Canadian Nuclear Society
Waste Management, Decommissioning and Environmental Restoration
For Canada's Nuclear Activities: Current Practices and Future Needs
Ottawa, Ontario Canada May 8-11 2005

RADIOLOGICAL SURVEYS OF LANDS AND RIVER SEDIMENTS TO SUPPORT DEFINING THE SCOPE OF THE WHITESHELL LABORATORIES DECOMMISSIONING PROJECT

M. Rhodes
Atomic Energy of Canada Limited
Whiteshell Laboratories, Pinawa, Manitoba, CANADA R0E 1L0
rhodesm@aecl.ca

ABSTRACT

In 1998, Atomic Energy of Canada Limited began planning the closure of the Whiteshell Laboratories in Pinawa, Manitoba. As part of the decommissioning licensing process, an environmental assessment of the decommissioning project was undertaken at the comprehensive level. Two radiological studies were conducted to finalize the scope of the decommissioning project and the environmental assessment. These were a radiological survey of approximately 3000 hectares of AECL property not impacted by nuclear operations and an assessment of the river sediments near the process water outfall.

1. INTRODUCTION

The Whiteshell Laboratories (WL) site was established in the early 1960s by Atomic Energy of Canada Limited (AECL) to carry out research and development activities for higher temperature versions of the CANDU reactor. A range of nuclear facilities were established at WL to support this program including:

- Whiteshell Reactor-1 (WR-1) (operated from 1965 to 1985);
- Building 300 Research Laboratories;
- Shielded Facilities;
- Decontamination Centre;
- Active Liquid Waste Treatment Centre (ALWTC);
- Concrete Canister Storage Facility;
- Waste Management Area (WMA).

Starting in the mid 1990s, AECL began consolidating research and development programs to the Chalk River site and in 1998, AECL received government concurrence to proceed with the planning actions necessary to achieve closure of the WL site. An environmental assessment of the decommissioning project was required pursuant to the *Canadian Environmental Assessment Act* (CEAA). Under the Act, the Canadian Nuclear Safety Commission (CNSC) and the Department of Fisheries and Oceans (DFO) were the Responsible Authorities. The CNSC determined that a comprehensive study[1] was required under the CEAA.

Early in the process, two key radiological studies were conducted to support finalizing the scope of the decommissioning project, and subsequently the environmental assessment. These were a radiological survey of the unaffected lands within the AECL property boundary and an assessment of the river sediments near the process water outfall.

2. UNAFFECTED LANDS

A large percentage of the WL property surrounding the main site was never utilized and was believed to be unaffected by site nuclear operations. After segregating the property into Affected and Unaffected Areas, a radiological survey of the Unaffected Area was performed to demonstrate that this was the case.

The process outlined below was used to remove the unaffected lands from the scope of the WL decommissioning project and environmental assessment.

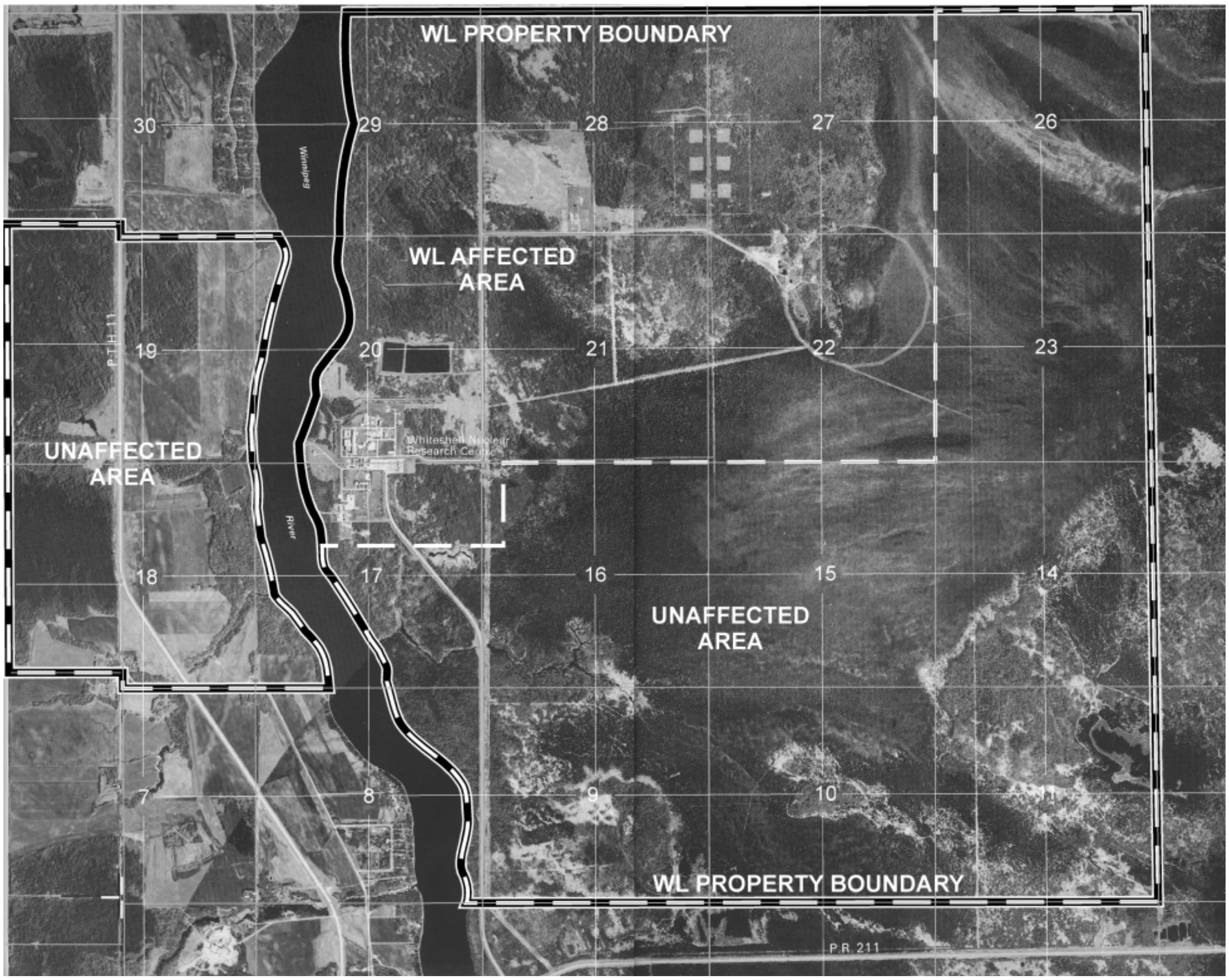
- Segregate the WL site into Affected and Unaffected Areas.
- Prepare a document that justifies the rational for selecting the Affected and Unaffected Area boundaries, and requests the removal of the Unaffected Area from the scope of the environmental assessment, and submit to the CNSC for review and acceptance.
- Prepare a Verification Survey Plan that details the methods that will be used to demonstrate that there has been no impact on the Unaffected Area by WL nuclear operations and submit to the CNSC for review and acceptance.
- Perform the Verification Survey and verify that there has been no impact from WL nuclear operations on the Unaffected Area.
- Prepare a report on the results of the survey and submit to the CNSC as supporting documentation for the request for a licensing amendment to remove the Unaffected Area from the WL site licence.

Land Designation

The total area of land included in the WL site, and under licence to the CNSC, is approximately 4,375 hectares. The land occupied by nuclear facilities and utilized by nuclear operations represents less than 5% (~220 hectares) of the total property. After inclusion of a suitable buffer zone around the utilized lands, AECL designated the balance of the property (~3,000 hectares) as the Unaffected Area. The unaffected lands include about 2,400 hectares on the east side of the Winnipeg River and all AECL property on the west side of the river (~600 hectares). Justification for this classification was based on a review of site records and documents; conversations with experienced AECL staff who have been associated with WL since about the beginning of operations; an evaluation of environmental monitoring data; and an inspection of the proposed Unaffected Area.

Refer to Figure 1 for an aerial photo mosaic of the property and an outline of the property boundary and area classifications.

Figure 1: WL Property Boundary and Area Classification
(1 cm ~ 0.5 km)



The Unaffected Area on the east side of the Winnipeg River consists of swamp, bog and dense forest and is mostly inaccessible. During the operational history of WL, access to these lands has been limited to clearing of right-of-ways for hydro-electric transmission lines, establishment of access trails for environmental monitoring sites, establishment of environmental monitoring sites and some timber cutting operations. In addition, the WL main access road traverses this area. The Unaffected Area on the west side of the river is approximately 45% cultivated/agricultural, 50% dense forest and 5% lightly treed. This area represents about 20% of the total Unaffected Area. Although the land on the west side of the river is AECL property, the cultivated areas have been leased to local farmers during the history of the site.

