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2021 NIRT Mini Drill After Action Report

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Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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SUMMARY

During the summer and fall of 2021, several functional area drills were held that focused on exercising Consequence Management's (CM) ability to extract and use data from RadResponder for the purpose of answering intermediate-phase questions presented as technical inject requests for information (RFI) in Sandia National Laboratories (SNL) Consequence Management Operational System (COSMOS) software. The scenario chosen was that of Northern Lights 2016 (NL16) which was a large-scale nuclear power plant (NPP) release exercise in the state of Minnesota. The NL16 data was extracted from the Radiological Assessment and Monitoring System (RAMS) event where it was created and was reformatted for implanting to a new RadResponder event. Next, the beta-version of a laboratory sample data simulator was used to generate more sample data that was injected to the event. Five "mini-drills" were devised with each prompt defined by a data-based need. For each drill, a team of assessment and NARAC scientists worked the problem using the drill prompt and the available data in RadResponder. The teams held a kickoff meeting, had several days to work the problem, and then reported their results as well as observations in a hotwash. Several areas for improvement in both the software and process were identified during the course of these drills. This report will document the process of addressing each RFI and the discovered gaps in both software capability and methodology so that they can be considered for future development and investment by the CM and NIRT programs.

ACKNOWLEDGEMENTS

The authors of this document would like to thank all of the participants who took time out of their busy schedules to plan and conduct this drill and provide meaningful and impactful feedback on both the CM process and tools used to conduct CM operations. This work will lead to improvements in equipment, procedures, and software that will make a positive impact in our nation's ability to respond to any nuclear incident.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND DEFINITIONS

Abbreviation	Definition
SNL	Sandia National Laboratories
LLNL	Lawrence Livermore National Laboratory
PNNL	Pacific Northwest National Laboratory
CM	Consequence Management
NL16	Northern Lights 2016
NIRT	Nuclear Incident Response Program
NARAC	National Atmospheric Release Advisory Center
RAMS	Radiological Assessment and Monitoring System
RASCAL	Radiological Assessment Systems for Consequence Analysis
COSMOS	Consequence Management Operational System
RR	RadResponder software
LSS	Lab Sample Simulator software
RFI	Request for Information
DQO	Data Quality Objective
VSP	Visual Sample Plan software
TF	Turbo FRMAC software
DRL	Derived Response Level
IL	Intervention Level
DIL	Derived Intervention Level

1. EXERCISE PLAN

1.1. Scope

This drill was focused on exercising the process for generating synthetic data to drive technical assessments during drills and exercises through the utilization of "mini-drills," each of which exercised a data-based request for information. Using newly developed tools such as the Lab Analysis sample data simulator (LSS) and the Lab Analysis functions in RadResponder, the simulation team generated a data set that will drive technical assessment and product scientist work to use these sample and measurement results (e.g. ground truth) for data products. The overarching goal of these constituent mini-drills was to find the gaps in current processes and tools as well as provide assessment the opportunity to determine the data analysis methods and tools that would make the job of using real radionuclide-specific result data in products more streamlined and consistent. The synthetic data generated for this drill focused on in-situ gamma spectroscopy measurement results and some limited sample analysis results. All the data available in the original event used for Northern Lights 2016 was ported over manually from RAMS to RadResponder through the use of export and import excel files.

1.2. Scenario

The scenario for this drill draws from Northern Lights 2016, a large-scale exercise that involved a severe nuclear power plant accident scenario. NARAC runs developed for this large-scale exercise were used as the core dataset for the simulator. The technical inject requests for information (RFIs) that form the basis of each mini-drill were designed around questions that may be asked in the intermediate phase of the response several weeks after a release has occurred. Refer to the original NL16 exercise plan or after-action report for specific details related to the simulated scenario.

1.3. Technical Inject RFIs

The RFIs examined in this report are as follows:

- Can these ranches return to using on-site feed/pasture?
- Can deer and fishing restrictions be lifted?
- Has sampled milk exceeded the intervention level?
- Does the original NARAC prediction model agree with available data?
- Should initial assumptions about the resuspension factor be changed based on data from the field?

Each of these drove the participating responders to pull radionuclide-specific data from RadResponder and develop products to address each RFI.

1.3.1. *Can these ranches return to using on-site feed/pasture?*

<u>Question:</u> Twelve dairy farms were put on feed/pasture restrictions following the event, switching to imported feed. Using the sampling data as justification, can these farms go back to using their stored feed and pasture? On average, the dairies use a 60/40 mix of stored feed and pasture to feed their livestock.

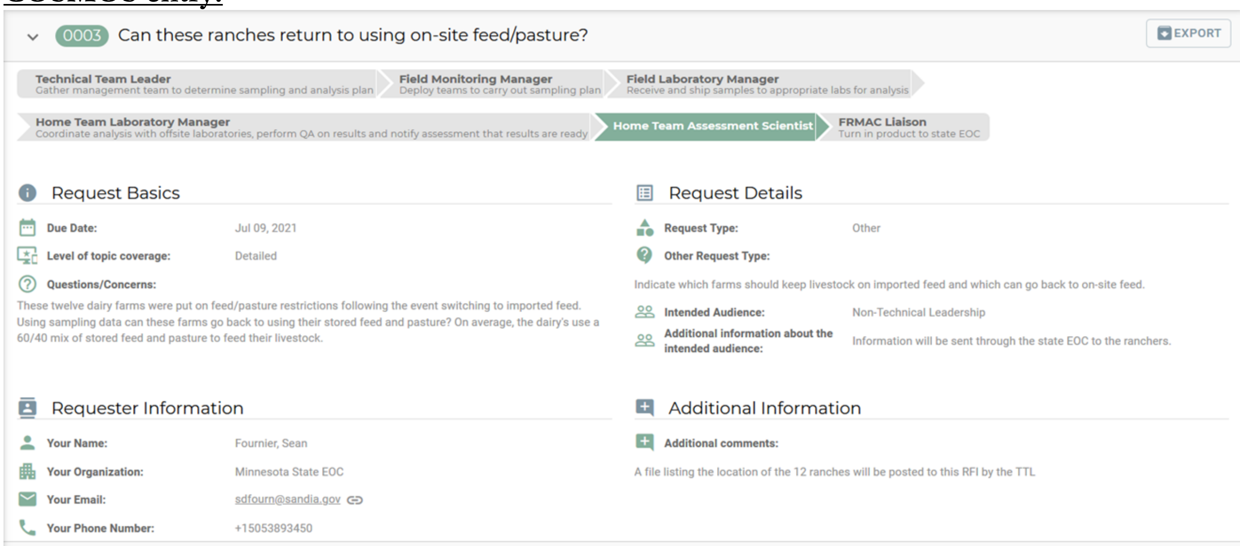
<u>Other Information Provided:</u>

- Ranches house dairy cattle that were switched to imported feed (guaranteed clean feed) before the release occurred and have been sheltered the entire time. Milking continued.
- Ranchers want permission to switch cattle back to a 60/40 mix of stored feed and pasture that is onsite and may have been contaminated
- The pasture and feed have been sampled and the results are now available for review
- Ranchers do not want to embargo any milk once this occurs for any period of time. In other words, they do not want any delay in their ability to sell the milk

Attachments:

- List containing the geocoordinates of the 12 ranches
- RASCAL source term .CSV file

COSMOS entry:



0003 Can these ranches return to using on-site feed/pasture?

EXPORT

Technical Team Leader — Gather management team to determine sampling and analysis plan
Field Monitoring Manager — Deploy teams to carry out sampling plan
Field Laboratory Manager — Receive and ship samples to appropriate labs for analysis
Home Team Laboratory Manager — Coordinate analysis with offsite laboratories, perform QA on results and notify assessment that results are ready
Home Team Assessment Scientist
FRMAC Liaison — Turn in product to state EOC

Request Basics

Due Date:	Jul 09, 2021
Level of topic coverage:	Detailed
Questions/Concerns:	

These twelve dairy farms were put on feed/pasture restrictions following the event switching to imported feed. Using sampling data can these farms go back to using their stored feed and pasture? On average, the dairy's use a 60/40 mix of stored feed and pasture to feed their livestock.

Request Details

Request Type:	Other
Other Request Type:	

Indicate which farms should keep livestock on imported feed and which can go back to on-site feed.

Intended Audience:	Non-Technical Leadership
Additional information about the intended audience:	Information will be sent through the state EOC to the ranchers.

Requester Information

Your Name:	Fournier, Sean
Your Organization:	Minnesota State EOC
Your Email:	sdfourn@sandia.gov
Your Phone Number:	+15053893450

Additional Information

Additional comments:

A file listing the location of the 12 ranches will be posted to this RFI by the TTL

Figure 1: COSMOS RFI for 12 ranches return to on-site feeding problem

Participants:

- Team 1(SNL): Steve Farmer, Sarah Goke, Nathan Elliott
- Team 2 (PNNL): Paul Johns, Richard Pierson
- Team 3 (EPA): Jen Mosser, Lowell Ralston, Wagnus Prioleau, Holly Arrigoni, Gary Chen

1.3.2. *Can deer hunting and fishing restrictions be lifted?*

Question: The Minnesota state government imposed a strict no-hunting or fishing order for most of the state following the incident at the plant. Now, the state would like assistance in determining how best to lift these restrictions in a systematic and defensible way.

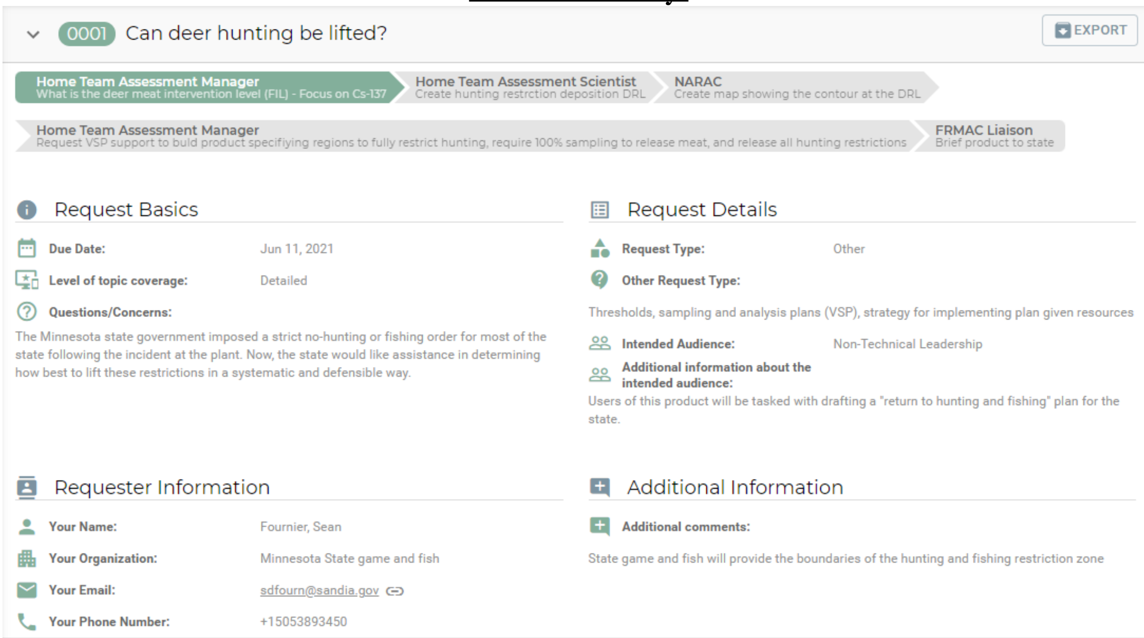
Other Information Provided:

- None

Attachments:

- .KML file showing the restricted region

COSMOS entry:



0001 Can deer hunting be lifted?

EXPORT

Home Team Assessment Manager – What is the deer meat intervention level (FIL) - Focus on Cs-137
Home Team Assessment Scientist – Create hunting restrction deposition DRL
NARAC – Create map showing the contour at the DRL
Home Team Assessment Manager – Request VSP support to buld product specifiying regions to fully restrict hunting, require 100% sampling to release meat, and release all hunting restrictions
FRMAC Liaison – Brief product to state

Request Basics

Due Date: Jun 11, 2021

Level of topic coverage: Detailed

Questions/Concerns:

The Minnesota state government imposed a strict no-hunting or fishing order for most of the state following the incident at the plant. Now, the state would like assistance in determining how best to lift these restrictions in a systematic and defensible way.

Request Details

Request Type: Other

Other Request Type:

Thresholds, sampling and analysis plans (VSP), strategy for implementing plan given resources

Intended Audience: Non-Technical Leadership

Additional information about the intended audience:

Users of this product will be tasked with drafting a "return to hunting and fishing" plan for the state.

Requester Information

Your Name: Fournier, Sean

Your Organization: Minnesota State game and fish

Your Email: sdfourn@sandia.gov

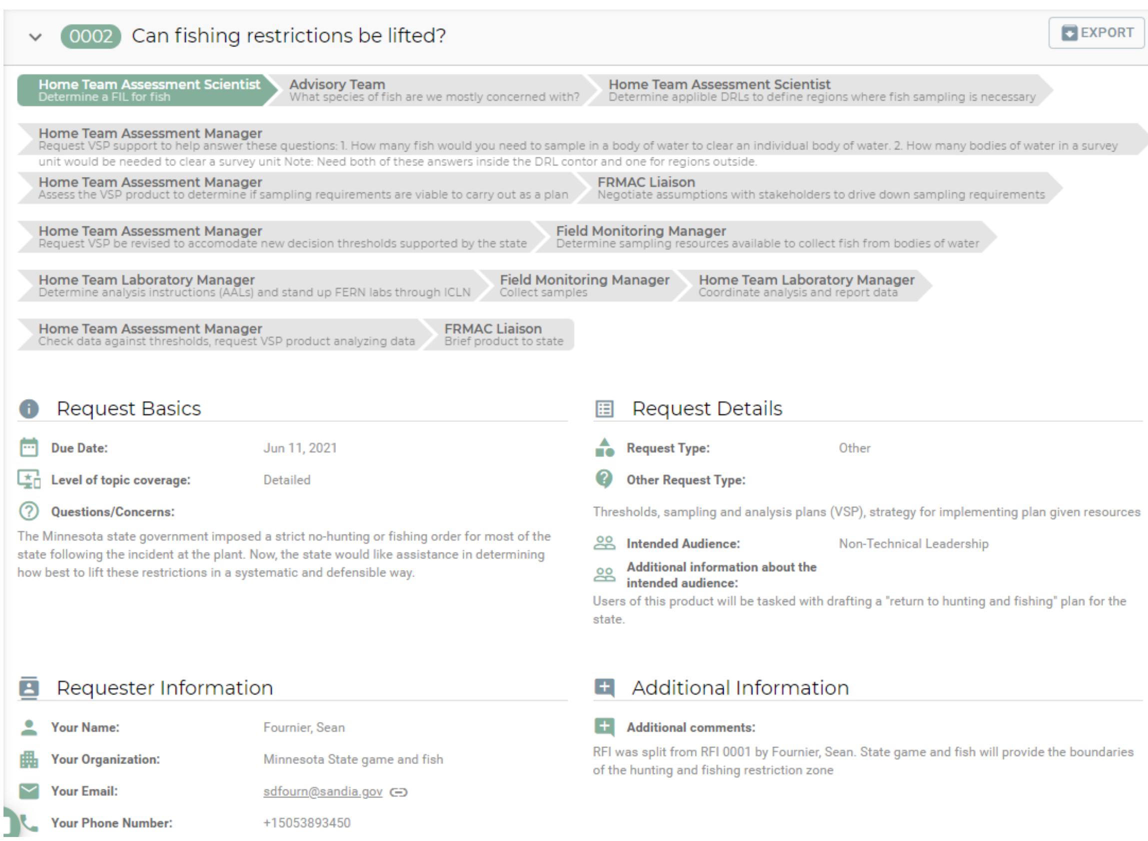
Your Phone Number: +15053893450

Additional Information

Additional comments:

State game and fish will provide the boundaries of the hunting and fishing restriction zone

Figure 2: Hunting restrictions RFI COSMOS entry



0002 Can fishing restrictions be lifted?

EXPORT

Home Team Assessment Scientist – Determine a FIL for fish
Advisory Team – What species of fish are we mostly concerned with?
Home Team Assessment Scientist – Determine applible DRLs to define regions where fish sampling is necessary
Home Team Assessment Manager – Request VSP support to help answer these questions: 1. How many fish would you need to sample in a body of water to clear an individual body of water. 2. How many bodies of water in a survey unit would be needed to clear a survey unit Note: Need both of these answers inside the DRL contor and one for regions outside.
Home Team Assessment Manager – Assess the VSP product to determine if sampling requirements are viable to carry out as a plan
FRMAC Liaison – Negotiate assumptions with stakeholders to drive down sampling requirements
Home Team Assessment Manager – Request VSP be revised to accomodate new decision thresholds supported by the state
Field Monitoring Manager – Determine sampling resources available to collect fish from bodies of water
Home Team Laboratory Manager – Determine analysis instructions (AALs) and stand up FERN labs through ICLN
Field Monitoring Manager – Collect samples
Home Team Laboratory Manager – Coordinate analysis and report data
Home Team Assessment Manager – Check data against thresholds, request VSP product analyzing data
FRMAC Liaison – Brief product to state

Request Basics

Due Date: Jun 11, 2021

Level of topic coverage: Detailed

Questions/Concerns:

The Minnesota state government imposed a strict no-hunting or fishing order for most of the state following the incident at the plant. Now, the state would like assistance in determining how best to lift these restrictions in a systematic and defensible way.

Request Details

Request Type: Other

Other Request Type:

Thresholds, sampling and analysis plans (VSP), strategy for implementing plan given resources

Intended Audience: Non-Technical Leadership

Additional information about the intended audience:

Users of this product will be tasked with drafting a "return to hunting and fishing" plan for the state.

Requester Information

Your Name: Fournier, Sean

Your Organization: Minnesota State game and fish

Your Email: sdfourn@sandia.gov

Your Phone Number: +15053893450

Additional Information

Additional comments:

RFI was split from RFI 0001 by Fournier, Sean. State game and fish will provide the boundaries of the hunting and fishing restriction zone

Figure 3: Fishing restriction RFI COSMOS entry

Participants:

- FRMAC Assessment (SNL, PNNL, EPA): Brian Hunt, Lainy Cochran, Gary Cerefice, Eric Becker, Jennifer Mosser
- NARAC Scientists (LLNL): Lydia Tai
- VSP Scientists (PNNL): Lisa Newburn, Nicole Benker

1.3.3. *Has sampled milk exceeded the intervention level?*

Question: Many regional dairy farms have had milk samples analyzed. Compare milk samples to the applicable intervention levels (ILs) and determine which dairies need to be embargoed.

Other Information Provided:

- None

Attachments:

- None

COSMOS entry:

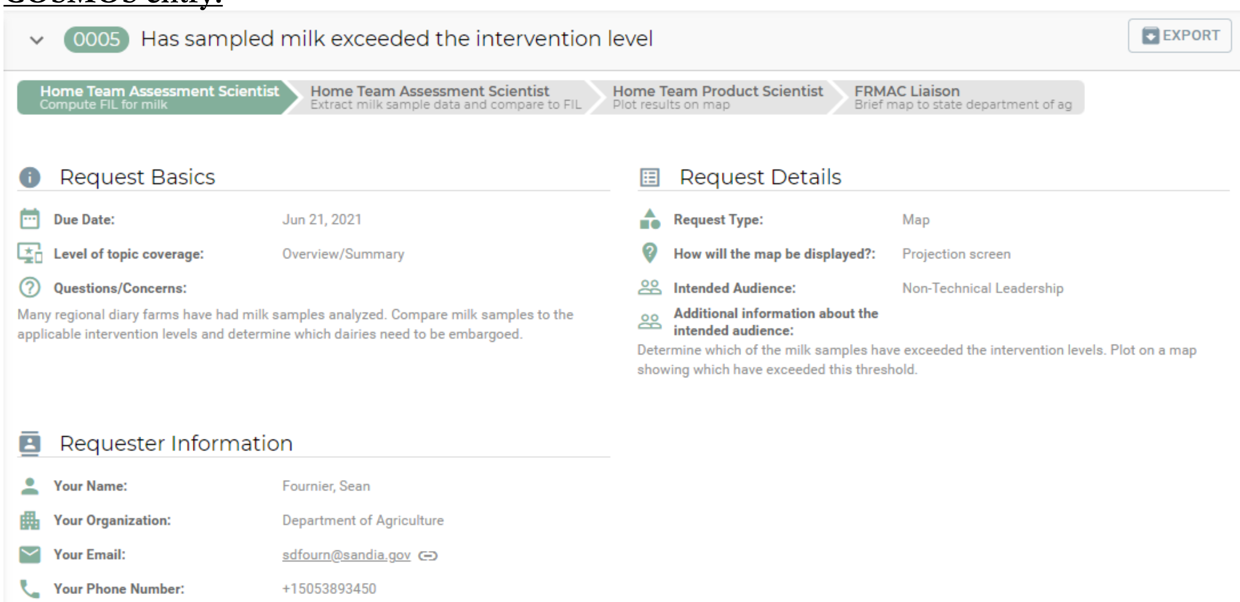


Figure 4: Milk ingestion level RFI COSMOS entry

Participants:

- Team 1(SNL): Steve Farmer, Sarah Goke, Nathan Elliott, Autumn Kalinowski
- Team 2 (PNNL): Cari Seifert, Mitchell Myjak

1.3.4. *NARAC Prediction Update*

Question: It is day 21 post-release and there have been many sample and measurement results uploaded to the data system. There are still products that will rely on NARAC predictions to extrapolate this ground-truth. Can the available data be used to update the NARAC predictions to improve data product accuracy?

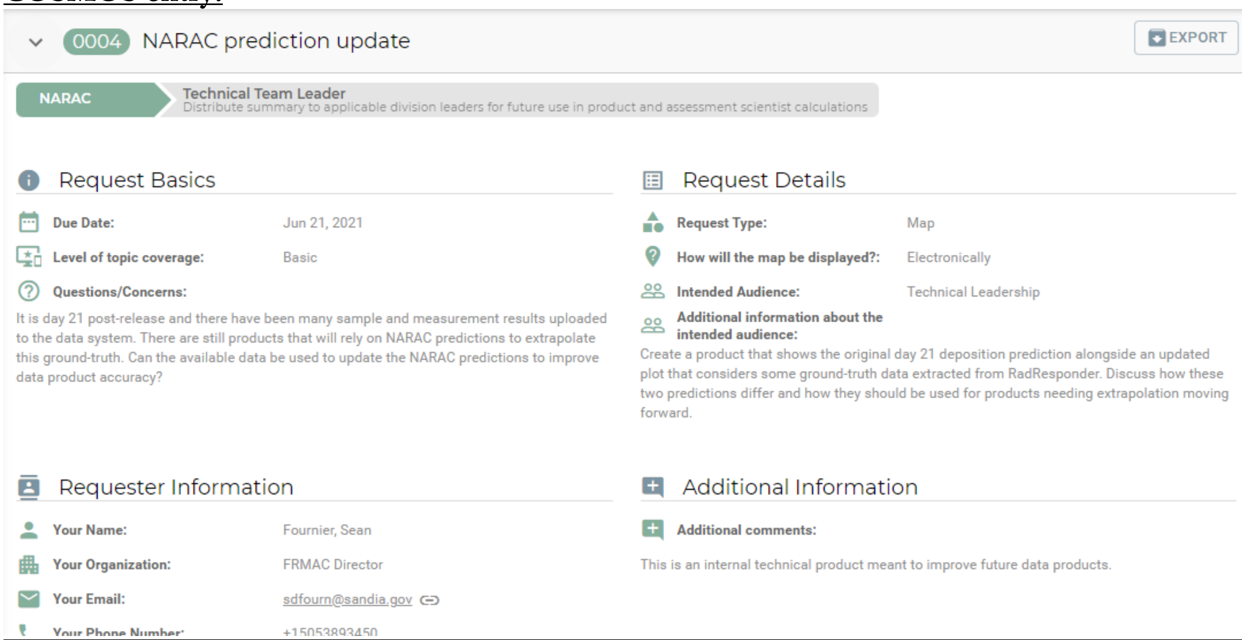
Other Information Provided:

- None

Attachments:

- None

COSMOS entry:



0004 NARAC prediction update

EXPORT

NARAC — Technical Team Leader
Distribute summary to applicable division leaders for future use in product and assessment scientist calculations

Request Basics

Due Date:	Jun 21, 2021
Level of topic coverage:	Basic

Questions/Concerns:
It is day 21 post-release and there have been many sample and measurement results uploaded to the data system. There are still products that will rely on NARAC predictions to extrapolate this ground-truth. Can the available data be used to update the NARAC predictions to improve data product accuracy?

Request Details

Request Type:	Map
How will the map be displayed?:	Electronically
Intended Audience:	Technical Leadership

Additional information about the intended audience:
Create a product that shows the original day 21 deposition prediction alongside an updated plot that considers some ground-truth data extracted from RadResponder. Discuss how these two predictions differ and how they should be used for products needing extrapolation moving forward.

Requester Information

Your Name:	Fournier, Sean
Your Organization:	FRMAC Director
Your Email:	sdfourn@sandia.gov
Your Phone Number:	+15053893450

Additional Information

Additional comments:
This is an internal technical product meant to improve future data products.

Figure 5: NARAC Update COSMOS Entry

Participants:

- NARAC Scientists (LLNL): Lydia Tai, Allison Bagley, Liza Diaz Isaac

1.3.5. *Should initial assumptions about the resuspension factor be changed for future calculations based on available data from the field?*

Question: The initial assumption for the resuspension factor was kept at the Turbo FRMAC default (1.0E-05 m^{-1}) to address RFIs for the first month of the response. Using available field data, is there sufficient information to evaluate if this assumption should persist and if so, can the data be used to calculate a representative resuspension factor to use for future calculations? Is there a need for more data to support this analysis? What information is needed that would feed into a monitoring and sampling plan?

<u>Other Information Provided:</u>

- None

<u>Attachments:</u>

- None

<u>COSMOS entry:</u>

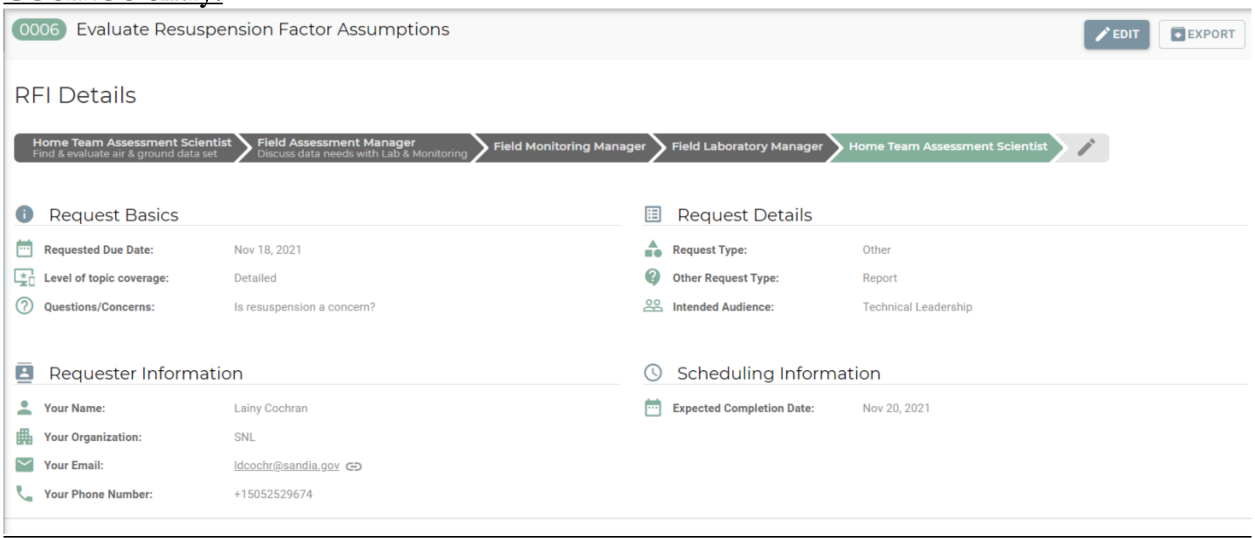


Figure 6: Evaluate Resuspension Factor Assumptions RFI COSMOS Entry

<u>Participants:</u>

- SNL: Sean Fournier, Sarah Goke, Brian Hunt, Lainy Cochran, Autumn Kalinowski, Kevin Hart

2. PROCESS TAKEN TO RESPOND TO RFI

2.1. Can these ranches return to using on-site feed/pasture?

To address this RFI, the participants had to determine what data was available at or nearby to the ranches, what threshold values the results should be compared against to make a recommendation, and devise a way to extract, manipulate, and compare the data to these thresholds in order to come up with a list of ranches that can have their restrictions lifted. An interesting result of this mini-drill was that each team had a different approach but came to roughly the same recommendation.

The finalized technical approach for this mini-drill began with requesting access to the proper RadResponder event "2021 NIRT Mini-Drill" in order to obtain the modeled estimate of the source term for this problem. During the waiting period for approval of access, Turbo FRMAC was used to generate area and mass derived response levels (DRLs). For this DRL generation, a 12 Ranches event mixture was created using the list of isotopes from "RASCAL source term_N16 not summed.csv." This event mixture was then copied into Turbo FRMAC, and the DRL calculation run. Turbo FRMAC parameters for this DRL calculation were set to the default assumptions as defined in Vol. 1 of the FRMAC Assessment Manual, and the results of the run saved as "12 Ranches 2021 NIRT Drill Milk DRLs Calculation – Mass.tfx" and "12 Ranches 2021 NIRT Drill Milk DRLs Calculation – Area.tfx." Once these calculations were completed, the marker radionuclides for both area and mass were selected and can be seen in Table 1 and Table 2. In this RFI, marker radionuclides are the radionuclides against which comparisons will be made. These are taken to be the most dose-contributing radionuclides in the mixture for the ingestion pathway.

