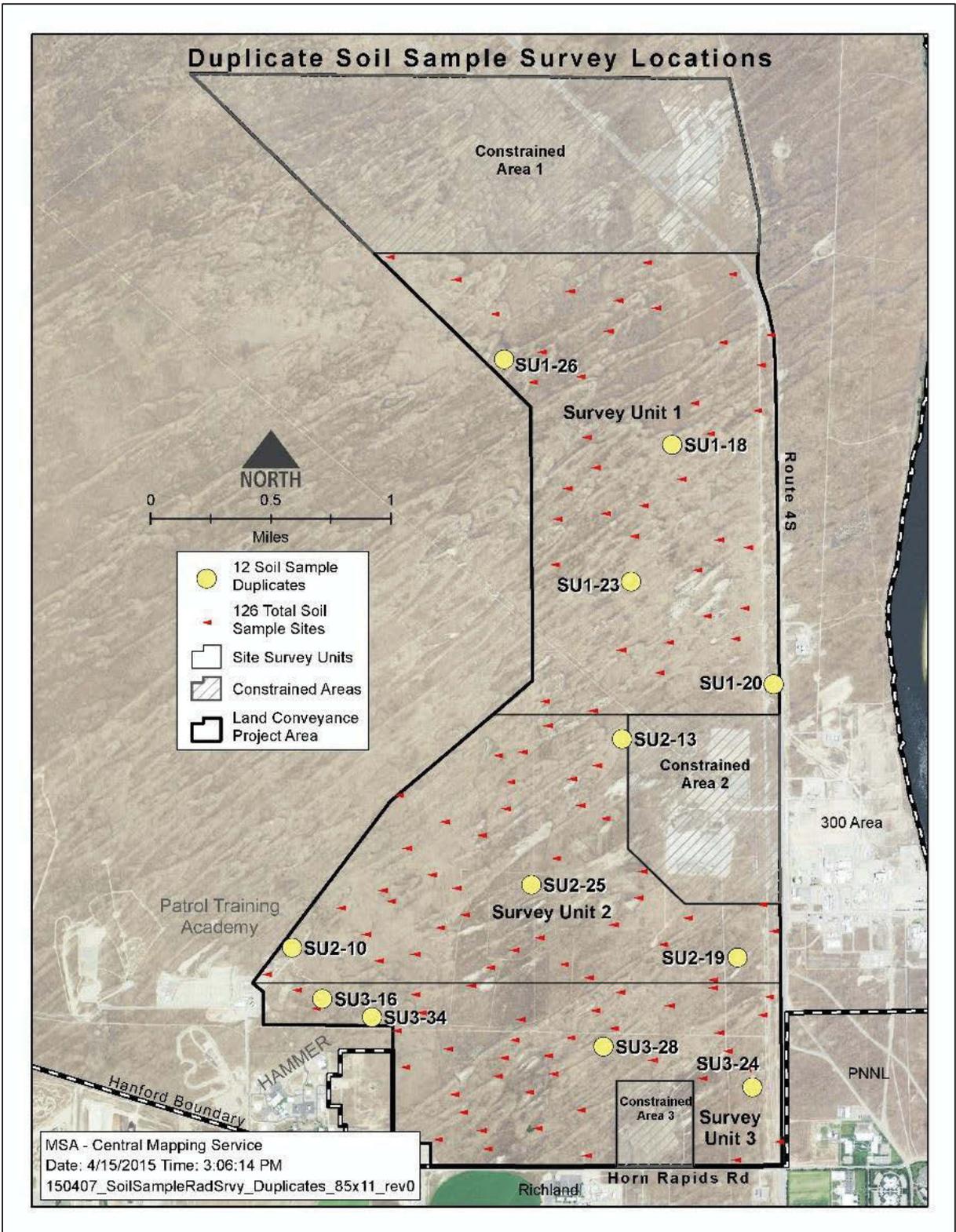


Figure 18. Map Showing Soil Sampling Duplicate Locations

As can be seen in the table, Of the 120 tests, only 3 exceeded a value of 3. Figure 19, *Histogram of Duplicate Error Ratios*, shows a histogram of the DERs. Having 3 of 120 in excess of the 99% value of 3 is acceptable, especially since the actual values measured are small and the relative uncertainties are large. Thus, the repeatabilities of the laboratory analyses are acceptable.

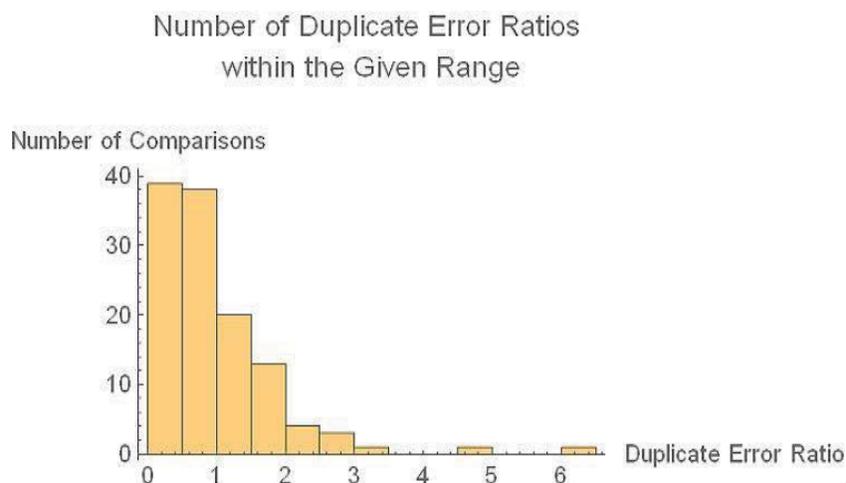


Figure 19. Histogram of Duplicate Error Ratios

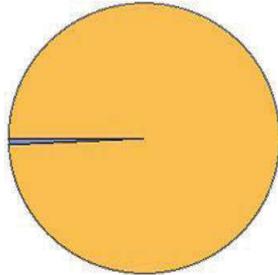
3.3.2.3 Comparison to ORISE’s Analytical Results

DOE’s independent verification contractor, Oak Ridge Institute for Science and Education (ORISE), took soil samples at 18 of MSAs site (6 in each survey unit) for analysis at their laboratory in order to determine if MSA’s results are sufficiently accurate to determine if the authorized limits have been met. See Figure 8, *Map Showing the Soil Sample Locations Common with ORISE*. To compare these results, the sum-of-fractions calculation was run for both MSA and ORISE in all three survey units and the results compared. As shown in Table 8, *Sums-of-Fractions by Survey Unit*, the values obtain are quite close to each other. This is illustrated graphically in Figures 20, *Charts Comparing Sums-of-Fractions Results Between MSA and ORISE for Survey Unit 1*; 21, *Charts Comparing Sums-of-Fractions Results Between MSA and ORISE for Survey Unit 2*; and 22, *Charts Comparing Sums-of-Fractions Results Between MSA and ORISE for Survey Unit 3*. These results confirm that MSA’s soil sampling results are sufficiently reliable to calculate the sums-of-fractions. Note that the charts use the term “ORAU” rather than “ORISE.” The Oak Ridge Institute for Science and Education (ORISE) is managed by Oak Ridge Associated Universities (ORAU).

Table 8. Sums-of-Fractions by Survey Unit

Survey Unit	MSA Results	ORISE Results
1	0.0074	0.0079
2	0.0089	0.0106
3	0.0088	0.0088

Pie Chart Showing
MSA's Fraction of the Allowable
Sum-of-Fractions Limit of 1
for Survey Unit 1



Pie Chart Showing
ORAU's Fraction of the Allowable
Sum-of-Fractions Limit of 1
for Survey Unit 1

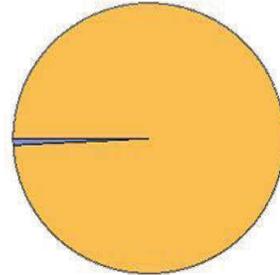
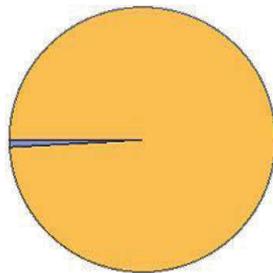


Figure 20. Charts Comparing Sums-of-Fractions Results Between
MSA and ORISE for Survey Unit 1

Pie Chart Showing
MSA's Fraction of the Allowable
Sum-of-Fractions Limit of 1
for Survey Unit 2



Pie Chart Showing
ORAU's Fraction of the Allowable
Sum-of-Fractions Limit of 1
for Survey Unit 2

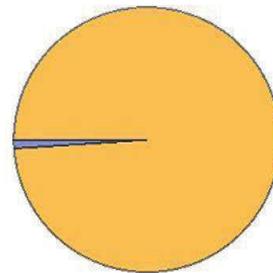


Figure 21. Charts Comparing Sums-of-Fractions Results Between
MSA and ORISE for Survey Unit 2

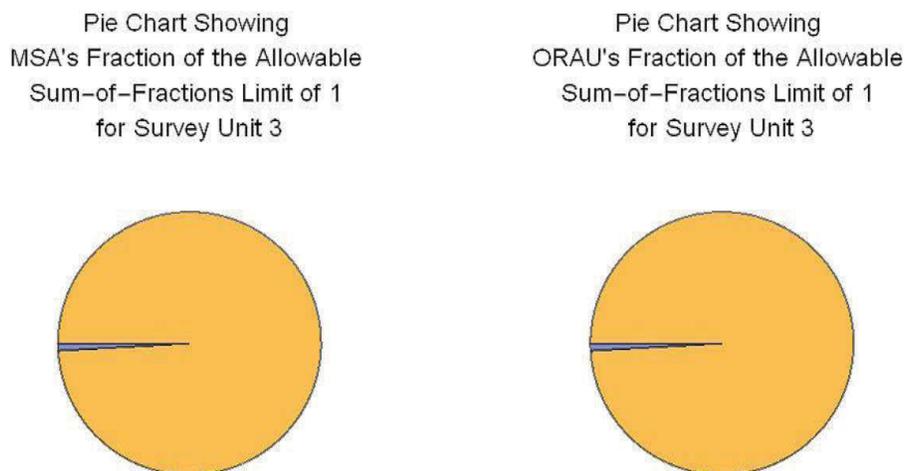


Figure 22. Charts Comparing Sums-of-Fractions Results Between MSA and ORISE for Survey Unit 3

3.4 THORIUM-232 AND RADIUM-226

DOE-HQ requested that, in addition to the radionuclides for which there are authorized limits, the concentrations of Th-232 and Ra-226 be measured in the soil samples. This was done for all 126 soil samples taken.

It is useful to compare the results reported by TestAmerica to the published background values for the Hanford Site (16). The background values for Th-232 are 0.945 ± 0.260 pCi/g with a maximum value of 1.58 pCi/g. The values for Th-232 measured in the Southern 600 Area are 0.618 ± 0.082 pCi/g with a maximum value of 0.989 pCi/g. The background values for Ra-226 are 0.561 ± 0.202 pCi/g with a maximum value of 1.16 pCi/g. The values for Ra-226 measured in the Southern 600 Area are 0.442 ± 0.065 pCi/g with a maximum value of 0.735 pCi/g.

These two sets of values are not strictly comparable, since the background set is for the entire site and the Southern 600 Area is a small part of the site. Also, the statistical values were calculated in slightly different ways. Nevertheless, this comparison shows that the concentrations of Th-232 and Ra-226 in the surface soil of the Southern 600 Area are at or near background values.

4.0 GAMMA SCANNING SURVEYS

For Class 3 survey units, which these survey are, MARSSIM's recommendation for elevated measurement areas is "judgmental." Thus, it is up to the judgment of the planner whether scanning is done at all, and, if so, how extensive that it should be.

4.1 AREAS TO BE SCANNED

As described in the main survey plan (8), six areas were chosen to gamma scan for elevated measurement areas (EMA), which might indicate the presence of excessive concentrations of

radioactivity in the soil in a small area. See Figure 23, *Map Showing the Gamma Scanning Areas Surveyed* for a map of the areas chosen.

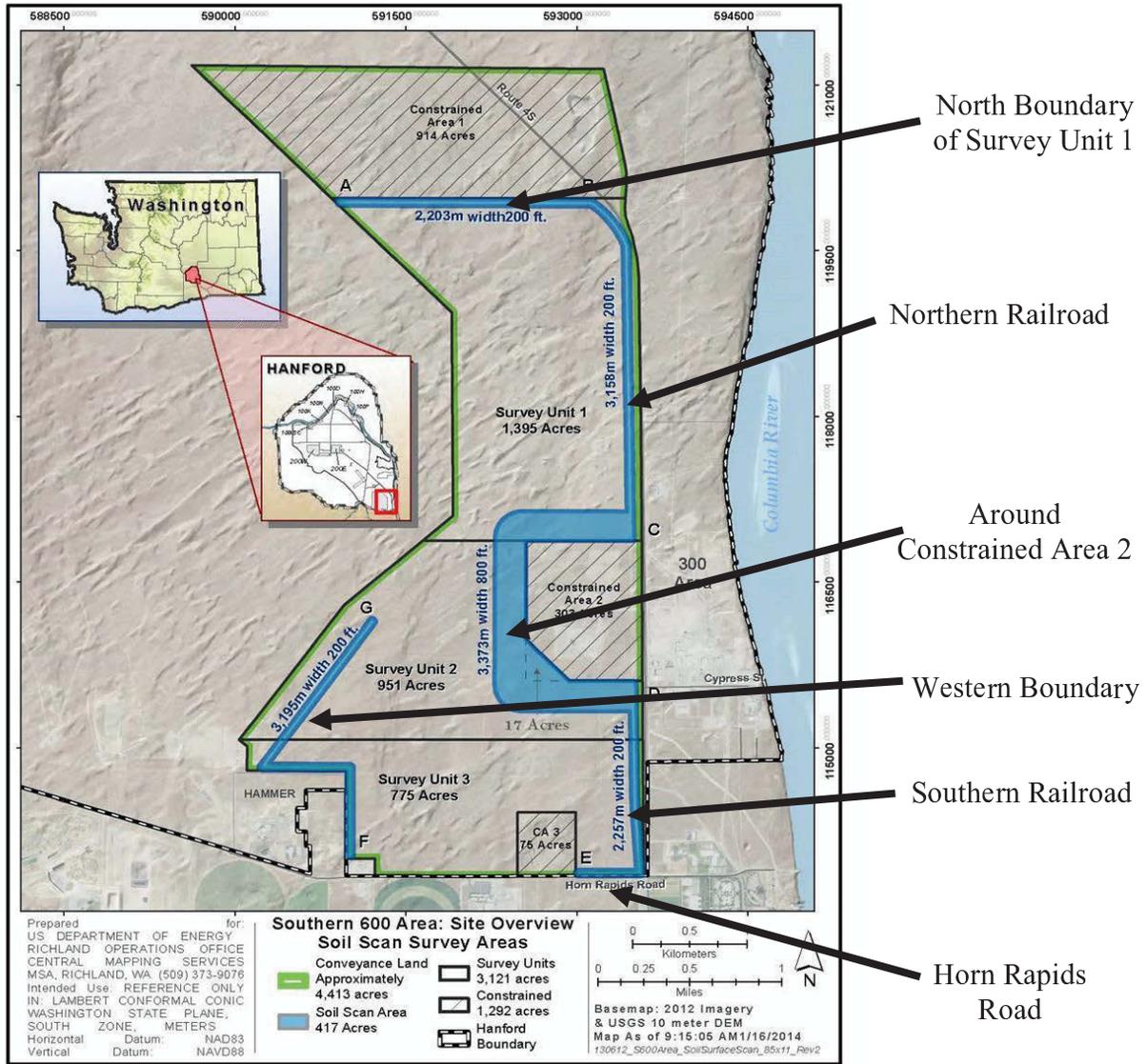


Figure 23. Map Showing the Gamma Scanning Areas Surveyed

4.2 METHOD USED FOR SCANNING

4.2.1 Detecting an Elevated Measurement Area

As described in the main survey plan (8), an area of 100 m² that was assumed to be contaminated to such a degree that a worker could get 2 mrem/y assuming 10% occupancy in the area was chosen as the basis for scanning. That is, the gamma scanning technique used had to be able to detect such an EMA. Four gamma emitters were chosen as indicators of such an EMA: Cs-137, Co-60, Am-241, and Pa-234m (U-238). The concentrations of each that would result in a calculated dose of 2 mrem/y were calculated. These concentration are Cs-137, 46 pCi/g; Co-60, 12 pCi/g; Am-241, 1,200 pCi/g; and Pa-234m (U-238), 1,300 pCi/g.

The primary scanning instrument, the Mobile Gamma Spectrometer, was calibrated to ensure that it could detect an EMA; this is discussed below.

4.2.2 Pre-Determined Scan Lines for Surveys

Prior to a gamma scanning survey, a map of the area to be scanned with pre-determined scan lines drawn was loaded into the spectrometer's operating software (RadAssist) in the on-board computer. The Mobile Gamma Spectrometer has a built-in GPS receiver, and the Mobile Gamma Spectrometer's live-time position is displayed on the map with the scan lines. The driver follows the scan lines to ensure that the survey is completed properly.

4.3 INSTRUMENTS AND INSTRUCTIONS USED FOR GAMMA SCANNING

Three specialized instruments were available to use for the gamma scans: the Mobile Gamma Spectrometer, the ORTEC Detective intrinsic germanium spectrometer, and the Berkeley Nucleonics SAM-940 NaI spectrometer. The primary instrument used was the Mobile Gamma Spectrometer. The ORTEC Detective was used to investigate two anomalous readings. In this case, the SAM-940 was only used in a general detection (no spectroscopy) mode.

4.3.1 Mobile Gamma Spectrometer

As mentioned above, the Mobile Gamma Spectrometer, shown in Figure 24, *Mobile Gamma Spectrometer*, was calibrated to ensure that it could see the EMA as defined. The calibration is described in LTS Technical Basis Document, *The Mobile Gamma Spectrometer's Scan MDC's Using Unstripped Data and Its Transect Spacing for the Southern 600 Area Elevated Measurement Area* (17). Based on quite conservative assumptions, the Mobile Gamma Spectrometer was shown to be able to detect the EMA. Based on a 1-second count and using unstripped background count rates (which are much higher than the stripped count rates actually used in the field), the calculated minimum detectable activities are Cs-137, 1.2 pCi/g; Co-60, 0.46 pCi/g; Am-241, 5.4 pCi/g and U-238 (Pa-234m), 108 pCi/g. "Stripped count rates" are the count rates in the four regions-of-interest for the four radionuclides after the counts in those regions-of-interest due to K-40, the U-238 decay chain and the Th-232 decay chain have been removed.

In addition to MDAs, sensitivities (cps/pCi/g) were also determined. These values, along with the count rate at the EMA limit for each radionuclide, are shown in Table 9, *Mobile Gamma Spectrometer Sensitivities and Count Rates at EMA Limits*.



Figure 24. Mobile Gamma Spectrometer

Table 9. Mobile Gamma Spectrometer Sensitivities and Count Rates at EMA Limits

Radionuclide	Sensitivity (cps/pCi/g)	EMA Limit (pCi/g)	Count Rate at EMA Limit (cps)
Cs-137	51.3	46	2,360
Co-60	110	12	1,320
Am-241	10.7	1,200	12,840
Pa-234m	0.42	1,300	546

As shown below, the actual count rates experienced in the field were much less than the expected count rates at the EMA limit.

4.3.2 ORTEC Detective

The ORTEC Detective intrinsic germanium spectrometer is used, in this application, for identifying radionuclides only and not for quantifying the amount of radioactivity present. The Detective self-calibrates its energy response using a small Cs-137 source built into its charging station. The Detective has very high resolution and a large built-in library of radionuclides that it

can identify. Spectra from the Detective can be analyzed using the *PeakEasy* spectrum analysis software (18) from Los Alamos National Laboratory.

4.3.3 Scanning Specific Survey Plan and Desk Instructions

These scans were conducted under a lower-level survey plan specifically written and approved for this task: LTS Test Plan, *Mobile Gamma Spectrometer Scan Surveys of the Southern 600 Area* (19). Several LTS desk instructions were also used, primarily *Operation of the Polaris Ranger Diesel*, *Operation of the RS-700 Mobile Gamma Spectrometer*, and *Operation of the ORTEC Detective DX-100 for Radionuclide Identification*.

4.4 ANALYSES OF SCANNING DATA

4.4.1 Methods of Analyses

Mathematica 10 (20) was used for all actual analyses, although some representations of the data were developed using *ArcGIS* (14). Output files from the *RadAssist* software (the Mobile Gamma Spectrometer's operating software) were collected daily and stored on a share drive that is backed up nightly. These files were later converted to Comma Separated Variable files using a utility in *RadAssist*. The Comma Separated Variable files were read into *Mathematica 10* where they were converted to nested lists used by *Mathematica*. All calculations were carried out in *Mathematica* and saved as *Mathematica* notebooks. The calculations carried out on the output files of the spectrometer were primarily descriptive statistics and sum-of-fraction calculations, as well as various graphics used in examining the data. For the plots on maps using *ArcGIS* (14), the data was extracted from *Mathematica* and sent to the cartographer for plotting. The data was exported using UTM Zone 11 coordinates, and the cartographer converted them to Washington State Plan, South Zone, before plotting.

4.4.2 Results of Analyses

4.4.2.1 Northern Boundary of Survey Unit 1

The scan of the Northern Boundary of Survey Unit 1 was conducted to check for any areas of elevated radioactivity from prior radiological activities north of the boundary. In particular, the 618-10 burial ground is located to the north of the boundary.

The results of the scan and the analyses are described in LTS Technical Note, *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Northern Boundary of Survey Unit 1 of the Southern 600 Area Completed on 8 October 2014*, Rev.0 (21).

1) Scan Outcomes

The results of this scan for the Cs-137, Co-60, Am-241, Pa-234m, and man-made regions of interest are shown in Figures 25–29. A couple of explanatory notes are in order. The color ramp or color function used in these figures varies from blue for the low count rates recorded to red for the high count rates recorded. The color ramp is simply applied to the range of counts recorded

in a given set of readings. For these figures, each dot represents a 1-second count and the appropriate color is applied. The color red does not imply that the count is at or even near any limit. The term “man-made” (sometimes “gross man-made”) does not imply that all of the counts in this region of interest are from man-made radioactivity. It just signifies the range of energies in which the gamma rays from man-made radionuclides generally fall. Gamma rays from natural radioactivity also fall in this region. In the cases discussed here, all or almost all of the counts in the man-made region are due to natural radioactivity. Three-second moving averages are used here to determine activity levels, since the data has a lot of random fluctuations from natural radioactivity and this reduces the fluctuations moderately. Note that in the case of Cs-137, Co-60, Am-241, and Pa-234m, the maximum count rates (cps) are very small compared to the count rates at the EMA limit. For the case of man-made (for which there is no EMA limit), the maximum value of 5,326 cps is comparable to the maximum value found in the background areas of 5,244 cps. The man-made region-of-interest was examined in order to detect any man-made radionuclides that were not specifically anticipated. This survey resulted in 9,806 measurements.

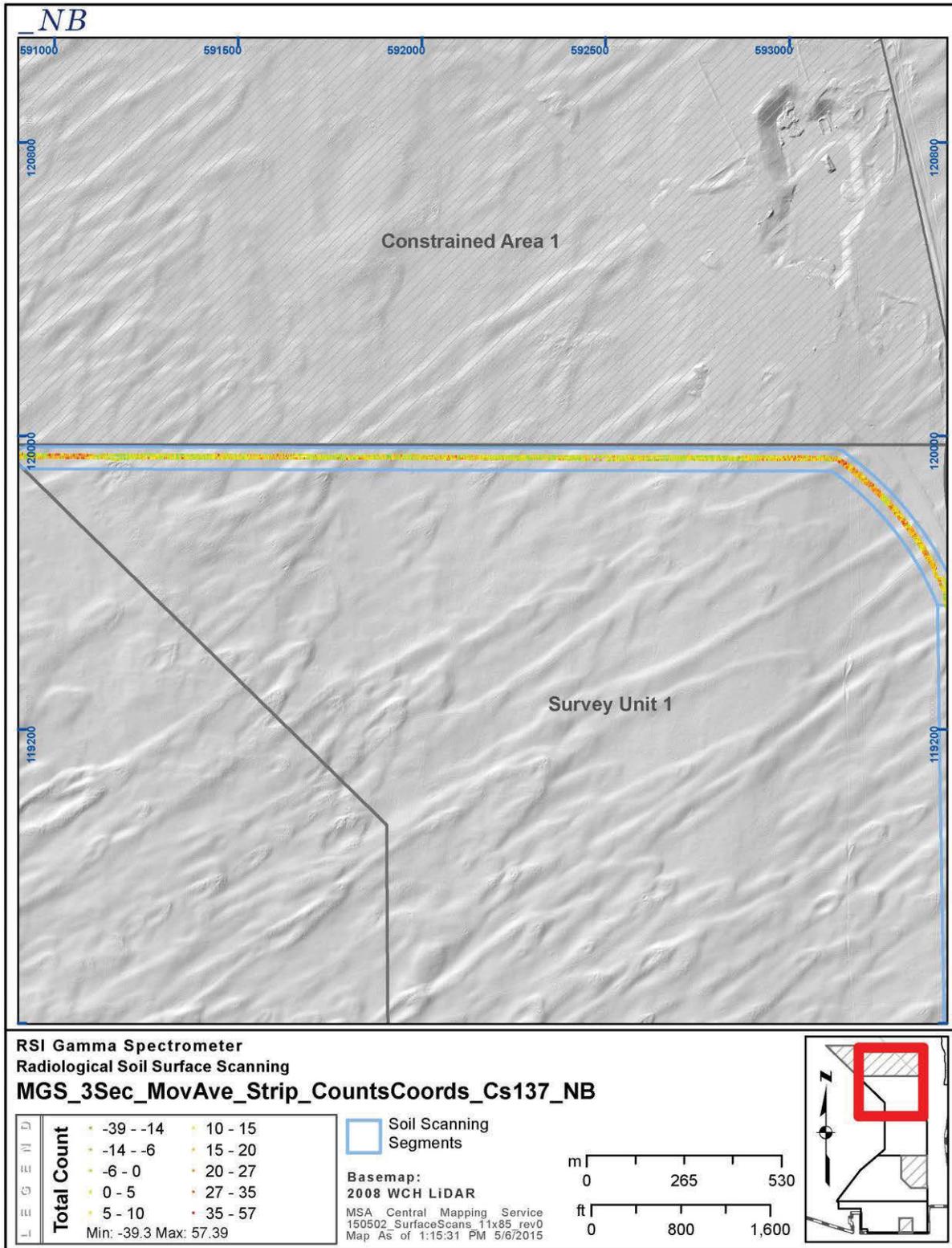


Figure 25. Three-Second Moving Average Count Rate (cps) for Cs-137 for the Northern Boundary Survey