Verification Survey Methodology

Subsequent to the acceptance of the justification document by the CNSC, AECL prepared a Verification Survey Plan to describe the minimum radiological survey requirements that would be performed to demonstrate that there has been no radiological impact on the Unaffected Area from operations at WL. The survey design was based on recommendations provided in NUREG-1575, Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)[2].

The approach was to evaluate lands both on and off of the WL site for radionuclide content and demonstrate that any radioactive material identified in the Unaffected Area was indistinguishable from levels present in the background reference areas. Soil sampling and *in situ* gamma spectroscopy were selected as the most appropriate techniques for achieving the sensitivities necessary to perform a valid comparison. The following summarizes the methodology proposed in the Verification Survey Plan.

- Define preliminary survey unit boundaries based on terrain type.
- Perform an airborne gamma scan survey of the entire WL site, including background reference areas outside of the property boundary to accomplish the following tasks:

    - map the naturally occurring and man-made gamma emitting radionuclides over the WL site and surrounding area,
    - provide the initial data to evaluate if any deposition exists in the Unaffected Area that could be attributed to WL nuclear operations,
    - finalize the survey unit boundaries, and
    - identify any areas where the soil sampling and gamma measurements should be focused.

- Perform a vehicle and foot based gamma scan survey of the accessible areas along the roads, trails and power line right-of-ways that access the Unaffected Area.
- Based on the airborne survey results, finalize survey unit boundaries and number of background reference areas required.
- Determine the number of samples required and identify sample locations for the survey units and background reference areas.
- Perform *in situ* gamma spectroscopy and soil sampling at the sample locations.
- Obtain duplicate soil samples for Quality Assurance purposes.
- Analyze the soil samples and perform a statistical evaluation of the survey results.

The following conditions were required to be satisfied in order to demonstrate that the Unaffected Area was free from the impact of nuclear operations at the WL site:

a. for radionuclides not present in background - no activity has been identified, and
b. for radionuclides normally occurring in background - it has been demonstrated that their presence is indistinguishable from background.

Once the Verification Survey Plan was accepted by the CNSC, AECL awarded a contract to Sanders Geophysics Ltd. (SGL), teamed with Gamma-Bob Inc., to carry out airborne and ground gamma scan surveys of the Unaffected Area and off-site background reference areas. SGL also was responsible for obtaining soil samples and *in situ* gamma spectroscopy readings at each of the sample locations identified by AECL.

The following provides a brief description of each of the survey components.

Airborne Gamma Scan Survey

The purpose of the airborne gamma scan survey was to identify and map the naturally occurring and man-made gamma emitting radionuclides to assist with identifying any deposition that could be attributed to WL site operations. The results were used to finalize the survey unit boundaries and to assist with determining biased survey locations. The survey was conducted using a twin-engine fixed-wing aircraft flown at a nominal height of 100 metres and a speed of 180 km/hr. The flight lines were spaced 50 metres apart and flown in an east-west direction for a total of 1663 line kilometres. The survey covered the entire WL property as well as off-site background reference areas on each side of the property boundary.

An Exploranium GR 820 spectrometer was used with three NaI(Tl) detector packs. Each detector pack houses four NaI(Tl) detectors for a total detector volume of 50.4 litres. The 256-channel spectrometer was configured with five windows to monitor for naturally occurring radionuclides ^{40}K, ^{232}Th (using the ^{208}Tl peak) and ^{238}U (using the ^{214}Bi peak) and the man-made radionuclides ^{60}Co and ^{137}Cs. The system logged the acquired spectrum and Global Positioning System (GPS) location at 1.0 second intervals and the barometric altimeter, radar altimeter and temperature at 0.25 second intervals. An additional window was configured to monitor cosmic background (3052 keV and above). An additional upward looking detector was available with each detector pack for monitoring cosmic radiation for background subtraction purposes however, since a large lake was nearby, SGL elected to perform background flights over the lake at the beginning and end of each flight session to determine the cosmic ray background contribution.

The GPS data was differentially corrected by post processing with base station GPS data acquired concurrently with the flights. The spectral data was processed using smoothing algorithms and spectral stripping and computer fitting techniques to improve the detection limit and estimate the total air kerma rate at the ground and radionuclide concentrations in the soil. The effective coverage of each 1-second spectrum when flown at an altitude of 100 metres (AGL) and a speed of 50 m/s is an oval 200 metres wide and 250 metres long. Because the flight lines were spaced 50 metres apart, the data from four adjacent spectrums was also used to improve the detection limit. The following maps were prepared by SGL to present the airborne survey results:

- Total Air Kerma Rate
- Potassium-40 Activity
- Equivalent Uranium-238 Activity
- Equivalent Thorium-232 Activity
- Cesium-137 Activity
- Equivalent Unshielded Point Source Activity of Cobalt-60
- Topography
- Boundaries, Sample Locations and Ground Survey Lines Overlays

Refer to Figures 2 & 3 for an example of the maps produced.