Table 1. 12 Ranches 2021 NIRT Drill Milk DRLs for Area.

Nuclide	Age	Organ or Tissue	Area DRL ($\mu Ci/m^2$)
I-131	One year old	Thyroid	8.79E-03
Sr-90	Fifteen year old	Bone Surface	4.46E-02
Cs-134	Adult	Whole Body	9.20E-02
Cs-137	Adult	Whole Body	1.34E-01
Sr-89	Infant	Whole Body	4.01E-01

Table 2. 12 Ranches 2021 NIRT Drill Milk DRLs for Mass

Nuclide	Age	Organ or Tissue	Mass DRL (µCi/kg)
I-131	One year old	Thyroid	1.26E-02
Sr-90	Fifteen year old	Bone Surface	3.21E-02
Cs-134	Adult	Whole Body	6.63E-02
Cs-137	Adult	Whole Body	9.68E-02
Sr-89	Infant	Whole Body	2.89E-01

In order to determine whether or not the cows on these ranches could return to grazing, comparison of the calculated DRLs seen above and the sampling data in RadResponder needed to be conducted. The data in RadResponder that was used included milk and ground deposition samples that corresponded as closely as possible to the 12 ranch locations provided in geocoordinates. The assumption made, specifically by the PNNL team, was that cows would graze withing a 5km radius of their ranch, so all analyzed samples from RadResponder would need to fall within this range to their respective ranch location. After completion of the comparison, any RadResponder radionuclide result that was over the nuclide-specific DRL was marked as "No" in response to the question of whether switching cattle back to onsite stored feed and/or pasture was acceptable. Final assessment of the twelve locations when compared to the Turbo FRMAC generated DRLs can be seen in Table 3.

Table 3. Results of comparison of RadResponder 12 Ranches sample data and calculated Turbo FRMAC DRLs

Ranch	Latitude	Longitude	Feed Result	Ground Deposition Result
1	45.34128	-93.8971	NOT OK to use: Over DRLs for Cs-137 & I-131	NOT OK to use: Over DRL for I-131
2	45.3691	-93.9837	NOT OK to use: Over DRLs for Cs-134, Cs-137, & I-131	NOT OK to use: Over DRL for I-131
3	45.3786	-94.0273	NOT OK to use: Over DRLs for Cs-134, Cs-137, & I-131	NOT OK to use: Over DRL for I-131
4	45.3822	-94.0298	NOT OK to use: Over DRLs for Cs-134, Cs-137, & I-131	NOT OK to use: Over DRL for I-131
5	45.40225	-94.0728	NOT OK to use: Over DRLs for Cs-134, Cs-137, & I-131	OK to use pasture, all nuclide results < DRL
6	45.36756	-94.0919	NOT OK to use: Over DRL for I-131	OK to use pasture, all nuclide results < DRL
7	45.29613	-94.032	OK to use feed, all nuclide results < DRL	OK to use pasture, all nuclide results < DRL
8	45.279	-94.1039	OK to use feed, all nuclide results < DRL	OK to use pasture, all nuclide results < DRL
9	45.28242	-93.9716	OK to use feed, all nuclide results < DRL	OK to use pasture, all nuclide results < DRL
10	45.27878	-93.9715	OK to use feed, all nuclide results < DRL	OK to use pasture, all nuclide results < DRL
11	45.26871	-93.9585	OK to use feed, all nuclide results < DRL	OK to use pasture, all nuclide results < DRL
12	45.22006	-94.0493	OK to use feed, all nuclide results < DRL	OK to use pasture, all nuclide results < DRL

2.2. Can deer hunting and fishing restrictions be lifted?

This RFI differed from the others in this report insomuch that data was not necessarily required to be used, but rather the team was required to hold tabletop discussions related to Data Quality Objectives (DQOs) so that a sampling and monitoring plan could be created that the state could then use to determine when and where restrictions could be lifted. This involved a very large area of the state of Minnesota; therefore, with limited resources, any sampling and analysis strategy must be optimized using the DQO process. Data for this exercise were obtained from the Minnesota Department of Natural Resources (DNR) and Minnesota Geospatial Commons websites. [1,2] Several tabletop discussions were held between the assessment scientists and Visual Sample Plan (VSP) scientists to come up with recommended strategies for clearing area restrictions while minimizing the need for sampling and analysis but still achieving an acceptable statistical confidence in the result. VSP can determine the number of samples, the maximum allowable number of unacceptable samples, and suggest *randomly distributed* sampling locations when given a statistical confidence limit and decision threshold but could not determine where sampling should occur based on land-use nor could it identify a population of interest. Population of interest can be identified by decision makers in consultation with local experts to determine the appropriate sampling locations. This approach works best for environmental sampling but breaks down and needs modification for the case of roaming populations over a land area which was the case for this RFI.

When working through the RFI, the team realized that the RFI for both hunting and fishing restrictions was much too broad to discuss together under one COSMOS RFI. Thus, the feature for splitting RFIs in COSMOS was used to break it out into two separate RFIs, one for hunting and one for fishing, which proved to work well. Once split, the team worked on the RFIs separately, generating two "products" that would help inform any future sampling and analysis plans. This process proved to be very useful and necessary when sampling and analysis resources are limited, and questions are broad and widescale. Sampling and analysis resources in the intermediate phase will almost always be very limited in a CM response and the team felt that VSP is a useful tool that can adequately employ statistics to optimize resource usage during a response. The technical products generated by the VSP team were in the form of stand-alone documents which are included as an appendix A in this document for future reference.

2.3. Has sampled milk exceeded the intervention level?

This RFI involved reviewing milk sample results in RadResponder against the intervention levels (ILs) in Turbo FRMAC to determine if a threshold had been exceeded. Participants had to use RadResponder to filter down and extract the data relevant to the question (milk samples), choose which radionuclides to consider in the analysis, age the RadResponder results to the same time (the time when milk would be placed on the market), and then compare the Turbo FRMAC IL results to these corrected RadResponder sample result values. Most participants skipped the aging step of the RadResponder data but noted this would be important if results were for many different reference times, or if the stakeholder was interested in evaluating different times to market. By default, CM requests labs decay-correct results to the moment of sample collection so assessment scientists can make accurate weathering corrections from that point. Therefore, we should expect that results reference date/times can vary greatly as sampling teams undergo a large sampling campaigns such as the one presented here (357 milk samples).

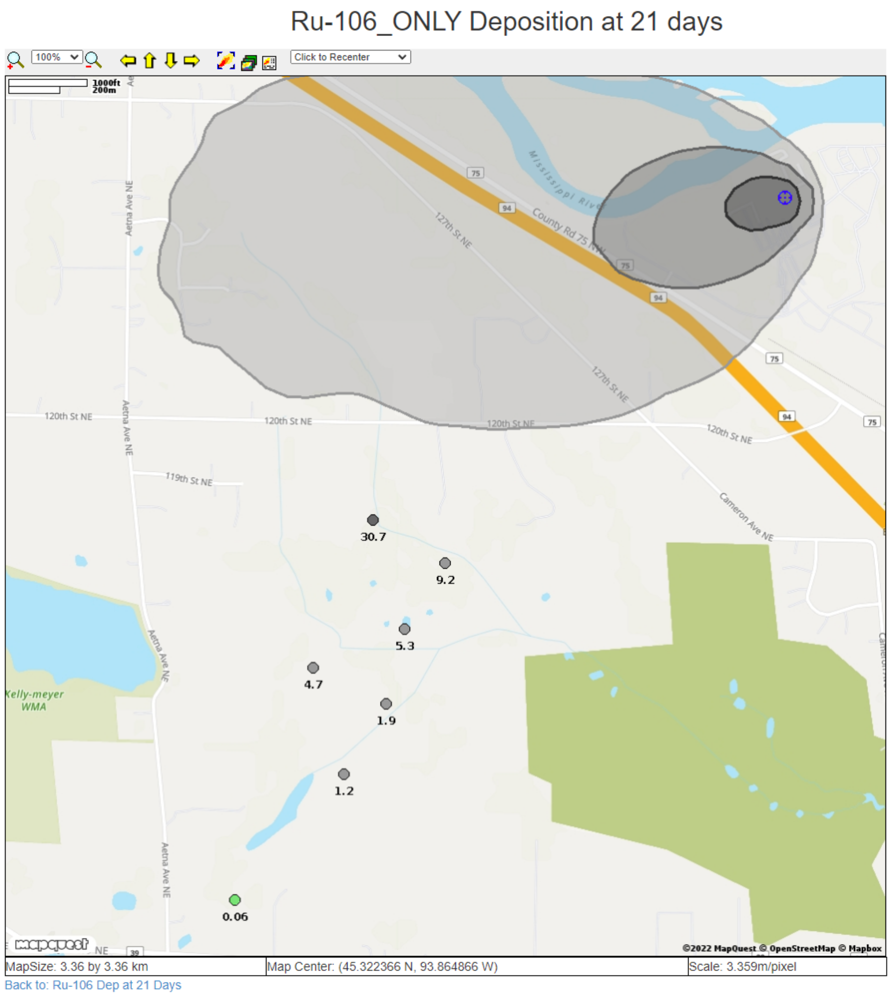
The technical process for answering this RFI is as follows. A RASCAL generated input .csv file was provided to upload into Turbo FRMAC. Integration between Turbo FRMAC and the RASCAL generated source term file has not been finalized, so the provided RASCAL .csv file had to be manually copied into Turbo FRMAC. Specifications within Turbo FRMAC were made to yield the ILs specifically for milk and used the "fresh cow's milk" ingestion rate assumption. Once generated, these derived intervention levels (DILs) were copied to Excel along with the pertinent result data from RadResponder in order to compare the two and determine if an IL had been exceeded for the observed evaluation time in question of 21 days. Any value below the DIL was filtered out, leaving only values that exceeded the DIL. These were tied to their corresponding sample IDs and locations where the milk could not be used due to exceeding the DIL. It was noted during the course of the exercise that the difference between the DRL and DIL is unclear and is a point of further necessitated training.

2.4. NARAC Prediction Update

This RFI involved reviewing all available data in RadResponder and how it could be used to verify/update the NARAC deposition model. Since the model itself was used to generate simulated data, some of the data was manually biased high to reflect a "hot spot" in the map. The goal of this exercise was to give NARAC the opportunity to practice a model update scenario as well as determine if the team could identify the hot region using existing tools.

NARAC Operations Assessors approached this RFI in two phases. In the first assessment, only the "Analytical Results" data type was downloaded from RadResponder, and from that set, only the isotope-specific activities from gamma spectra measurements were used to compare the initial model estimate to the simulated measurement data. Since this RFI scenario began 21 days post-release, NARAC focused on the measurements for longer-lived radionuclides such as -^{137}Cs, ^{134}Cs, and ^{106}Ru, to simplify calculations and comparisons.

NARAC generated individual ground deposition plots at 21 days post-release for comparison to the measurements. An example of the ^{106}Ru deposition plot at 21 days is shown below in Figure 7. Note that the map contour levels are initially set at default values of 100, 10, and 1 μCi/m^2, but the model calculation includes ground deposition results below 1 μCi/m^2 outside the map contours.



Concentration Levels

	Description	(uCi/m2) Extent Area	Population
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>100 0.2km 0.04km2	30
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>10 0.8km 0.3km2	90
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>1 2.4km 2.8km2	220

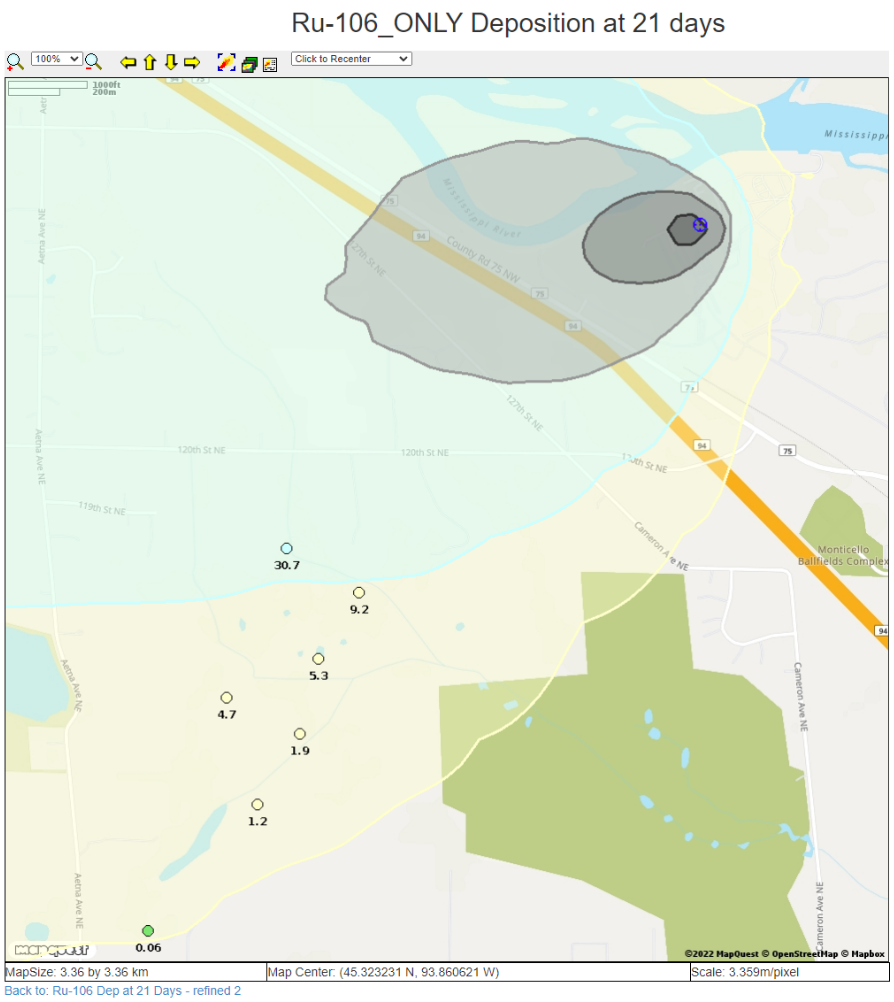
Note: Areas and counts in the table are cumulative.
Population Source = LandScan USA V1.0.

Effects or contamination at October 17, 2016 14:00 UTC

Figure 7: Initial ^{106}Ru deposition contours compared to measurements

The isotopic activity results for ^{106}Ru are also plotted on this map, with the color of each marker comparing the measured value to the map contour thresholds. For example, the high value of 30.7 μCi/m^2 is shown in medium gray, indicating that the value of that measurement corresponds to the middle contour of the map (greater than 10 but less than 100 μCi/m^2). From this visual comparison of measurements to model-calculated values, it is clear that the initial estimate of the source term is too small.