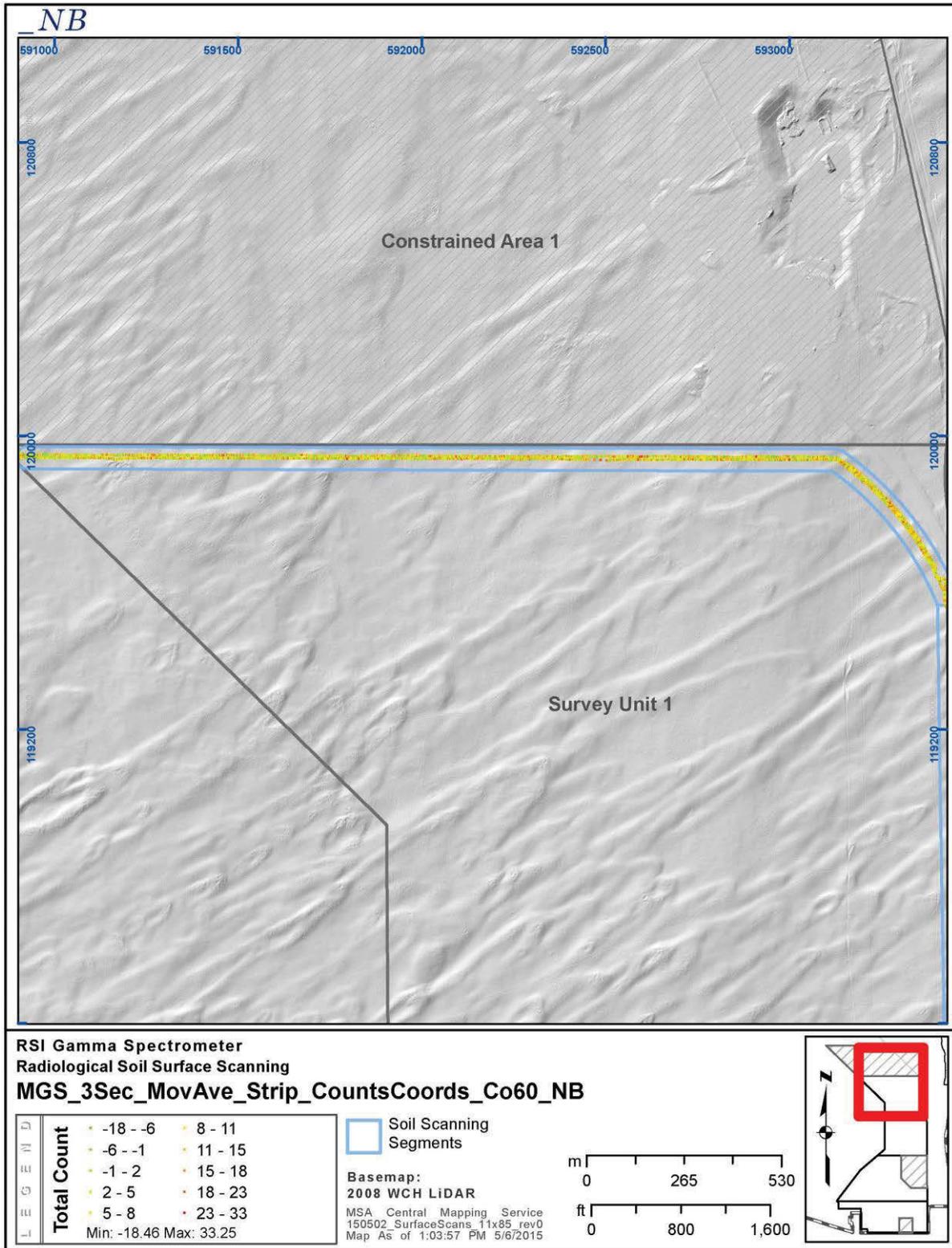


Figure 26. Three-Second Moving Average Count Rate (cps) for Co-60 for the Northern Boundary Survey

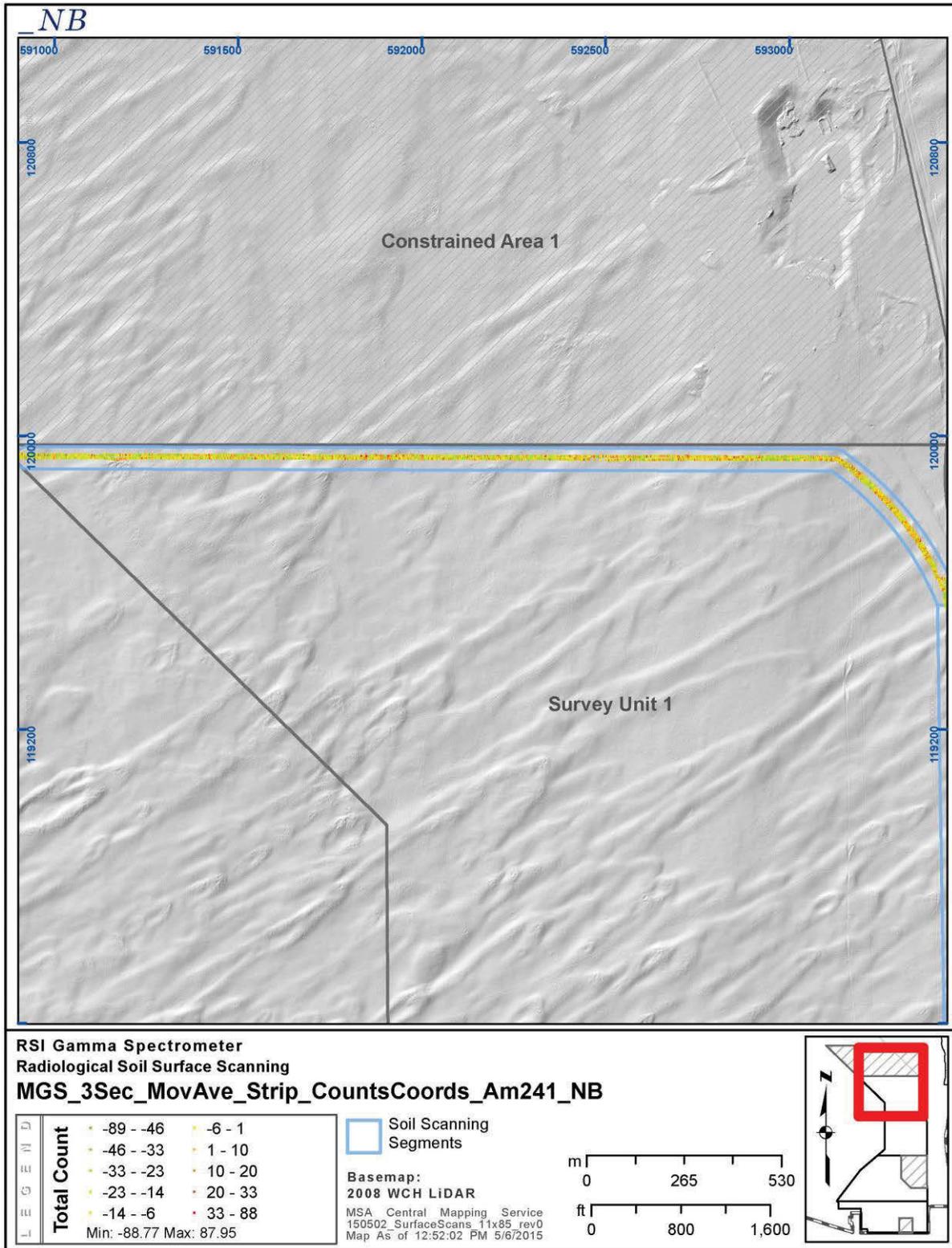


Figure 27. Three-Second Moving Average Count Rate (cps) for Am-241 for the Northern Boundary Survey

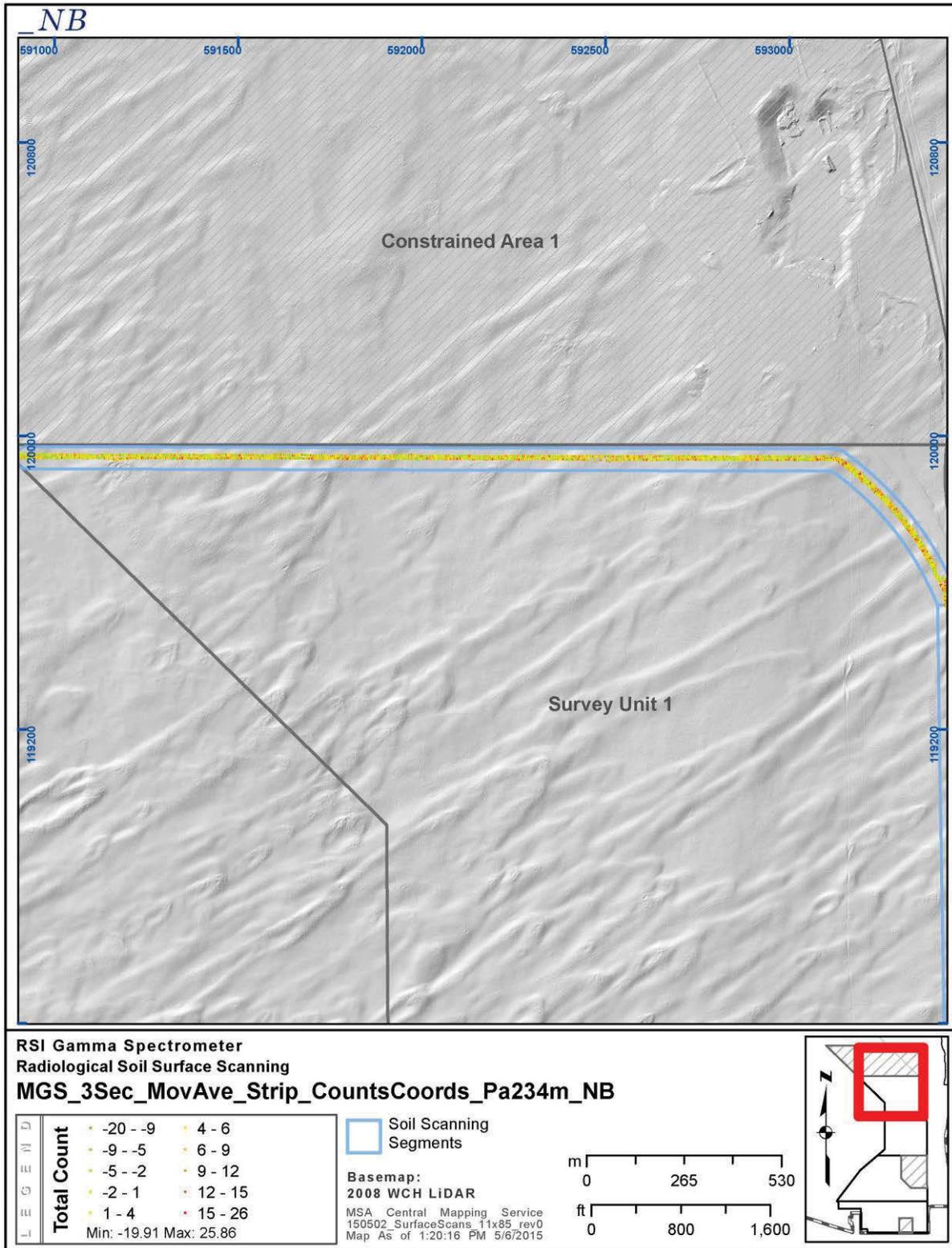


Figure 28. Three-Second Moving Average Count Rate (cps) for Pa-234m for the Northern Boundary Survey

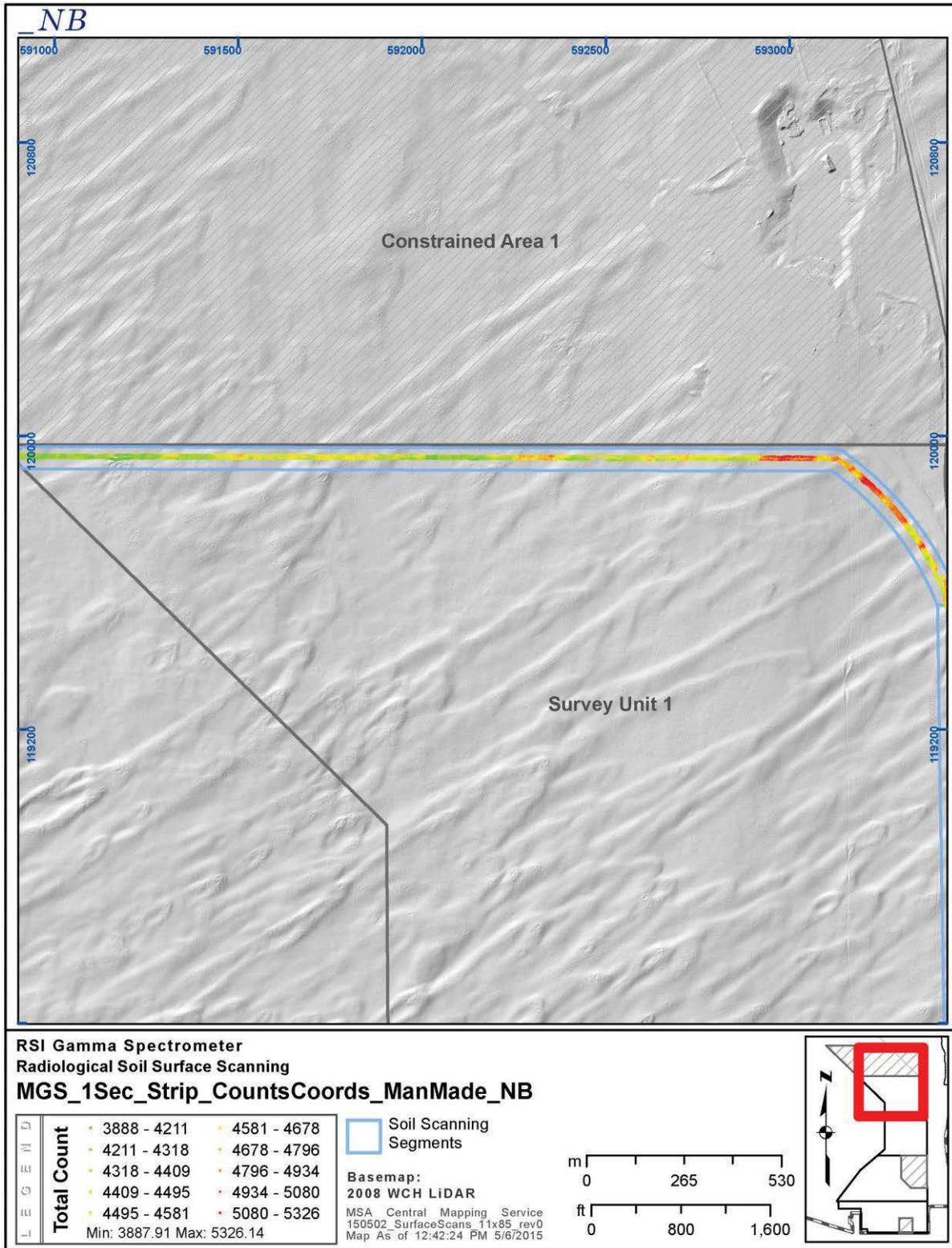


Figure 29. One-Second Moving Average Count Rate (cps) for Man-Made Region of Interest for the Northern Boundary Survey

2) Sum-of-Fractions

For each measurement, in this case 9,806, the sum-of-fractions calculation using the count ratios at the EMA limit was calculated. A word of explanation is in order. Each of the four radionuclides in Table 9 is a gamma-detectable component of a mixture of radionuclides (except for Co-60 which is considered alone). When the gamma-detectable radionuclide is at the level given in Table 9 under “EMA Limit (pCi/g),” the mixture is calculated to deliver 2 mrem/y to an industrial worker. Two mrem/y was chosen as a reference value and is not a regulatory limit of any kind. The count rates seen by the mobile gamma spectrometer for the gamma-detectable radionuclides when the individual mixtures are at the 2 mrem/y level are given in Table 9 under “Count Rate at EMA Limit (cps).” To determine if the count rates are sufficient to deliver the reference value of 2 mrem/y, the count rate of each radionuclide is divided by the count rate at the EMA limit for that radionuclide and the four results summed. This is the sum-of-fractions calculation. A value of 1 would indicate a measurement that is at the defined EMA limit. An EMA at the limit would result in 2 mrem/y to an industrial worker. In this case, the maximum of all values found was 0.08. All values for this survey are shown plotted in Figure 30, *Three-Second Moving Average EMA Sum-of-Fractions for Northern Boundary Survey Unit 1 Survey vs. Location in Northern Boundary of Survey Unit 1 Survey*. See also Table 10, *Maximum EMA Sum-of-Fractions Value for Each Survey Area*. Therefore, no EMA of concern was detected by this survey.

3-Second Moving Average Sum-of-Fractions for Northern Boundary Survey Unit 1 Survey
vs. Location in Northern Boundary of Survey Unit 1 Survey

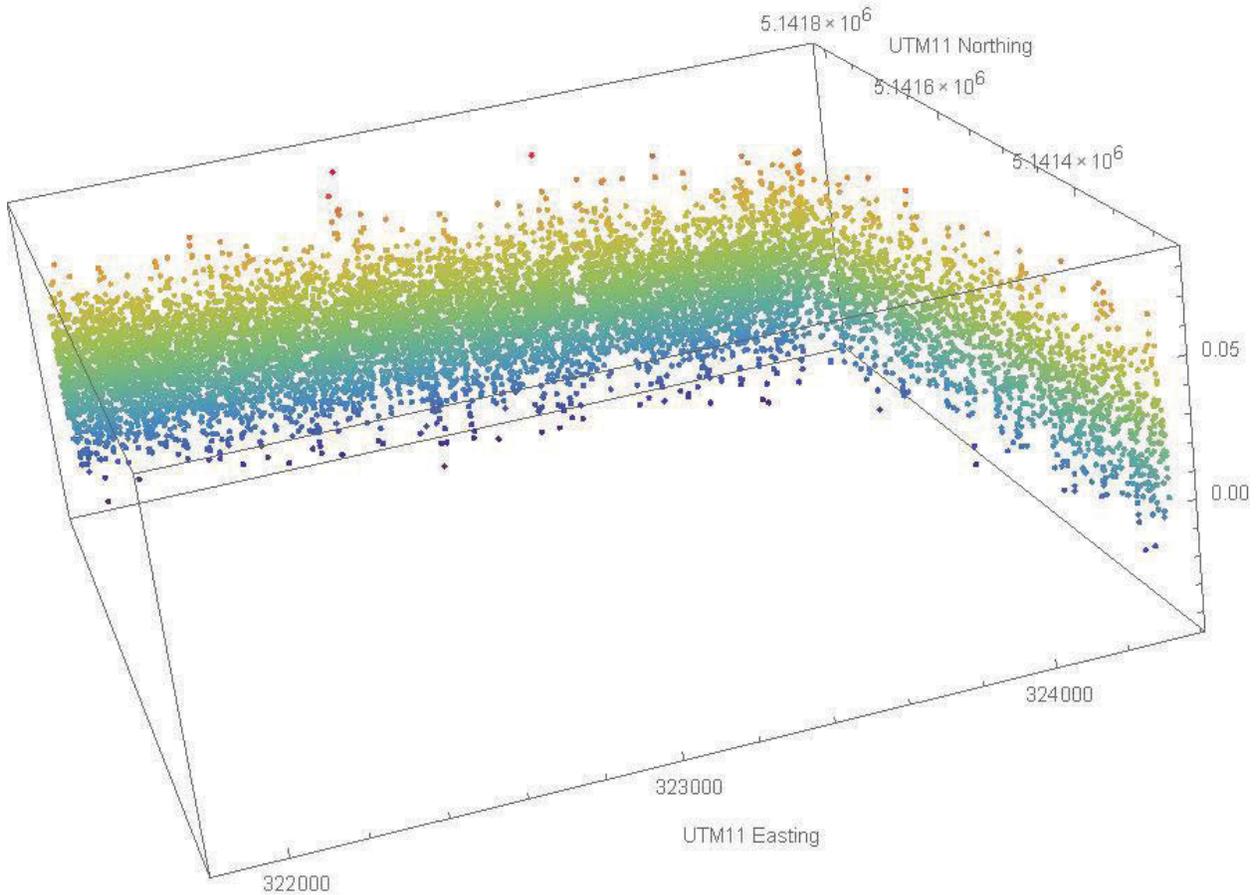


Figure 30. Three-Second Moving Average EMA Sum-of-Fractions for Northern Boundary Survey Unit 1 Survey vs. Location in Northern Boundary of Survey Unit 1 Survey

Table 10. Maximum EMA Sum-of-Fractions Value for Each Survey Area

Survey Area	Maximum Sum-of-Fractions Value
North Boundary of Survey Unit 1	0.08
Northern Railroad	0.12
Around Constrained Area 2	0.10
Southern Railroad	0.09
Horn Rapids Road	0.08
Western Boundary	0.08

3) Comparison to Background

It is useful to compare the statistical values of the count rates found in the Northern Boundary of Survey Unit 1 survey to those found in the background areas of the site. These values are shown

in Table 11, *Comparison to Background Statistical Values for Northern Boundary of Survey Unit 1*. An examination of this table will show that the statistical values for the measurements from this survey are very similar to those from the background areas. Therefore, the radioactivity levels in the soil are very similar. The count rate values used in this comparison are 1-second unstripped (background not subtracted) count rates.

Table 11. Comparison to Background Statistical Values for Northern Boundary of Survey Unit 1

		Mean (cps)	Standard Deviation (cps)	Coefficient of Variation (%)	Inter - quartile Range (cps)	Minimum (cps)	Maximum (cps)	Skewness	Kurtosis
Cs-137	Background	159.2	15.63	9.82	22	104	223	0.117	2.9
	North Boundary	155.4	16.21	10.43	22	95	233	0.323	3.24
Co-60	Background	104.6	10.52	10.05	15	65	154	0.122	3.01
	North Boundary	102	10.94	10.72	15	57	145	0.15	2.93
Pa-234m	Background	82.9	9.31	11.62	13	47	130	0.125	3.03
	North Boundary	79.4	9.79	12.33	13	45	124	0.151	3.05
Am-241	Background	140.7	30.96	22	42	101	289	0.039	2.98
	North Boundary	128	30.48	23.81	42	11	261	0.014	2.97
Gross Man-made	Background	4642	152	3.27	197	4204	5244	0.512	3.01
	North Boundary	4538	234	5.15	290	3884	5320	0.706	3.23

4.4.2.2 Northern Railroad

This scan, which was a single scan on each side of the railroad track, was conducted because the railroad was used in the past to transport radioactive material from the 300 Area to the 200 Area and vice versa.

The results of the scan and the analyses are described in LTS Technical Note, *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Northern Railroad of the Southern 600 Area Completed on 9 October 2014, Rev.0 (22)*.

1) Scan Outcomes

The scan consisted of 8,695 measurements. As can be seen from Figures 31–34 for count rates from Cs-137, Co-60, Am-241, Pa-234m were quite low compared to their respective EMA limits. However, in Figure 35 the maximum man-made count rate is somewhat greater than expected. This anomaly is discussed below.

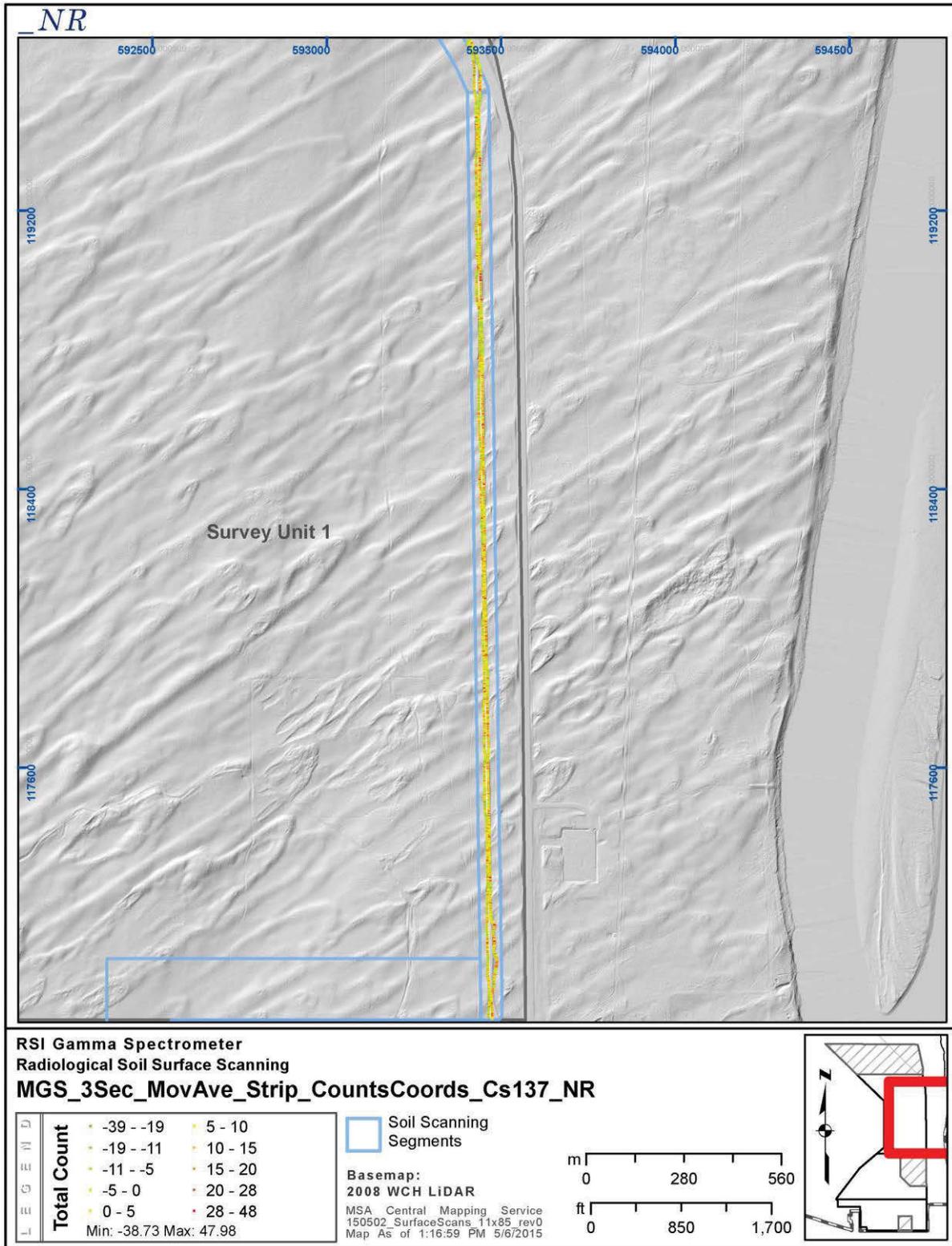


Figure 31. Three-Second Moving Average Count Rate (cps) for Cs-137 for the Northern Railroad Survey