Figure 2: Total Air Kerma Rate

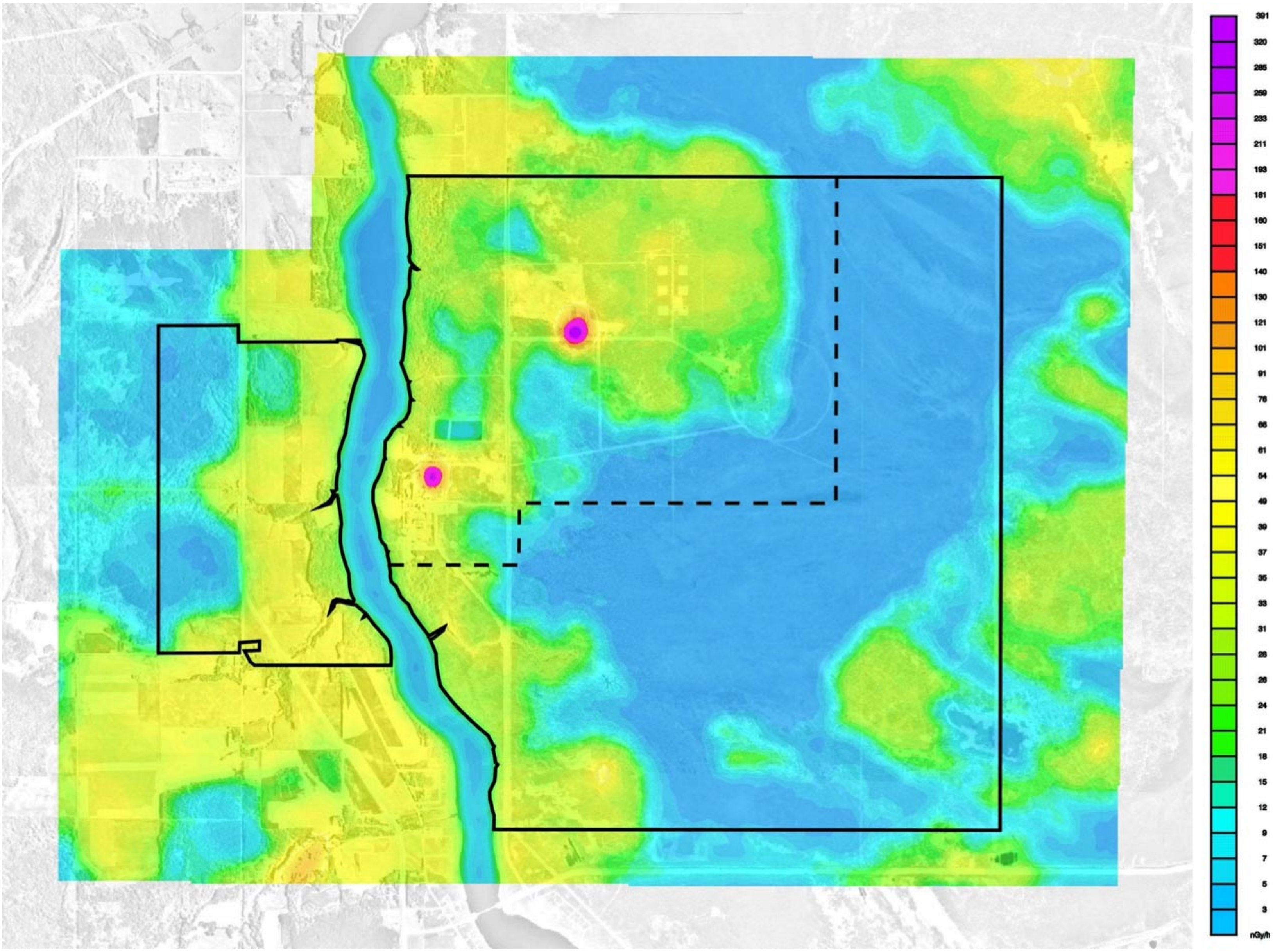
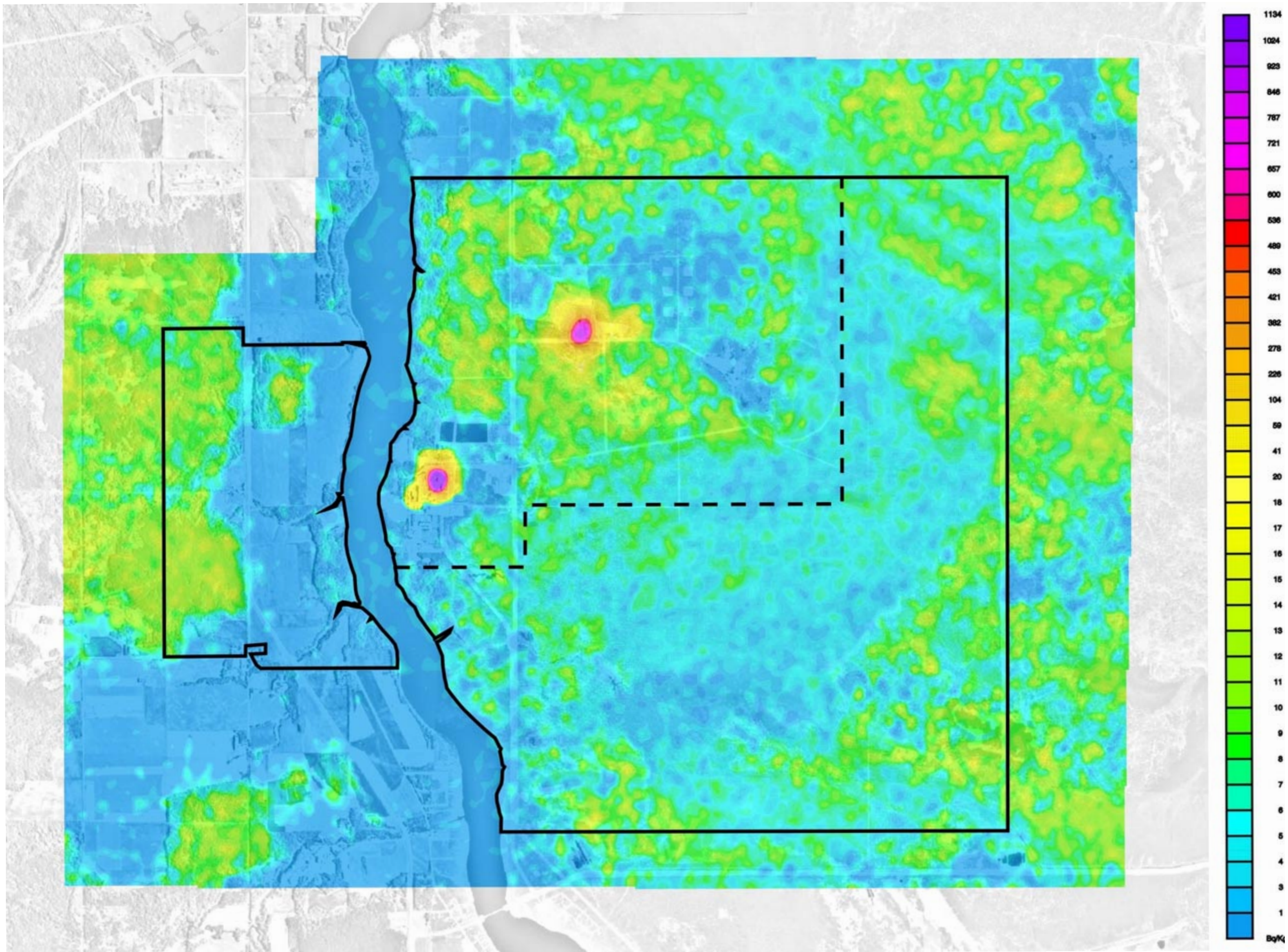


Figure 3: ^{137}Cs Concentration



Ground Gamma Scan Survey

The purpose of the ground gamma scan survey was to identify and graph the naturally occurring and man-made gamma emitting radionuclides along the roads, trails and power line right-of-ways that access the Unaffected Area to assist with identifying any deposition that could be attributed to WL site operations. The ground gamma scan survey requirements were to survey 5% to 10% of the accessible sections of these areas and a total of 12 lines were conducted. The surveys were performed using Exploranium GR320 portable spectrometers with 7.6 cm x 7.6 cm NaI(Tl) detectors and GPS units to log positions.

The lines conducted on the main access road were performed with the spectrometer mounted 50 cm above the ground on a small trailer and towed behind a vehicle traveling at 2 km/hr. One line was conducted along the centre of the road surface and three at 2-metre spacing from each shoulder. A sampling time of 30 seconds was selected as the best compromise between counting statistics and good ground resolution.

The foot-borne scans were carried out in areas where accessibility was difficult. The majority of the property in the unaffected area is very wet and mostly inaccessible. These surveys were conducted with the detector at 50 cm above the ground at a speed of ~2 km/hr. A sampling time of 100 seconds was selected to improve the detection limit in these areas since the potential for localized deposition of radioactive material was considered remote.

The ground gamma scan spectral data was processed in a similar manner to the airborne data.

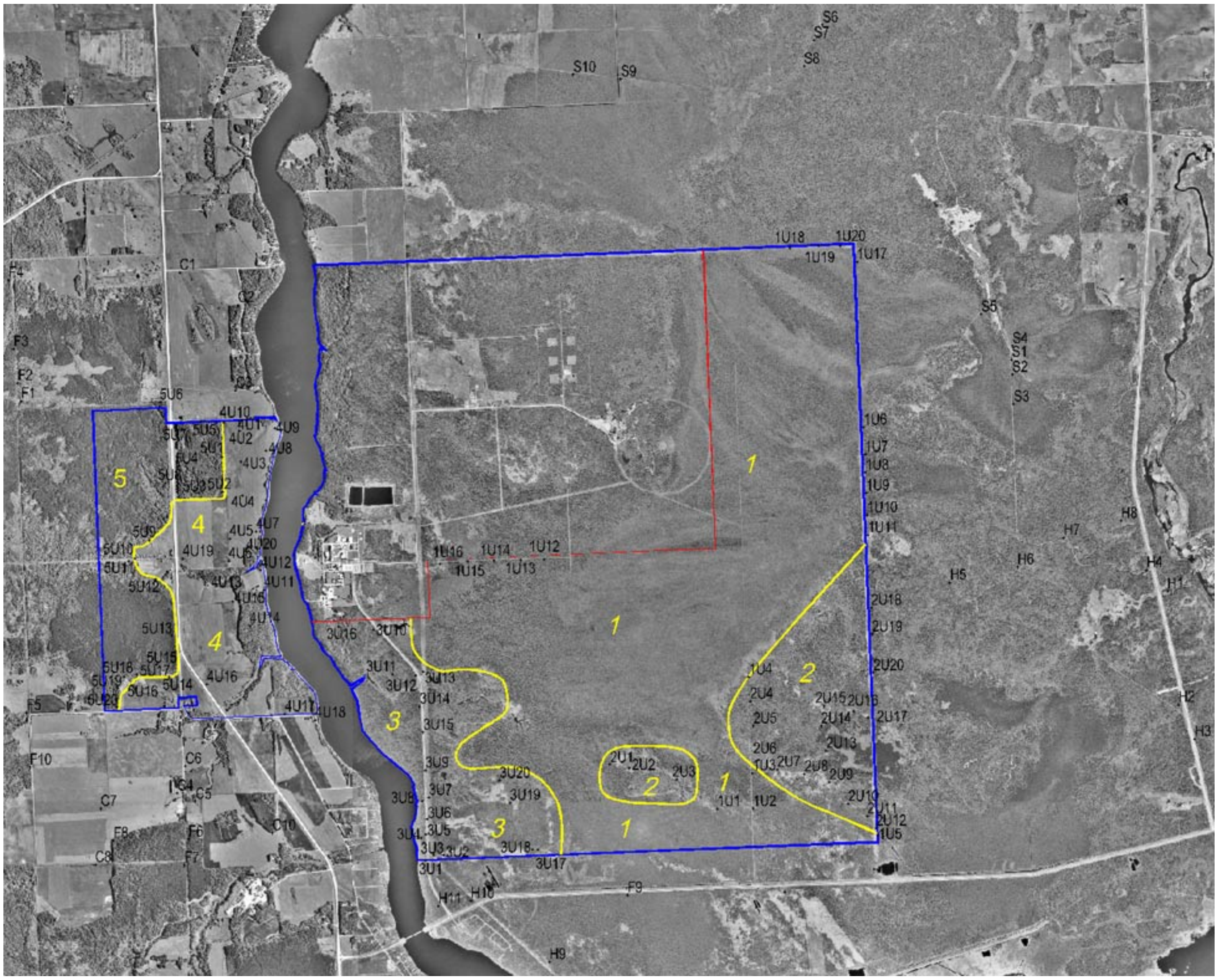
Survey Unit Boundaries

The approximate breakdown of terrain types in the Unaffected Area is as follows.