The NARAC system allows assessors to review and compare “matched pairs,” that is, each measurement value that has a model predicted value at the same time and location. This ratio of measured-to-computed values is called the *r*-value, and the average *r*-value for all matched pairs can be applied to the initial source term estimate to improve the model match to measurements. In this exercise, the initial source term estimate was increased by a factor of 36 to better match the measurement data. Due to the small number of measurements that could specifically be applied to this ^{106}Ru deposition calculation, NARAC could not identify any hot spots during this phase of the exercise. Figure 8 shows the revised model projection and additional contour levels compared with the seven available ^{106}Ru measurements.



Concentration Levels

	Description	(uCi/m2) Extent Area	Population
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>10,000 0.1km 0.02km2	10
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>1,000 0.5km 0.1km2	60
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>100 1.5km 1.0km2	140
		>10 4.6km 9.8km2	290
		>1 56.6km 694km2	145,000

Note: Areas and counts in the table are cumulative.
Population Source = LandScan USA V1.0.

Effects or contamination at October 17, 2016 14:00 UTC

Figure 8: Refined ^{106}Ru deposition contours compared to measurements

In a follow-up analysis, NARAC obtained additional simulated measurement data from RadResponder by downloading the complete report of "Survey" data. From this set, the gamma dose rate measurements were filtered to include only measurements taken between days 16–24 following the release, to minimize the effect of short-lived radionuclides contributing to the early dose rate measurements. As in the previous analysis, these simulated measurement results were then compared to the model-calculated dose rate values.

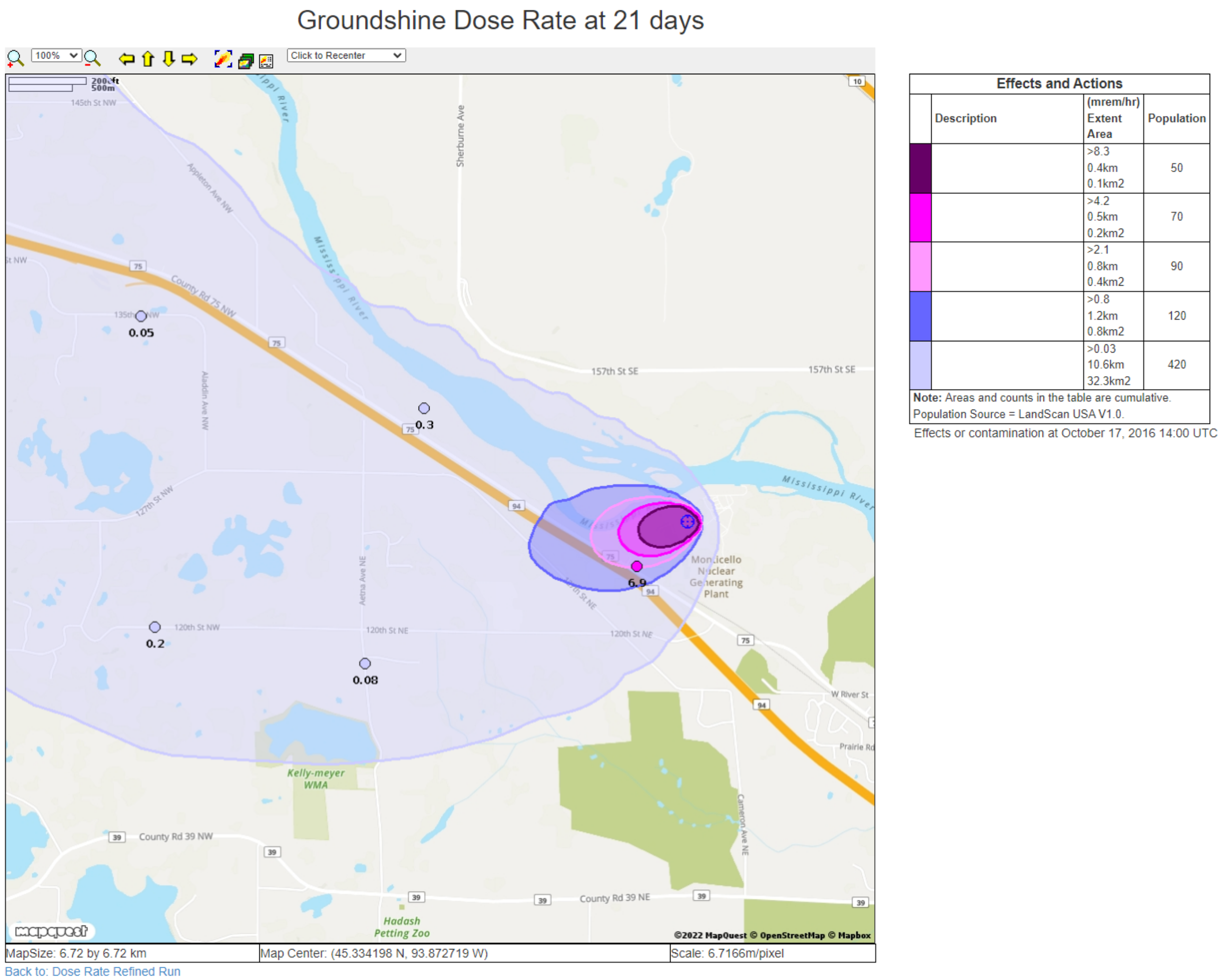


Figure 9: Refined groundshine dose rates compared to measurements

In general, the *r*-values for the gamma dose rate survey results indicated a reasonable match between the model projection and the measurement data. However, further review of the matched pairs showed a small number of measurements that were a factor of 14–18 times higher than the computed values for that time and location. Due to the asynchronous nature of this exercise, these results were simply considered outliers and not included in the final source adjustment factor.

In a real-world situation, NARAC would consult with the CM Home Team to determine the validity of the results, and whether other circumstances might be taken into consideration to explain the apparent "hot spots." Sample explanations can include precipitation or complex terrain or meteorology. Field studies of NARAC models have shown that for simpler meteorology, terrain, and release scenarios, NARAC model predictions have been within a factor of 2 of measured values, while in more complex scenarios, typical model predictions can be within a factor of 5 to 10 of measured values.

2.5. Assumptions about resuspension factor

This RFI involved using available data stored in RadResponder or if proved insufficient, developing a plan to acquire the data needed in order to determine if the original default resuspension factor assumptions remained valid. The assessment team discussed the technical approach and table-topped the formation of a request for field data and subsequent laboratory analysis. The thought-process and any discovered technical gaps or bugs were documented in a case narrative that may help standardize a process for conducting this type of analysis in the future, and the resulting technical approach is outlined below. A corresponding decision tree for this process can be found in Appendix B .

The process to answer this RFI can be generally applied to most situations where an extensive data set is available and began with determining if currently available data was sufficient to answer this problem. RadResponder was used to locate the most radioactive air sample in the area of concern in order to identify what was in the released mixture to be resuspended. This data was input to Turbo FRMAC and the dose parameters were calculated. The Dose Roll Up tool in Turbo FRMAC was used to find the major dose contributor(s), and one or two (depending on the mix) were selected to act as marker radionuclides for calculating resuspension. Once the marker radionuclide(s) were determined, paired samples of air and ground deposition were investigated in the stored RadResponder data to determine if current data was sufficient. Criteria for determining resuspension sensitivity based on relative external to inhalation dose by radionuclide must be set, much of which can be done prior to data collection for many radionuclides. Several questions must be asked at this point to ensure the data available met the need including:

- How many sample pairs are needed for a representative sample?
- How far apart can samples be in both distance and time?
- How close to the surface do air samples need to be?
- Has there been a weather event between sample collections?
- What were the wind conditions during sample collection?

Depending on the answers to these data questions, it could be determined whether or not available data will suffice to answer the question. For the purpose of this exercise, it was determined that the RadResponder data was insufficient.

The question then became whether or not there were currently samples in the lab for analysis that could be used in the near future. These samples would need to have been collected from areas where there was enough expected contamination to yield a signal strong enough on which to base the calculation. To determine this, a detection limit threshold for the nuclide(s) of concern must be established, then stored in COSMOS for reference during the rest of the RFI response. After the detection limit threshold was established, this value could be multiplied by the inverse of the suspected resuspension factor in order to yield the required ground deposition activity to get a reasonable air sample result. This ground deposition radioactivity could then be converted to a contact dose rate or direct alpha/beta screening result for an air sample using data from Turbo FRMAC. The sample contact dose rates or field screening results could then be observed, along with other samples and field dose rates collected nearby. From this, a list of potential samples that could be used to answer this RFI could be established. With this list the Lab Analysis team could ask the laboratories for the status and expected results of the samples, as well as if results could be expedited. For the purpose of this exercise, it was assumed that analysis will not meet the need or would take too long to finish, therefore new samples would need to be taken. Working through this process showcased the need for evaluating this screening data (contact dose rate and field screening results) prior to requesting laboratory analysis. In many cases, pre-screening samples can reduce the burden on laboratories when the purpose of sampling is to evaluate the resuspension factor and a negative result would not be useful.

Should new samples be needed, criteria for determining what areas were representative to take samples needed to be established. The team determined samples would need to be taken at three representative location types including **residential areas**, **commercial areas such as parking lots**, and **grassy common areas such as parks or soccer fields**. The team determined that three sample locations for each location type would be needed to adequately answer this question, and three representative ground samples and one air sample taken at each sample location. This leads to a total of 27 ground deposition samples, and 9 air samples.

To determine the type of sample needed at these locations, air and ground samples must be co-located. For ground samples, the decision must be made to either use a ground deposition sample, or an in-situ gamma spectroscopy measurement (or SpecFIDLER measurement in scenarios involving Plutonium dispersal). Ground deposition has the potential for higher sensitivity measurements and measurements of non-gamma emitting radionuclides but often comes with long turnaround times. In-situ measurement by HPGe or SpecFIDLER instruments have the potential to be biased due to source inhomogeneity but yield results as fast as analysts can process the spectra. For air samples, the size of filter used and total volume collected must be determined, and the collection efficiency must be determined. Filter collection efficiencies should be tabulated for easy reference by CM analysts. Furthermore, air sampling volumes and the impact to *a priori* detection limits should be tabulated ahead of time for quick reference during sample campaign planning.

Collected data could then be used to determine the representative resuspension factor. To do this, the three data points at each sample location must be fit to a distribution, and either the median (if a sample in the set appears to be an outlier) or average (if no outlier exists) of the points taken. Then, the air sample value for this location could be divided by the representative ground sample to yield the resuspension factor for the location. This was repeated for every sample location. The resuspension factors at the three sample locations for each sample location type could then be compared in a similar manner to yield a representative value for each location type. At this point, there would be one representative resuspension factor for each location type, which could then be compared across location types. Professional judgment must then be used to determine which resuspension factor to report if the resuspension factors show significant difference, and the final answer reported back in COSMOS to answer the RFI.

3. EXERCISE OBSERVATIONS

Observations were gathered by exercise players and controllers and were discussed during the hotwash after the drills. Observations are given a title, description, category, and priority.

3.1. Categorization

Exercise observations were categorized into items related to:

- RadResponder
- Turbo FRMAC
- Lab Sample Data Simulator
- VSP
- COSMOS
- General Assessment Science Processes and Procedures
- Technical shortfalls in documented methodology
- General questions arising from the drill

3.2. Prioritization

Each observation was given a prioritization

- Urgent – This is an issue identified as critical to mission success and should be addressed as soon as possible to avoid any impacts to our ability to successfully conduct the CM mission; when related to software, this priority relates to a bug in the software for which there is not an easy workaround that has a major impact.
- Important – This is an issue identified as an important fix to operations needed within the next development/funding cycle that will have a large impact to mission success/efficiency; this priority relates to a feature/function in software that if addressed, would have a major impact to mission success/efficiency.
- Improvement Opportunity – These issues/ideas are items that need to be investigated for future development to either improve existing capabilities for marginal impact or create a new capability that does not yet exist.

3.3. RadResponder

- **Improved data awareness in RadResponder** - In general, Assessment staff had a difficult time figuring out the best way to understand the scope of all the data in the system and determine the best way to extract it. The team requires more training and experience in extracting data from RadResponder and perhaps there is some room for improvement on the user interface (UI) to make it more intuitive. However, once shown how to most effectively extract data, users were able to do it the next time with relative ease.

- **Improvements to analytical result filtering** - RadResponder should allow users to filter analytical results by all sample information, this is not an available filter currently in the analytical results view. The Quick Search bar only matches against *ID/Barcode*, *analysis request name*, *type*, and *nuclide*. This is confusing as normally users would assume the search result is matching against every available column of sample information. The search bar should either have better labels or should be matching against all columns.
- **Improved clarity in sample date/time fields**. Some analysts did not understand the differences between all the dates in the system under samples and results. Analysts need to know clearly when a sample was collected and when the results are decay-corrected to (the result reference date/time). This may result in fixes to field display names in the software and improved training on how to handle sample results by assessment scientists.
- **Improvements to mapping application when used as a data curation tool** - Effectively filtering the map down to what is needed is somewhat counter-intuitive as the user must first toggle on the layer they wish to see and then go in and adjust the filters down to see only the sample types that are important for the RFI. Furthermore, viewing samples should automatically give the user access to the available results under those samples. It was not clear how to filter the available results down by sample type. More targeted hands-on training is needed in the map tool when used as a way to query for data. Consider perhaps a dense dataset that users can be given challenge questions on where they have to go in and curate their own data set using the tools within the UI.
- **Development of tool to bulk-age sample result data** – For RFIs with extensive sample populations, there is the need for the capability to age and decay correct sample data in bulk. This capability would streamline the process of data analysis, especially with results are asked to be evaluated at times other than the sample time reported in RadResponder.

3.4. Turbo FRMAC

- **Turbo FRMAC Updates** – Many drill participants were not using the latest version of the Turbo FRMAC and therefore were unable to use the latest FRMAC methodology for calculating Ingestion Derived Response Levels. In the case, the impact of the revised methodology on the end result of the drill was significant. The potential significance of Turbo FRMAC updates to existing calculations should be made clear to users in release notes and training. Additionally, the availability of Turbo FRMAC in a web environment where the latest version is easily accessible by users would eliminate the issue of needing to work through administrative issues with installing and running the latest version.
- **Default Mixtures in Mixture Manager** – The appropriate use of default mixtures available in Mixture Manager for use in Turbo FRMAC calculations should be made clearer to users. For example, the NPP Monitored Mixture is not an offsite release mixture and should not be used in most Turbo FRMAC assessments. Also, the Inventory After Shutdown mixtures for nuclear power plants do not have release fractions applied. Plans are in place to update these mixtures based on the defaults provided in the FRMAC Assessment Manual, Volume 2 Pre-Assessed Scenarios, currently in draft.
- **Entering Mixture Information** – Various calculations in Turbo FRMAC require mixtures to be entered in specific units, but often mixture data is not available in the required units. The Paste Mixture GUI for calculations should reflect the units expected for the calculation.

Expectations for using release information that might not be in the appropriate units should be made clearer in training and the software.