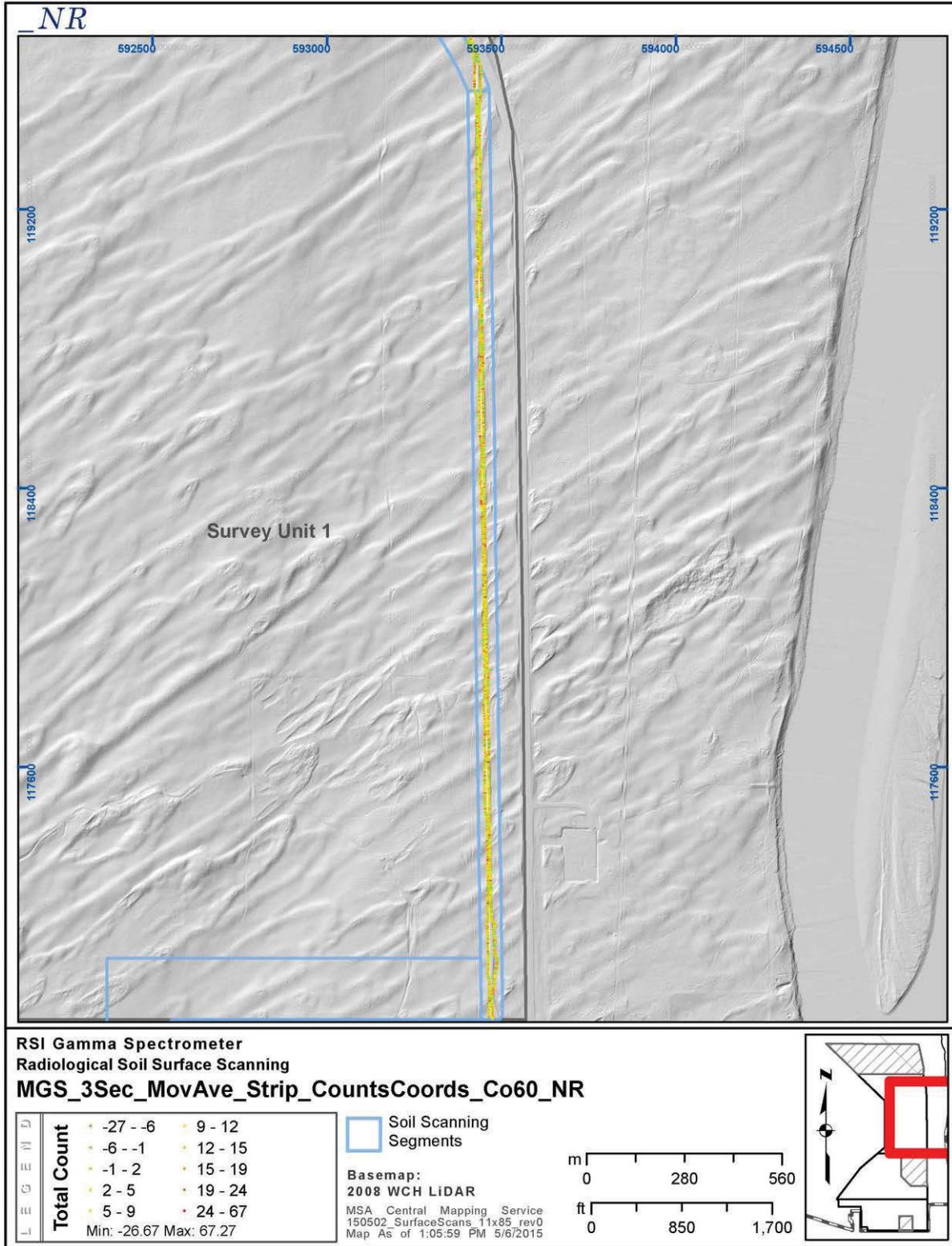


Figure 32. Three-Second Moving Average Count Rate (cps) for Co-60 for the Northern Railroad Survey

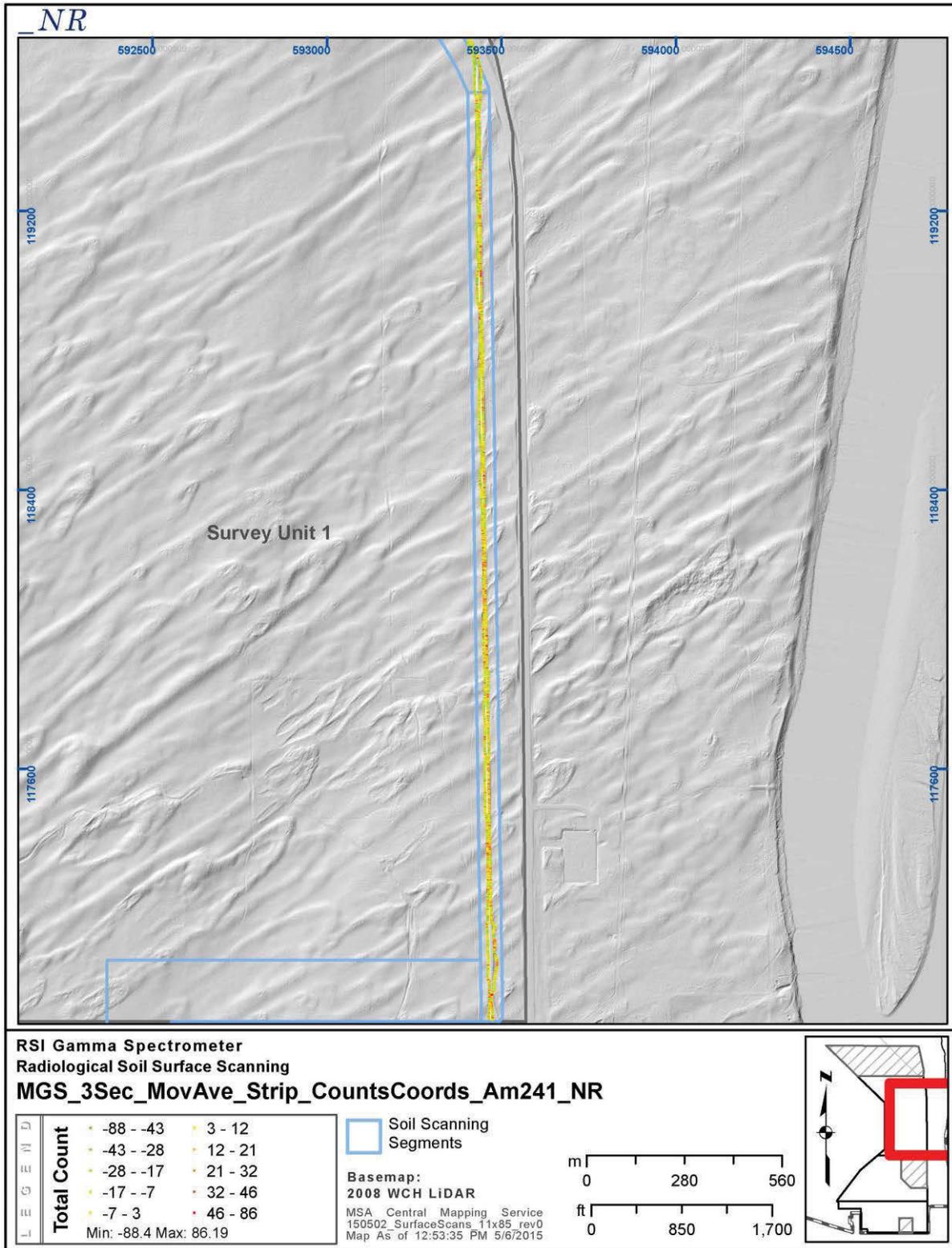


Figure 33. Three-Second Moving Average Count Rate (cps) for Am-241 for the Northern Railroad Survey

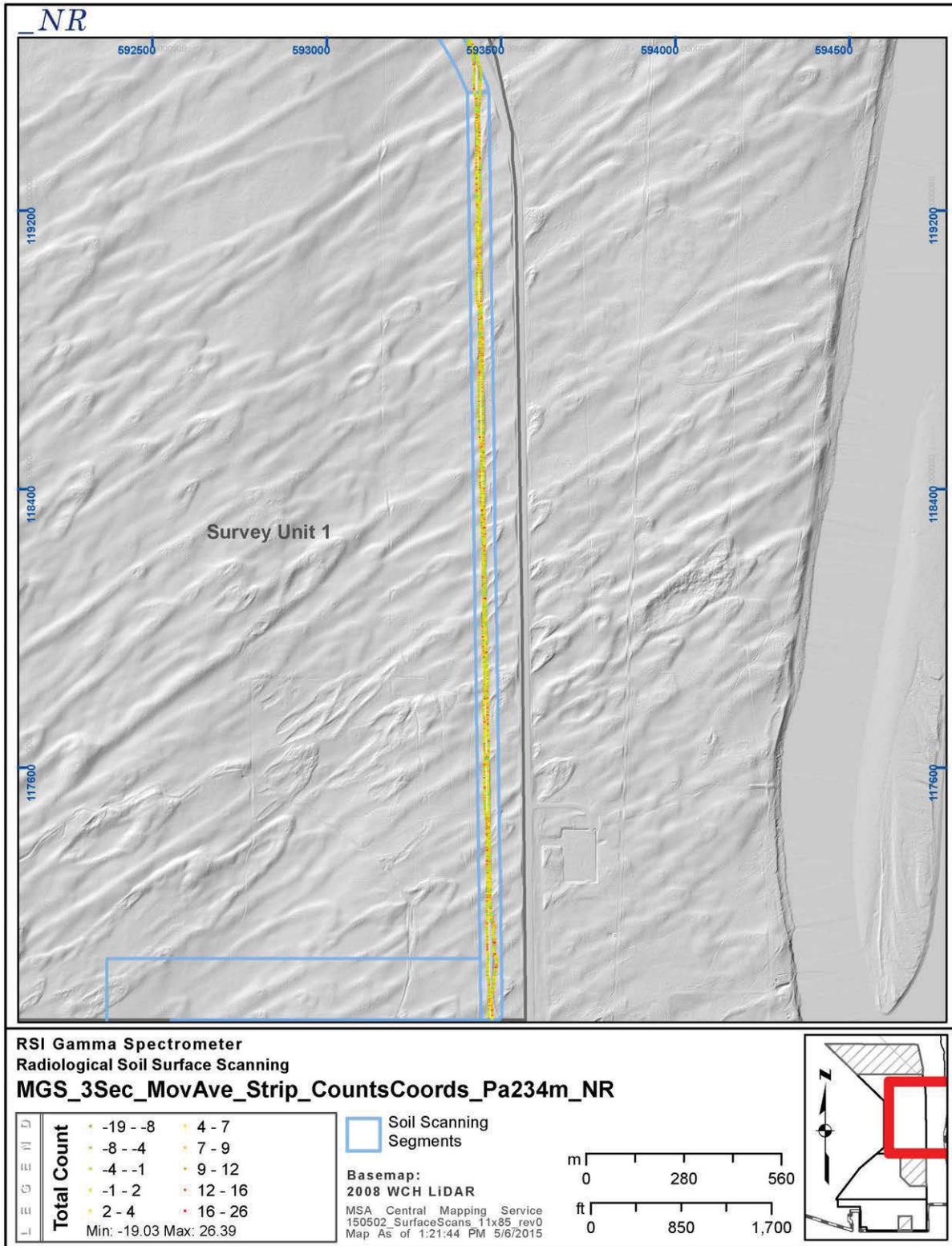


Figure 34. Three-Second Moving Average Count Rate (cps) for Pa-234m for the Northern Railroad Survey

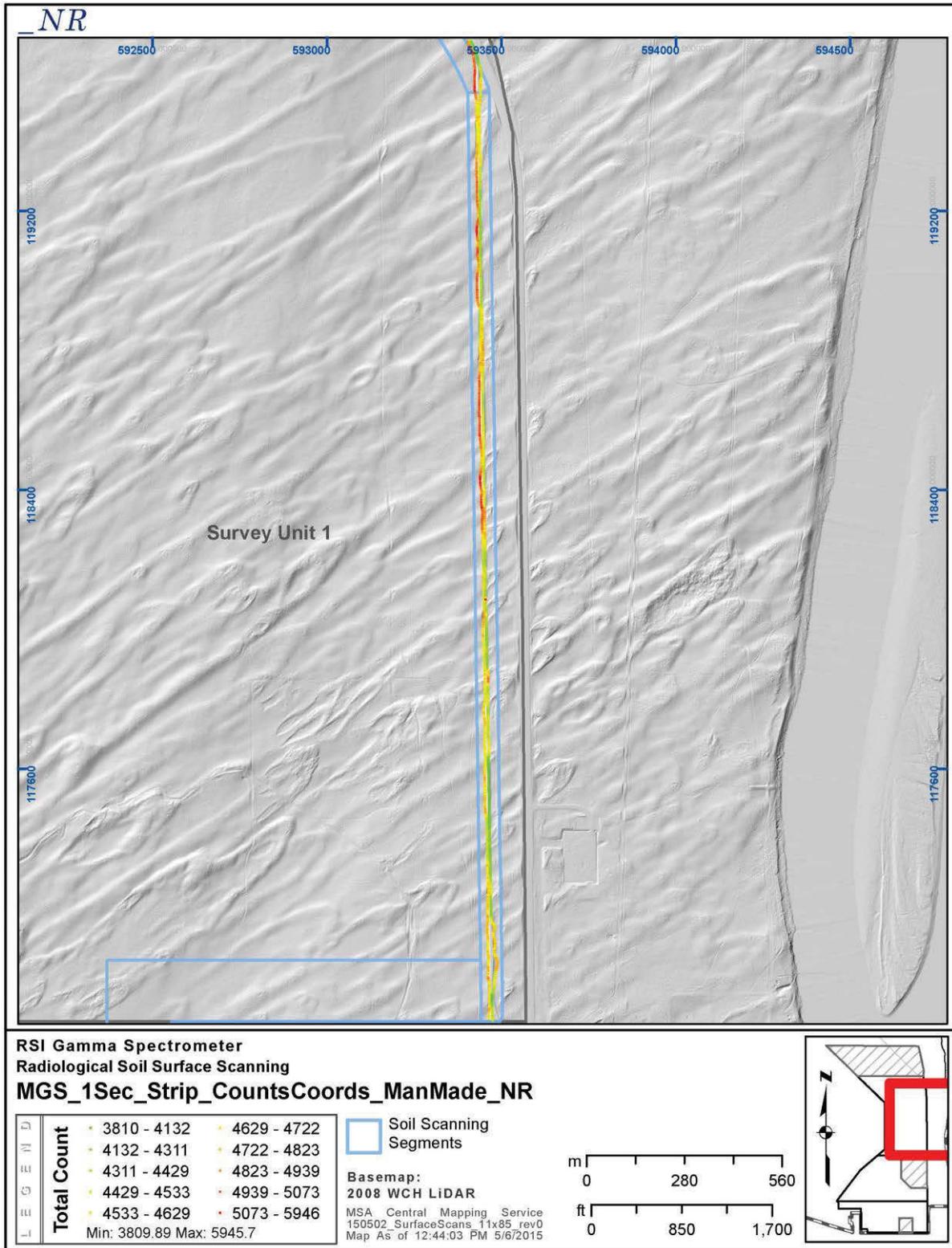


Figure 35. One-Second Moving Average Count Rate (cps) for Man-Made Region of Interest for the Northern Railroad Survey

2) Sum-of-Fractions

Figure 36, *Three-Second Moving Average EMA Sum-of-Fractions for Northern Railroad Survey vs. Location in Northern Railroad Survey*, shows that all sum-of-fraction values are considerably less than 1. However, one narrow area is markedly greater than the others. It is visible in this figure as a vertical sequence of red dots. This is discussed further in the next section.

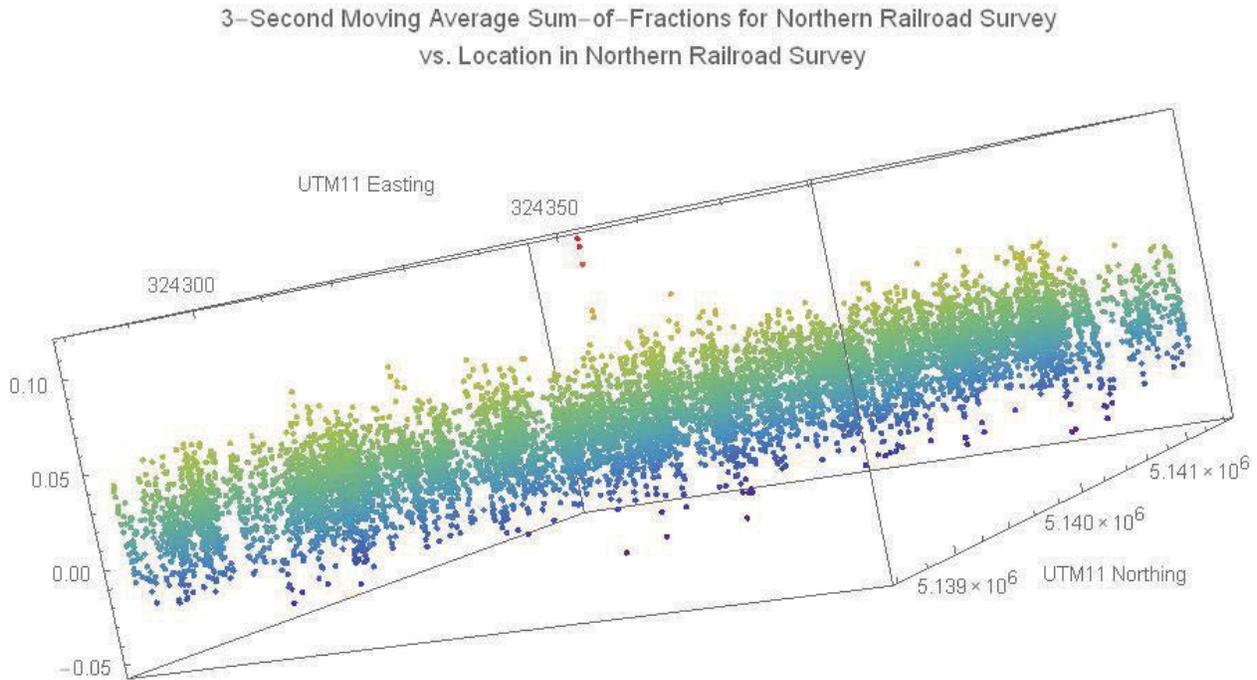


Figure 36. Three-Second Moving Average EMA Sum-of-Fractions for Northern Railroad Survey vs. Location in Northern Railroad Survey

3) Investigation into Anomalous Readings

As mentioned above, an anomalously high reading was experienced during the scan of the eastern side of the Northern Railroad. Although this reading was considerably below the limit, it was possible that it signaled a higher reading nearby. Figure 37 clearly shows this measurement.

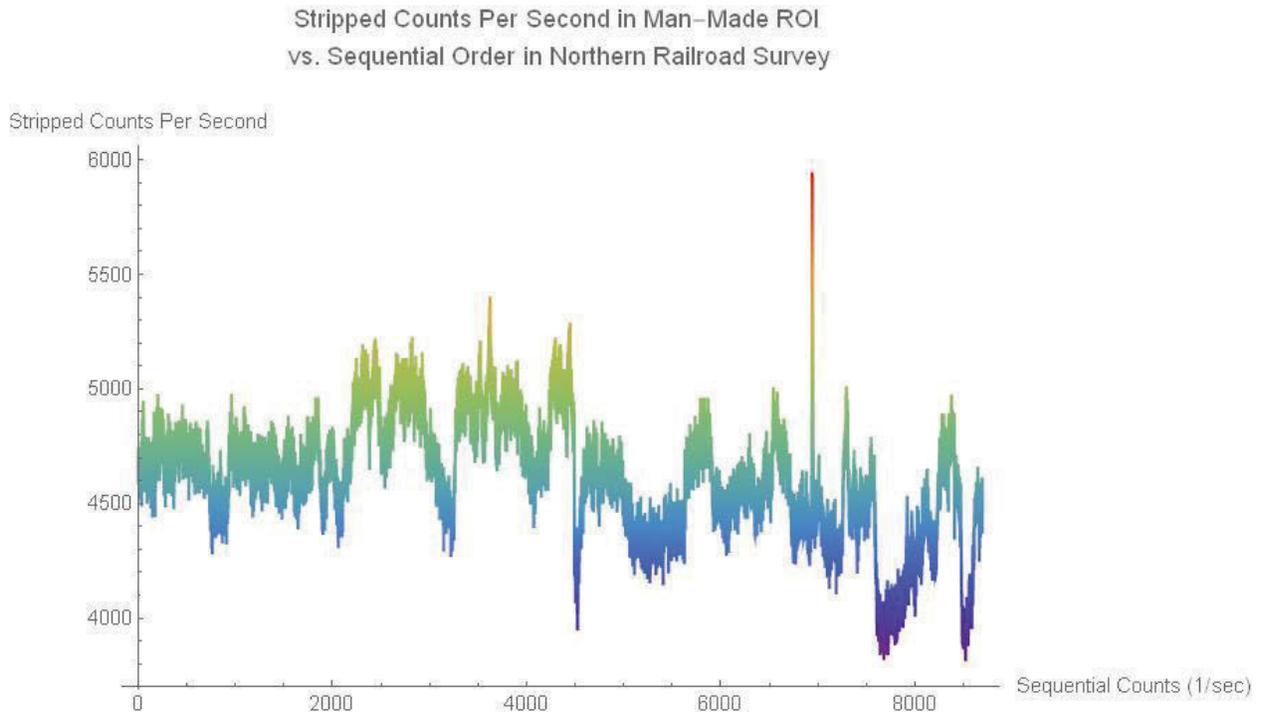


Figure 37. Stripped Counts Per Second in Man-Made ROI vs Sequential Order in Northern Railroad Survey

This spot was identified with GPS coordinates and a survey team returned to the site for additional measures. The team consisted of two experienced Senior Radiological Control Technicians and the Lead Health Physicist. The area was re-surveyed with several instruments. The area was re-surveyed with the mobile gamma spectrometer and no elevated reading was found. The area was then re-surveyed with both a 3" × 3" NaI detector and a 2" × 2" NaI detector and again no elevated reading was found. Finally, the ORTEC Detective intrinsic germanium detector was used to acquire spectra at the both the area of interest and an area along the track at some distance from the elevated area. At the time of the measurements the ORTEC Detective did not identify any unexpected radionuclides. Later, the two spectra were directly compared and they showed the same energy pattern. Therefore, they failed to identify any unusual radioactivity.

Figure 38 shows the ORTEC Detective at the site of the elevated reading. Figure 39 shows the two ORTEC Detective spectra superimposed.

It has been concluded that whatever caused the elevated reading is no longer present at the original site. The cause of the reading is not definitely known. The most likely cause was that a truck of rad waste on a nearby highway passed the mobile gamma spectrometer during the original survey. The gamma spectra captured by the mobile gamma spectrometer is consistent with a uranium source, which is a possibility for a rad waste shipment.



Figure 38. ORTEC Detective on Northern Railroad Elevated Reading Site

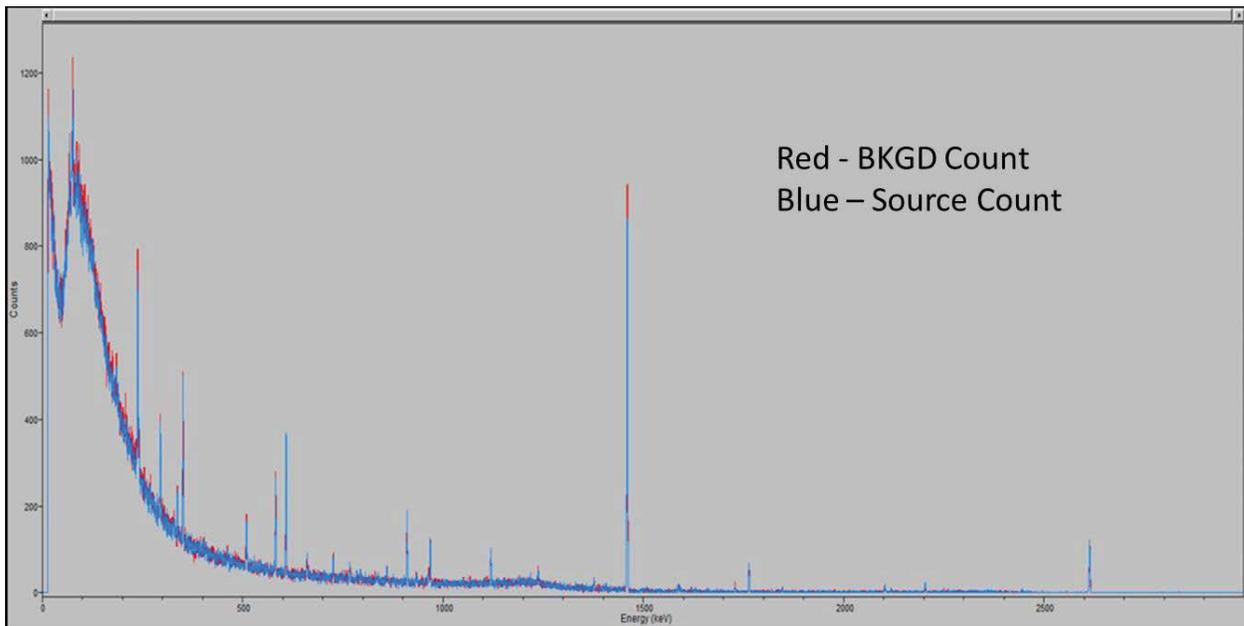


Figure 39. Spectra from the Northern Railroad Elevated Reading Site

As part of the review of the data from the scan of the Northern Railroad, a 60-second moving average calculation on the Am-241 counts revealed a sharp peak at the southern end of the survey area. See Figure 40, *Sixty-Second Moving Average of Stripped Counts Per Second in Am-241 ROI vs 60 second Moving Average Location in Northern Railroad Survey*. Although the count rate was small compared to the EMA limiting values for Am-241, it was unexpected. To investigate this, some field measurements were taken.

Two Senior Radiological Control Technicians returned to the location of the Am-241 anomaly guided by a cartographer using GPS data. The area was surveyed with the Berkeley Nucleonics SAM-940 spectrometer and no elevated readings were found. Spectra were acquired at the suspect location and at a background area with the ORTEC Detective and the spectra compared; no substantial differences were seen in the gamma spectra. See Figure 41, *ORTEC Detective on Northern Railroad Am-241 Elevated Reading Looking North*, for a photograph of the ORTEC Detective mounted on its tripod at the suspect location. See Figure 42, *Spectra from the Northern Railroad Am-241 Elevated Reading Site*, for the gamma spectra of the background area and of the suspect area.

No indication of Am-241 radioactivity was found at the site. After review, it was concluded that the elevated 60-second moving average calculation resulted from the way the net Am-241 count rate is determined in an unusual set of circumstances and that no elevated Am-241 is present.