- Dense forest – 45%
- Swamp – 30%
- Lightly treed – 15%
- Cultivated/agricultural – 10%.

Initially, the unaffected area was divided into six survey units based on an estimate of the terrain type boundaries as identified from the site aerial photo mosaic. After receiving the preliminary results from the airborne survey, the boundaries of these units were adjusted to reflect the variance in total air kerma radiation levels and the number of survey units were reduced to a total of five. Refer to Figure 4 for the boundaries of Survey Units 1 through 5 as implemented in the survey.

Figure 4: Unaffected Land Survey Unit Location



Note: Survey units are in yellow and survey points are black.

Sample Location Determination

The minimum number of samples required for each survey unit is determined by the statistical tests used to evaluate the survey data and the error values that are deemed acceptable. The purpose of the generic statistical tests recommended in MARSSIM is to compare nonparametric survey data, for various scenarios, to a release criterion. The approach adopted for this survey was to demonstrate that any radiological contaminants identified in the soil were indistinguishable from background. A distribution free version of the Wilcoxon Rank Sum (WRS) test was selected as the most appropriate statistical test for evaluating the data sets.

Three reference areas with ten sample locations each were identified in the initial plan for comparison against the survey unit results. It was clear from the preliminary air kerma map that the largest variation of terrain type air kerma rates was in the forested areas. Therefore, an additional forested reference area was added to ensure that sufficient background reference data would be available for all forested area types in the Unaffected Area.

Based on the use of the WRS test, the minimum number of samples required was calculated to be 28.4. The final number of sample locations for the reference area/survey unit pairs was set to 30 for the swamp and cultivated areas, where a reference area was to be compared to a single survey unit, and 40 for the forested areas, where a reference area was to be compared to three survey units. This resulted in a total of 100 survey unit and 40 reference area samples. Refer to Table 1 for a summary of the sampling requirements.

Table 1: Summary of Samples Requirements

Terrain Type	Survey Units	Reference Area	Survey Unit
Swamp	1	10	20
Forested	2, 3 & 5	20	20
Cultivated	4	10	20

Access to the Unaffected Area was very limited because the majority of the area is swamp, bog and very wet forested areas. Accessible areas were limited to those that could be reached on foot or with an all terrain vehicle. As no anomalies were apparent from the airborne and gamma scan surveys, the Unaffected Area sample locations were selected using the following criteria.

- Obtain samples from the roads, trails and power line right-of-ways that access the Unaffected Area.
- Obtain samples from the accessible cut lines that access and border the Unaffected Area.
- Obtain samples from the accessible areas with the most probable deposition from site air effluents given the predominate wind directions for the site.
- Obtain random samples from all accessible areas.

The reference area sample locations were randomly selected from off-site areas with similar terrain to the Unaffected Area lands.

Soil Sampling and In situ Gamma Spectroscopy

The purpose of the soil sampling and in situ gamma spectroscopy readings was to determine if any radionuclides could be identified that could be attributable to WL site operations. A soil sample, 300 second gamma spectrum and GPS location was obtained at each Survey Unit and Reference Area sample location. The GR320 NaI(Tl) detector was mounted on a tripod 1 metre from the ground providing an effective field of view of ~3 m^2. Duplicate soil samples were obtained at each location for QA purposes and each sample was collected within the gamma detector's field of view.

The soil samples were processed and analyzed by gamma spectroscopy by AECL's Environmental Monitoring Group. The results were reported in Bq/kg dry weight. Each *in situ* gamma spectrum was used to calculate air kerma rates and evaluated for ^{40}K, equivalent ^{232}Th, equivalent ^{238}U and man-made radionuclide concentrations in the soil.

Survey Results and Data Evaluation

No man-made radionuclides other than fall-out levels of ^{137}Cs, and only background levels of ^{232}Th and ^{238}U, were identified in the Unaffected Area by the gamma scan surveys. The air kerma rates were typical of those found by the Geological Survey of Canada for similar terrain types in southeastern Manitoba[3].

The following tests were performed on the soil sample and *in situ* gamma spectroscopy results.

- Evaluation for radionuclides not present in background.
- Elevated Measurement Comparison (EMC) Test.
- Wilcoxon Rank Sum (WRS) Test.

No man-made radionuclide other than ^{137}Cs was identified in the soil and *in situ* results. The investigation level for the EMC test was determined by adding 3.09 standard deviations to the arithmetic mean of the corresponding background radionuclide data set. This represents a false positive rate of 0.1% or 1 false alarm per 1000 data points. The EMC test was performed on the soil sample results as well as the radionuclide specific and air kerma rate results from the *in situ* gamma spectroscopy data. Only three ^{137}Cs data points were flagged for all of the soil results and none in the ^{137}Cs *in situ* gamma spectroscopy results. These occurred in Survey Unit 4 which includes all of the cultivated lands on the west side of the Winnipeg River and a small amount of forested areas that exist between the cultivated lands and the river. All three sample locations that exceeded the ^{137}Cs flag were in these forested areas where higher concentrations are expected. The arithmetic mean of all of the Unit 4 ^{137}Cs results was within one standard deviation of the reference area results. All of the ^{137}Cs dry weight soil sample results were within the decay corrected levels from weapons testing identified in an independent survey near the WL site (Zach *et al.*, 1989)[4]. As only fallout levels of ^{137}Cs were identified by both the soil sampling and *in situ* gamma spectroscopy results, analysis of ^{90}Sr was not performed.

A distribution-free version of the Wilcoxon Rank Sum (WRS) Test was used to test if there was a difference between the populations of the survey unit and the background reference area data. This test was performed on all of the ^{137}Cs soil and *in situ* data sets as additional conformation that there has been no impact on the Unaffected Area from WL site operations. The WRS test was performed at a significance level (α) of 0.005 (represents a significance level of 99.5% and a z value of 2.576). The null hypothesis (H_o) was that no difference exists between the reference and sample populations (H_o: $\Delta = 0$). Because the concern was whether the ^{137}Cs survey unit results exceeded those of the reference area, a one-sided version of the test was selected and the alternate hypothesis (H_a) was that the sample population contains higher levels of radioactive material than the reference area population (H_o: $\Delta > 0$).

The critical values for WRS Test [$w(\alpha,m,n)$] are calculated using the following formula:

$$w(\alpha, m, n) = n(n + m + 1)/2 + z\sqrt{nm(n + m + 1)/12}$$

Where: n = number of survey unit samples.
m = number of reference area samples.
z = z statistic for α level of significance to test the null hypothesis.

The null hypothesis is rejected if: $W_s \geq w(\alpha, m, n)$

The null hypothesis is accepted if: $W_s < w(\alpha, m, n)$

The critical level for 30 sample reference area/survey area data sets is 369. The critical level for 40 sample reference area/survey area data sets is 505. The critical level was not exceeded in any of the tests therefore, the null hypotheses that no difference exists between the reference and sample populations is accepted. Refer to Table 2 for a summary of the EMC Test results and Table 3 for a summary of the WRS Test results for the cultivated lands on the west side of the river (Survey Unit 4).