3.5. Lab Sample Data Simulator

- **Improved generation of sample IDs in Simulator** – There is a need to be able to generate unique sample IDs in the data simulator. This portion of the hand-manipulation of data from the simulator takes the most time and can easily be done by the simulator tool with an update to the UI. The design is laid out in the simulator design document.

- **Improved integration of Lab Sample Data Simulator with RadResponder** - As it stands, the data generated in the simulator must go through multiple formatting steps before being acceptable in RadResponder. These steps include the following:
  - Generate sample collection date/times
  - Organize data by sample type so it can be planned in appropriate sample specific import tab
  - Associate sample to a field team
  - Associate a sample result to a laboratory
  - Generate sample sizes and units for each sample
  - Migration of data from output sheet to RR template
  - Ensure laboratory syntax matches required syntax
  - Ensure qualifiers match syntax
  - Conversion of ground dep results from μCi/m2 to μCi/kg to match what a lab would provide
  - Entry of sample size as analyzed value for ground dep (used 370 g)
  - Manual calculate and apply mass as analyzed (different than sample size)

  The more steps that must be manually taken to shift data from one software to another, the higher chance of mistakes being integrated into the data. To assure the preservation of data quality, improvement of integration of data between the simulator and RadResponder is necessary.

3.6. VSP

- **Improvement of VSP functionality** – There is a need to further develop the functionality of VSP in order to make future applications of the software easier as well as require fewer manual steps and less advanced VSP knowledge from the user. This takes the form of:
  - Option to automatically assign different colors and color schemes for each sample area upon import
  - Using different area layers as masks for importing
  - Auto-counting areas within a boundary
  - Update shapefile map loading to allow new parameters to be created as List type parameters upon loading. A List type user parameter can be used for quickly selecting areas by parameter such as Zone or Management Type, and for coloring areas according to parameter.
  - Recognize and automatically map parameter values for NARAC shapefile import

- Save data schema for importing from spreadsheet, so that RadResponder Excel files with many columns can be more easily imports.
- Direct data import from RadResponder or another data source

- **More experience/procedure development needed with VSP** - When developing sampling and analysis plans or when using Visual Sample Plan for developing thresholding criteria for sample results there needs to be some guidance for choosing confidence intervals to use to begin with pending guidance from decision makers.

3.7. COSMOS

- **Better integration of sample data with COSMOS** - There is a need to better tie samples and results to the submitted RFI in COSMOS so that it is easy to look up results.

3.8. General Assessment Science Processes and Procedures

The drills were incredibly valuable for recognizing gaps in the data assessment process for Assessment. Guidance and training in this area is lacking, which led to vastly different results among multiple Assessment Scientist teams working on the same problem, which is a concern as these results are often the basis of highly impactful protective action decisions for the public. This inconsistency should be addressed, potentially through development of job aids, training, and data assessment tools. Gaps of note are captured below.

- **Radionuclide Mixture Assumptions for Ingestion** – Ingestion PAGs are addressed on a per-radionuclide basis according to FDA guidance. Large fission product mixtures like those from nuclear power plant releases make comparison of measurement and sample results against Derived Response Levels and Intervention Levels for decisions such as allowing cattle to graze on contaminated pasture difficult, particularly when results are not available for all radionuclides assumed to be released, and considering the complexity of handling decay and in-growth for the timing of the question being asked, versus when the product might be consumed, versus when the sample results were reported. Guidance is needed on how radionuclide mixtures should be defined for establishing detection requirements, comparing sample results to Intervention Levels, etc.

- **Ingestion DRL Assumptions** – Default Ingestion Derived Response Level assumptions are conservative and are mostly based on the default assumptions for FDA Derived Intervention Levels. Guidance for deviating from these assumptions should be developed, including basis for deviation (e.g., better science, available data) and potential impact on results so it can be properly messaged to the Advisory Team. Additionally, the definitions of various time inputs for Ingestion Derived Response Level calculations are unclear. Practical guidance on how to use the time inputs should be provided in training.

- **FDA Grouped Radionuclides** – Guidance and training on how to compare measurement or sample results to FDA Derived Intervention Levels for grouped radionuclides (e.g., Cs-134 + Cs-137) is needed. Automated data analysis tools that appropriately handle results for grouped radionuclides are desired.

- **Data Quality Assessment Process** – Criteria for determining which measurement and sample types are appropriate to use for answering specific questions are unclear. Examples include converting dose/exposure rate measurements into deposition quantities for comparison to a Milk Derived Response Level, or converting a milk sample result into a deposition quantity for incorporation into a NARAC model. Criteria should consider the question being asked, the data quality objective, and the availability of better suited data to answer the question. Additionally, a tool (other than RadResponder) for curating and tracking data sets used for a given Request for Information is needed.

- **Tabletops for Assessment Scientist Training** – Participants noted that they found this drill more valuable than the typical Turbo FRMAC calculation problems included as part of Assessment Science Continuing Education training. An effort should be made to provide tabletop scenarios like this for training billeted Assessment Scientists. It is suggested that tabletops utilize the approach and materials used in the design of these drills, and expand to other typical questions FRMAC is likely to be asked during a response. Exercising the Assessment process end-to-end in development of these tabletops will also help establish a more uniform approach to data assessment that can be captured in FRMAC/CM documents, training, and used to establish requirements for development of data assessment tools.

- **Better integration of VSP products in FRMAC – **There is a need for FRMAC Liaisons to be trained to interpret and brief on VSP products and for assessment scientists/product scientists on how to coordinate generating one. Considerations should be made on how VSP experts can be embedded into the CM response to utilize VSP's ability to assist in sample and analysis planning and data analysis. Additionally cross-training, and regular involvement in CM drills and exercises would be valuable for PNNL VSP experts for them to become more familiar with typical and atypical FRMAC/CM needs and timelines so that software can continue to grow to support this mission space.

- **Filter efficiency lookup tables –** There is a need for a table of lookup values for air collection efficiency to use for correction of air results to expedite the data correction process.

- **Sample collection and laboratory analysis resources monitoring –** There is a need within CM for a tool to aid in the accurate monitoring of both sample collection and laboratory analysis resources, specifically for use as input in sample planning tools such as VSP.

3.9. Technical Shortfalls in Documented Methodology

- **Documenting technical approaches for future reference** – There is a need to develop a process and location for documenting technical approaches taken to solve problems/RFIs that are presented to Consequence Management. This was a noted shortfall for both the assessment and NARAC scientists in this exercise.

- **Quick lookup tool for sample analysis detection limits for key radionuclides –** Tools used by Lab Analysis to quickly calculate *a priori* estimates of detection limits for key radionuclides in environmental matrices should be consolidated and operationalized in software that can be quickly used in sampling campaign planning efforts during the response.

- **Applying variance in field measurements** – It was unclear what variance to use in calculations using field measurements. This information is not typically stored next to measurements as it is for laboratory analysis data. There should be an established FRMAC protocol for determining an appropriate variance to use for different classes/types of field measurement data that considers calibration variance and user error in a way that is agreed upon by the interagency working group. This approach must be able to be applied to measurements in a bulk fashion and when possible, use performance data associated to the specific instruments used.

- **Develop methods for using secondary/derived values in MARSSIM protocol decisions** – Determine if assessment can and should use secondary or derived measurements or values to replace a strict MARSSIM protocol for clearing an area. For example, if fish is the product in question, could assessment use deposition on lake water or ground near a lake or body of water as the source of evaluation data rather than the fish itself?

- **Handling Spatially-Varying Data** – Guidance is needed for data acceptance and rejection when comparing measurements to modeled results (e.g., from NARAC), particularly for radionuclide mixtures that in reality will not uniformly deposit but are largely assumed to do so when modeled.

- **Addressing Uncertainty** – Measurement and sample results might have accompanying uncertainty information, however Assessment-calculated quantities such as Derived Response Levels and Intervention Levels currently do not. Criteria for "how close" a measurement or sample result can be to a Derived Response Level or Intervention Level is unclear.

- **Decay and Weathering Correction** – Data from RadResponder is likely to be taken at different times relative to the time of release. A capability to bulk decay and weather correct data so that it aligns with NARAC model results and Derived Response Levels is needed.

- **Use of field-measurements to pre-screen samples prior to analysis** – Any formal Data Quality Objectives (DQOs) planning should employ the use of field measurement as applicable to pre-screen results prior to unnecessarily tying up laboratory resources during an incident. This is particularly important when the question at hand relies on the positive detection of radionuclides at threshold levels or requiring radioactivity levels where uncertainty is minimized such as a measurement that is used to determine a resuspension factor or radionuclide mixture ratio. Pre-screening tools to measure dose rate or gross alpha/beta radioactivity could ensure samples yield enough signal to yield reliable interpreted results.

- **Monitoring sample collection and laboratory analysis resources** – There is a need for the capability to accurately monitor both sample collection and laboratory analysis resources, specifically for use as input into sample planning tools like VSP.

3.10. General Questions Arising from the drills.

- **Determining usability of gross alpha/beta data** – During the course of the event, the question of how gross alpha/beta measurements, and how gross alpha/beta measurements on the ground could be appropriately utilized during the course of a response.

- **Data pedigree** – Specifically arising from the resuspension factor mini-drill comes the question of consideration of the data pedigree. It is suggested that the collecting organizations discuss data pedigree methods in future exercises. Furthermore, it is suggested that FRMAC determine a process to set acceptance criteria for existing (or secondary) data.

4. CONCLUSION

Overall, this drill was successful in uncovering several bugs, critical lessons learned, and opportunities for improvement in the assessment of measurement and sample result data for answering technical requests for information. The assessment scientists and NARAC rarely get the opportunity to practice with realistic and dense data sets. Future training and exercises are needed that focus on using real or realistically simulated data sets that have realistic brevity that drive the need for automated data analysis methodology and tools. This can be more easily achieved if effort is spent on curating these datasets for several of the likely threat scenarios. These curated data sets can then be deployed to events in the various data systems and software tools for use with any technical RFIs. As a result of the lessons learned during these mini-drills, the team hopes to address many of the critical gaps as well as perform more of these data-focused drills in future continuing education training efforts.

5. REFERENCES

[1] MN Department of Natural Resources (2021). *Deer Permit Areas.* https://www.dnr.state.mn.us/mammals/dee/management/dpas.html

[2] MN Department of Natural Resources (2019). *2019 Minnesota Deer Harvest Report.* https://files.dnr.state.mn.us/wildlife/deer/reports/harvest/deerharvest_2019.pdf

[3] MN Department of Natural Resources. (2009, June 29). *Camp Lake Survey.* https://www.dnr.state.mn.us/lakefind/showreport.html?downum=71012300

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[5] MN Department of Natural Resources. (2020, November 17). *Public Fishing Sites in Minnesota.* Minnesota Geospatial Commons. https://gisdata.mn.gov/dataset/struc-fishing-sites-in-minnesota

APPENDIX A: TECHNICAL PRODUCTS

A.1. Hunting Restriction Technical Product

Event: 2021 NIRT MINI-DRILL
COSMOS RFI: Can deer hunting be lifted? (#0001)
To answer this question, we considered each of the Deer Permit Areas (DPAs) from the Minnesota Department of Natural Resources (DNR) as a separate decision unit. From the DNR website [1]:

> Wildlife managers use landscape features such as rivers and roads to divide Minnesota into 130 areas that have similar habitat, land uses, deer populations and deer hunter distribution.

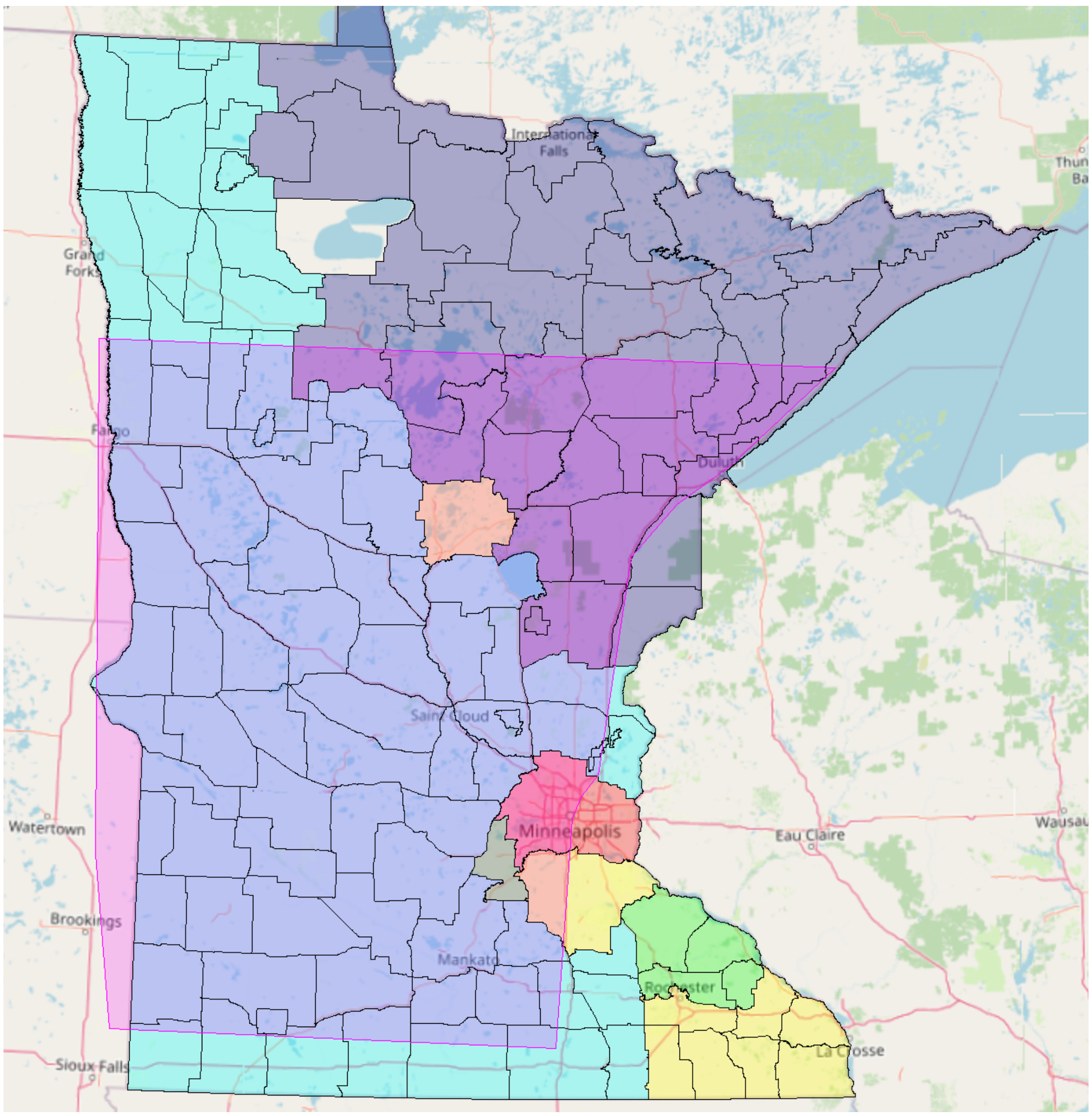


Figure 10: Deer Permit Areas colored according to the state zone designation overlaid with the hunting restriction area (pink)

To meet this RFI, we first wanted to identify which DPAs are within the area where modeling predicts contamination levels in excess of the risk-based DRL for deer consumption. We then developed a graded sampling approach for the other areas where there is not evidence to suggest that the deer consumption DRL would be exceeded, but some sampling is necessary to establish a basis for lifting restrictions.