60-Second Moving Average of Stripped Counts Per Second in Am-241 ROI
vs. 60-Second Moving Average Location in Northern Railroad Survey

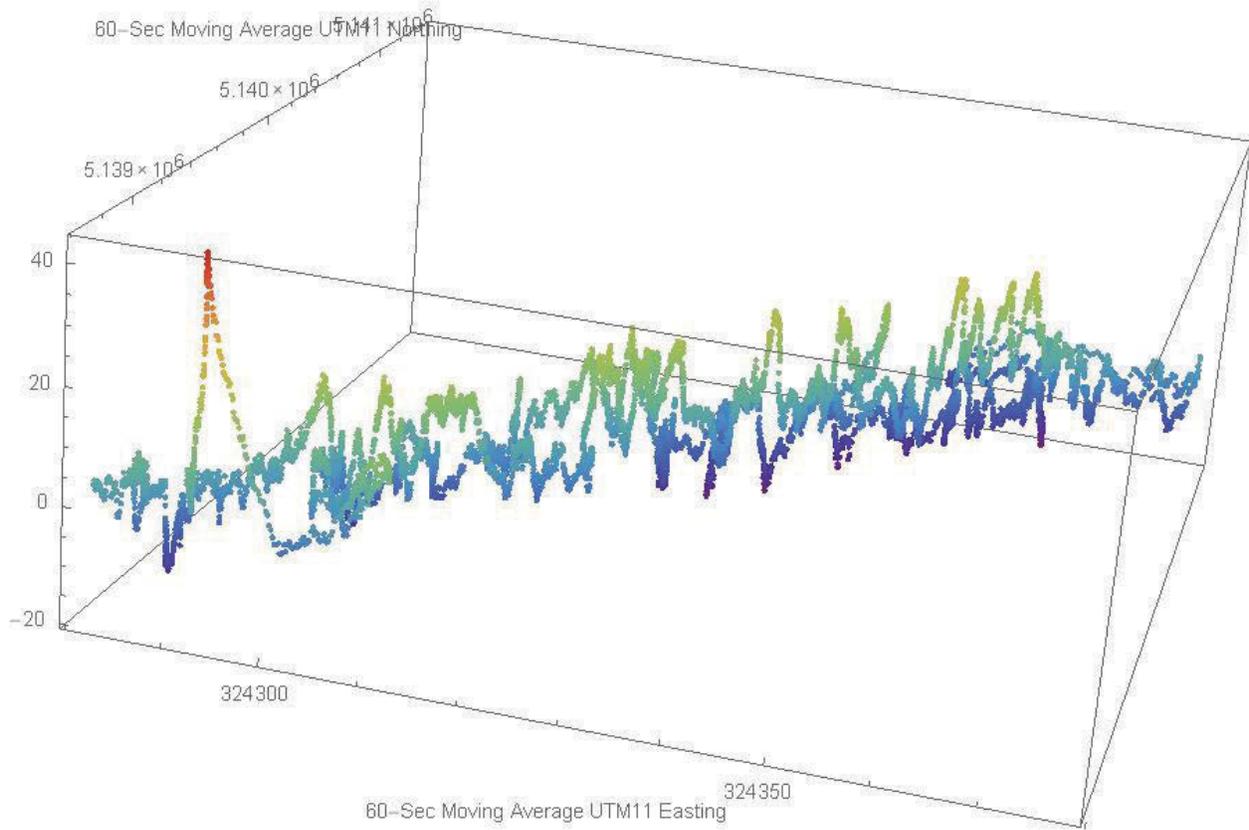


Figure 40. Sixty-Second Moving Average of Stripped Counts Per Second in Am-241 ROI vs
60-Second Moving Average Location in Northern Railroad Survey



Figure 41. ORTEC Detective on Northern Railroad Am-241 Elevated Reading Looking North

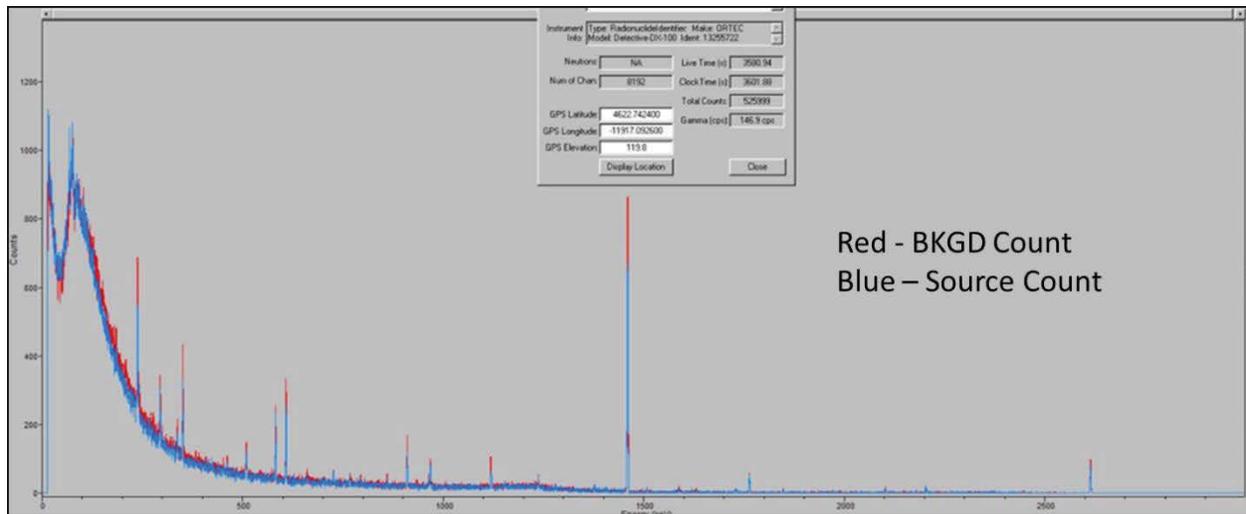


Figure 42. Spectra from the Northern Railroad Am-241 Elevated Reading Site

4) Comparison to Background

The statistical values from the Northern Railroad survey are compared to the statistical values from background surveys in Table 12, *Comparison to Background Statistical Values for Northern Railroad*. The statistics for Cs-137, Co-60, Pa-234m, and Am-241 are very nearly the same, except that the minimum values are somewhat less. These reduced minimum values very likely resulted from the mobile gamma spectrometer being over the pavement briefly when it turned around at the northern end of the site. The “gross man-made ROI” (same as “man-made ROI”) show both a decreased minimum and an increased maximum. The decreased minimum is likely due to the spectrometer briefly being over the pavement, and the increased maximum is due to the anomaly discussed above. The increases in standard deviation, coefficient of variation, and inter-quartile range are due to the low minimum and high maximum. Therefore, the soil concentrations of radioactive material in the Northern Railroad survey area are similar to those in the background areas.

Table 12. Comparison to Background Statistical Values for Northern Railroad

		Mean (cps)	Standard Deviation (cps)	Coefficient of Variation (%)	Inter - quartile Range (cps)	Minimum (cps)	Maximum (cps)	Skewness	Kurtosis
Cs-137	Background	159.2	15.63	9.82	22	104	223	0.117	2.9
	Northern Railroad	152.6	16.1	10.55	21	83	211	-0.005	2.96
Co-60	Background	104.6	10.52	10.05	15	65	154	0.122	3.01
	Northern Railroad	102.5	12.81	12.5	17	56	167	0.025	3.09
Pa-234m	Background	82.9	9.31	11.62	13	47	130	0.125	3.03
	Northern Railroad	77	11	14.11	16	42	124	0.07	2.87
Am-241	Background	140.7	30.96	22	42	101	289	0.039	2.98
	Northern Railroad	139.1	30.64	22.03	42	24	288	0.003	3.03
Gross Man-made	Background	4642	152	3.27	197	4204	5244	0.512	3.01
	Northern Railroad	4611	253	5.49	318	3807	5940	-0.242	3.39

4.4.2.3 Around Constrained Area 2

The survey of Around Constrained Area 2 is by far the largest of all gamma scan surveys performed. It covered about 171 acres and collected 309,504 1-second gamma spectra. Because this area was thought to have the highest probability of contamination, the scan lines were close together so that the detector fields of view touched each other along the scan lines.

The results of the scan and the analyses are described in LTS Technical Note, *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Area Around Constrained Area 2 of the Southern 600 Area Completed on 5-23 February 2015*, Rev.0 (23).

1) Scan Outcomes

The results of the gamma scans for Cs-137, Co-60, Am-241, and Pa-234m are shown in Figures 43–46. There are at least three environmental factors that can affect the count rate in the detector while surveying land: soil type, topology, and radon concentration. The absorption of some radionuclides, Cs-137 for example, is fairly strongly affected by the type of soil. The topology of the land will affect the count rate. For instance, the count rate will go up when the detector is at the bottom of a hill. The radon concentration (and daughters) seen by the detector varies with weather conditions.

In Figure 43, the count rate for the Cs-137 region of interest varies sharply by soil type. The low count rate areas, shown in green, are over sand dunes and dirt roads, and the higher count rates, orange and red, are over less sandy soil.

Figure 44 shows the results for Co-60. The count rate pattern across the site shows little variation. The detector is seeing background counts only in this region of interest.

Figure 45 shows the results for Am-241. The count rates are slightly higher in the inner part of Around Constrained Area 2. This is due to an increase in radon counts during the days when these readings were taken. This increase in radon is discussed further below.

Figure 46 shows the results for Pa-234m (U-238). There is very little variation across this survey area.

In all cases, the count rates are small compared to the EMA limiting value.

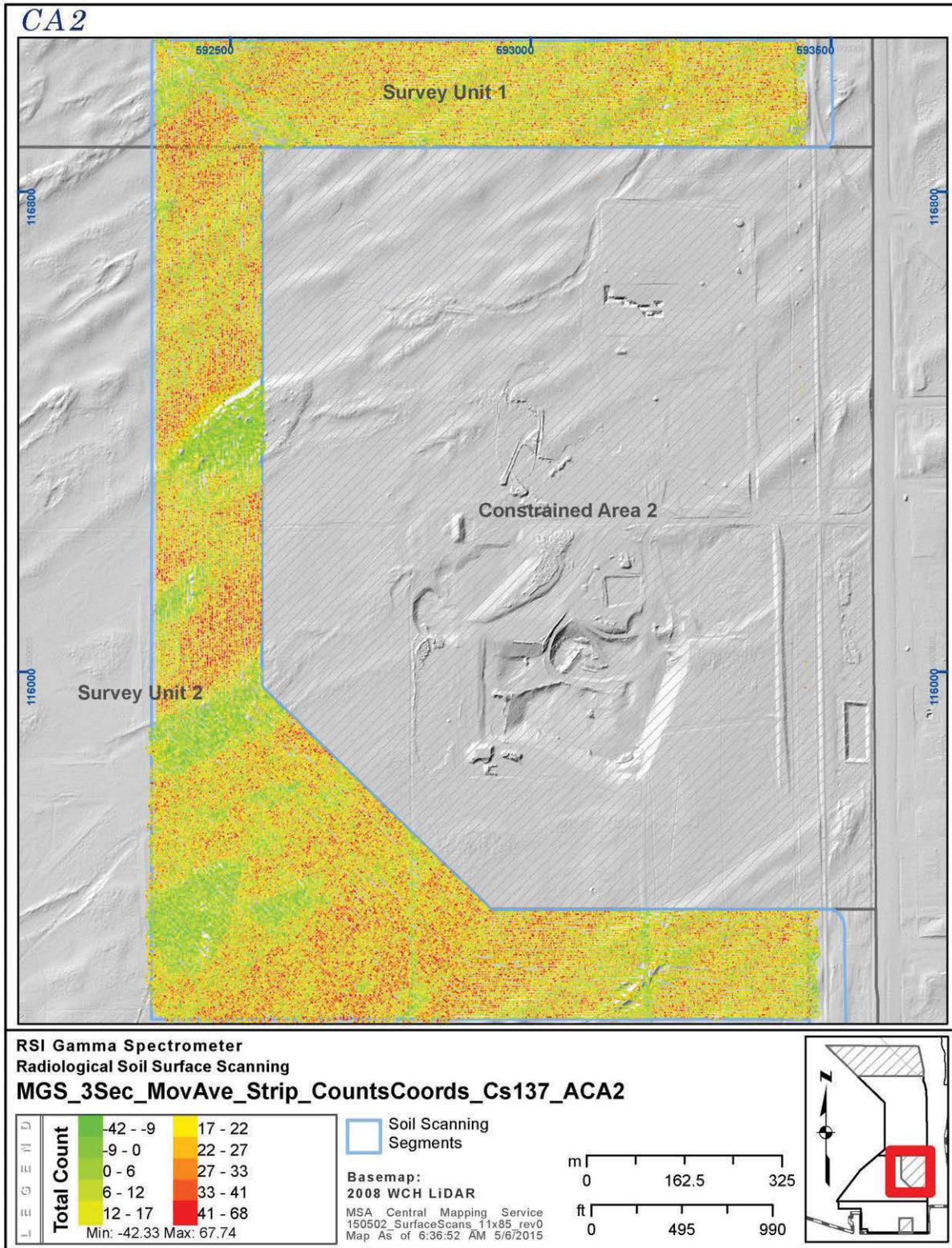


Figure 43. Three-Second Moving Average Count Rate (cps) for Cs-137 for the Around Constrained Area 2 Survey

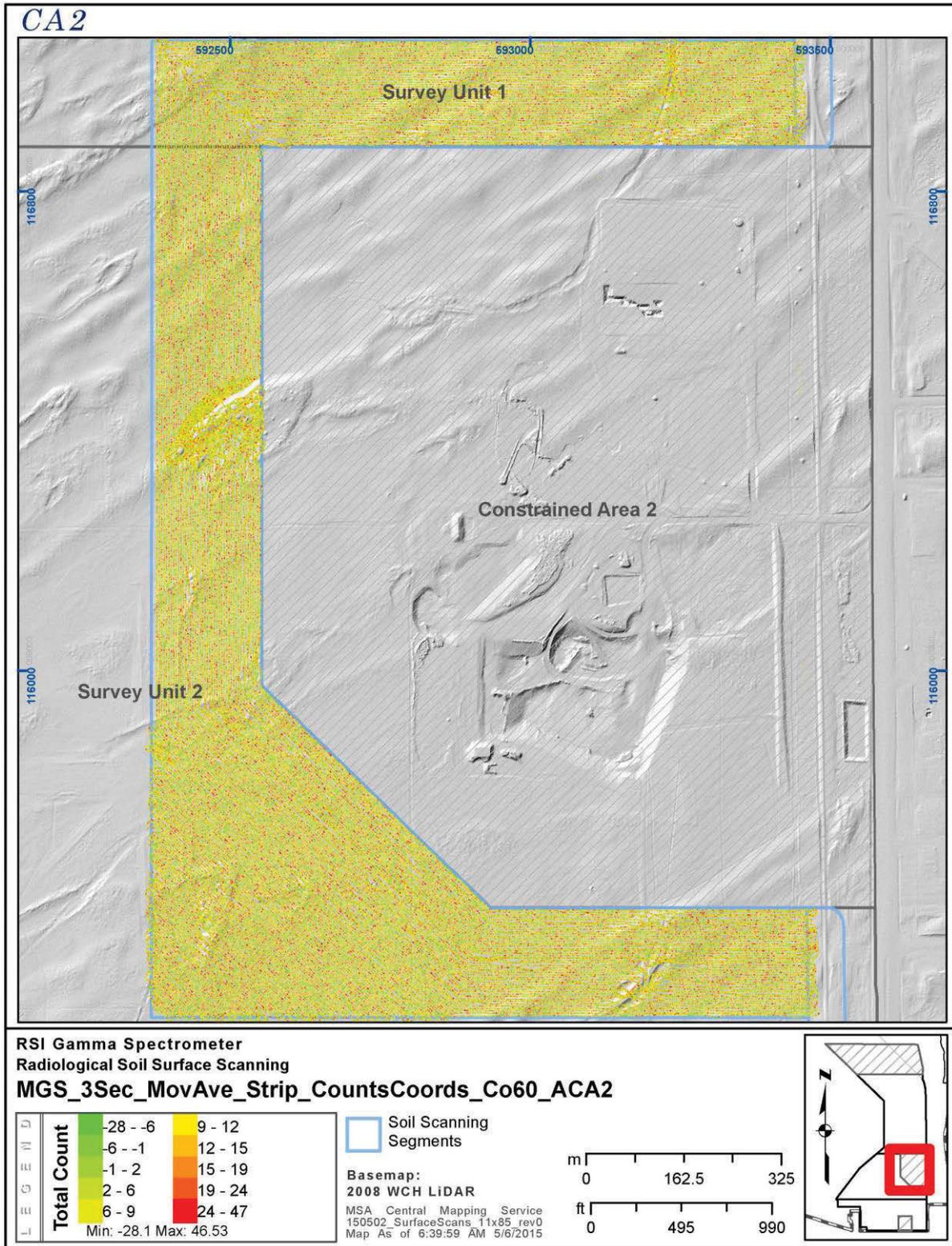


Figure 44. Three-Second Moving Average Count Rate (cps) for Co-60 for the Around Constrained Area 2 Survey

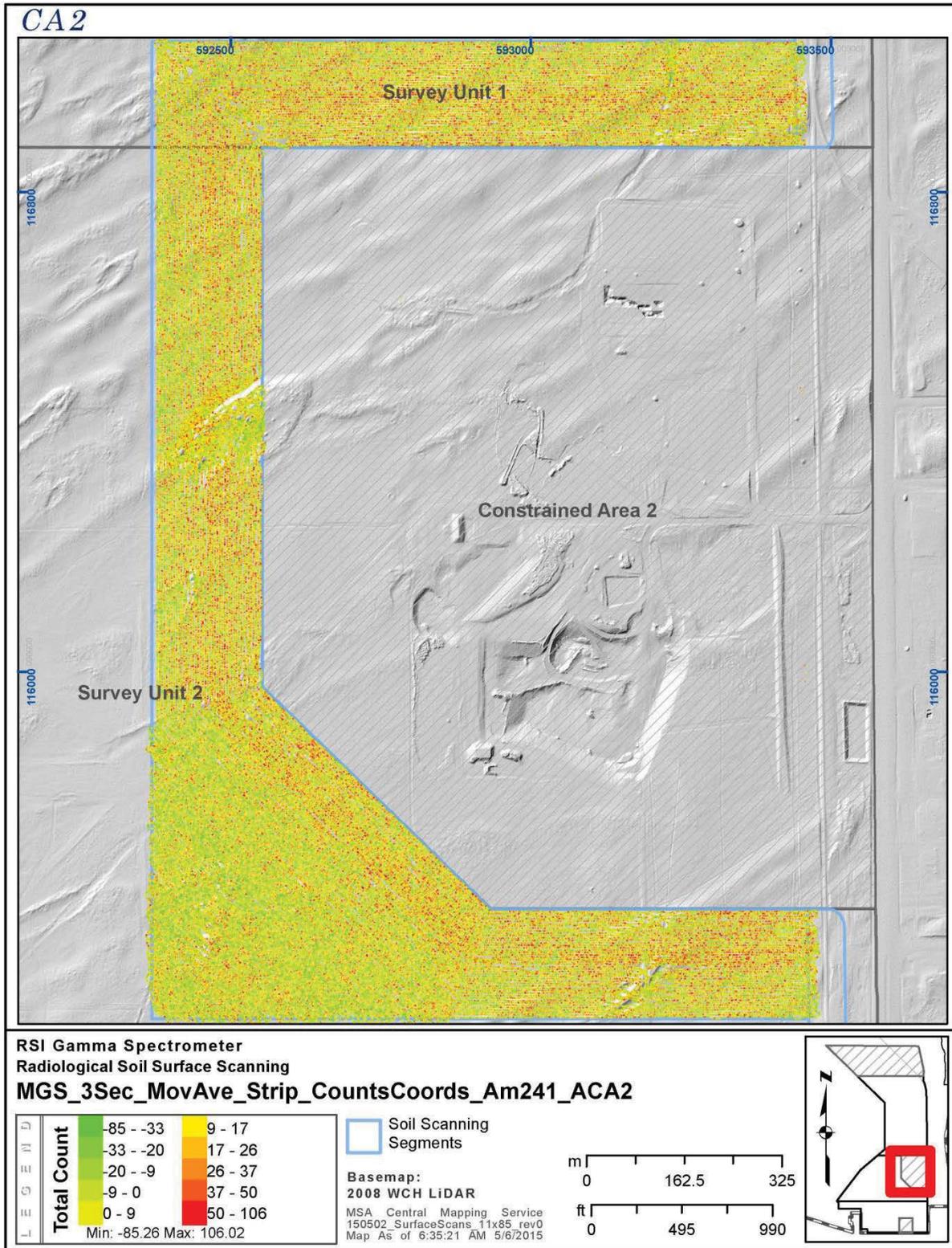


Figure 45. Three-Second Moving Average Count Rate (cps) for Am-241 for the Around Constrained Area 2 Survey

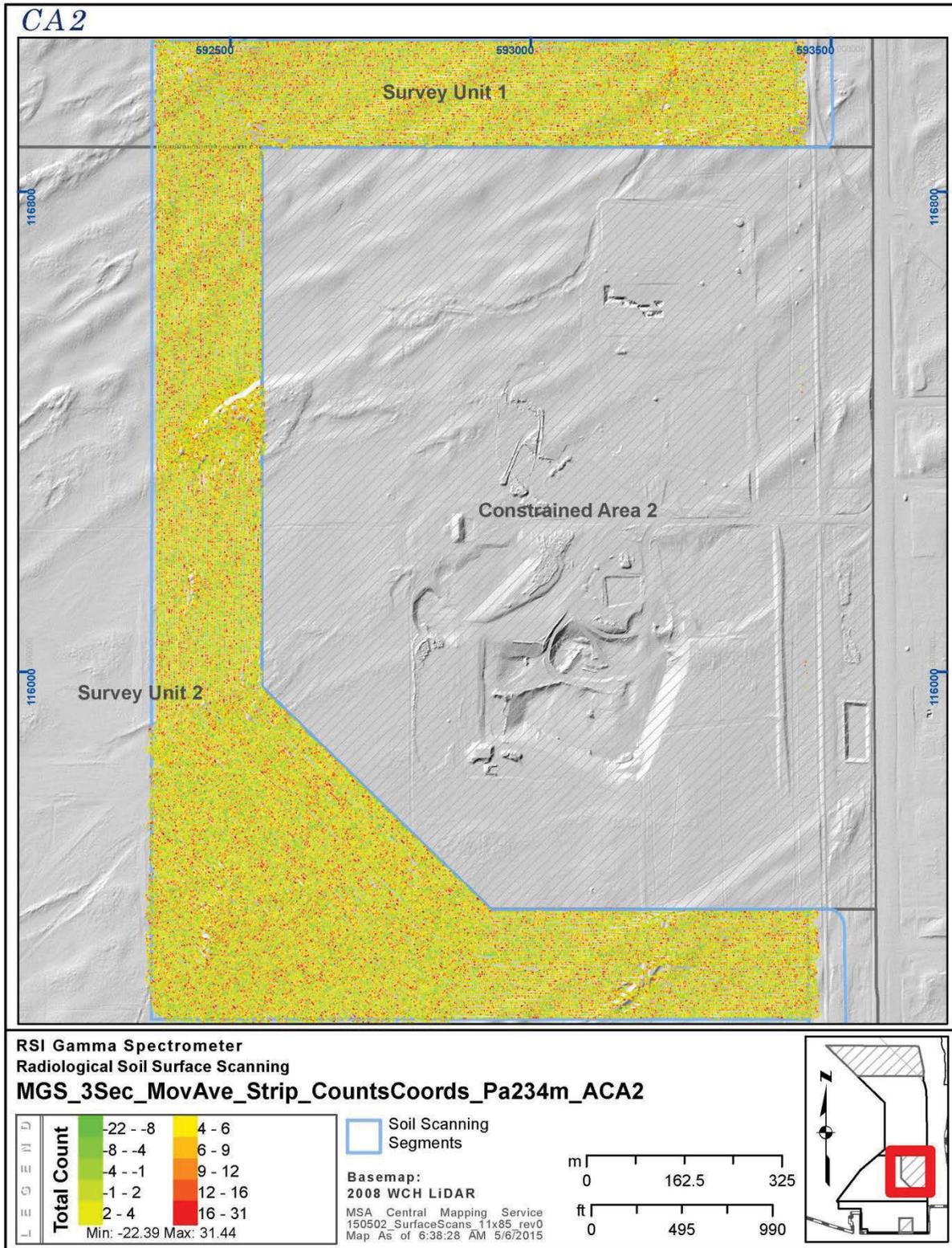


Figure 46. Three-Second Moving Average Count Rate (cps) for Pa-234m for the Around Constrained Area 2 Survey

2) Sum-of-Fractions

The EMA sum-of-fractions for each of the 309,504 measurements in the Around Constrained Area 2 survey is depicted in Figure 47, *Three-Second Moving Average EMA Sum-of-Fractions for Around Constrained Area 2 Survey vs. Location in Around Constrained Area 2 Survey*. As can be seen from the graph, the maximum value of the EMA sum-of-fractions found is less than 0.1, or about 10% of the limiting value.

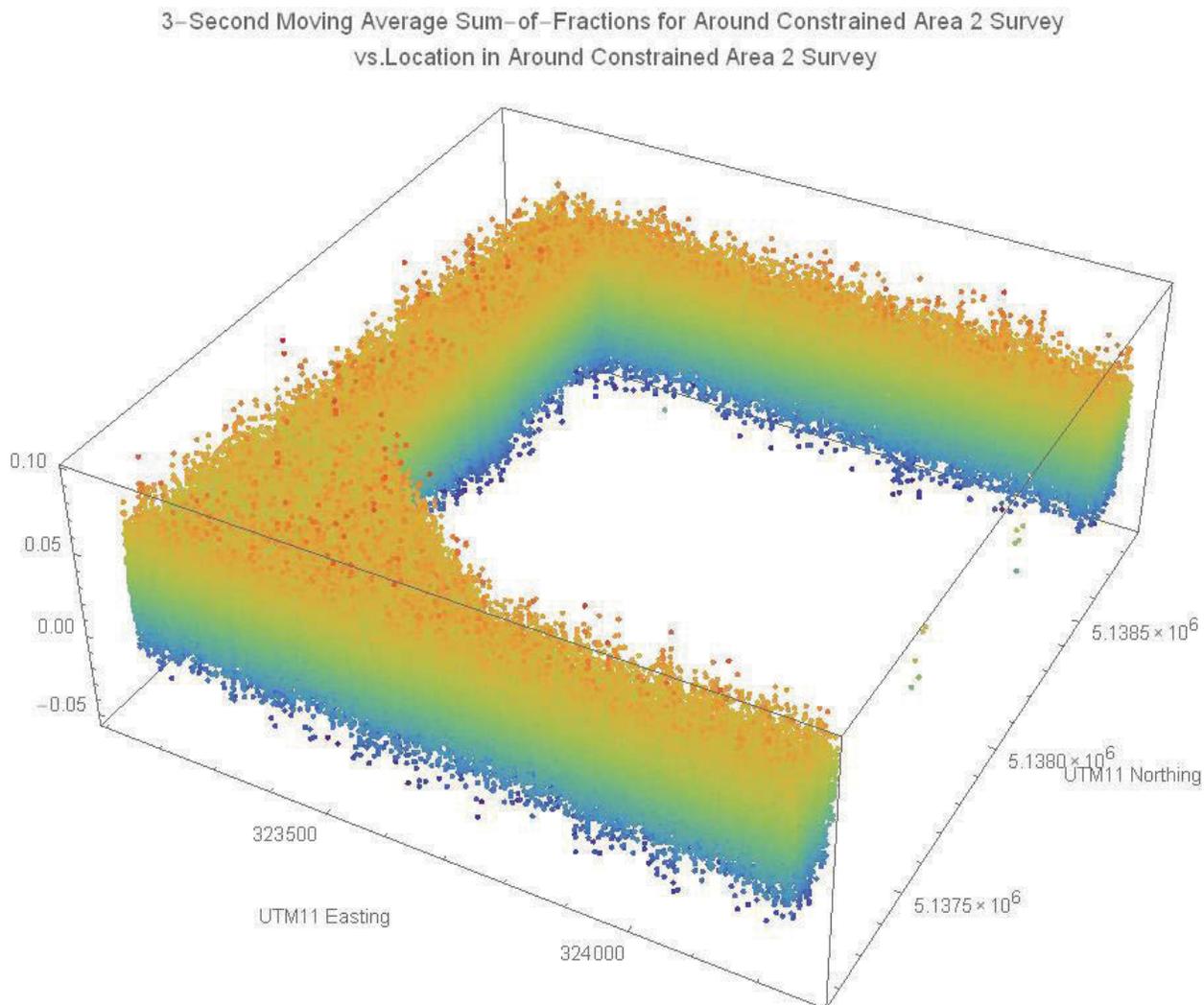


Figure 47. Three-Second Moving Average EMA Sum-of-Fractions for Around Constrained Area 2 Survey vs. Location in Around Constrained Area 2 Survey

Figure 48, *Stripped Counts Per Second in Made-Made ROI vs Location in Around Constrained Area 2 Survey*, clearly shows the effect of radon concentration on the count rate of the detector. The bright red and orange band shows the high count rate on one day due to radon. This effect is also shown in Figure 49, *Stripped Counts Per Second in Made-Made ROI vs Sequential Order in Around Constrained Area 2 Survey*.