Table 2: EMC Test Results for Survey Unit 4

Sample ID	Soil Dry Weight		Soil Wet Weight		*In situ* Gamma Spectroscopy			
	Cs-137 (Bq/kg)	2s Error (Bq/kg)	Cs-137 (Bq/kg)	2s Error (Bq/kg)	K-40 (Bq/kg)	U-238 (Bq/kg)	Th-232 (Bq/kg)	Cs-137 (Bq/kg)
4U1	13	2.5	11.2	2.2	394	32.7	25	5.5
4U2	11.4	2.7	9.6	2.2	383.1	25.9	22.3	6.3
4U3	8.6	2.1	7.3	1.8	382.4	28.2	22.4	4
4U4	6.3	1.6	5.4	1.4	420.3	26.1	23.3	4.4
4U5	10	3.1	8.2	2.5	449.2	31.3	28.6	8.6
4U6	12.1	3.1	9.4	2.4	485.7	29.7	28.4	5.5
4U7	10.6	2.7	9.4	2.4	431.3	19.6	18.1	0.9
4U8	9.3	3.2	8.4	2.8	440.7	29.4	22.6	3.4
4U9	7	2.5	6.2	2.2	469.5	27.8	31	5.3
4U10	4.5	2.1	3.7	1.7	388.5	21.8	24.8	6.3
4U11	12.7	3	10.4	2.4	421.1	33.1	32	12.2
4U12	12.4	3.4	10	2.7	438.8	31.8	25.5	7
4U13	**19.3**	2.5	14.8	1.9	346	23.7	23.4	9.7
4U14	**19.6**	3.1	14.1	2.2	384.2	24.9	22.3	7.4
4U15	9	3	7.7	2.5	447.8	27.9	32.1	6.2
4U16	12.7	2	10.2	1.6	463.7	25.9	28.8	6.7
4U17	10.6	1.8	8.5	1.4	455.6	29.9	31.4	7.6
4U18	5.8	3.1	4.5	2.4	364	28	24.3	9.1
4U19	11.8	2	10	1.7	488.3	22.2	27.4	1.9
4U20	**20.9**	3.2	17	2.6	391.3	17.3	22.7	9
Mean	11.4	2.7	9.3	2.2	422.3	26.9	25.8	6.4
Stdev	4.4		3.3		41.2	4.3	3.9	2.7
Min	4.5	1.6	3.7	1.4	345.98	17.35	18.1	0.95
Max	20.9	3.4	17	2.8	488.31	33.1	32.09	12.19
Bkg Mean	9.3				393.09	24.13	25.68	5.76
Bkg Stdev	2.2				84.5	4.95	4.38	2.63
3.09*s* Bkg	6.9				261.11	15.29	13.54	8.14
Flag	16.2				654.2	39.42	39.22	13.9

Table 3: WRS Test Results for Survey Unit 4

	Soil Sample Results					*In situ* Gamma Spectroscopy									
Sample ID	Cs-137 (Bq/kg)	Sample Type	Overall Rank	Sample Rank	Reference Rank	Cs-137 (Bq/kg)	Sample Type	Overall Rank	Sample Rank	Reference Rank	Air Kerma (nGy/h)	Sample Type	Overall Rank	Sample Rank	Reference Rank
C1	10.2	R	15		15	9.3	R	28		28	40.7	R	11		11
C2	8.6	R	8		8	7.1	R	19		19	33.9	R	2		2
C3	5.5	R	2		2	4.4	R	8		8	43.8	R	17		17
C4	8.9	R	11		11	5.3	R	11		11	41.9	R	14		14
C5	12.5	R	23		23	7.9	R	23		23	45.4	R	20		20
C6	8.6	R	9		9	2.5	R	4		4	46.7	R	23		23
C7	10.4	R	16		16	4.4	R	7		7	39.4	R	5		5
C8	7.7	R	7		7	8.3	R	24		24	47.2	R	26		26
C9	7.5	R	6		6	1.2	R	2		2	45.8	R	21		21
C10	12.8	R	26		26	7.2	R	20		20	30.6	R	1		1
4U1	13	S	27	27		5.5	S	12	12		43	S	16	16	
4U2	11.4	S	19	19		6.3	S	15	15		39.8	S	7	7	
4U3	8.6	S	10	10		4	S	6	6		40.1	S	9	9	
4U4	6.3	S	4	4		4.4	S	9	9		41.4	S	13	13	
4U5	10	S	14	14		8.6	S	25	25		47	S	24	24	
4U6	12.1	S	21	21		5.5	S	13	13		48.1	S	30	30	
4U7	10.6	S	17.5	17.5		0.9	S	1	1		37.4	S	3	3	
4U8	9.3	S	13	13		3.4	S	5	5		42.7	S	15	15	
4U9	7	S	5	5		5.3	S	10	10		47.1	S	25	25	
4U10	4.5	S	1	1		6.3	S	16	16		39.6	S	6	6	
4U11	12.7	S	24.5	24.5		12.2	S	30	30		47.8	S	28	28	
4U12	12.4	S	22	22		7	S	18	18		44.9	S	18	18	
4U13	19.3	S	28	28		9.7	S	29	29		40	S	8	8	
4U14	19.6	S	29	29		7.4	S	21	21		41	S	12	12	
4U15	9	S	12	12		6.2	S	14	14		47.5	S	27	27	
4U16	12.7	S	24.5	24.5		6.7	S	17	17		46.2	S	22	22	
4U17	10.6	S	17.5	17.5		7.6	S	22	22		48	S	29	29	
4U18	5.8	S	3	3		9.1	S	27	27		40.5	S	10	10	
4U19	11.8	S	20	20		1.9	S	3	3		45.1	S	19	19	
4U20	20.9	S	30	30		9	S	26	26		38.8	S	4	4	
		Total	465	342	123		Total	465	319	146		Total	465	325	140

Summary

An airborne gamma scan survey was performed of the WL site that included an ~ 2.5 km wide section of off-site background reference areas. Ground gamma scan surveys were performed along the roads, trails and power line right-of-ways that access the Unaffected Area. Soil samples and *in situ* gamma spectroscopy readings were obtained at 100 sample locations within the Unaffected Area and 40 locations in off-site background reference areas. The following summarizes the results.

- No man-made radionuclides other than fall-out levels of ^{137}Cs were identified.
- Only background levels of ^{232}Th and ^{238}U were identified.
- The data evaluation indicates that the samples from the Unaffected Area are indistinguishable from the samples in the Reference Area.
- The air kerma rates in the Unaffected Area are typical of those found by the Geological Survey of Canada for similar terrain types in southeastern Manitoba[3].
- The dry weight soil concentrations of ^{137}Cs are typical of those found by an independent survey near the WL site (Zach *et al*., 1989)[4].
- The survey results demonstrate that there has been no impact on the Unaffected Area from WL site operations.

Upon review of the survey report, the CNSC concurred with the conclusions that there has been no impact from WL nuclear operations on the Unaffected Area.

3. RIVER SEDIMENTS

The process water outfall from WL releases radioactive and other contaminants to the Winnipeg River in accordance with federal and provincial requirements. The contaminants are continuously monitored and, with few exceptions, the releases were always below the relevant standards. A radiological survey was conducted of the river sediments to obtain sufficient data for a preliminary estimate of the inventory to support an assessment of the impact of contaminated sediments on biota in the river and on humans. This assessment was performed to verify that the operation of WL within it's regulated release permits had led to no significant impact in the river sediments and that no decommissioning activities associated with the sediments was required.

The survey was limited to two areas with known radiological deposition at levels with the potential to exceed 10 times the background activity levels as identified by AECL environmental monitoring data and historical river assessment documents. The Outfall Study Area is located near the WL process water outfall pipe and the Downstream Study Area is centred in a bay 500 metres downstream of the outfall pipe. The survey was conducted using divers equipped with two gamma detectors, configured for underwater use, and a global positioning system (GPS), to log data collection locations. It was conducted over a period of 6 days and included an upstream background reference area for comparison to the two study areas.

Survey Details

There were six main objectives of the survey:

- determine if the radionuclide distribution was relatively constant throughout the study areas,
- determine a gross count rate to dose rate conversion factor at the surface of the sediment (referenced to air kerma rate),
- map the extent of the radiological contaminants in the study areas,
- obtain river surface sediment samples of background and the highest activity areas to evaluate the types of contaminant present,
- obtain river sediment core samples of background and the highest activity areas to evaluate the types of contaminant present and the contaminant depth profile, and
- obtain clam samples of background and the highest activity areas to evaluate the potential impact on aquatic biota.