Results:

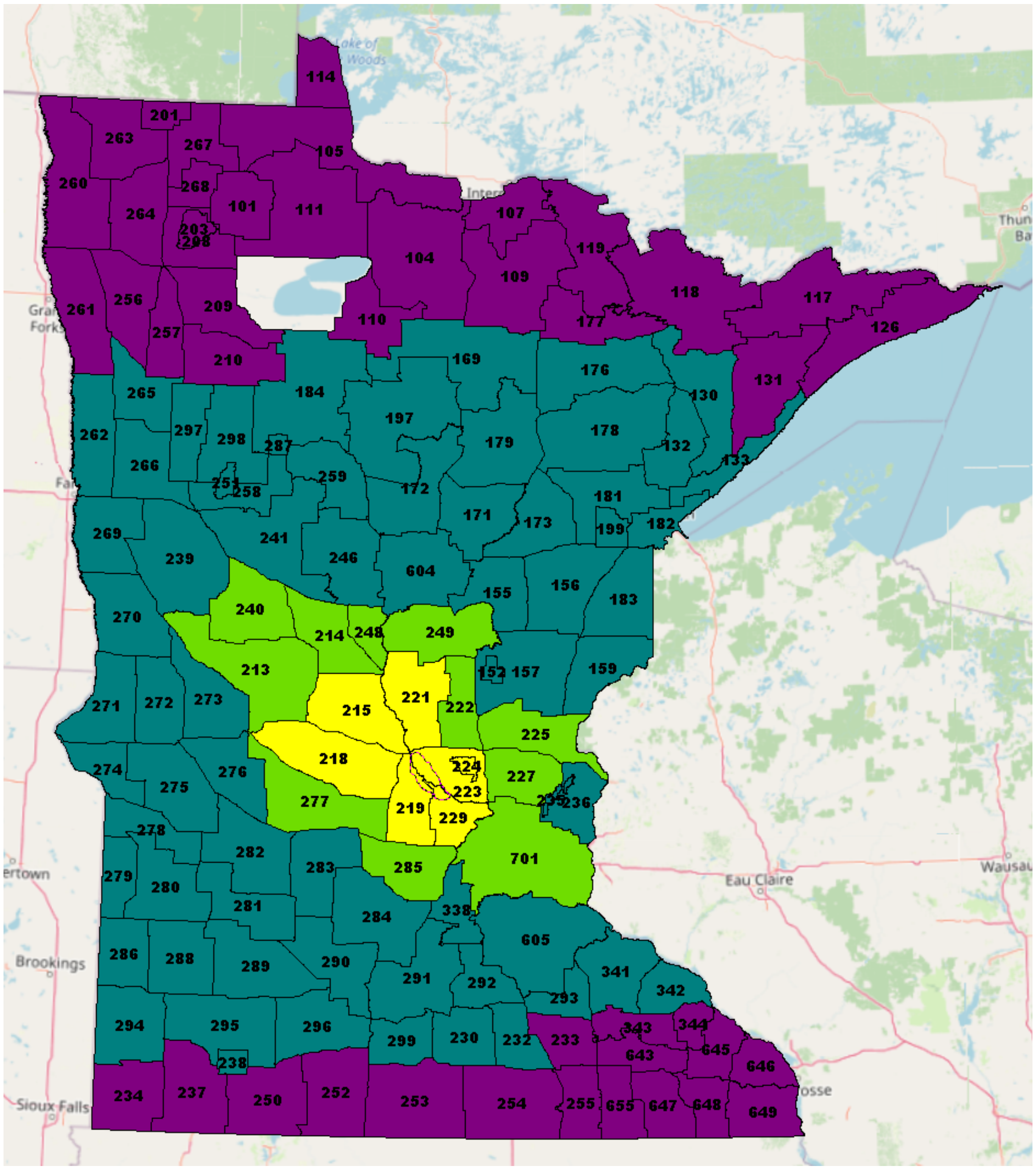
Each DPA within the restricted zone is classified according to its potential for contamination following the release. The modeled plume boundary and Cs-137 milk samples were used to inform the classification as the provided ground sampling results were not extensive enough to characterize each of the designated areas..

The criteria for defining each characterization status category, along with the recommended sampling strategy, is shown in the table below, with the category of each hunting unit color coded on the map.

Table 4. A description of different contamination classifications with associated legend color and sampling criteria.

Color	Characterization Status Category	Criteria	Sampling Strategy	Sampling Requirements (95% Confidence)
	Non-Impacted	Outside of hunting restriction area	No restrictions	None
	Likely Uncontaminated	Within hunting restriction area Not adjacent to "Likely Contaminated" units	Require hunters to submit deer for sampling until item sampling criteria met	If 59 deer are sampled and are below DRL, lift restrictions
	Potentially Contaminated	Within hunting restriction area Adjacent to "Likely Contaminated" units	Soil sampling, 95% confidence that average is below DRL (MARSSIM Sign Test) If Sign Test passes, reclassify as "Likely Uncontaminated" and require hunters to submit deer for sampling	Collect at least 11 representative soil samples If Sign Test fails, continue restrictions If Sign test passes, require harvested deer sampling until 59 are found to be below DRL
	Likely Contaminated	DRL plume contour overlaps or is within 2 miles of area	Continue restrictions	NA

Figure 11. Statewide map of DPAs, colored according to the different sampling requirements.



Explanation:

TurboFRMAC was used to determine a value for a DRL of 0.113 uCi/m^2 for Cs-137 for deer consumption. The NARAC-produced plume DRL contour for this value served as the basis for classification of areas for different possibilities of contamination.

Areas overlapping, or within 2 miles (selected based on the maximum typical ranging area of whitetail deer), of the plume contour were conservatively classified as likely to exceed the DRL, or "Likely Contaminated". Areas adjacent to these "Likely Contaminated" areas were classified as "Potentially Contaminated", and all other areas within the hunting restriction zone were classified and "Likely Uncontaminated".

- <u>Potentially Contaminated Sampling Strategy</u>

Because of the higher potential for contamination, soil sampling is recommended to establish some baseline information about the levels of soil Cs-137 within the area. While a non-parametric MARSSIM approach is recommended, it should be highlighted that the size of the Deer Permit Areas (DPAs) greatly exceeds the MARSSIM area size recommendations that are geared towards sites with previous known contamination.

Figure 3 below shows the design dialog in VSP with the inputs that resulted in a sample size of 11. The estimated standard deviation was based on the available soil sample data from RadResponder located outside of the DRL contour, and the lower bound of the gray region was set to the sample mean of that data. Part of the data quality assessment once sampling is conducted is to see whether the estimated standard deviation is consistent with the data collected.

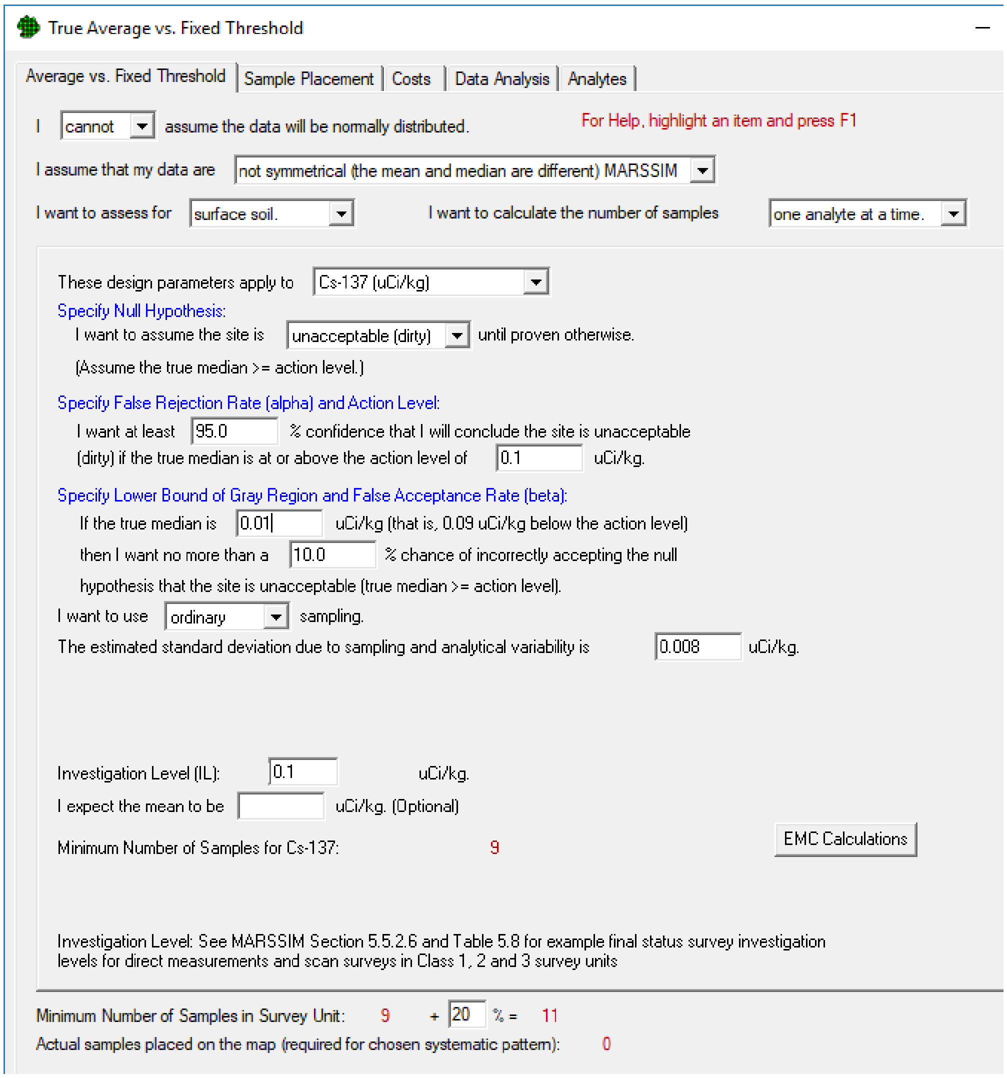


Figure 12.

- <u>Likely Uncontaminated Sampling Strategy</u>

For "Likely Uncontaminated" DPAs, the recommended number of harvested deer to sample is based on an item compliance sampling strategy for 95% confidence that 95% of the population is acceptable. The figure below shows the inputs in VSP that resulted in a recommended sample size of 59.

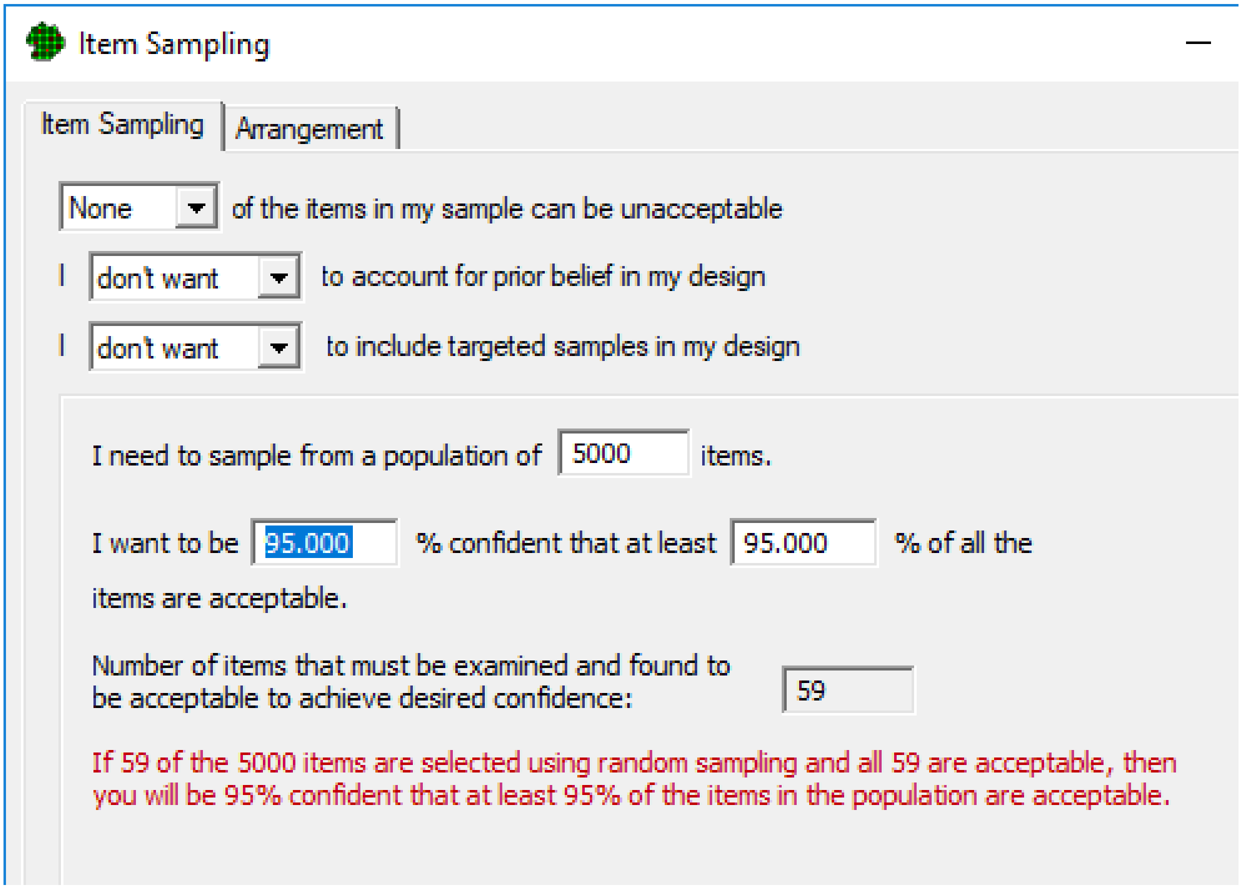


Figure 13.

This sample size requirement is based on the maximum level of prior harvest in all MN DPAs in 2019 [2]. To optimize sample size by unit, the population size can be updated based on the historical harvest count for the particular DPA.