Stripped Counts Per Second in Man-Made ROI
vs. Location in Around Constrained Area 2 Survey

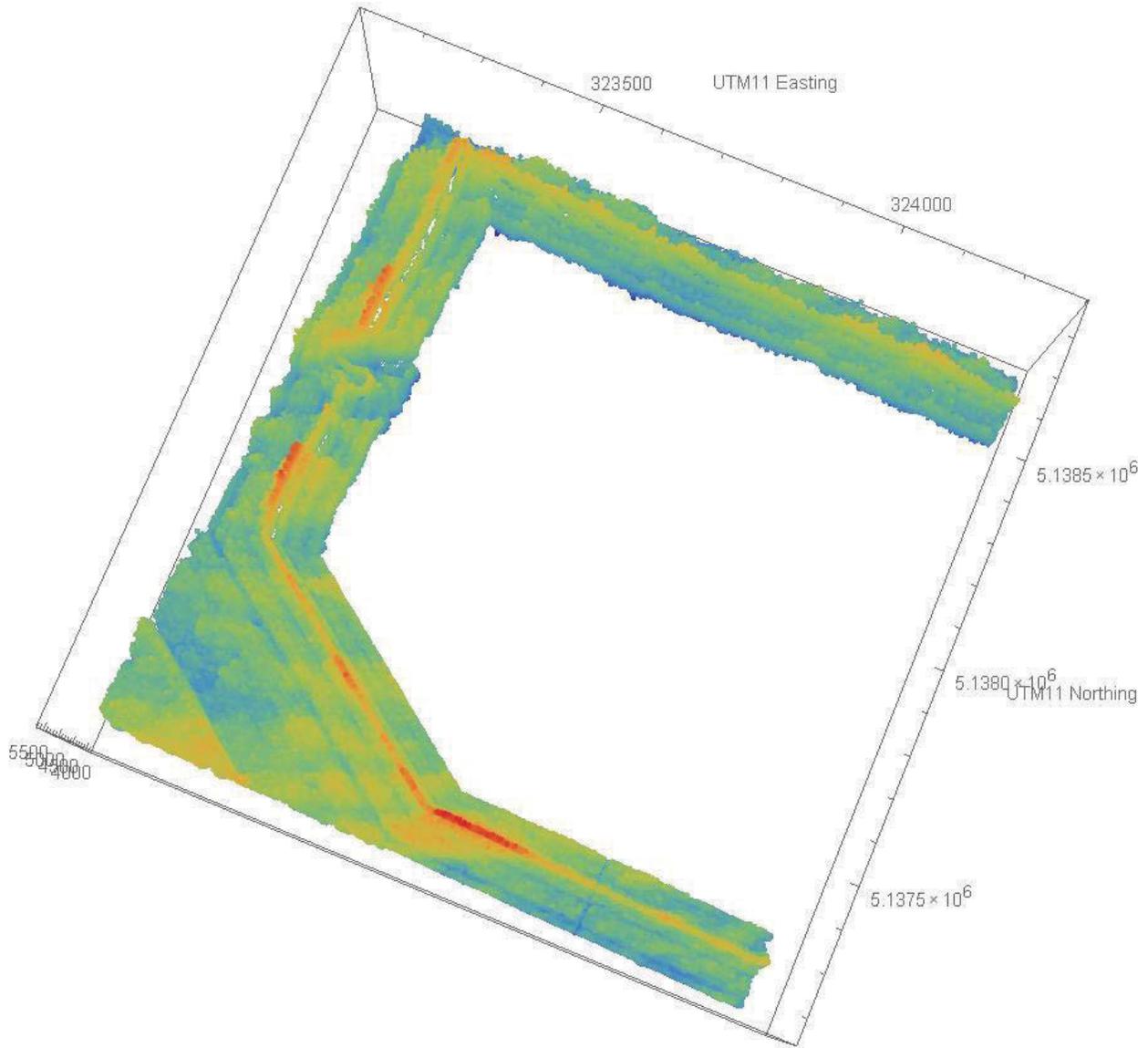


Figure 48. Stripped Counts Per Second in Made-Made ROI vs Location in Around Constrained Area 2 Survey

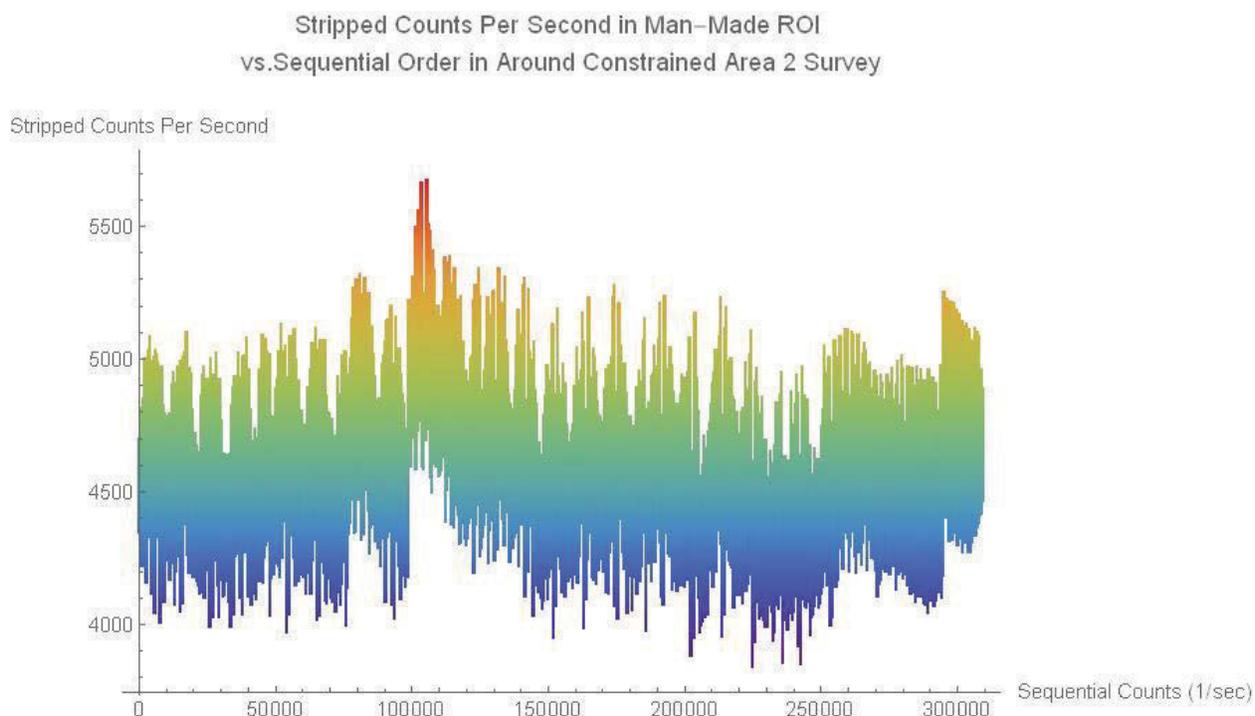


Figure 49. Stripped Counts Per Second in Made-Made ROI vs Sequential Order in Around Constrained Area 2 Survey

3) Comparison to Background

Table 13, *Comparison to Background Statistical Values for Around Constrained Area 2*, shows the relative statistical values derived from the count rates in the various ROIs. Note that, for Cs-137, Co-60, Am-241, and Pa-234m, the statistical values are very nearly the same. For gross man-made ROI, the mean values are the same, but the values associated with the variation of the count rate are greater in the case of Around Constrained Area 2 than for the background areas. The lower value of the minimum count rate is due to the presence of very sandy areas in the area Around Constrained Area 2 that are not present in the background areas. The higher value is due to unusual radon conditions, as discussed above. Therefore, in general, the radioactivity in the soil in the area Around Constrained Area 2 is very similar to that found in the background area.

Table 13. Comparison to Background Statistical Values for Around Constrained Area 2

		Mean (cps)	Standard Deviation (cps)	Coefficient of Variation (%)	Inter - quartile Range (cps)	Minimum (cps)	Maximum (cps)	Skewness	Kurtosis
Cs-137	Background	159.2	15.63	9.82	22	104	223	0.117	2.9
	Around CA2	159	16.75	10.54	23	94	254	0.196	3.06
Co-60	Background	104.6	10.52	10.05	15	65	154	0.122	3.01
	Around CA2	101.3	10.69	10.56	14	52	154	0.159	3.08
Pa-234m	Background	82.9	9.31	11.62	13	47	130	0.125	3.03
	Around CA2	78.5	9.15	11.66	13	41	123	0.119	3.01
Am-241	Background	140.7	30.96	22	42	101	289	0.039	2.98
	Around CA2	148.2	31.94	21.55	43	107	300	0.038	3.01
Gross Man-made	Background	4642	152	3.27	197	4204	5244	0.512	3.01
	Around CA2	4577	213	4.64	287	3836	5672	0.55	3.46

4.4.2.4 Southern Railroad

The survey of the Southern Railroad comprised a single scan on each side of the railroad. It collected 6,021 measurements along the scan path. The radioactivity levels measured were either at or below background levels.

The results of the scan and the analyses are described in LTS Technical Note, *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Southern Railroad of the Southern 600 Area Completed on 16 October 2014, Rev.0 (24)*.

1) Scan Outcomes

The results of the gamma scans for Cs-137, Co-60, Am-241, Pa-234m, and man-made ROI are shown in Figures 50–54. The count rates seen for Cs-137, Co-60, Am-241, and Pa-234m are small compared to the EMA limiting value. The values seen for man-made ROI are small compared to background values.

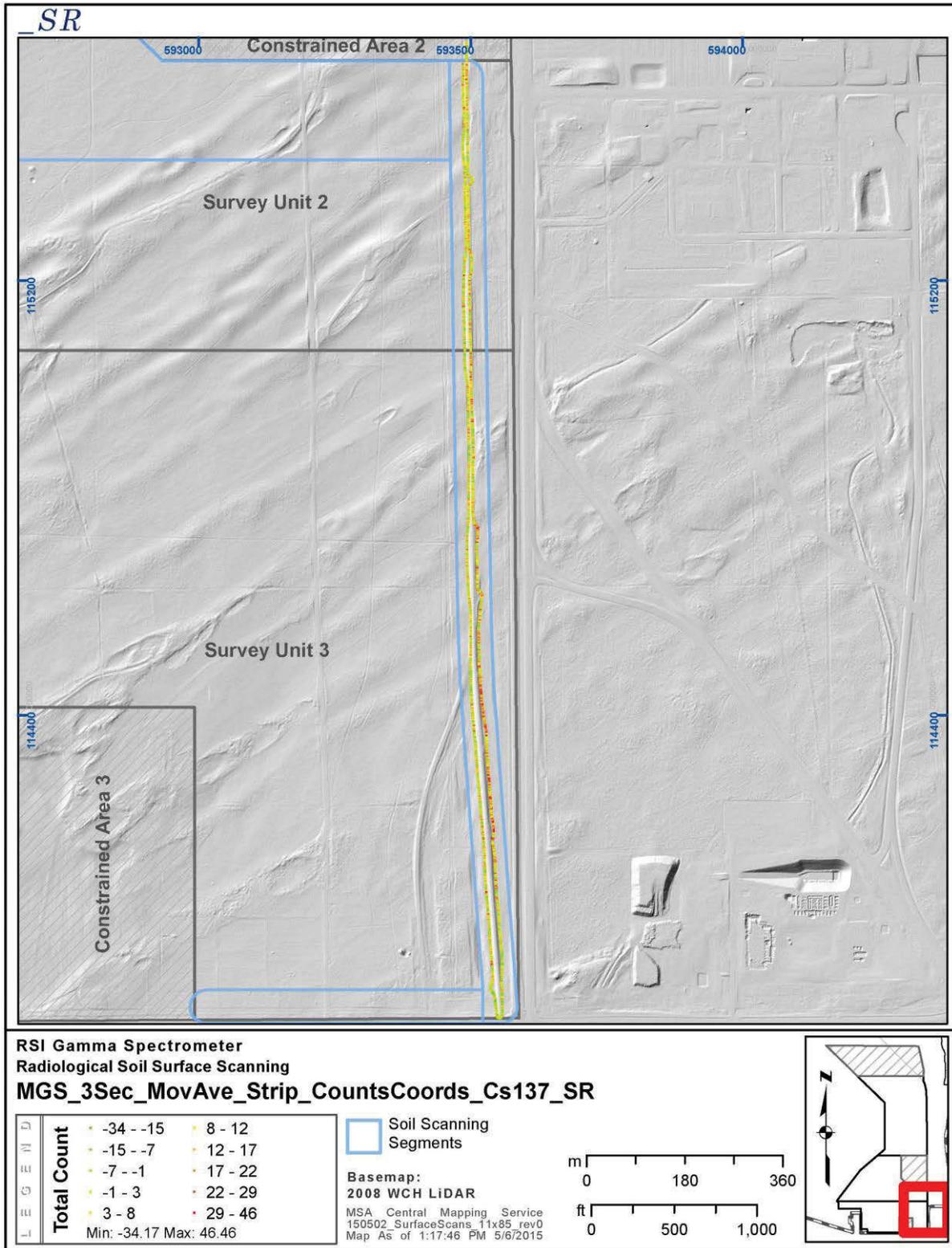


Figure 50. Three-Second Moving Average Count Rate (cps) for Cs-137 for the Southern Railroad Survey

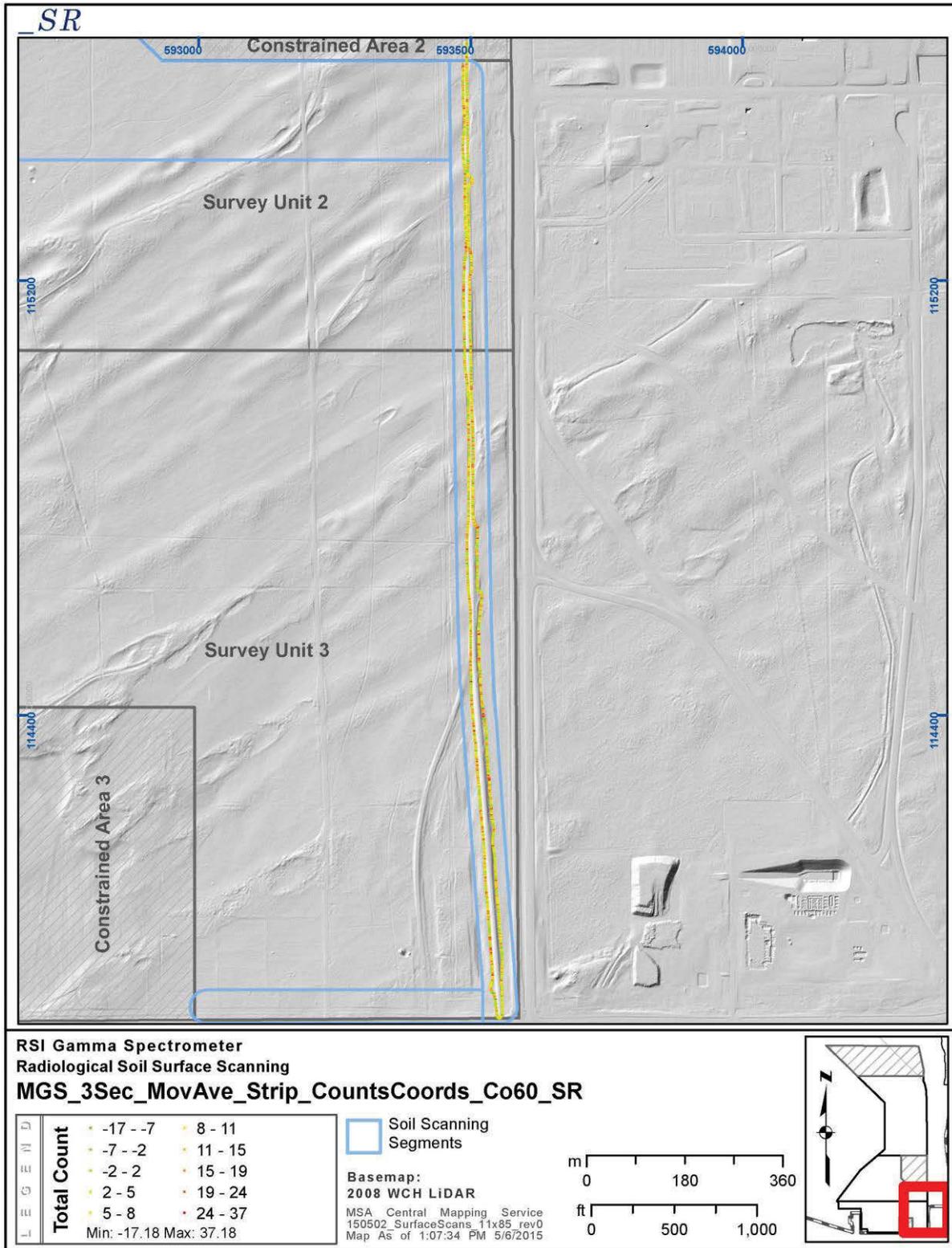


Figure 51. Three-Second Moving Average Count Rate (cps) for Co-60 for the Southern Railroad Survey

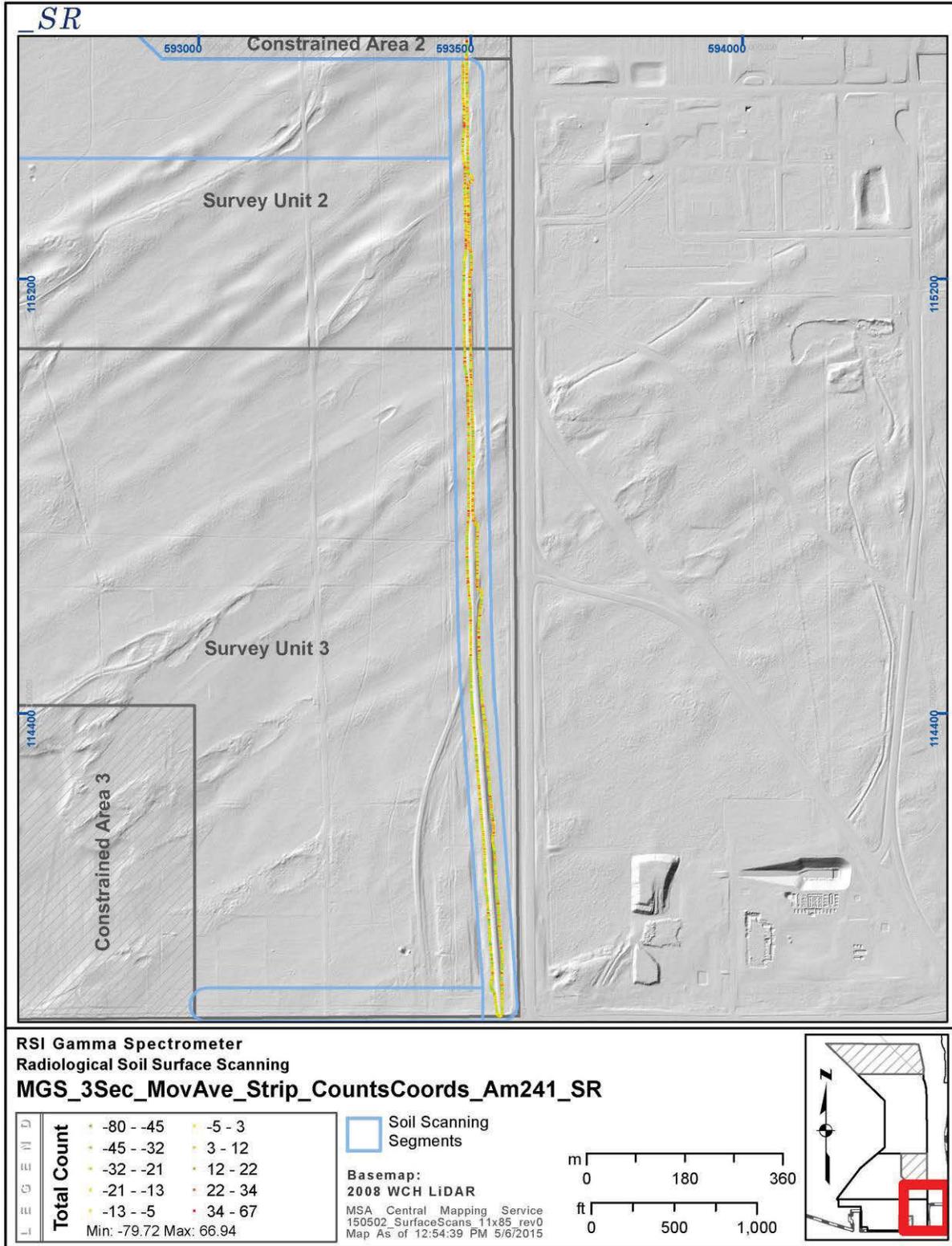


Figure 52. Three-Second Moving Average Count Rate (cps) for Am-241 for the Southern Railroad Survey

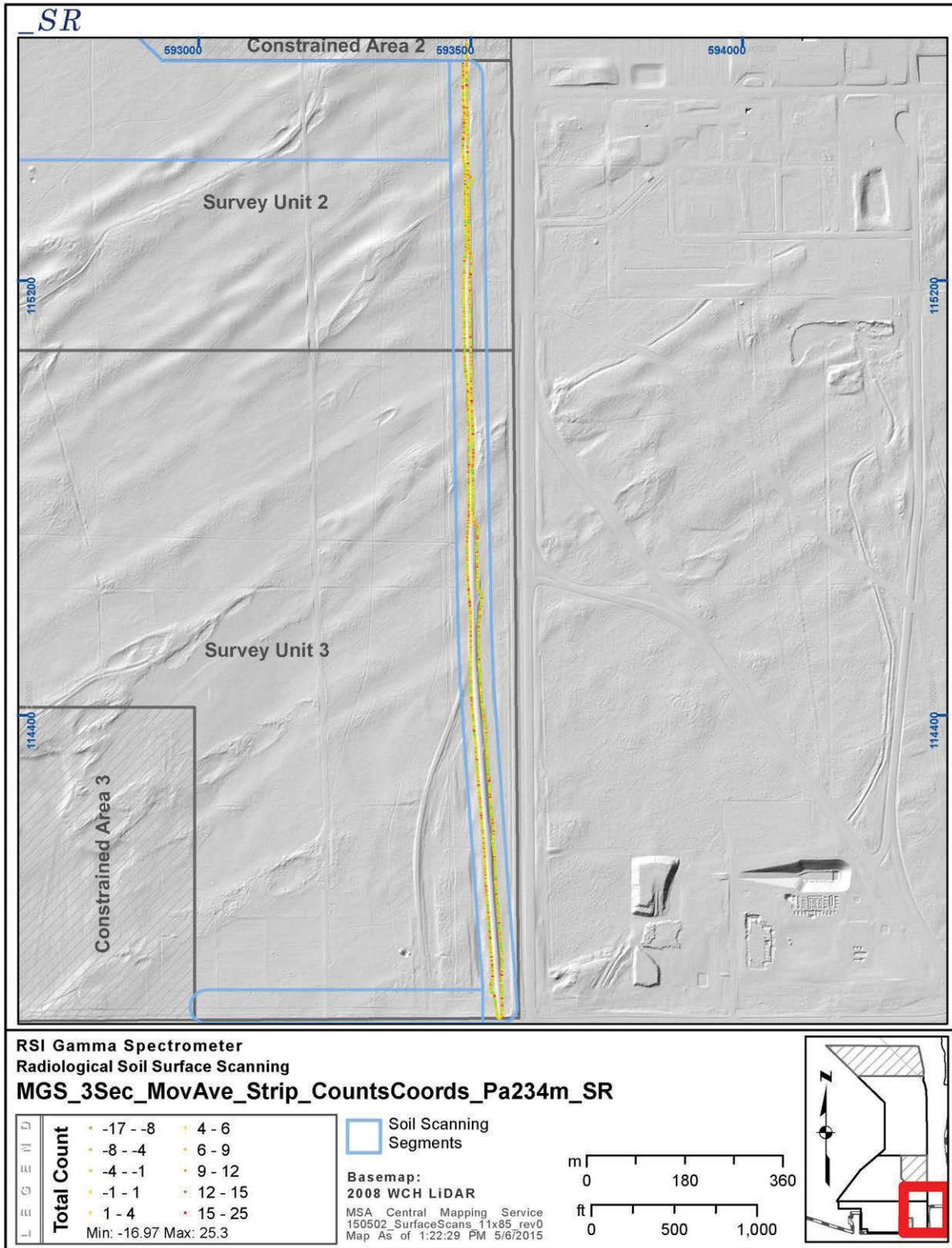


Figure 53. Three-Second Moving Average Count Rate (cps) for Pa-234m for the Southern Railroad Survey

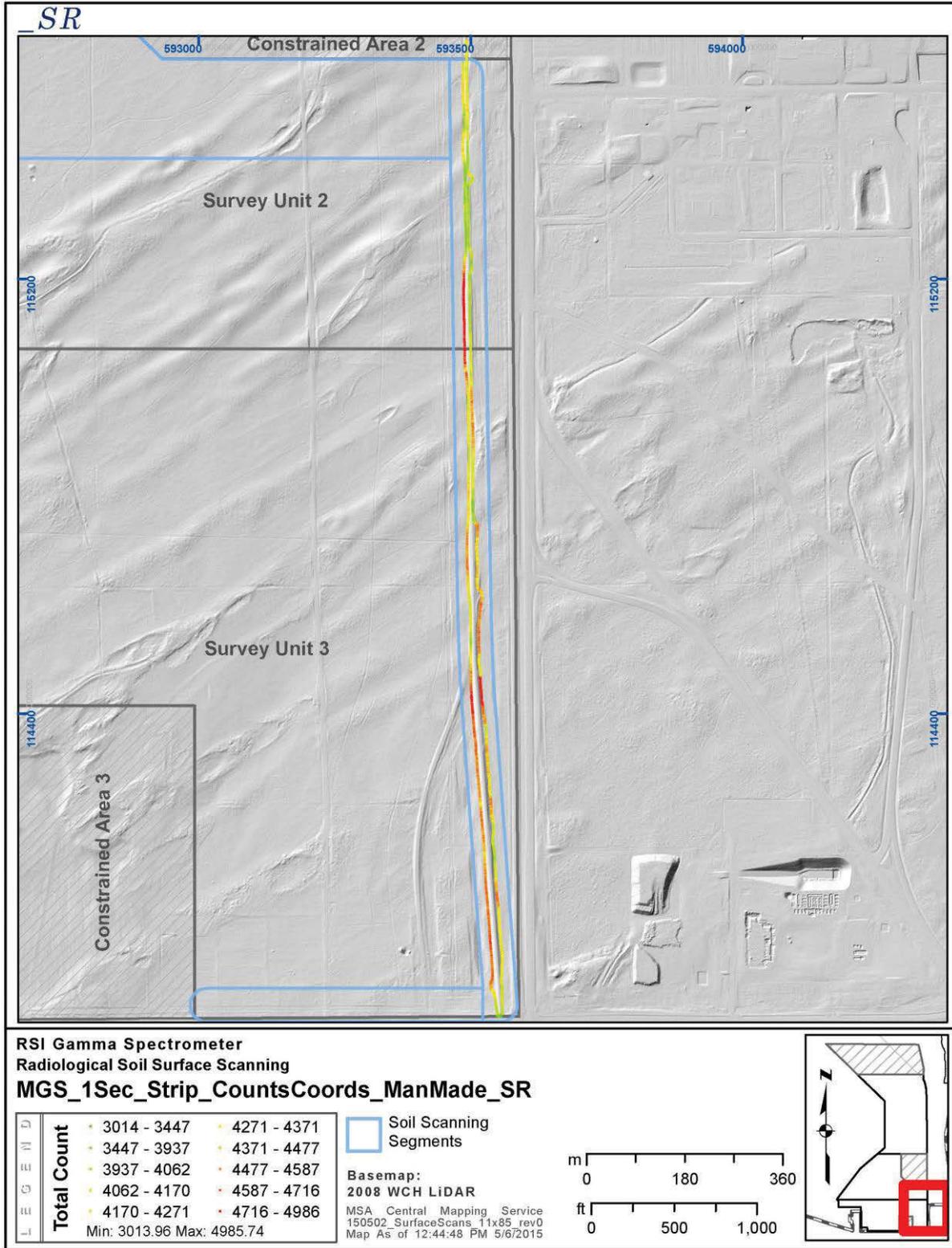


Figure 54. One-Second Moving Average Count Rate (cps) for Man-Made Region of Interest for the Southern Railroad Survey

2) Sum-of-Fractions

The EMA sum-of-fractions for each of the 6,021 measurements in the Southern Railroad survey is depicted in Figure 55, *Three-Second Moving Average EMA Sum-of-Fractions for Southern Railroad Survey vs. Location in Southern Railroad Survey*. As can be seen from the graph, the maximum value of the EMA sum-of-fractions found is less than 0.1 or about 10% of the limiting value.