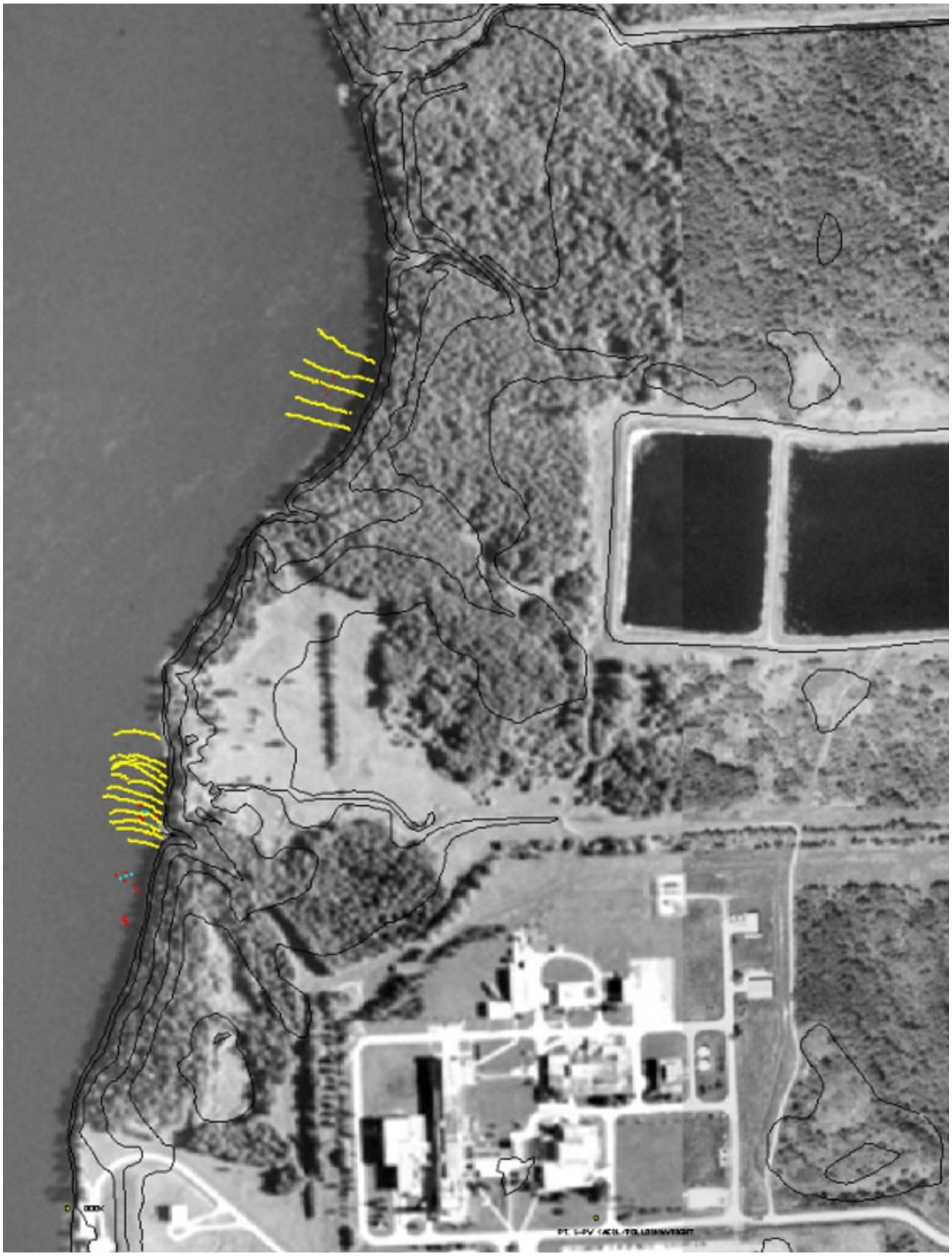
The survey and diving operations were staged from a small barge. Transect sample locations were identified by placing a weighted line marked in 2-metre increments along the river bottom. The line was anchored to the shore and stretched out slightly upriver of a line perpendicular to the shoreline using a boat. The end of the line was marked with a buoy and weighted with an anchor to ensure a rapid decent. The intent was to obtain a line perpendicular to the shoreline once the line had settled to the bottom. Due to the strong river current in the Outfall Study Area, the resulting transect lines in this area were not straight and bowed downriver in the middle section of each transect. Once a transect was marked, the barge was positioned along the transect by anchoring to both the shore and out in the river with long ropes. This allowed the barge to be moved, as required, to follow the divers' progress. The following data and samples were collected:

- gross gamma count rate at 2-metre increments along each transect line from the shore until the activity level was ≤ 5 times background for 5 consecutive sample points,
- *in-situ* gamma spectroscopy readings in areas of elevated activity,
- composite sediment samples,
- core sediment samples, and
- clam samples.

The *in-situ* gamma spectroscopy data was obtained to identify the gamma emitters and cross-calibrate the gross count rate data for the inventory estimates. The survey also included obtaining video footage of the outfall pipe and river bottom.

Refer to Figure 5 for the location of the study areas.

Figure 5: Location of Outfall and Downstream Study Areas



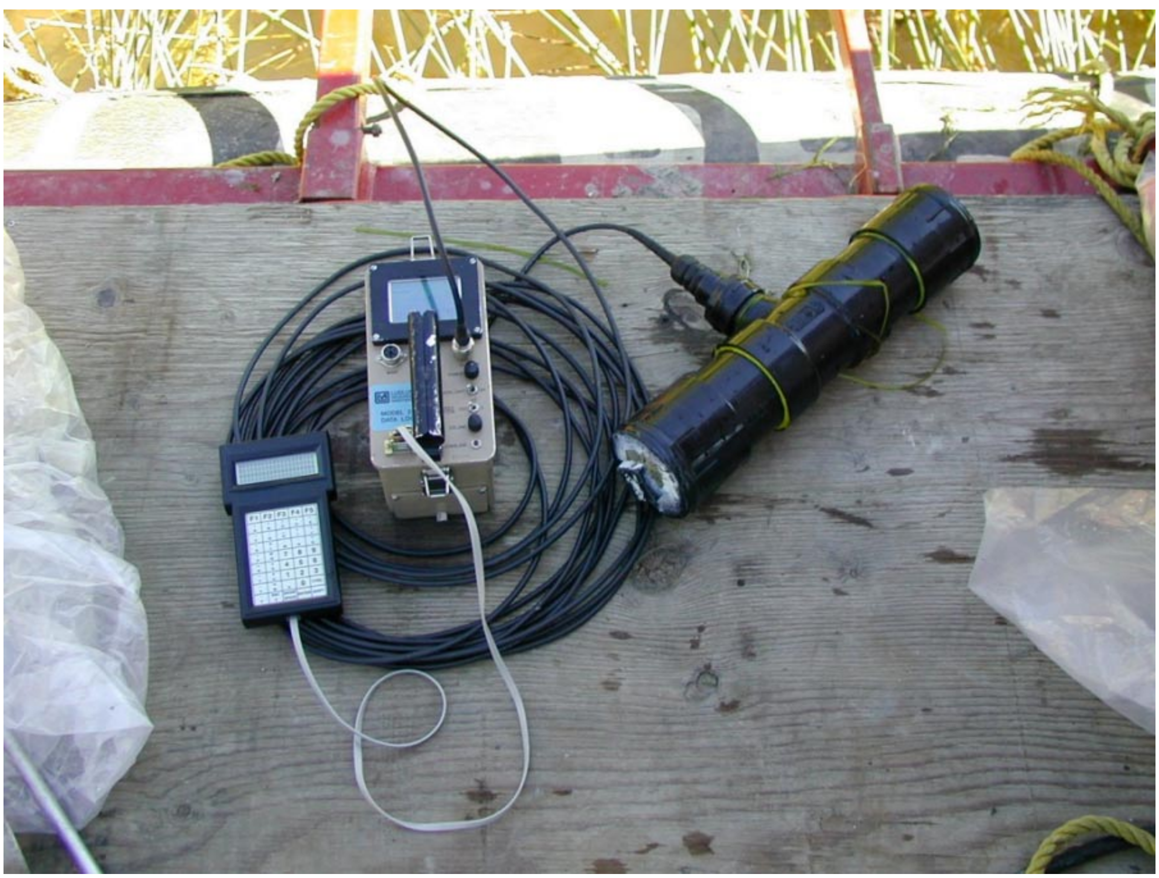
Instrumentation

The following instrumentation was used to perform the survey:

- Ludlum Model 2350 Data Logger with Model 44-10 NaI(Tl) Detector (Thallium activated Sodium Iodide Detector)
- Exploranium GR-320 Portable Gamma Spectroscopy System with a 3 inch x 3 inch NaI(Tl) Detector
- Trimble GPS System

The 2350 Data Logger and NaI(Tl) detector system was used to record gross gamma count data at 2-meter increments along each transect line. The detector was mounted in a waterproof housing and a 100-metre cable was connected to minimize the repositioning requirements of the barge. All background gamma readings were obtained with 60-second counts and all transect gamma readings were taken with 30-second counts. Refer to Figure 6 for a picture of the system.

Figure 6: Ludlum Model 2350 with Underwater Detector



The GR-320 was used to obtain spectral data from several locations in the background and study areas. The detector was mounted in a waterproof housing and a 60-metre cable was connected. This data was used to cross-calibrate the gross gamma count rate readings to equivalent air kerma rates. The spectral data was also used to identify any gamma emitting contaminants that were encountered. Once the survey was completed, the GR-320 system was sent to Gamma-Bob, Inc. to process the spectral information and calibrate the system, as used, to air kerma rate. All *in situ* gamma spectra were acquired with 300-second counts. Refer to Figure 7 for a picture of the system.

Figure 7: Exploranium GR-320 with Underwater Detector

The GPS antenna was mounted on a small floatation device and connected by a rope to the diver. Whenever survey data was obtained, the rope was pulled taut and the GPS location logged. A few of the data points were not logged close to shore where tree interference prevented adequate reception from the GPS satellites.