Recommendations to Expand VSP Capabilities

- Update shapefile map loading to allow new parameters to be created as List type parameters upon loading. A List type user parameter can be used for quickly selecting areas by parameter such as Zone or Management Type, and for coloring areas according to parameter.
- Recognize and automatically map parameter values for NARAC shapefile import
- Save data schema for importing from spreadsheet, so that RadResponder Excel files with many columns can be more easily imports.
- Direct data import from RadResponder or another data source

References

[1] MN Department of Natural Resources (2021) *Deer permit areas*
https://www.dnr.state.mn.us/mammals/deer/management/dpas.html

[2] MN Department of Natural Resources (2019). *2019 Minnesota Deer Harvest Report*
https://files.dnr.state.mn.us/wildlife/deer/reports/harvest/deerharvest_2019.pdf

A.2. Fishing Restriction Technical Product

Event: 2021 NIRT MINI-DRILL
COSMOS RFI: Can fishing restrictions be lifted? (#0002)
To answer this question, two topics were examined: 1) the sampling of fish in an individual body of water, and 2) the sampling of fishing locations in the restricted area. Available contextual and survey data were obtained from the Minnesota Department of Natural Resources (DNR) and Minnesota Geospatial Commons websites, which provided valuable information in designing and performing the analyses.
VSP item sampling analyses were performed to produce requirements related to the number of samples taken from a population in a given area, the maximum number of unacceptable samples, the confidence levels, and the estimated percentage of acceptable items across a population. However, these analyses do not select the locations where sampling should be performed. Additionally, populations of interest (e.g., a desired representative set of fish, species of fish, or bodies of water in an area) should be identified by decision makers in consultation with local experts before determining sampling locations.

Note: lakes are already routinely surveyed for public health studies (surveys for water quality, phosphorous, mercury, etc.) and biological studies (fish species, aquatic plant surveys, oxygen levels pertaining to winterkill, etc.). It is expected that state natural resource officials are likely to have some existing familiarity with statistical sampling methods, confidence intervals, and the false positives expected at low intervention levels, as they pertain to non-radiological scenarios.
Results:
1.) Sampling of Fish in a Body of Water

Using the Item Sampling feature in VSP, we determined that for a population of 4932 fish, if 98 fish are sampled across the 4 lakes and all 98 are below the intervention level (assuming no false positives), there is 95% confidence that at least 97% of fish in the lakes are below the intervention level.
However, given a low DRL, it is expected that there will be some number of false positives. Table 1 shows the requirements for the number of sampled items and maximum allowed false positives for a 95% fixed confidence level for the estimated total population of all for lakes, as a function of % of acceptable items. The maximum percentage of unacceptable samples is 5% for all values but falls below 5% as the increased sampling raises the percentage of acceptable items above 95%. This is because the difference between the amount of the total population (100%) and the percentage of acceptable items falls below 5%. For example, if we want 97% of a population to be acceptable, then no more than 100%-97% = 3% can be unacceptable

Table 1: Item Sampling in Masford, Jones, Crescent, and Camp lakes.

Items sampled (estimated population: 4932)	maximum # of unacceptable samples (capped at 5%)	% of the items acceptable with 95% confidence level
24	3	70
34	4	75
50	5	80
93	8	85
284	20	90
3855	182	95
4278	121	97
4417	83	98
4598	43	99
4686	0	100

Note that as the requirement for acceptable items approaches 95% (two sigma), the requirement for items sampled increases from around 5% of the population to over 50% of the population, and the maximum number of unacceptable samples begins to decrease.

Additionally, if an estimated population and a number of samples taken is provided, accounting for limited sampling due to resource constraints, the associated confidence intervals could instead be calculated accordingly (Figure 1).

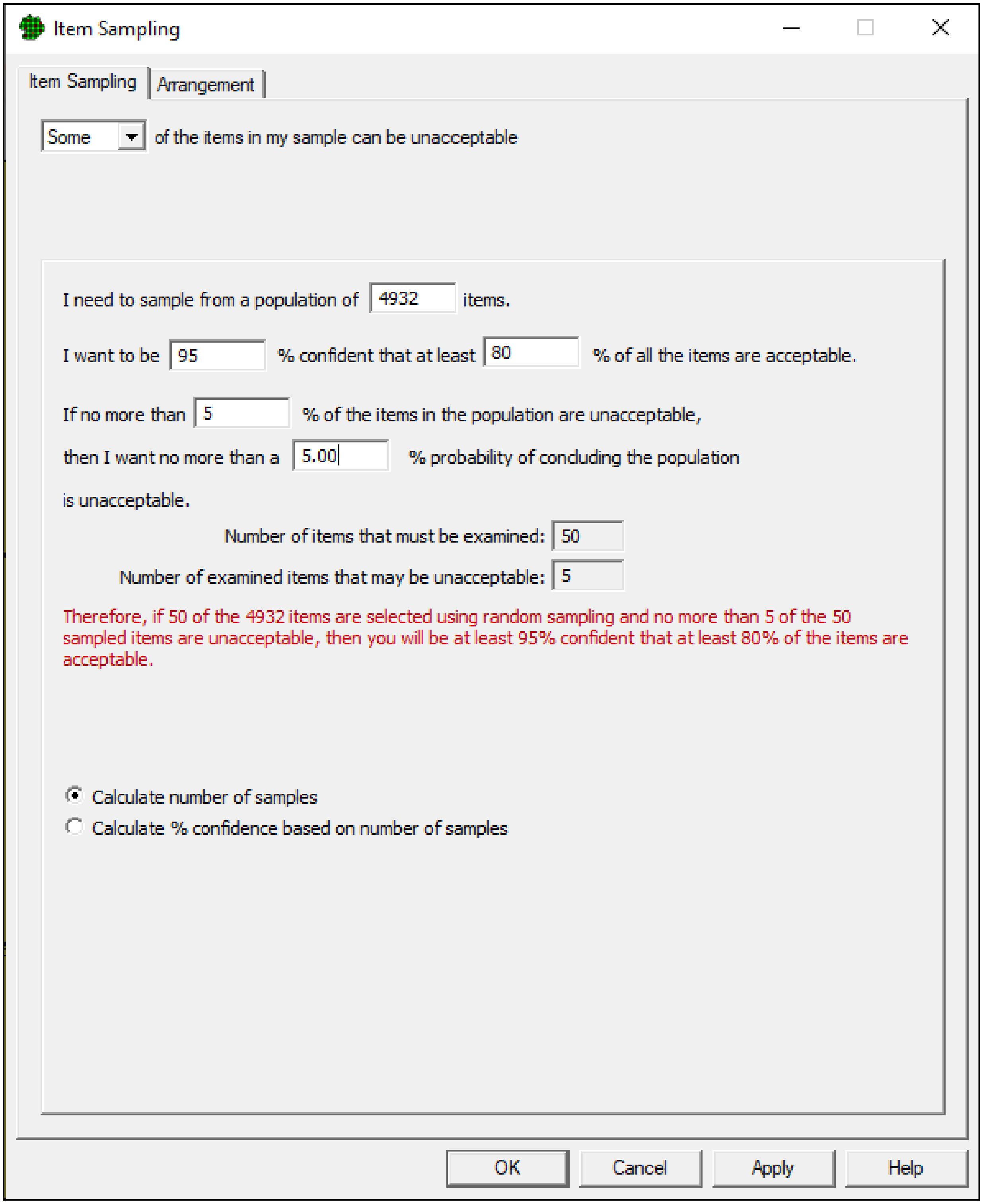


Figure 14: Item Sampling Selection in VSP

2.) Sampling of Fishing Locations in the Restricted Area

a. Sampling Randomly Over the Restricted Area

Similar to Part 1, VSP was used to calculate the number of fishing areas required for sampling, with a fixed 95% confidence level (Table 2). However, it is assumed that if fishing restrictions are to be lifted in a region, none of the sampled bodies of water in that region can be unacceptable. Example: if 27 fishing sites are surveyed and none of those sites are unacceptable, it can be stated with 95% confidence that at least 90% of fishing sites in the entire restricted area are acceptable.

Table 2: Item sampling: public fishing sites in restricted area vs desired total amount deemed acceptable. Does not allow for any sampled areas to be deemed unacceptable.

Items sampled (estimated population: 264)	% of the items acceptable with 95% confidence level
9	70
11	75
14	80
18	85
27	90
53	95
83	97
114	98
179	99
251	100

b. Stratified Sampling Based On Plume Modeling

Using modeled plume areas from NARAC, the Stratified Compliance Sampling design in VSP was applied. This sampling design applies preferential weights to plume areas, focusing on the areas most likely to be of most concern (i.e., near the DRL), so fewer resources can be devoted to the areas of least concern. The recommended total number of sampled fishing sites using this is 14, allocated among the contour-bounded areas (Table 3). The confidence level and total percent acceptable were fixed at 95% with no unacceptable sampled areas allowable; i.e., if all sampled areas are acceptable, we can state with 95% confidence that 95% of the total areas in all sampled strata are acceptable (Figure 2). The details on how each value was obtained are detailed in the next section.

Table 3: Number of Fishing Sites Recommended for Sampling Per Stratum

	Contour Level (NARAC Estimated) (uCi/m^2)	**Relative Likelihood**	**Recommended Number of Sampled Fishing Sites**
Level001	0.12 (Fish consumption DRL)		
Level002	0.098	0.817	4
Level003	0.075	0.765	4
Level004	0.053	0.54	3
Level005	0.03	0.30581	2
Level006	0.008 (MDA)	0.0816327	1
	Total for All Contours		**14**

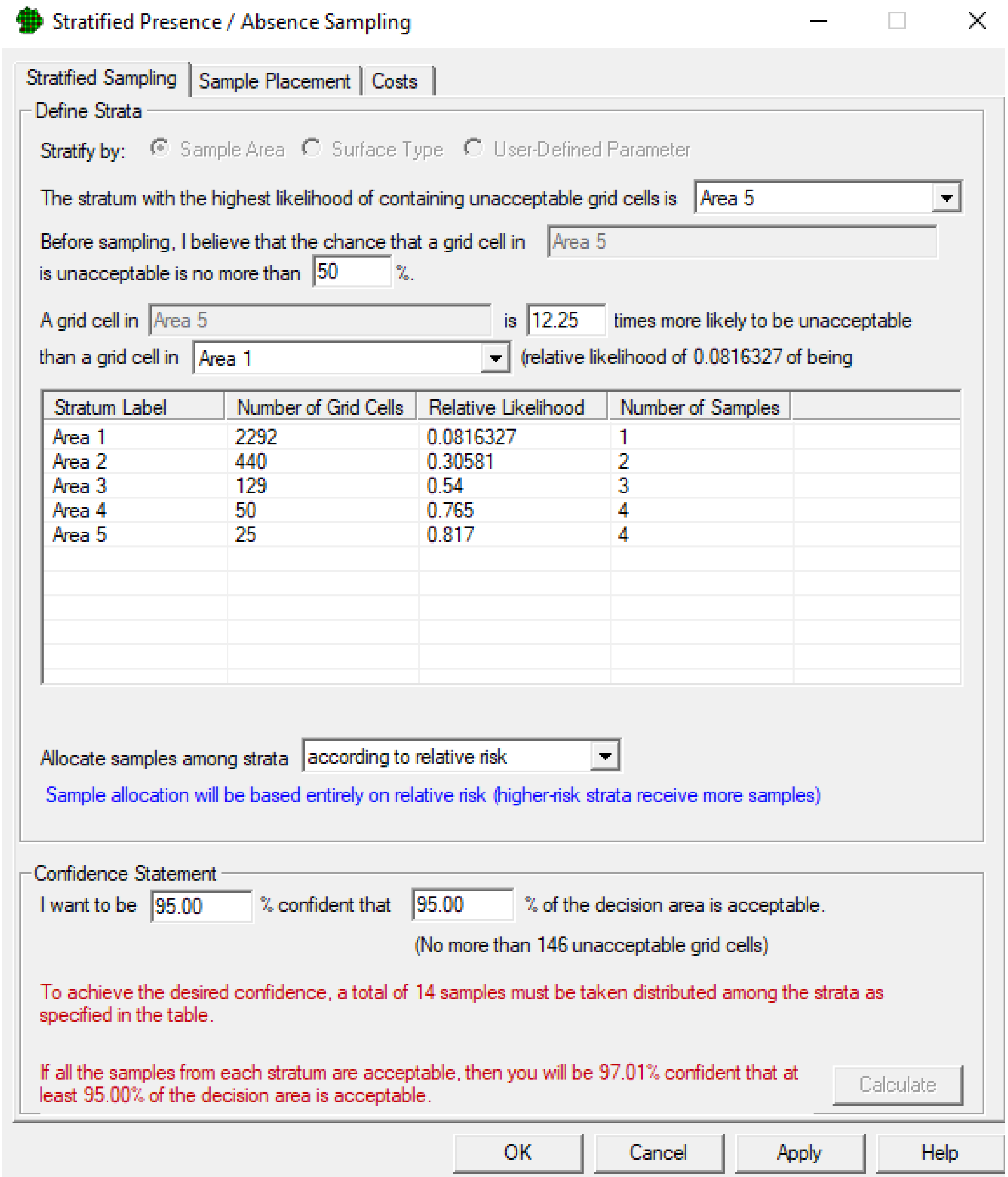


Figure 15: Stratified Sampling in VSP

Explanation:

1.) Sampling of Fish in a Body of Water

For this part of the exercise, the evaluation area is restricted to four adjacent lakes in Sherburne County: Masford Lake, Crescent Lake, Camp Lake, and Jones Lake.
To effectively model the scenario, starting assumptions must be made and justified.

- What species are expected to be fished in these lakes, and are they restricted to certain fishing seasons?
- How do we model sampling from a representative cross-section of the variety of available species?
- Can we estimate an expected population to sample?

To answer these questions, we looked for information on previous lake surveys and found a 2009 survey of the fish in Camp Lake. In the survey, 1402 fish were caught, compared to the previous survey in 1980 during which 1200 were caught [1]. *Had survey information not been available, it may have been necessary to reach out to Department of Natural Resources representatives to help inform our assumptions.*

- The survey identified 8 species of fish: black bullhead, black crappie, bluegill, hybrid sunfish, largemouth bass, northern pike, pumpkinseed, and walleye. Most of the population (89.5%) consisted of bluegill and black bullhead, which may be caught year-round.
  - Therefore, it can be expected that fish in these lakes may be caught by members of the public shortly after the restriction is lifted.
- Due to the variety of capture methods used in the 2009 survey (including different types of nets and electrofishing), it is assumed that the lake was thoroughly fished, such that the number of fish likely to be caught in a similar survey is comparable to the catchable population of the lake, both in terms of species representation and aggregate population.
  - Therefore, it is recommended for a similar variety of capture methods to be used to survey the fish in these lakes for the purpose of determining the necessity of fishing restrictions, since different methods will capture across different species and sizes (ages) of fish.
- The four lakes are assumed to be similar in composition, since they are similar in area and adjacent to one another. Given the known area of the previously surveyed Camp Lake, along with the estimated catchable population from the 2009 survey and the area of the other 3 lakes [2], the total catchable population of the combined lakes can be estimated using

$$\frac{Camp\ Lake\ catch\ total}{Camp\ Lake\ area} = \left(\frac{total\ catchable\ population}{total\ lake\ area}\right)$$

  Solving for the total catchable population yields an estimate of 4932 fish.