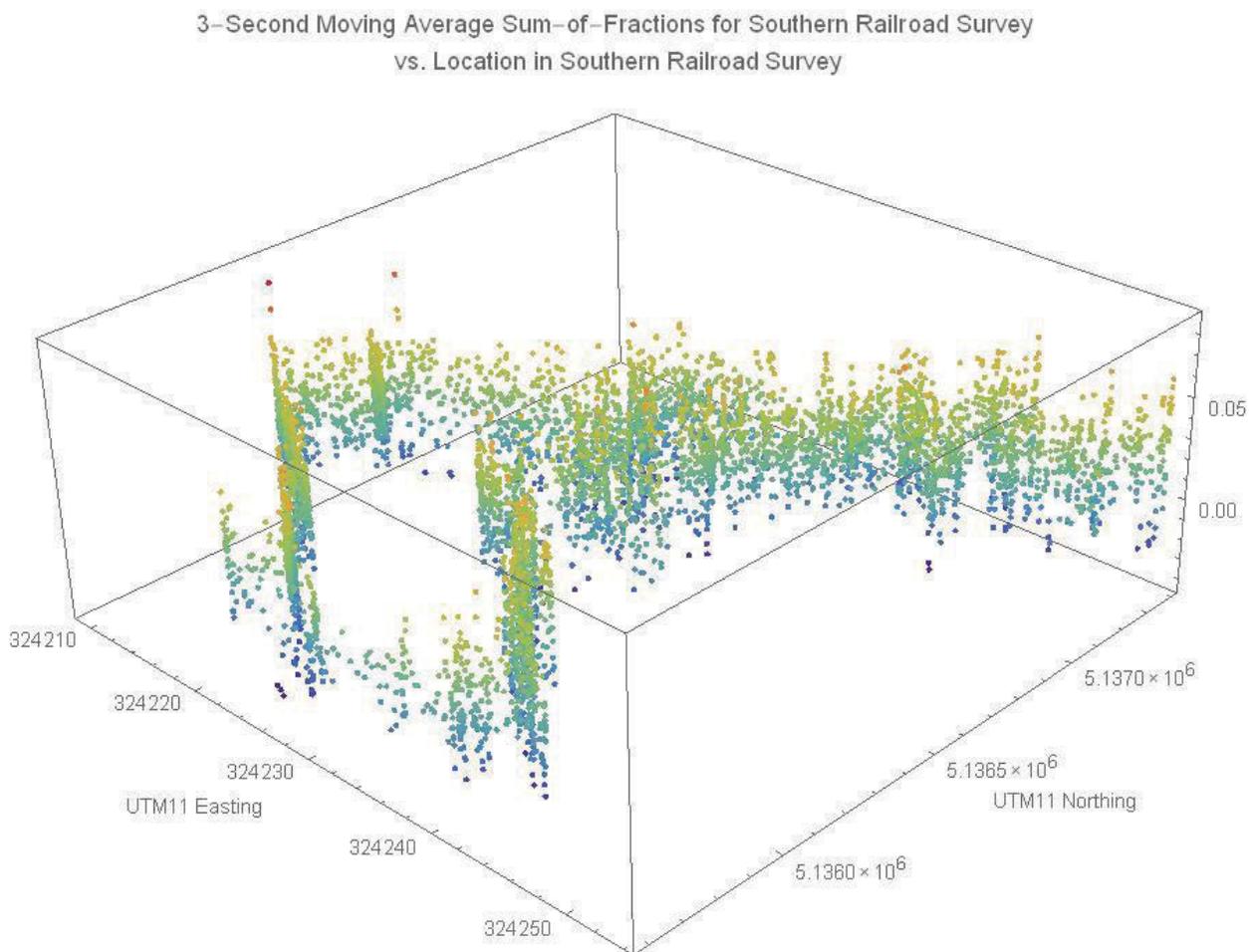


Figure 55. Three-Second Moving Average EMA Sum-of-Fractions for Southern Railroad Survey vs. Location in Southern Railroad Survey

3) Comparison to Background

Table 12, *Comparison to Background Statistical Values for Southern Railroad*, shows the relative statistical values derived from the count rates in the various ROIs. Note that mean values and maximum values are at or less than background values. These lower values probably result from the disturbed soil along most of the survey path. The low minimum values result from the mobile gamma spectrometer being over the pavement briefly when it turned around at

the southern end of the railroad. In general, the count rates found in the Southern Railroad survey are comparable to background values.

Table 14. Comparison to Background Statistical Values for Southern Railroad

		Mean (cps)	Standard Deviation (cps)	Coefficient of Variation (%)	Inter - quartile Range (cps)	Minimum (cps)	Maximum (cps)	Skewness	Kurtosis
Cs-137	Background	159.2	15.63	9.82	22	104	223	0.117	2.9
	Southern Railroad	143.04	16.51	11.54	22	77	207	0.072	3.18
Co-60	Background	104.6	10.52	10.05	15	65	154	0.122	3.01
	Southern Railroad	97.4	12.61	12.94	17	53	146	0.014	2.9
Pa-234m	Background	82.9	9.31	11.62	13	47	130	0.125	3.03
	Southern Railroad	76.3	10.51	13.78	14	33	113	0.031	2.93
Am-241	Background	140.7	30.96	22	42	101	289	0.039	2.98
	Southern Railroad	124	29.68	23.93	40	17	288	0.033	2.98
Gross Man-made	Background	4642	152	3.27	197	4204	5244	0.512	3.01
	Southern Railroad	4318	246	5.71	357	3012	4980	-0.307	4014

4.4.2.5 Horn Rapids Road

The survey parallel to Horn Rapids Road comprised one continuous scan down and back. It collected 2,151 measurements along the scan path. The radioactivity levels measured were at or near background values.

The results of the scan and the analyses are described in LTS Technical Note, *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Horn Rapids Road Area of the Southern 600 Area Completed on 2 February 2015, Rev.0 (25)*.

1) Scan Outcomes

The results of the gamma scans for Cs-137, Co-60, Am-241, Pa-234m, and man-made ROI are shown in Figures 56–60. The values seen for Cs-137, Co-60, Am-241, and Pa-234m are small compared to the EMA limiting value. The values seen for man-made ROI are somewhat less than the background values.

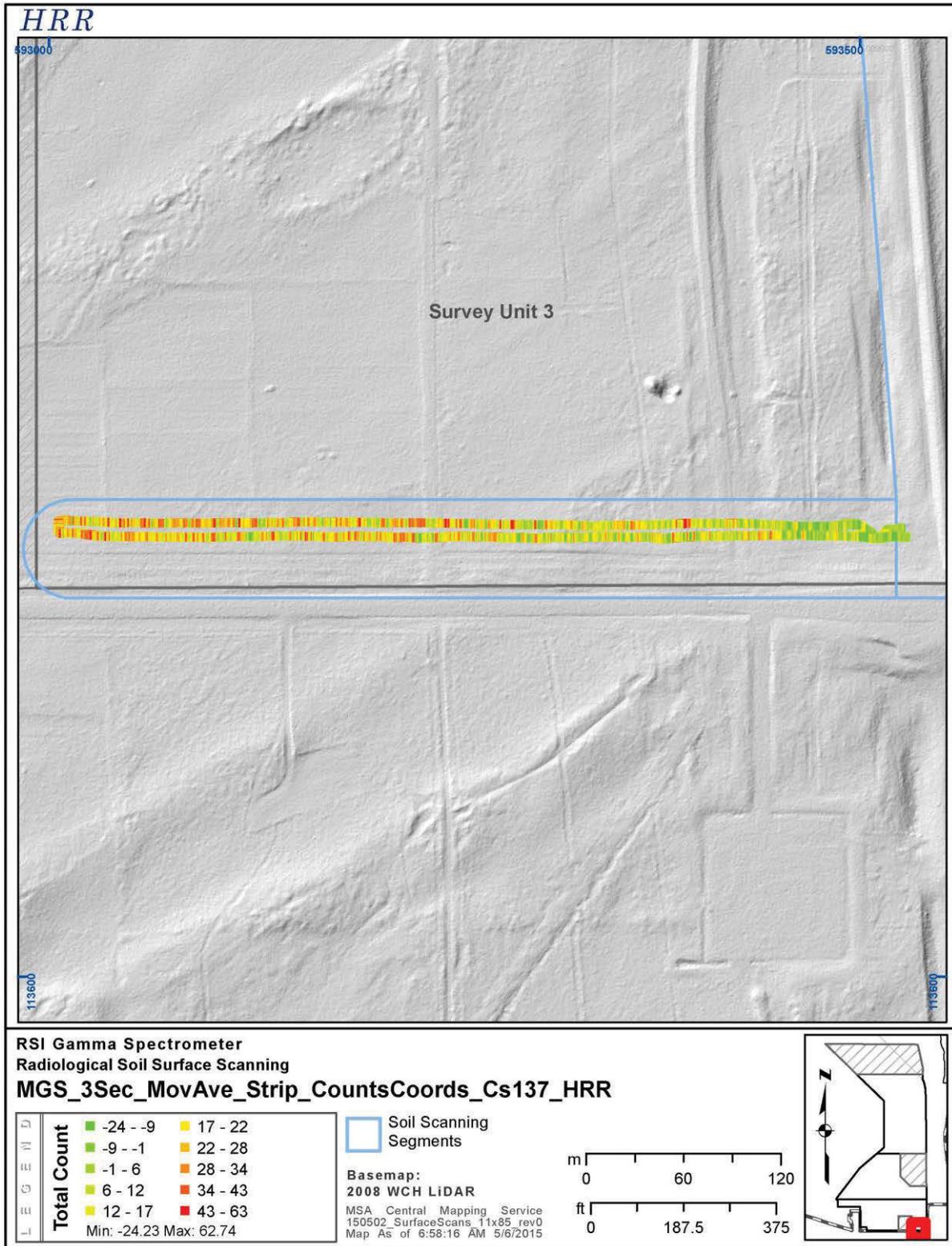


Figure 56. Three-Second Moving Average Count Rate (cps) for Cs-137 for the Horn Rapids Road Survey

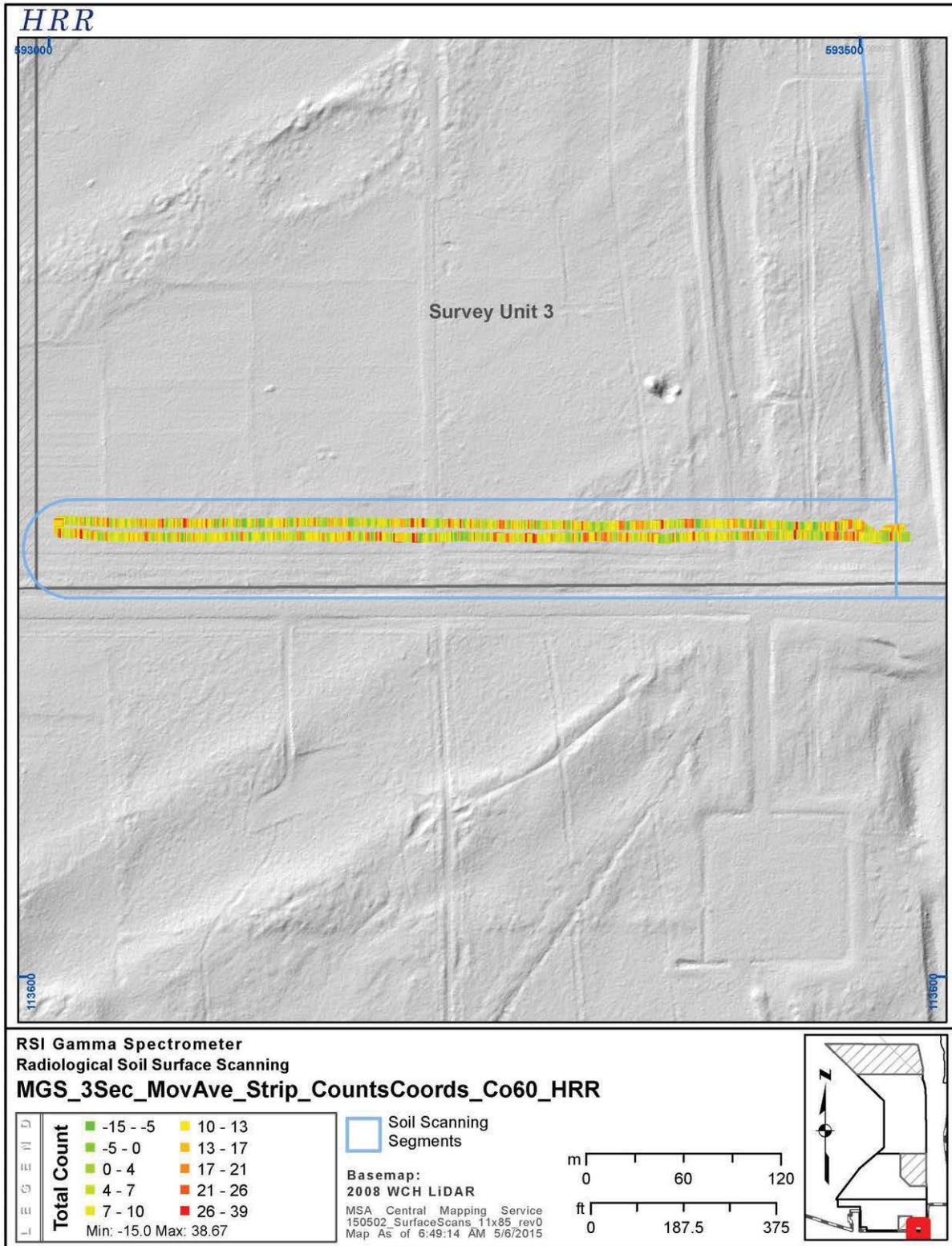


Figure 57. Three-Second Moving Average Count Rate (cps) for Co-60 for the Horn Rapids Road Survey

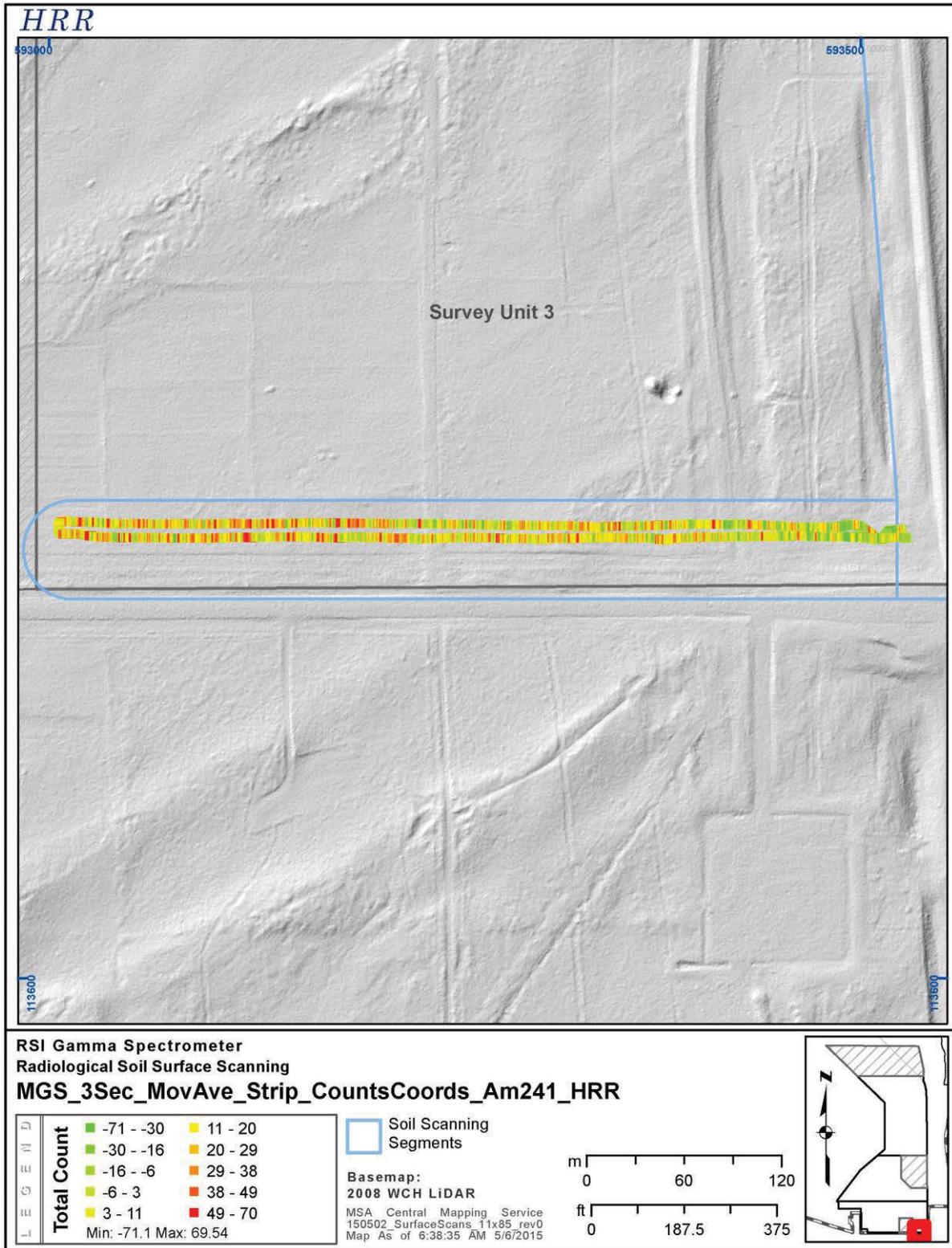


Figure 58. Three-Second Moving Average Count Rate (cps) for Am-241 for the Horn Rapids Road Survey

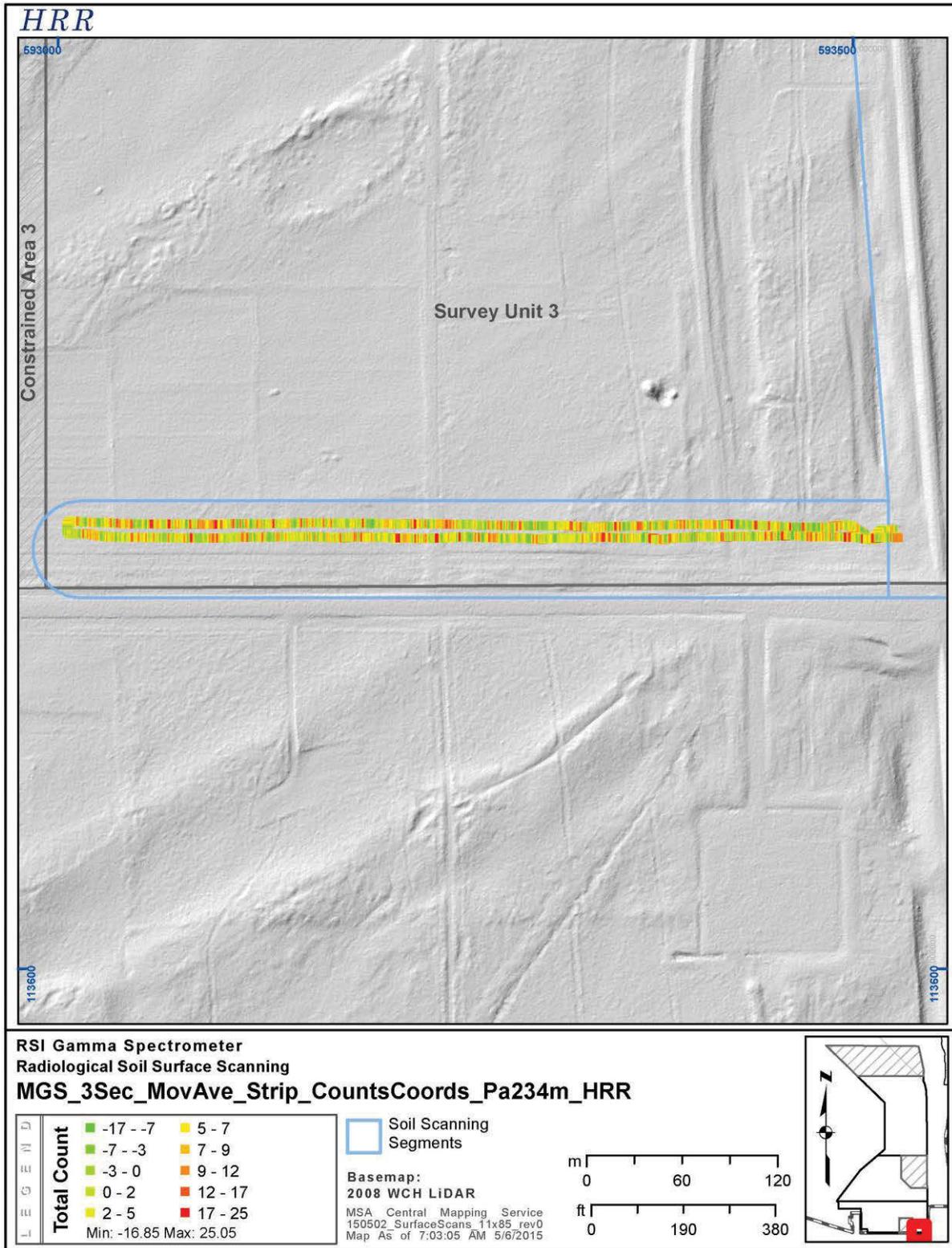


Figure 59. Three-Second Moving Average Count Rate (cps) for Pa-234m for the Horn Rapids Road Survey

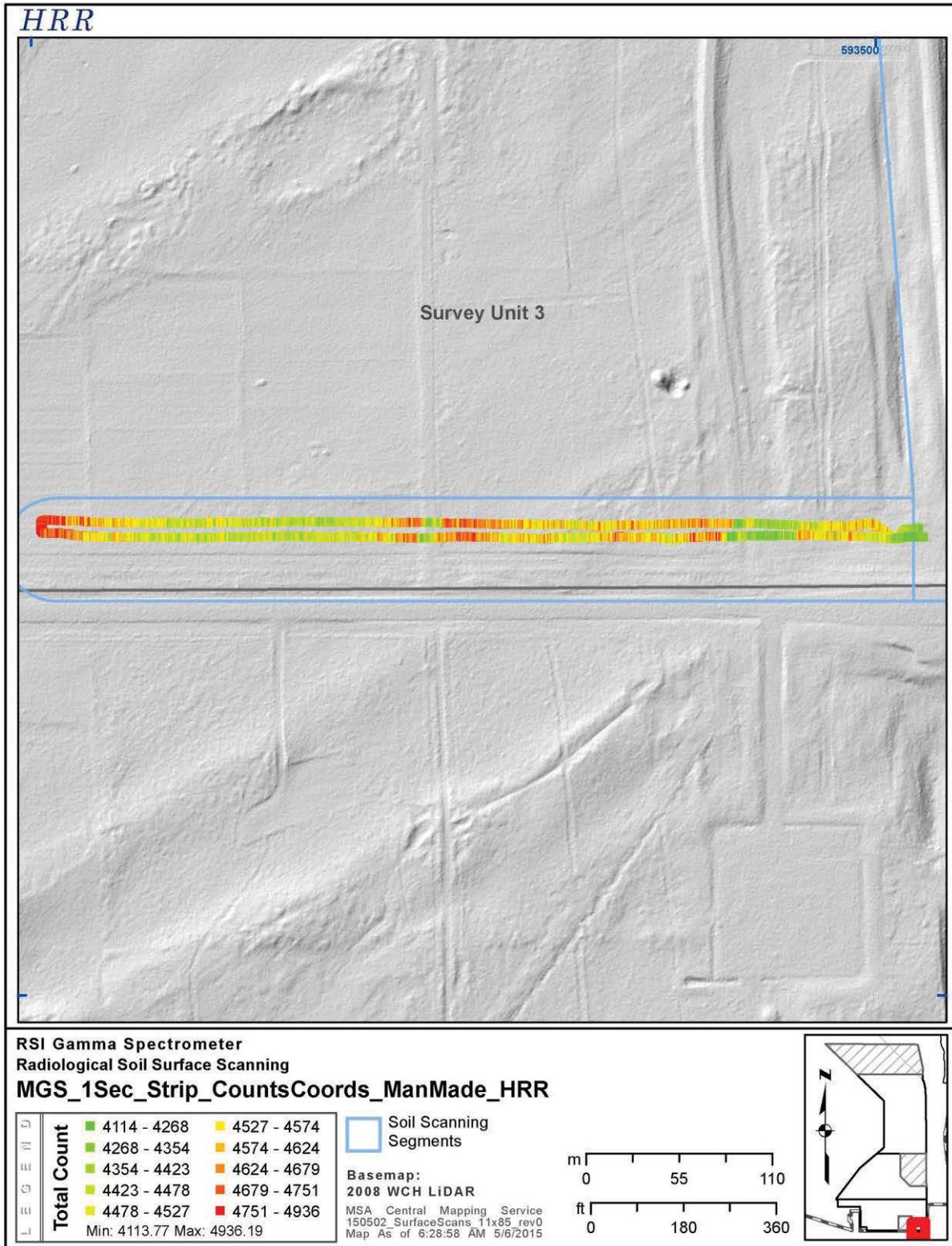


Figure 60. One-Second Moving Average Count Rate (cps) for Man-Made Region of Interest for the Horn Rapids Road Survey

2) Sum-of-Fractions

The EMA sum-of-fractions for each of the 2,151 measurements in the Horn Rapids survey is depicted in Figure 61, *Three-Second Moving Average EMA Sum-of-Fractions for Horn Rapids Road Survey vs. Location in Horn Rapids Road Survey*. As can be seen from the graph, the maximum value of the EMA sum-of-fractions found is less than 0.08 or about 8% of the limiting value.