Background Reference Areas

Two background areas were evaluated centred ~ 50 and 100 metres upstream of outfall pipe. Both rocky and silty bottomed areas were included to account for the different conditions encountered during the survey. The following data was collected from this area:

- 9 *in situ* gamma spectroscopy readings,
- 3 core samples (~30 cm deep),
- 1 large area surface sediment composite sample, and
- 6 clams.

Outfall Study Area

The Outfall Study Area extends from approximately 10 metres above the outfall pipe to 100 metres downstream of the pipe and includes an area of approximately 6300 m^2. The following data was collected from this area:

- 310 gamma readings from 12 transects that ranged from 34 metres to 64 metres long,
- 6 *in situ* gamma spectroscopy readings,
- 3 core samples (~30 cm deep),
- 1 large area surface sediment composite sample, and
- 11 clams.

Refer to Figure 8 for the location of the Background Area and Outfall Study Area core, *in situ* gamma spectroscopy and transect sample locations.

Downstream Study Area

The Downstream Study Area is centred 500 metres downstream from the outfall pipe. The following data was collected from this area:

- 184 gamma readings from 5 transects that ranged from 66 metres to 86 metres long,
- 4 *in situ* gamma spectroscopy readings,
- 1 large area surface sediment composite sample, and
- only 1 clam as they were mostly absent from the area.

Survey Results

The river bottom varies from fine silt near the shore to very rocky in the area downstream of the outfall pipe. The average background count rate in the rocky area is estimated to be ~ 100 cps.

- Maximum reading ~ 54 times background, average ~ 4 times background.
- Area representing 10 times background (Evaluation Area) is limited to the area from the outfall pipe end, out 20 metres and downstream ~ 80 metres (1600 m^2).
- The average reading in the Evaluation Area is ~ 7 times background.

Refer to Figure 9 for a map of the Outfall Study Area results and Figure 10 for a map of the Evaluation Area results.

Figure 8: Background Area and Outfall Study Area Sample Locations

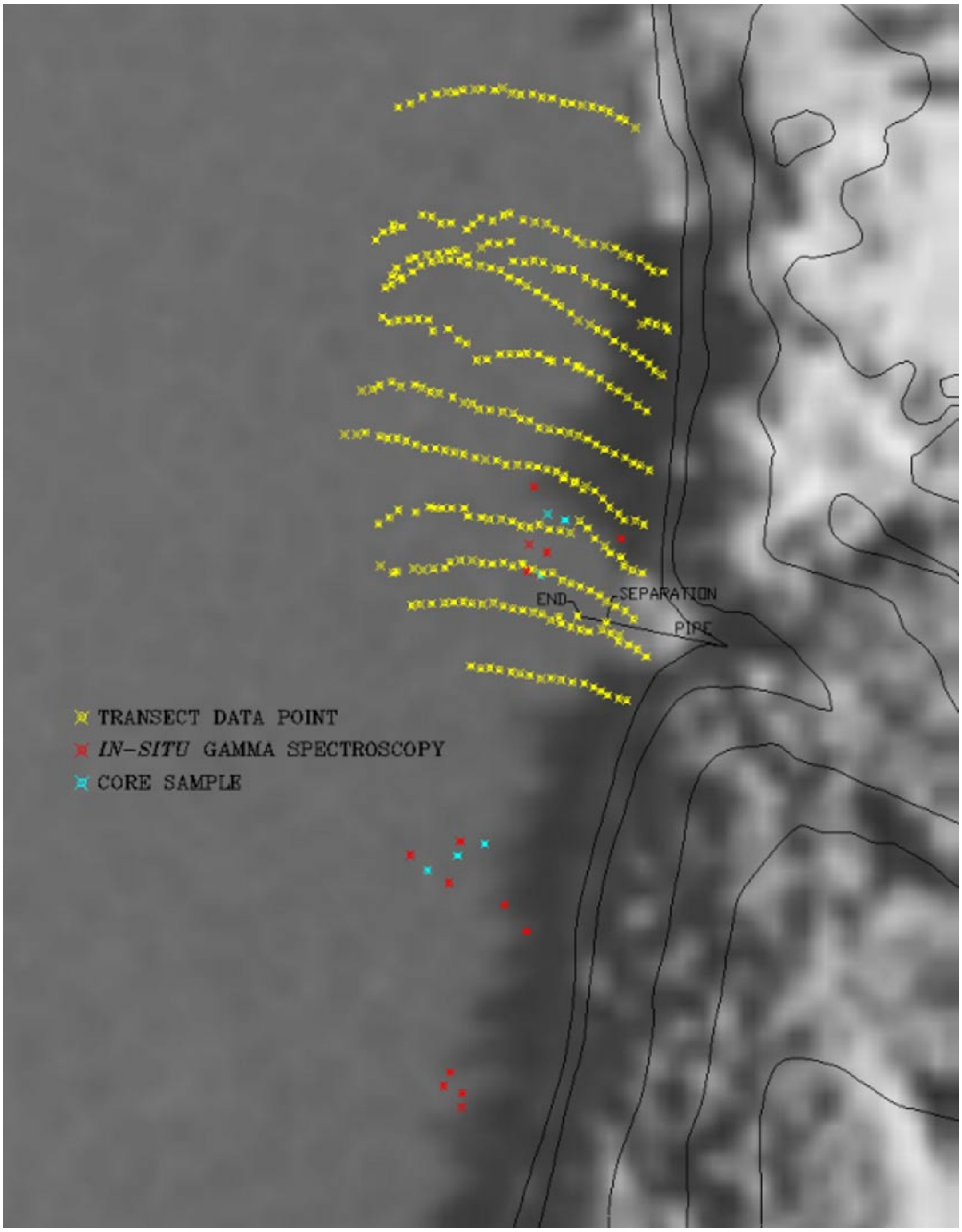
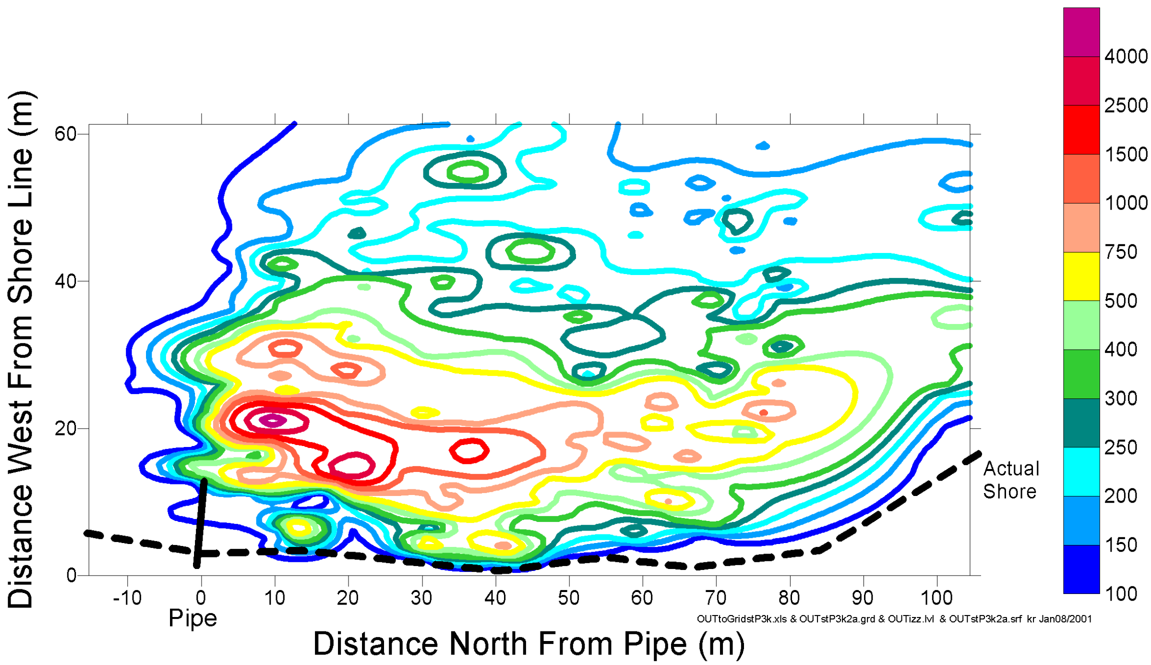
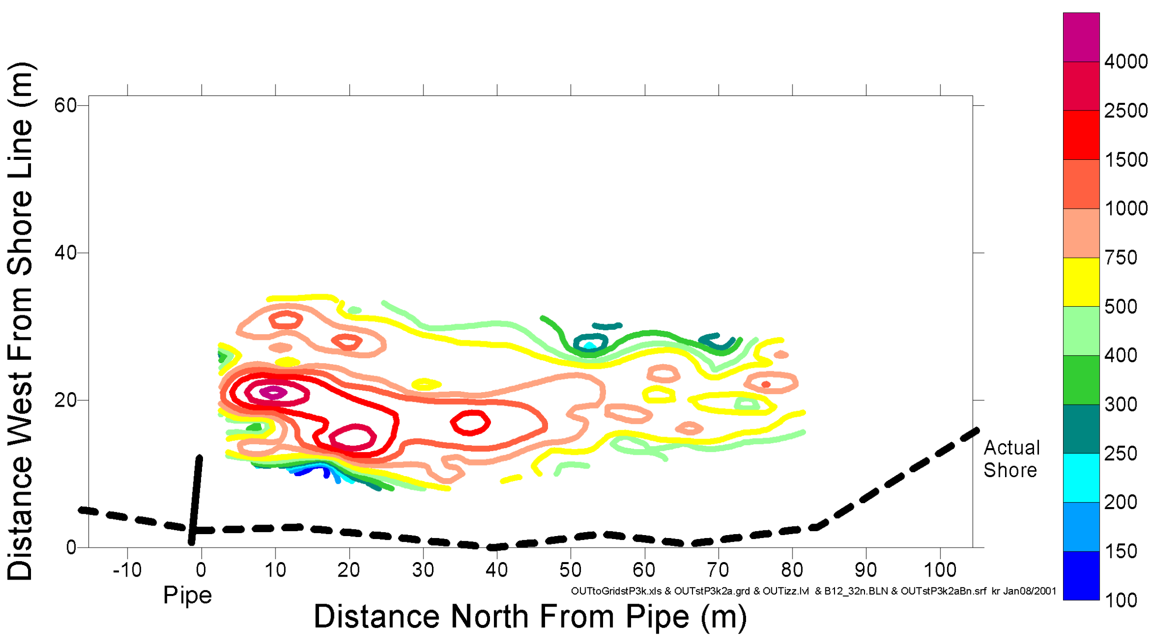