2.) Sampling of Fishing Locations in the Restricted Area

For this part of the exercise, the evaluation area is limited to the area with restricted fishing in Part A, and to the NARAC-modeled plume contours in Part B.

a. Sampling Randomly Over the Restricted Area

Starting assumptions for the first approach:

- The entire restricted region is treated uniformly, assuming any two locations within the restricted region are equally likely to contain fish with values above the DRL, and does not consider areas with differing DRLs.
- Population of interest: due to the number of public water basins in the state, it is desirable to focus sampling on lakes most likely to be fished by the public, and to exclude small, remote, or farm lakes that are unlikely to be fished.
    - MN Geospatial Commons has a dataset on all public water basins, including wetlands, totaling over 21,000 objects. Over 11,000 of these are lakes. A narrower cross-section of sampling locations is desired.
    - MN Geospatial Commons has data on locations considered public fishing sites [3], including fishing piers, shore fishing sites, breakwater fishing sites, and bank fishing sites. The dataset is accurate and authoritative as of 11/17/2020. There are 264 public fishing sites in the restricted area. This dataset, shown in Figure 3, was identified as more suitable to the goal of addressing the impact to public health and safety of lifting fishing restrictions.
        - Some of the fishing locations are on the same body of water. For example, some lakes contain more than one pier classified as a public fishing site, and some watercourses contain multiple fishing sites along their length. It was decided that this would not have a negative impact on sampling; value may still be gained from sampling on opposite sides of a large lake, or upstream and downstream locations on a watercourse. Notably, the Mississippi River contains multiple public fishing locations, and passes very throughout the restricted area and close to the event location.
- If restrictions are to be lifted, we assume that none of the sampled lakes can be unacceptable. However, this does NOT make assumptions about false positives within the sampled fish population of a single lake (i.e. individual fish measurements considered to be false positives)—only about the lake result as a whole.
- Assumptions are not made regarding the fishing methods, whether they are performed as in Part 1 or via some other method. It is only assumed that the fishing method produces data of sufficient quality and quantity to fulfill DQO requirements.

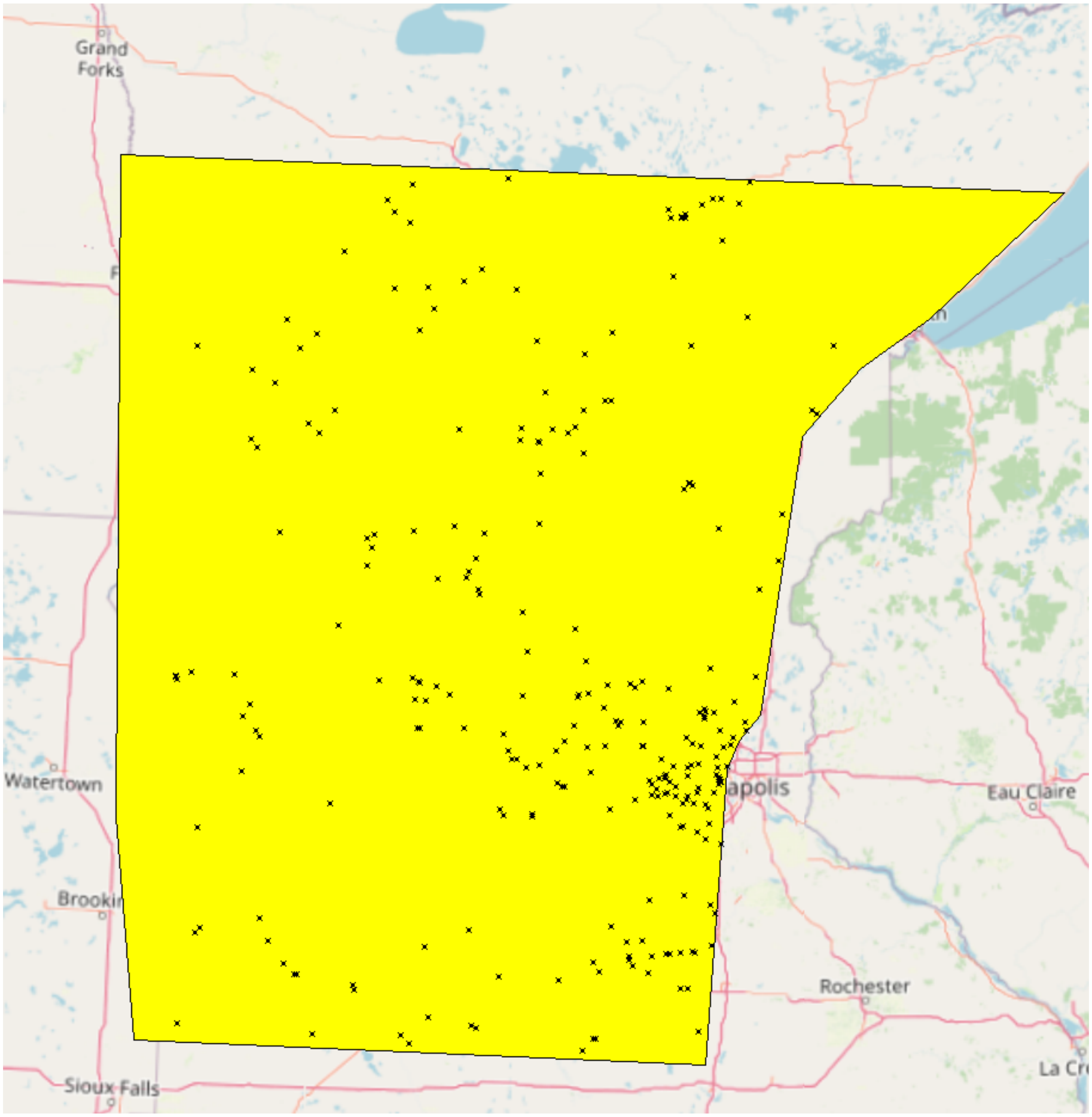


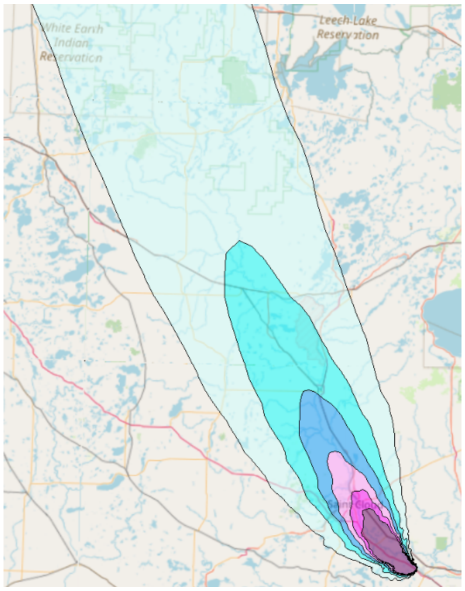
Figure 16: Public Fishing Sites in Restricted Area

b. Stratified Sampling Based On Plume Modeling

For this objective we incorporated the NARAC plume model to develop a stratified sampling approach for prioritizing sampling. The contour boundary of the innermost area (Level001) shown below represents the fish consumption DRL, and areas within that contour are expected to meet or exceed the fish consumption DRL. This would therefore likely require continued restrictions or extensive sampling to clear individual fishing areas or bodies of water, and so the area within this contour was excluded from the sampling calculations.

For the other contour-bounded areas (Level002-Level006), we propose a Stratified Compliance Sampling approach. The objective of this design is to demonstrate with high probability that a high percentage of the population is acceptable, provided that none of the sampled bodies of water are deemed unacceptable. In these areas, modeling indicates that some contamination could be present above the MDA but is not expected to exceed the DRL.

The estimated activity at each of the contour boundaries (Figure 4) can be used to define the relative likelihood of contamination within each area and prioritize the number of fishing sites to sample within each contour.



Contour Name	Contour Activity Level (NARAC Estimated) (uCi/m^2)
Level001	0.12 (Fish consumption DRL)
Level002	0.098
Level003	0.075
Level004	0.053
Level005	0.03
Level006	0.008 (MDA)

Figure 17: NARAC contour areas (left) and estimated activity levels (right)

Based on the contour level, we can define a relative likelihood metric as follows:

$$Relative\ likelihood = \frac{Contour\ Activity\ Level\ (Outer\ Boundary)}{Contour\ Activity\ Level\ (Inner\ Boundary)}$$

For example, for the Level003 stratum, the likelihood of an unacceptable area relative to the Level002 stratum is 0.075/0.098 = 0.765. Calculating the relative likelihood for all strata results in the values shown in the Relative Likelihood column in Table 3.

If the Level001 stratum was to be used for sampling, since it does not contain an inner boundary and is the most likely area to contain contamination, it would be assigned a relative likelihood of 1. Figure 5 shows the selected number of samples distributed throughout the various strata; however, the points in Figure 5 do not represent recommended sampling locations. Sampling locations must be selected by decision makers in consultation with local experts to determine the locations that would best represent fishing locations used by the general public, and would ideally include water basins and watercourses. An example is the Mississippi River, which flows through the entire plume area and immediately adjacent to the release area, and contains many public fishing sites. The dataset used in Part 2a does not fully provide a set of sampling points that satisfies the sampling requirements, as it does not contain points that correspond with every contour.

Additionally, we recommend avoiding sampling south of the plume area where the gradient of the estimated activity is extremely steep (contour-bounded areas are very narrow and close together) as minor errors in plume modeling could result in rejection of the entire contour area because of high readings near the event location. Similarly, clustering sampling sites too close together in a contour should be avoided since this could result in a failure of the sampling to be representative of activity levels across the entire contour area.

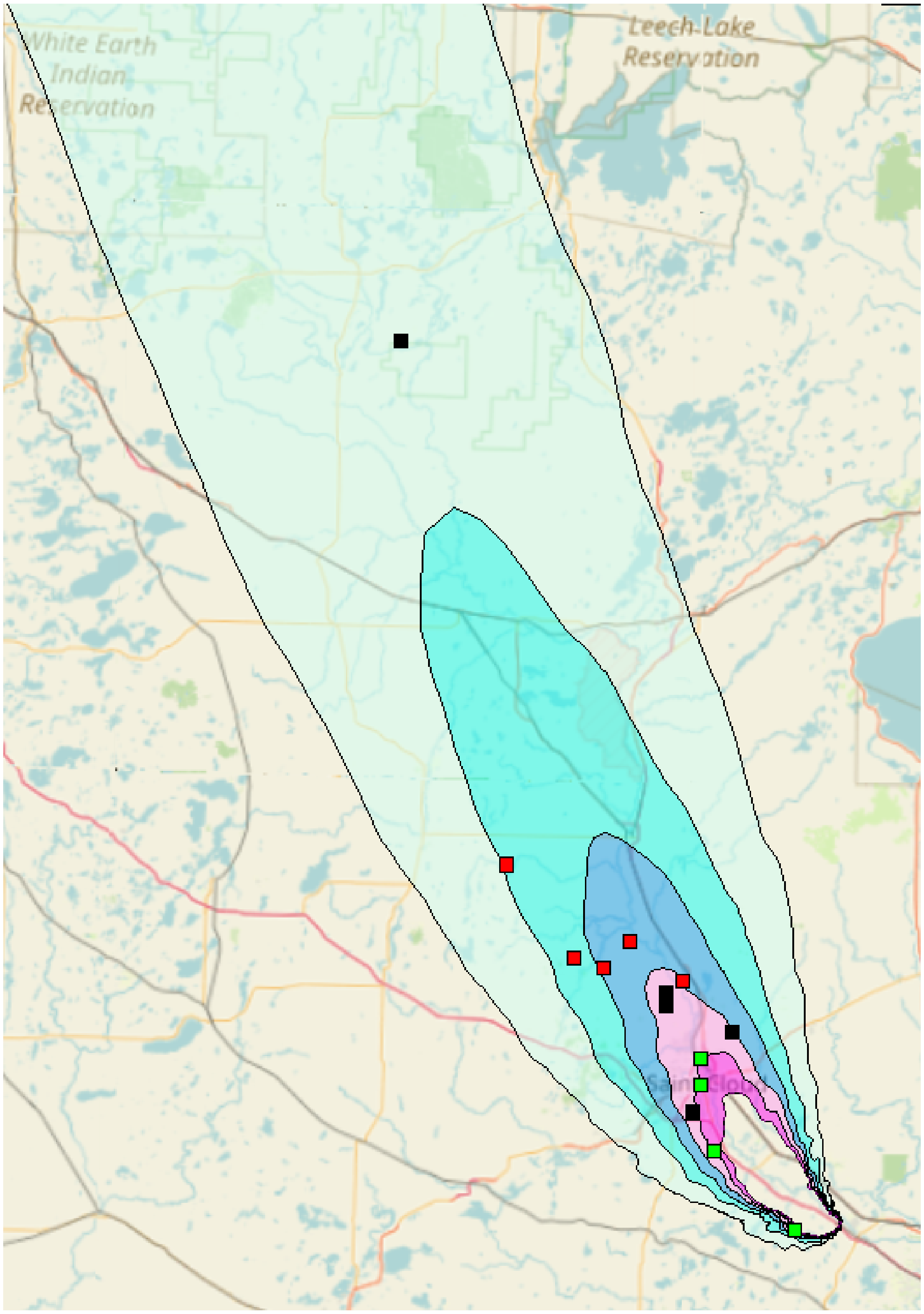


Figure 18: Visual Representation of the Number of Sampling Points in Strata

Recommendations to Expand VSP Capabilities

Instead of importing radiological measurement data and analyzing the effectiveness of the sampling or determining the number of samples needed in a single area, this exercise demonstrated an application of VSP in a way the software is not typically used: designing a sample plan using

NARAC plume maps and local wildlife and geospatial data, in a statistically informed and defensible manner. During this exercise, opportunities for further development of VSP's functionality were identified that would make future similar applications easier and require fewer manual steps and less advanced VSP knowledge from the user.

- Option to automatically assign different colors (and color schemes) for each imported sample area upon import.
    - Example: importing plume maps and choosing a color scheme and transparency layer upon import instead of going into the map and changing the visual characteristics of each plume area to allow for viewing the map below, as well as any other imported map areas in the same location as the plume areas.
- Using different area layers as masks for importing.
    - Example: only importing water basin areas from geospatial datasets that lie within an already-loaded plume area.
- Auto-counting areas within a boundary.
    - Example: counting how many public fishing sites lay within a plume area, rather than zooming in and dragging the map around to count manually.

References

[1] MN Department of Natural Resources. (2009, June 29). *Camp Lake Survey*. https://www.dnr.state.mn.us/lakefind/showreport.html?downum=71012300

[2] Wikipedia contributors. (2021, June 5). *List of lakes of Minnesota*. Wikipedia. https://en.wikipedia.org/wiki/List_of_lakes_of_Minnesota

[3] MN Department of Natural Resources. (2020, November 17). *Public Fishing Sites in Minnesota*. Minnesota Geospatial Commons. https://gisdata.mn.gov/dataset/struc-fishing-sites-in-minnesota

APPENDIX B : PROCESS FOR EVALUATING RESUSPENSION FACTOR