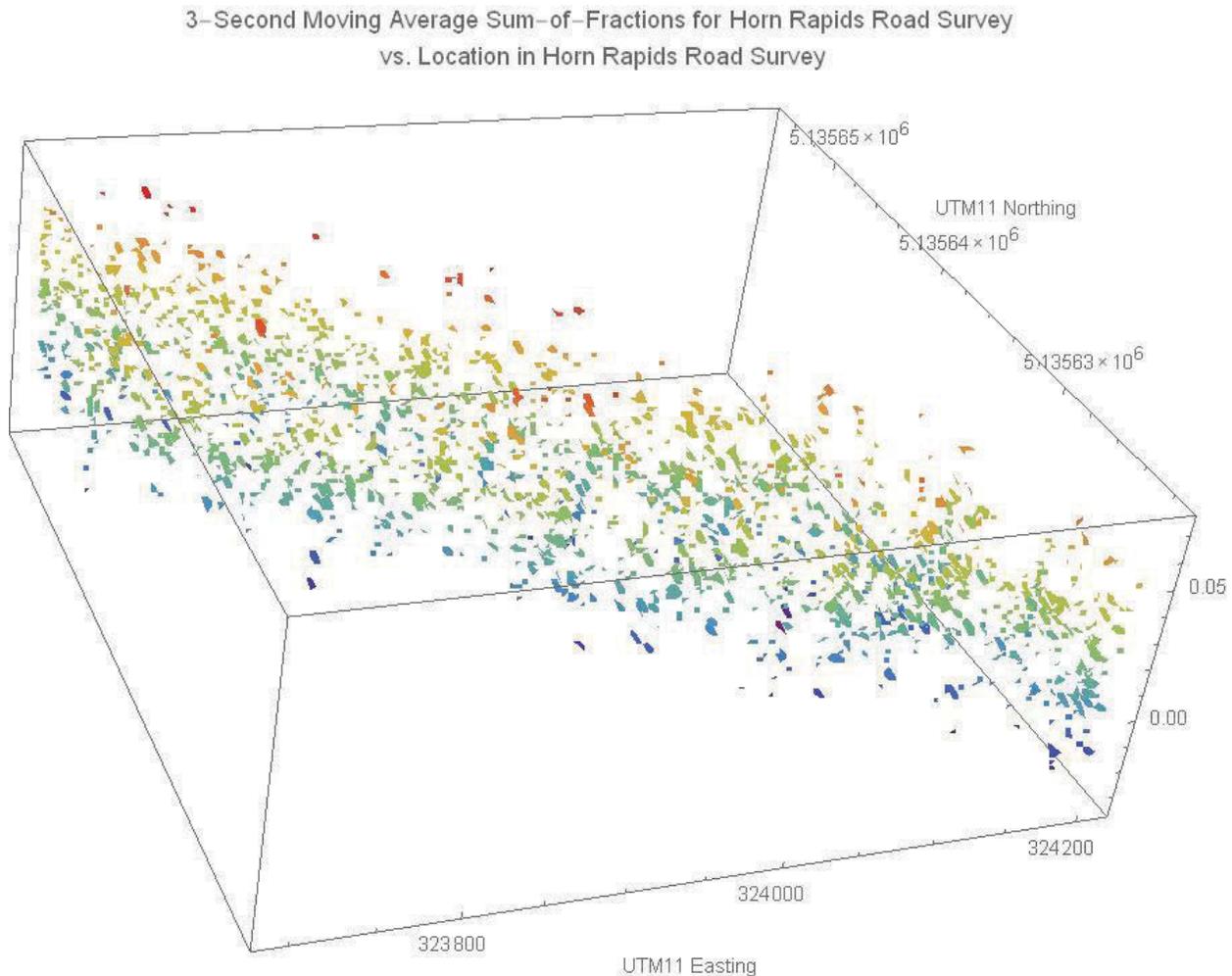


Figure 61. Three-Second Moving Average EMA Sum-of-Fractions for Horn Rapids Road Survey vs. Location in Horn Rapids Road Survey

3) Comparison to Background

Table 15, *Comparison to Background Statistical Values for Horn Rapids Road*, shows the relative statistical values derived from the count rates in the various ROIs. The values for the Horn Rapids Road statistics are at or near the background statistics.

Table 15. Comparison to Background Statistical Values for Horn Rapids Road

		Mean (cps)	Standard Deviation (cps)	Coefficient of Variation (%)	Inter - quartile Range (cps)	Minimum (cps)	Maximum (cps)	Skewness	Kurtosis
Cs-137	Background	159.2	15.63	9.82	22	104	223	0.117	2.9
	Horn Rapids Road	155.1	13.84	8.92	18	107	201	0.027	3.01
Co-60	Background	104.6	10.52	10.05	15	65	154	0.122	3.01
	Horn Rapids Road	99.8	10.58	10.6	14	66	142	0.115	3.01
Pa-234m	Background	82.9	9.31	11.62	13	47	130	0.125	3.03
	Horn Rapids Road	76.29	8.87	11.63	12	40	107	0.039	3.06
Am-241	Background	140.7	30.96	22	42	101	289	0.039	2.98
	Horn Rapids Road	149.8	31.92	21.3	44	37	262	0.008	2.99
Gross Man-made	Background	4642	152	3.27	197	4204	5244	0.512	3.01
	Horn Rapids Road	4520	123	2.72	159	4108	4931	-0.225	3.1

4.4.2.6 Western Boundary

The survey along the Western Boundary comprised a single scan from north to south. It collected 5,998 measurements along the scan path. The radioactivity levels measured were at or near background levels.

The results of the scan and the analyses are described in LTS Technical Note, *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Western Boundary of the Southern 600 Area Completed on 2 February 2015*, Rev.0 (26).

1) Scan Outcomes

The results of the gamma scan for Cs-137, Co-60, Am-241, Pa-234m, and man-made ROI are shown in Figures 62–66. The values for Cs-137, Co-60, Am-241, and Pa-234m are small compared to the EMA limiting value. The values seen for man-made ROI are comparable to the measured background values.

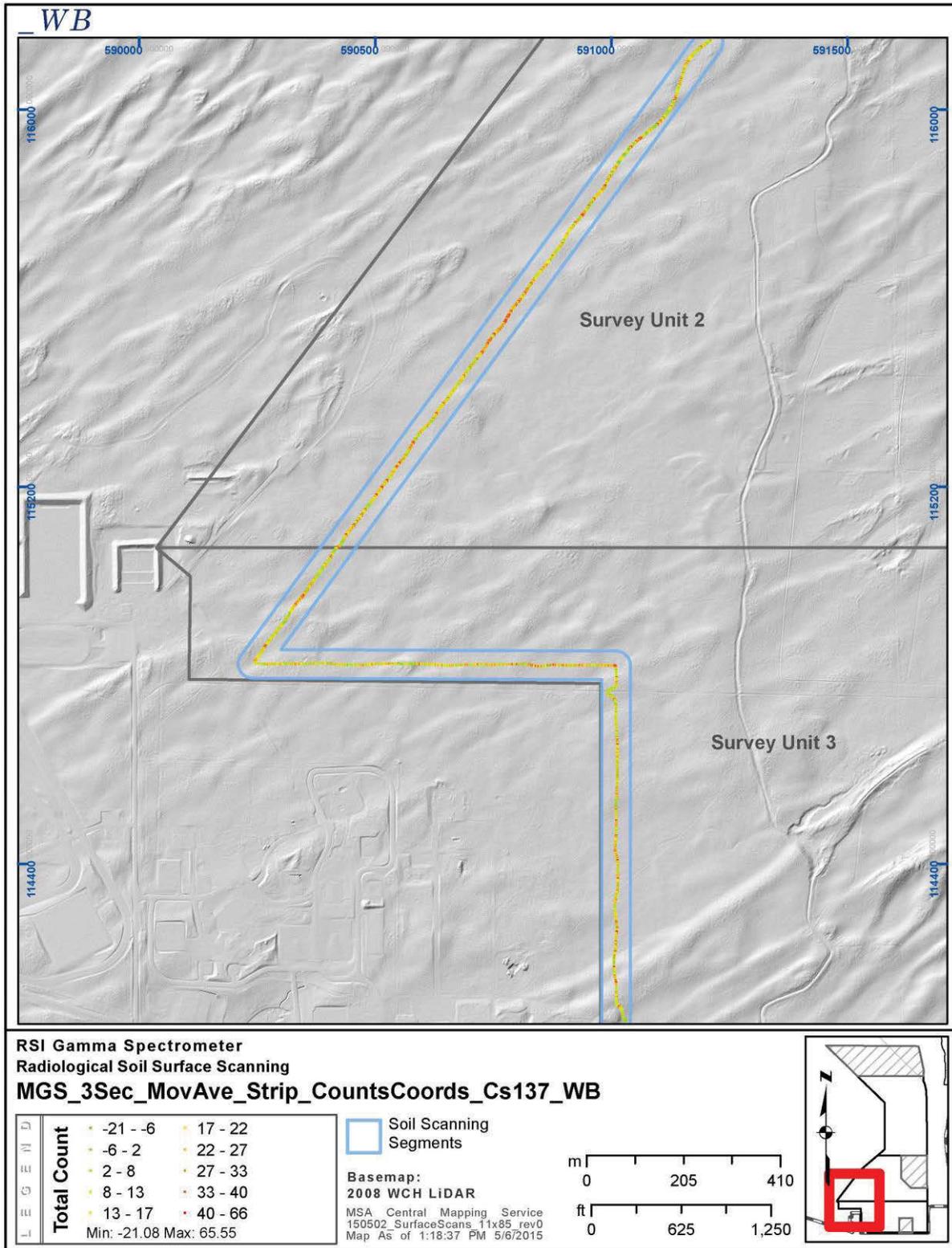


Figure 62. Three-Second Moving Average Count Rate (cps) for Cs-137 for the Western Boundary Survey

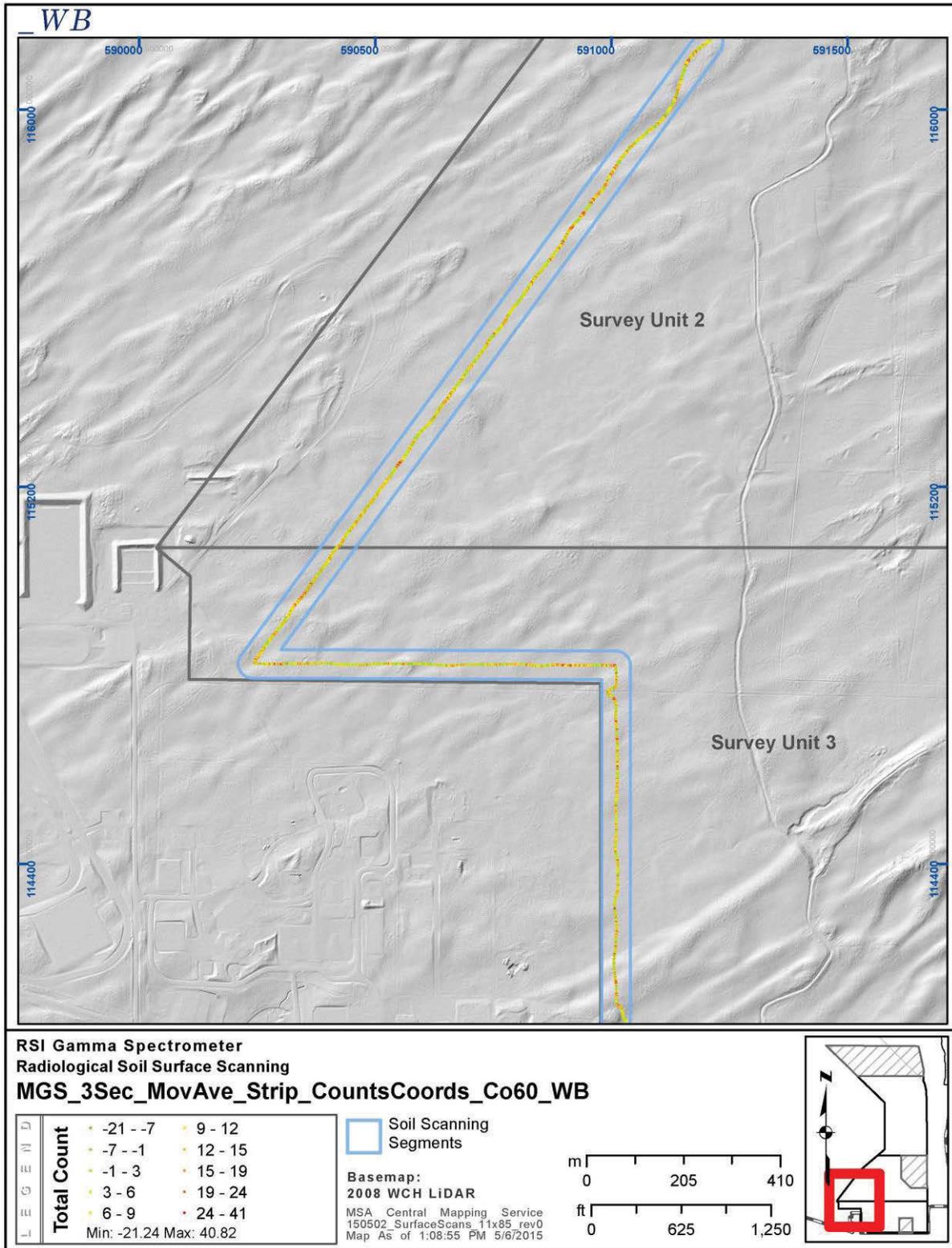


Figure 63. Three-Second Moving Average Count Rate (cps) for Co-60 for the Western Boundary Survey

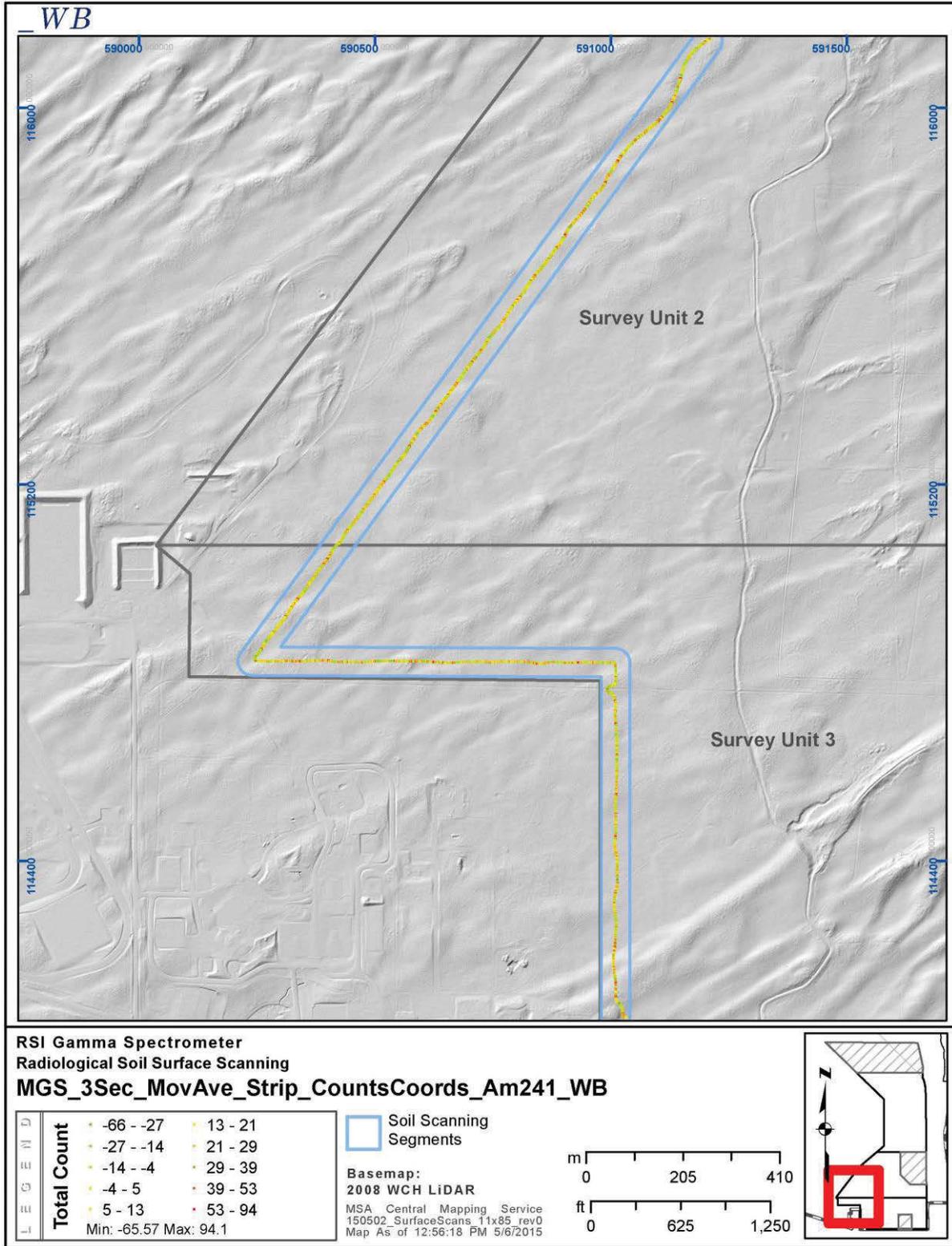


Figure 64. Three-Second Moving Average Count Rate (cps) for Am-241 for the Western Boundary Survey

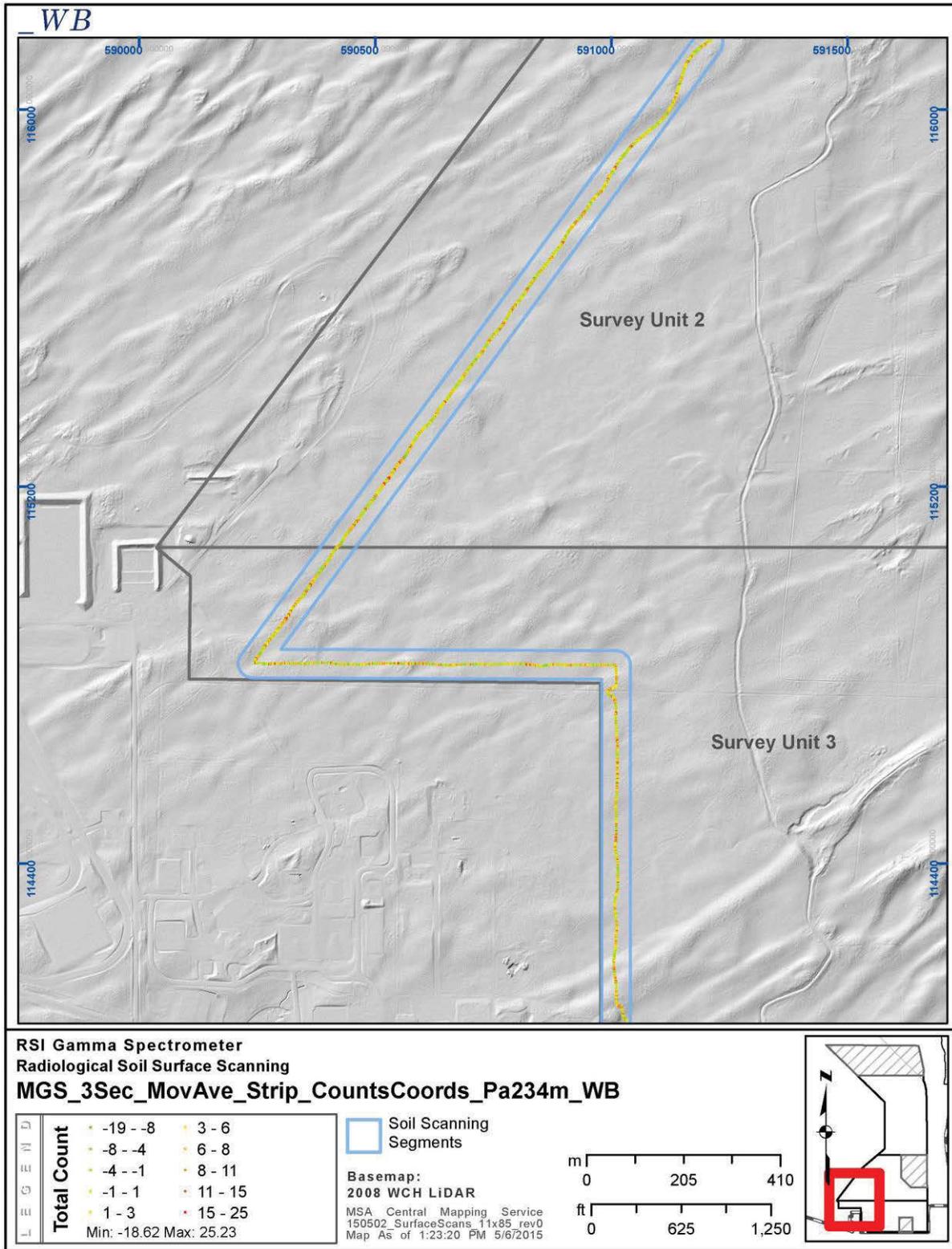


Figure 65. Three-Second Moving Average Count Rate (cps) for Pa-234m for the Western Boundary Survey

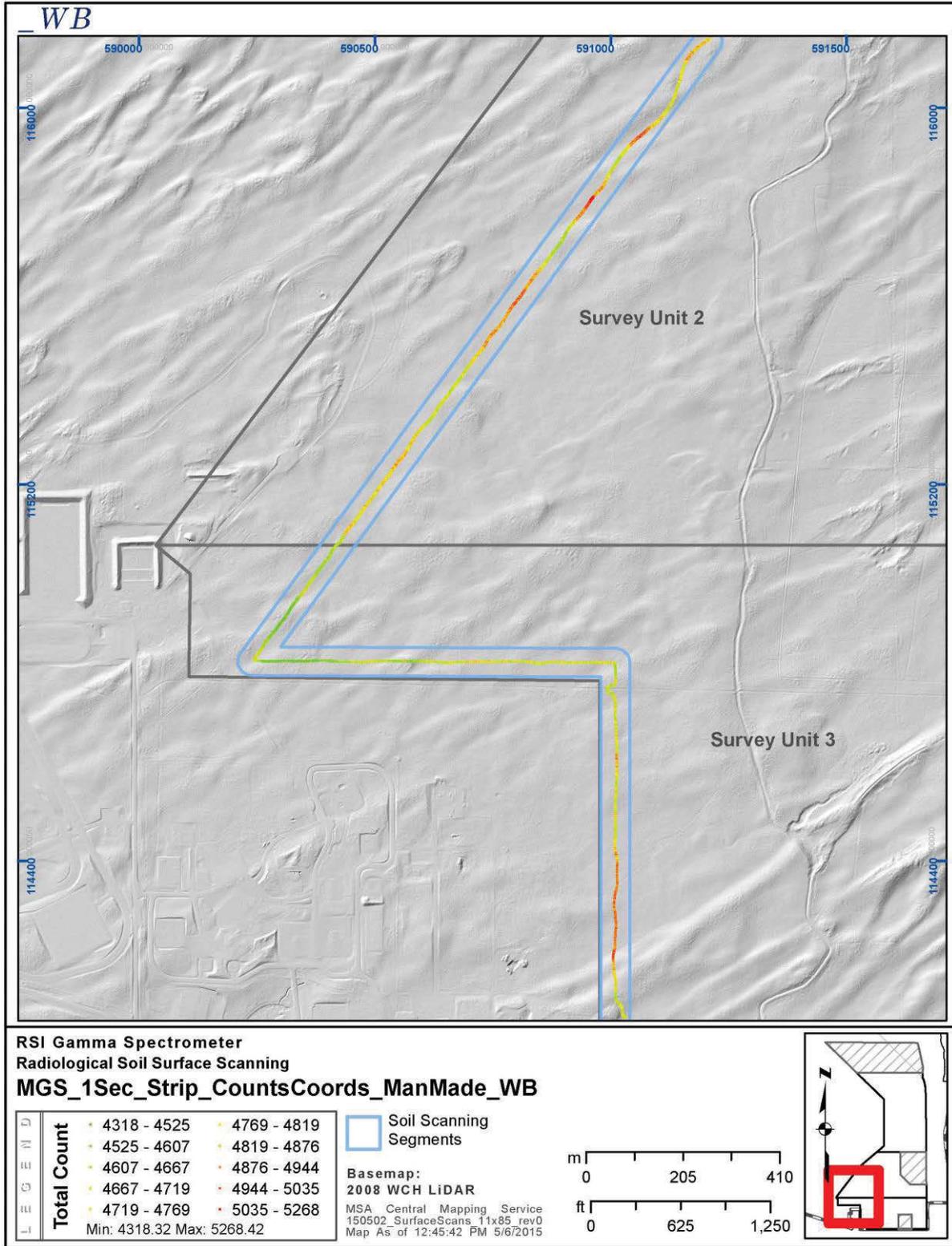


Figure 66. One-Second Moving Average Count Rate (cps) for Man-Made Region of Interest for the Western Boundary Survey

2) Sum-of-Fractions

The EMA sum-of-fractions for each of the 5,998 measurements in the Western Boundary survey is depicted in Figure 67, *Three-Second Moving Average EMA Sum-of-Fractions for Western Boundary Survey vs. Location in Western Boundary Survey*. As can be seen from the graph, the maximum value of the EMA sum-of-fractions found is less than 0.09 or about 8% of the limiting value.

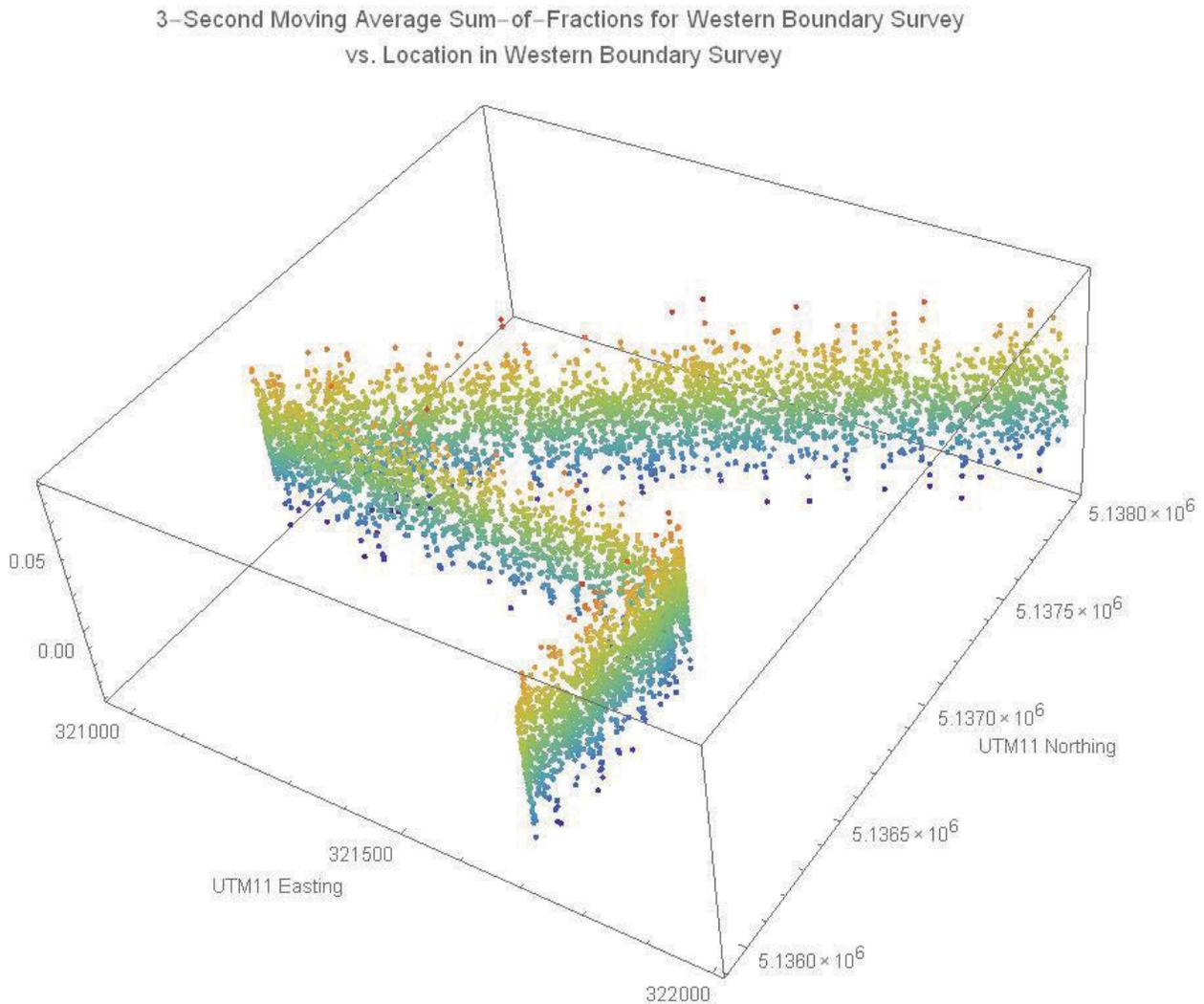


Figure 67. Three-Second Moving Average EMA Sum-of-Fractions for Western Boundary Survey vs. Location in Western Boundary Survey

3) Comparison to Background

Table 16, *Comparison to Background Statistical Values for Western Boundary*, shows the relative statistical values derived from the count rates in the various ROIs. The values found for the Western Boundary statistics are at or near background statistics. Therefore, the radioactivity levels in the soil in the area of the Western Boundary survey are comparable to those in the background area.