Figure 9: Map of Outfall Study Area Transect Results



COUNT RATE FROM OUTFALL STUDY AREA

Figure 10: Evaluation Area Map



COUNT RATE FROM OUTFALL STUDY AREA

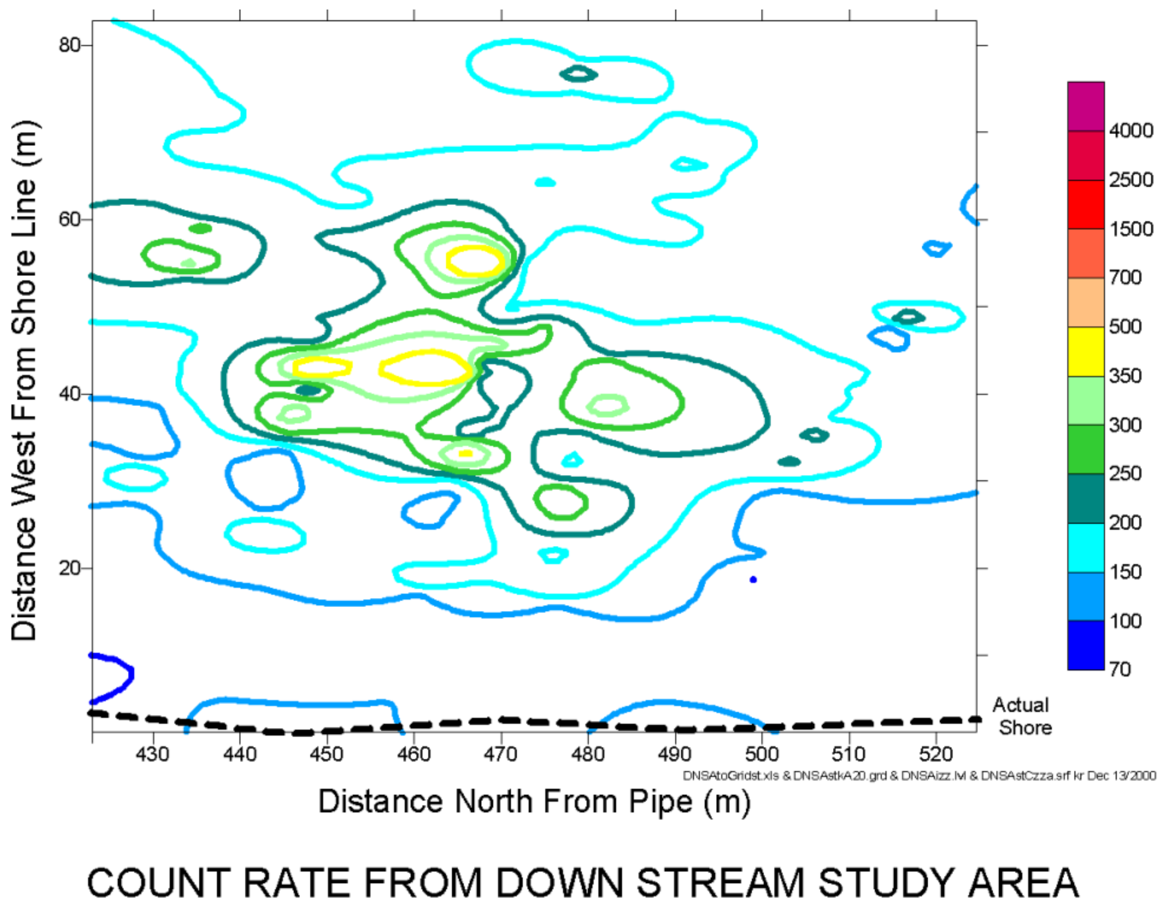
Downstream Study Area

The Downstream Study Area is a large bay with a slight upriver (back eddy) flow. The bottom consists mostly of fine silt with very few rocks present indicating a depositional zone. The average background count rate in this area is estimated to be ~ 70 cps.

- No area > 10 times background identified.
- Maximum reading ~ 6.5 times background, average ~ 2 times background.

Refer to Figure 11 for a map of the results.

Figure 11: Map of Downstream Study Area Transect Results



In Situ Gamma Spectroscopy Results

Refer to Table 4 for a summary of the *in situ* gamma spectroscopy results for the background reference and study areas.

Table 4: *In situ* Gamma Spectroscopy Results

Outfall Study Area*			Rocky Upstream Area		
Air Kerma (nGy/h)	Count Rate (cps)	Conv. Factor (cps/nGy/h)	Air Kerma (nGy/h)	Count Rate (cps)	Conv. Factor (cps/nGy/h)
659.9	2210.3	3.35	67.4	143.3	2.13
2897.2	7926.3	2.74	56.2	125.1	2.23
607.3	1842.2	3.03	43.4	95.1	2.19
886.1	3098.0	3.50	44.2	93.1	2.11
336.1	1263.2	3.76			
Average		**3.3**	**52.8**	**114.2**	**2.2**
Stdev		0.4	11.4	24.3	0.1
Min		2.7	43.4	93.1	2.1
Max		3.8	67.4	143.3	2.2

Downstream Study Area*			Silty Upstream Area		
Air Kerma (nGy/h)	Count Rate (cps)	Conv. Factor (cps/nGy/h)	Air Kerma (nGy/h)	Count Rate (cps)	Conv. Factor (cps/nGy/h)
188.3	495.4	2.63	39.6	90.2	2.28
74.5	218.8	2.94	32.1	72.8	2.27
150.4	443.9	2.95	36.2	76.5	2.11
89.8	259.3	2.89	37.4	80.3	2.15
			31.7	69.8	2.20
			44.2	93.1	2.11
Average		**2.9**	**36.9**	**80.5**	**2.2**
Stdev		0.1	4.7	9.4	0.1
Min		2.6	31.7	69.8	2.1
Max		3.0	44.2	93.1	2.3

* Only ^{137}Cs and ^{40}K were identified by *in-situ* gamma spectroscopy.

Conclusion

The resulting inventory estimates were used to assess the potential effects on humans and non-human biota in the river. It was determined that, even with extremely conservative dose estimation methods, the doses would be below accepted guidelines. Therefore, it was confirmed the operation of the Whiteshell Laboratories had led to no significant impact in the river sediments and remediation of the sediments was not required as part of the WL decommissioning project. The CNSC and DFO agreed with this conclusion.

4. REFERENCES

[1] "Whiteshell Laboratories Decommissioning Project Comprehensive Study Report," 2001 November.

[2] NUREG-1575 "Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)," US Nuclear Regulatory Commission, December 1997.

[3] GSC, "Airborne Geophysical Survey of Southeast Manitoba 1995," Hetu, R.J. and Holman, P.B., Geological Survey of Canada Open File 2725, 14pp.

[4] Zach, R., J.L. Hawkins and K.R. Mayoh, "Transfer of fallout cesium-137 and natural potassium-40 in a boreal environment," Journal of Environmental Radioactivity 10, 19-45, 1989.