Table 16. Comparison to Background Statistical Values for Western Boundary

		Mean (cps)	Standard Deviation (cps)	Coefficient of Variation (%)	Inter - quartile Range (cps)	Minimum (cps)	Maximum (cps)	Skewness	Kurtosis
Cs-137	Background	159.2	15.63	9.82	22	104	223	0.117	2.9
	Western Boundary	172.15	14.29	8.3	19	118	230	0.197	3.13
Co-60	Background	104.6	10.52	10.05	15	65	154	0.122	3.01
	Western Boundary	108.4	10.5	9.68	14	75	148	0.154	3.02
Pa-234m	Background	82.9	9.31	11.62	13	47	130	0.125	3.03
	Western Boundary	79.8	8.95	11.21	12	52	122	0.12	3.01
Am-241	Background	140.7	30.96	22	42	101	289	0.039	2.98
	Western Boundary	157.4	31.41	19.95	42	38	261	-0.009	3.05
Gross Man-made	Background	4642	152	3.27	197	4204	5244	0.512	3.01
	Western Boundary	4753	129	2.72	166	4314	5260	0.115	3.16

5.0 LAND FEATURES SURVEYS

5.1 LOCATIONS OF LAND FEATURES (MAPS)

During the site reconnaissance of the Southern 600 Area, many features, such as old trash piles, holes in the ground, pipe protruding from the ground, buckets, and cans, were observed. Almost all of them found within the current three survey units were obviously benign. Although none showed an obvious risk of potential radioactive contamination, a few could be considered to have a higher risk than others.

5.1.1 How Survey Locations Were Chosen

In the interest of prudence, a set of 12 was chosen by the Lead Health Physicist, who took part in the site reconnaissance, and these received a confirmatory radiological survey using hand-held instruments and normal survey methods, as well as gamma spectral review in some cases. The Lead Health Physicist reviewed a large number of photographs of these land features that were taken during the site reconnaissance and at other times and pick those he thought might have a higher—yet still quite low—probability of being contaminated. Some of these features were chosen because they had no apparent explanation. One example of these was a set of small pipes, clustered together, that were protruding vertically from the ground. Another was an obviously man-made hole in the ground. Other items chosen were metal objects that might have originated from Hanford operations. An example of this was an old, rusty compressed gas cylinder. See Figure 68, *Map Showing the Locations of Land Features Surveyed*, for their locations. See Table 17, *Land Features List with Survey Date & MSA Survey Report Number*, for a brief description of the items to be surveyed, the date surveyed and the MSA Survey Number.

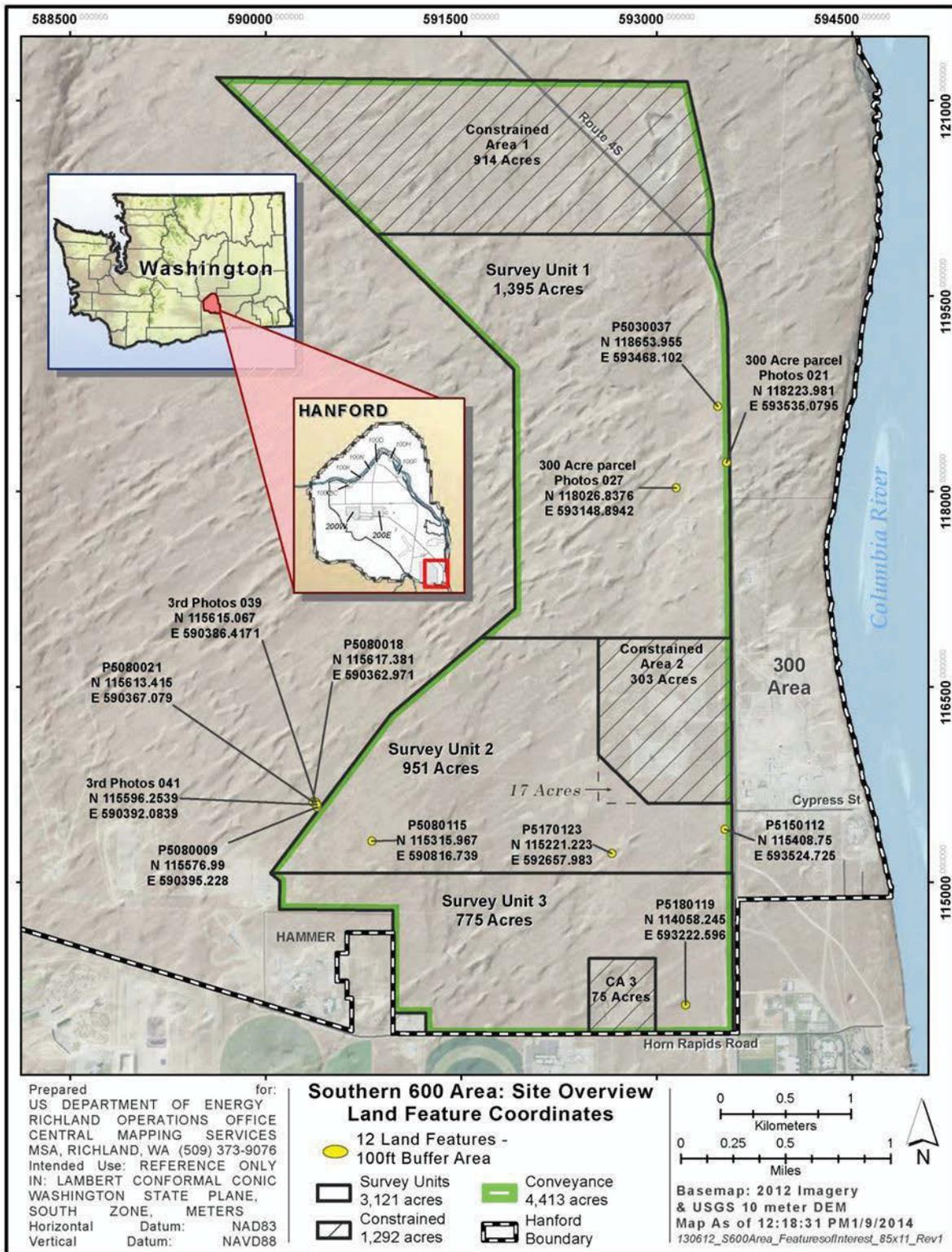


Figure 68. Map Showing the Locations of Land Features Surveyed

Table 17. Land Features List with Survey Date & MSA Survey Report Number

Land Feature	Date	MSA Survey Number
Land Feature P5030037 (Hole in the ground)	09 Sept 14	SR-14-1303
Land Features Survey Sheet 300 Acre Parcel Photos 021 (Mostly buried metal object)	06 June 14	SR-14-0938
Land Features Survey Sheet 300 Acre Parcel Photos 027 (Depression in ground)	09 Sept 14	SR-14-1303
Land Features Survey Sheet P5150112 (Concrete pad and metal frame)	06 June 14	SR-14-0938
Land Features Survey Sheet P5170123 (Pipes from ground)	09 Sept 14	SR-14-1303
Land Features Survey Sheet P5080115 (Partially buried piece of metal)	20 Aug 14	SR-14-1174
Land Features Survey Sheet P5180119 (Pile of 300 Area Looking Stuff)	20 Aug 14	SR-14-1174
Land Features Survey Sheet P5080018 (Old gas cylinder)	20 Aug 14	SR-14-1174
Land Features Survey Sheet 300 Acre Parcel Photos 039 (Shredded white metal containers)	20 Aug 14	SR-14-1174
Land Features Survey Sheet P5080021 (Heavy stainless metal)	20 Aug 14	SR-14-1174
Land Features Survey Sheet 300 Acre Parcel Photos 041 (Partially buried metal objects)	20 Aug 14	SR-14-1174
Land Features Survey Sheet P5080009 (Large depression in ground)	09 Sept 14	SR-14-1303

As examples, see Figure 69, *Photo of Rusty Old Gas Cylinder*, and Figure 70, *Photo of Pipes Protruding from the Ground*.



Figure 69. Photo of Rusty Old Gas Cylinder

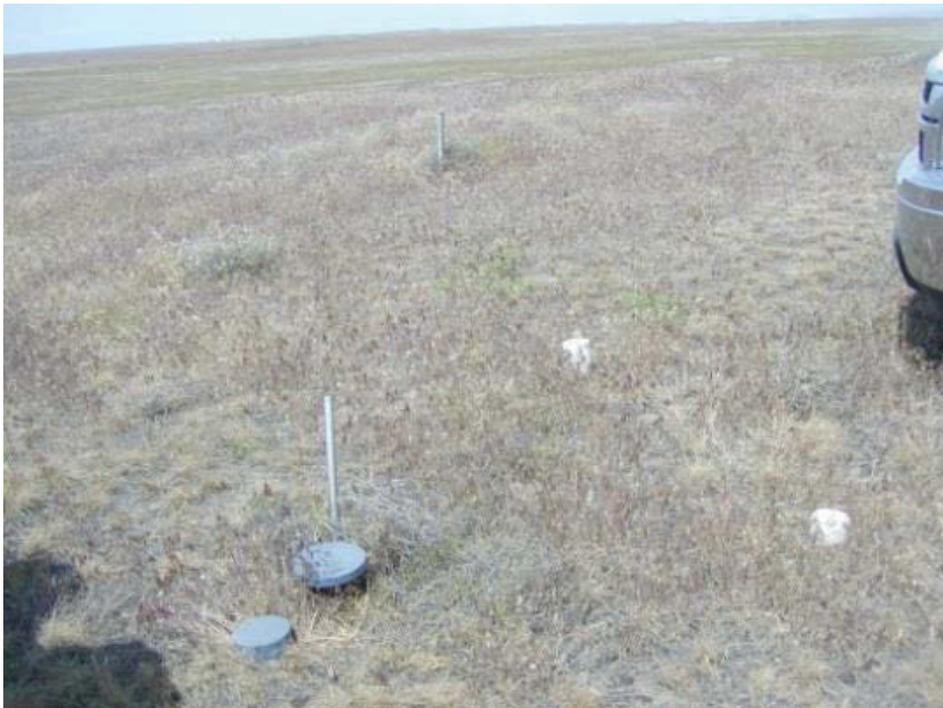


Figure 70. Photo of Pipes Protruding from the Ground

5.1.2 How Surveys Were Done and Controlled

As discussed above, a detailed sub-tier survey plan was written describing the land features to be surveyed and how each specific item was to be surveyed. Small items were surveyed with standard Hanford beta/gamma and alpha detectors using techniques that are adequate to detect DOE's radiological surface contamination limits. Land features such as pipes protruding from the ground and depressions in the ground were surveyed with standard survey instruments, as well as a hand-held 3-inch x 3-inch NaI spectrometer. The Berkeley Nucleonics SAM-940 spectrometer was used to acquire gamma spectra by the land feature and these spectra were directly compared to spectra taken in the area by away from the feature. This survey plan was LTS Test Plan *Land Features Survey Plan for the Southern 600 Area*, and it was approved by the Lead Health Physicist. The surveys were performed by two experienced Lead Radiological Control Technicians. The RCTs were accompanied by the Lead Health Physicist and a DOE health physicist, who observed the surveys being performed.

5.2 RESULTS OF SURVEYS

Of the 12 planned surveys, 11 were performed. One item to be surveyed could not be found, although GPS coordinates were available for all items and areas to be surveyed. It is believed that this item was collected by a remediation contractor. In summary, all items and areas surveyed were found to be free of detectable man-made radioactivity. One item, the rusty gas cylinder, had total surface alpha activity in excess of the DOE surface contamination guidelines. However, such rusty surfaces are commonly found to have such levels and they are due to Po-210 in the natural U-238 decay chain, not man-made radioactivity. Therefore, since the radioactivity is natural and not man-made, the cylinder was not removed for purposes of contamination control.

As an example of the comparative NaI gamma spectra found, see Figure 71, *Comparative Plot of a Background Gamma Spectrum and an Investigative Gamma Spectrum for a Depression in the Ground*. As can be seen, the two spectra almost exactly overlay each other and there is no discernable difference.

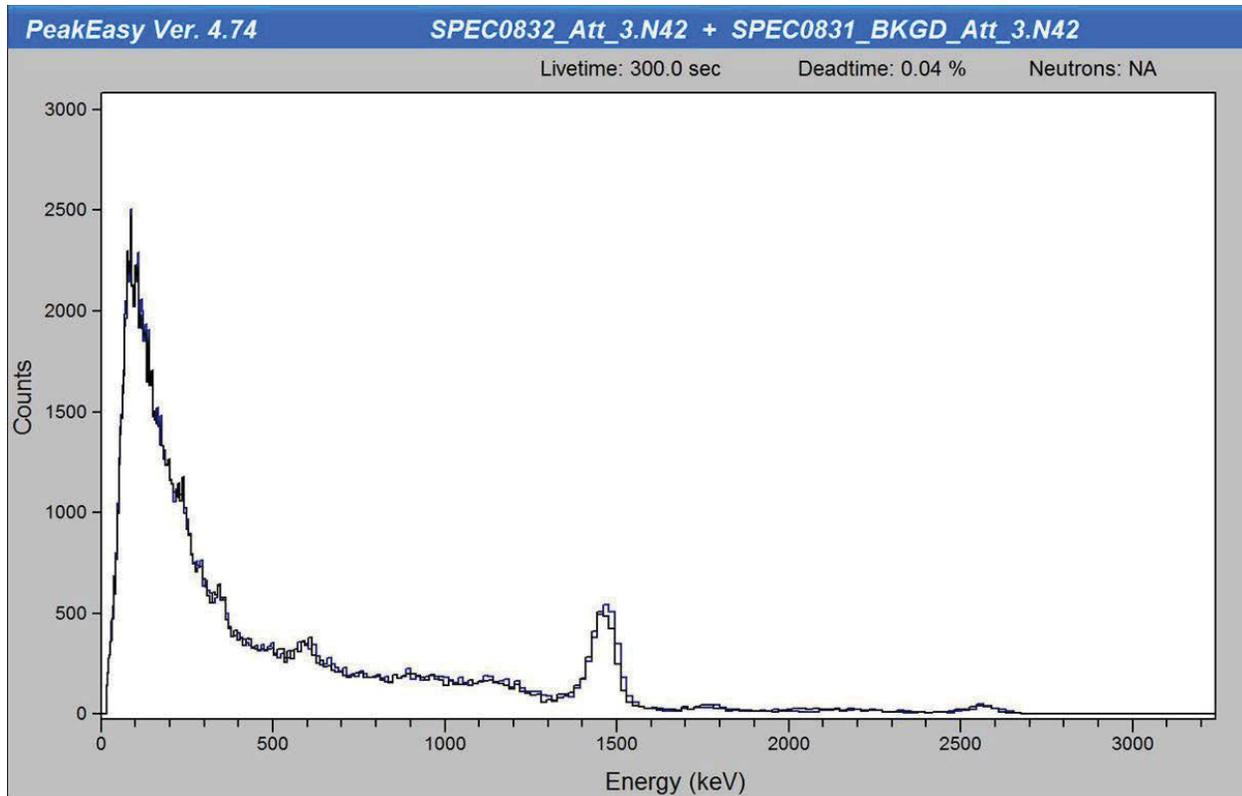


Figure 71. Comparative Plot of a Background Gamma Spectrum and an Investigative Gamma Spectrum for a Depression in the Ground

After a review of the data, a final report on the surveys, LTS Technical Note, *Analyses of the Land Features Surveys in the Southern 600 Area for Land Clearance* (27) was written and approved.

None of the land features surveyed showed any signs of Hanford contamination.

6.0 ALARA ASSESSMENT AND MQOS

6.1 REASON FOR AN ALARA ASSESSMENT

DOE O 458.1, *Radiation Protection of the Public and the Environment*, requires that the ALARA principle be implemented. An ALARA assessment is customarily completed prior to authorized limits being issued. However, in this case, since no analytical data was available at that time to base an ALARA assessment on, DOE postpone the assessment until after the soil sampling and other data had been collected.

6.2 ALARA ASSESSMENT

The ALARA principle requires the assessment of practical alternative courses of action to determine the course with the minimum over all detriment. However, in this case, there are no practical options to clearing the land without any remediation. Since the radionuclide

concentrations in the soil are near or at background levels, the replacement of the soil to a depth of, say, one foot with soil from offsite would be very costly and would result in essentially no dose reduction. Thus, the proposed transfer satisfies the ALARA principle as is.

6.3 MEASUREMENT QUALITY OBJECTIVES

Measurement Quality Objectives (MQOs) are required by DOE O 458.1 (1) and discussed in the main survey plan (8).

6.3.1 MQOs for Soil Sampling

These MQOs are for the sampling activity only. This is discussed in the main survey plan (8).

1. **Accuracy.** The sampling locations were determined by a cartographer using an accurate GPS instrument. A composited 5-point sample was taken at each location by trained personnel using written instructions.
2. **Completeness.** At least 35 of the 42 planned samples per survey unit had to be taken for a complete sample. For all these survey units, all 42 samples were taken.
3. **Representativeness.** As discussed in the main survey plan (8), a representative sample was planned for each survey unit. In all three cases, the soil samples were taken as planned.
4. **Comparability.** The data gathered by MSA was directly compared to that gathered by ORISE and found to be essentially comparable in that it resulted in very similar sum-of-fractions results.

6.3.2 MQOs for Gamma Scanning

1. **Specificity.** The mobile gamma spectrometer successfully supplied information specific to the regions-of-interest for Cs-137, Co-60, Am-241, and Pa-234m as required.
2. **Ruggedness.** The mobile gamma spectrometer proved to be rugged enough to function properly in rough desert terrain. It remained stable at all times during the surveys.
3. **Detection Capability.** The technical basis document for the mobile gamma spectrometer (17) showed that it could easily detect an Elevated Measurement Area (EMA), as defined by the surveys.
4. **Completeness.** The mobile gamma spectrometer was able to complete the required surveys. In the area of highest probability of contamination—Around Constrained Area 2—it completed a very dense survey that was completely adequate for the task.

5. **Representativeness.** In the one area requiring a dense survey, Around Constrained Area 2, the scan lines were planned to give a 100% probability of seeing a 100 m² EMA. With only minor variations in very rough areas, the scanning was dense enough to cover all areas. It is very unlikely that an EMA was missed.
6. **Comparability.** The data in the Southern 600 Area gamma surveys is directly comparable to the background information used, since these were gathered with the same machine, operated in the same way. The MSA data was not compared to the ORISE data because the areas scanned were different and the instruments were considerably different.

7.0 PANEL REVIEW

The main survey plan (HNF-57979) requires that a panel of knowledgeable individuals review the data collected and methods used and determine if they were sufficient to support a conclusion that the authorized limits have been met and no Elevated Measurement Areas exist.

7.1 COMPOSITION OF PANEL

The panel was composed of a DOE-RL health physicist; two independent health physicists from Dade Moeller, Inc.; the two Lead Senior Radiological Control Technicians who took substantial roles in the project; and the Lead Health Physicist who lead the radiological clearance. All of the team members had experience with this and/or other clearance projects and were collectively knowledgeable of the regulatory, technical and practical aspects of land clearance.

7.2 PANEL REVIEW

The panel met on the 12th and 14th of May 2015 for review and discussion, leaving the 13th open for individual review of data and information presented. The Lead Health Physicist reviewed the project and presented the data and data analyses. Reasonably detailed information was presented on all radiological aspects of the clearance work. The panel discussed questions as they arose during the presentation. In addition, the panel members were given packets of documents and data to assist them in their review.

7.3 CONCLUSIONS OF PANEL

After the panel review, the panel concluded that the methods used and the data collected were sufficient to demonstrate that the authorized limits had been met and that no Elevated Measurement Areas exists in the areas scanned. The members believe that the actual levels of man-made radioactive material in the soil is low and at or near background levels. In particular, the two health physicist from Dade Moeller, Inc., documented their opinion in a letter. See Attachment, *Letter Documenting the Opinion of Two Health Physicist from Dade Moeller, Inc., on the Radiological Clearance.*

8.0 CONCLUSIONS

Based on the information presented above, several conclusions can be drawn, as listed below.

1. The Hanford radioactivity levels in the soil in the three survey units are well below, about 1%, the authorized limits. This conclusion is established by the determination of the actual soil concentrations using a valid statistical method, which demonstrated that the actual levels are far below the authorized limits. It is also supported by a comparison of the measured soil concentrations to site background concentrations, which concluded that the soil concentrations in the Southern 600 Area is near or at site background levels. It is further supported by the conclusions of the Historical Site Assessment, including the scoping measurements, which concluded that there are only small variations in radioactivity across the site and these are near background levels.
2. There are no Elevated Measurement Areas in the areas scanned; the maximum levels of radioactivity found are well below the EMA level and at or near background levels. This conclusion is supported by extensive gamma scanning in the areas most likely to have EMAs, which did not find a single EMA. It is further supported by a comparison between the results of the gamma scans in the scanning areas to results found in a site background area, which were very similar.
3. There is very little chance of any man-made radioactivity on any of artifacts or other land features found in the three survey units. This conclusion is supported by conclusions of the Historical Site Assessment, which found little actual indication of Hanford radioactivity during the site reconnaissance, including the scoping measurements. It is further supported by field measurements of land features considered to have the highest probability of Hanford radioactivity, however small. No evidence of Hanford contamination was found.
4. The man-made radioactivity level in the soil in the three survey units is at or near background levels. This conclusion is supported by the conclusions of the Historical Site Assessment, the measurement and analysis of soil samples and the gamma scanning. All of these concluded that Hanford activity in the Southern 600 Area is at or near background areas.
5. The dose to an industrial worker on this land from Hanford radioactivity would very likely be less than 1 mrem/y. This conclusion is supported by the results of the soil sampling and the gamma scanning. The sum-of-fractions from the soil sampling is about 0.01, which corresponds to about 0.25 mrem/y dose since the authorized limits are based primarily on 25 mrem/y dose. The sum-of-fractions for the Elevated Measurement Areas was about 0.1, which corresponds to about 0.2 mrem/y. Thus, the total dose to an industrial worker from Hanford radioactivity would probably not exceed 1 mrem/y.

A review of the data by two independent health physicists supported these conclusions.

9.0 REFERENCES

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- (11) LTS Test Plan, *Mobile Gamma Spectrometer Scan Surveys of the Southern 600 Area*, Mission Support Alliance, 30 September 2014.
- (12) LTS Test Plan, *Land Features Survey Plan for the Southern 600 Area*, Mission Support Alliance, 23 June 2014.
- (13) *Wolfram Mathematica 10 Documentation Center*, Wolfram Research, Champaign, IL
- (14) *ArcGIS Help Reference* at esri.com. Esri, Inc., Redlands, CA

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- (16) DOE/RL-96-12, Rev.0, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, September 1996, U.S. Department of Energy.
- (17) LTS Technical Basis Document *The Mobile Gamma Spectrometer's Scan MDC's Using Unstripped Data and Its Transect Spacing for the Southern 600 Area Elevated Measurement Area*, Rev.0, 17 October 2014
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- (19) LTS Test Plan, *Mobile Gamma Spectrometer Scan Surveys of the Southern 600 Area*, Mission Support Alliance, 30 September 2014.
- (20) *Wolfram Mathematica 10 Documentation Center*, Wolfram Research, Champaign, IL
- (21) LTS Technical Note *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Northern Boundary of Survey Unit 1 of the Southern 600 Area Completed on 8 October 2014*, Rev.0.
- (22) LTS Technical Note *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Northern Railroad of the Southern 600 Area Completed on 9 October 2014*, Rev.0.
- (23) LTS Technical Note *Analysis of the Results from the Mobile Gamma Spectrometer Survey of the Area Around Constrained Area 2 of the Southern 600 Area Completed on 5-23 February 2015*, Rev.0.
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**ATTACHMENT – LETTER DOCUMENTING THE OPINION OF
TWO HEALTH PHYSICISTS FROM DADE MOELLER,
INC., ON THE RADIOLOGICAL CLEARANCE**



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May 15, 2015

Mr. W. Joel Millsap
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Re: Southern 600 Area Land Clearance Review Board; Dade Moeller CHP Opinion

Dear Mr. Millsap:

The two undersigned Dade Moeller Certified Health Physicists (CHP) were members of the Southern 600 Area Land Clearance Review Board. We evaluated the following key areas of the project:

- Historical Site Assessment (*Ikenberry was a participant/author*)
- Authorized Limits (*Ikenberry was lead technical author*)
- Survey Plan (*Bump was a consultant*)
- Operating Instructions & Training
- Soil Sampling and Results
- Gamma Scanning and Results
- Land Features Survey
- ALARA Assessment
- Records
- Conclusions

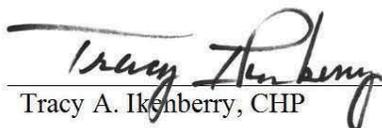
An important part of our understanding was the detailed presentation and information package provided by you and members of your project team on May 12, 2015, and the follow-up meeting on May 14, 2015. We focused primary upon those areas of the project related to the survey planning, soil sampling, land scanning, data collection, and results – bullets 3 through 10 above.

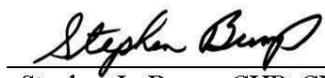
Based upon our review of the information provided to us and the responses to our questions, it is our opinion that the project has gathered sufficient information and has adequate technical justification and documentation to show that 1) there is very little potential for residual radioactivity in the areas to be cleared; 2) the Authorized Limits can be readily met; and 3) other requirements of DOE O 458.1 *Radiation Protection of the Public and the Environment* have also been met. Potential doses to future inhabitants will be much less than 25 mrem/year and are likely to be less than 1 mrem/year. Our review of the soil sampling and scanning results and data compilations and statistical analysis indicate that concentrations of radionuclides in the area are consistent with background.

We further believe that the methods employed for this project and the data gathered have value that extends well beyond just the Southern 600 Area Land Clearance Project. These data should be compiled into a technical basis document that should be used as a source of updated background soil concentrations and information for future Hanford land and facility clearance projects. The compilation and statistical analysis that have been done make them very valuable for the entire Hanford Site.

The soil sampling and land scanning techniques have demonstrated their effectiveness, and that they can be used to demonstrate and verify the clearance of other lands and facilities at Hanford and elsewhere. We highly recommend that the project methods and results be published in a peer-reviewed publication such as *Operational Radiation Safety*.

Please don't hesitate to contact us if you need additional information.


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