Innovative Data Management System in Support of Remedial Actions for Legacy Radioactive Contamination - 17280

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ABSTRACT

The Port Hope Area Initiative (PHAI) is a project mandated and funded by the Government of Canada to remove contamination from properties with legacy low-level radioactive waste (LLRW) contamination arising from a crown-owned radium and, later, uranium refinery in the Town of Port Hope, Ontario. From 1976 to 1981, a community clean-up project was undertaken, with the specific purpose to decrease the level of historic LLRW contamination within Port Hope. Since then, residual LLRW has been managed by the Low Level Radioactive Waste Management Office (LLRWMO) (and its predecessors). The PHAI and the Port Hope Project (PHP) were initiated in 2001 with a formal agreement between affected municipalities and the federal government to develop a safe, long-term management solution for the historic LLRW remaining within Port Hope.

An important activity of the PHP is the survey of about 4,800 “small scale sites” (SSS) throughout the community to confirm the presence or absence of LLRW. This involves surveys of properties based on the measurement of exterior gamma, contaminated objects and surfaces, soil concentrations and indoor radon and classification to Port Hope project specific criteria. A very large amount of information is involved in the project including; scheduling individual field visits to the properties, capture of field data and comments, laboratory sample tracking, QA/QC, report generation and internal and client project reporting at regular schedules. Field data collection of exterior gamma radiation surveys includes direct (real time) and interactive loading of data into the Information Management (IM) system to support initial QA/QC and reporting back to the field on radiation levels. Screening soil measurements including X-ray fluorescence (XRF) and gamma radiation are collected from all 20 cm increments in each borehole in addition to down-hole gamma radiation measurements and logging of soil characteristics which are used in documentation and interpretation of the property condition.

The IM system outlined in this paper was developed to respond to the requirements for radiological surveys in Port Hope. The IM system continues to evolve as a part of continuing review and improvement. The IM system incorporates Web-enabled field tools and cloud hosted data and applications, provides increased field efficiency, timeliness in reporting, real time QA/QC analysis, and consistency in tracking project advances and changes made to the data for decision-making and reporting on an ongoing basis. Examples of specific applications are provided.

INTRODUCTION AND BACKGROUND

The IM system outlined in this paper was developed to respond to the requirements for radiological surveys in Port Hope Ontario. The initial IM specifications were developed through a consultative process involving radiation specialists, geographical information systems (GIS) technician, data management experts, IM specialists, and project managers to meet the client's project requirements. The IM system continues to evolve as a part of continuing review and improvement from lessons learned. The IM system incorporates Web-enabled field tools and cloud hosted data and applications, provides increased field efficiency, timeliness in reporting, real time QA/QC analysis, and consistency in tracking project advances and changes made to the data for decision-making and reporting on an ongoing basis.

Source of Contamination

Historic low-level radioactive contamination is present in Port Hope due to the processing of high-grade uranium ores from the Port Radium mine in the Northwest Territories at an existing industrial site adjacent to the harbour in Port Hope Ontario. The reason for this was that it was more economic to process the high-grade (pitchblende) ore in Port Hope than at the Port Radium mine site. During the early years of refinery operations, the Port Radium ores were processed for the recovery of radium. By 1942, Eldorado had become a federal crown corporation and the refinery was focussed on uranium refining although radium refining continued to 1954. Port Radium ores continued to be processed at the refinery until 1966 after which, only uranium concentrate from uranium mines has been processed at the refinery.

The pitchblende ores from Port Radium ores not only contained uranium and its radioactive decay products, notably Ra-226, but also, significant amounts of other minerals containing various elements among them, arsenic, cobalt, copper and nickel which ended up in elevated concentrations in wastes from the refining and processing operations at the refinery.

Early waste management practices were not effective in limiting the spread of the radiological and non-radiological contaminants to the surrounding environment. Various waste materials were also used as construction materials in homes and buildings and as a source of fill material for construction and landscaping throughout the community. This practice was stopped when it was realized that it contributed to the spread of contamination within the community.

From 1948 to 1955, Eldorado managed wastes at the Welcome Waste Management Facility (WMF) in the Township of Hope. In 1955, the Welcome WMF closed and a new facility, the Port Granby WMF, opened near Port Granby in the Township of Clarington.

Approach to Management of Wastes

From 1976 to 1981, a community clean-up project was undertaken under the auspices of a Federal Provincial Task Force on Radioactivity (FPTFR), with the specific purpose of decreasing the level of historic LLRW contamination within the Municipality of Port Hope. Since 1982, the residual LLRW has been managed by the LLRWMO which has conducted individual characterization programs, directed remediation and implemented a pre-construction survey program for new properties being developed or modifications to currently developed properties.

The PHAI and the PHP were initiated in 2001 with a formal agreement between affected municipalities and the federal government to develop a safe, long-term management solution for the historic LLRW remaining within the Municipality of Port Hope. Since its formation, the Port Hope Area Initiative Management Office (PHAI MO) has directed the planning, design and approvals process (Phase 1) for the PHP in preparation for its implementation (Phase 2). Phase 2 of the PHP was approved by the Canadian Nuclear Safety Commission (CNSC) on November 15, 2012, thus authorizing Atomic Energy of Canada (AECL), now Canadian Nuclear Limited (CNL) to move forward with construction of the long-term waste management facility, integration of waste from the existing Welcome WMF and clean-up and remediation of the historic waste within Port Hope. [For further information on the Port Hope Project see http://www.phai.ca/en/home/port-hope-project/default.aspx]

An early activity of Phase 2 of the PHP is the radiological survey of approximately 4,800 small-scale sites throughout the community to confirm the presence or absence of LLRW. The identification and remediation of the LLRW soil materials is made complex by its seemingly random distribution throughout the community, and even on an individual property. Further complications are that contaminated soils generally occur in isolated patches typically affecting 10-20% of a property.

The radiological survey process required the PHAI to conduct a number of preparatory steps prior to the actual property surveys. These included the development of clean-up criteria, the collection of available data for each property, preparation of Historical File Reviews (HFR's) for each property, obtaining permission from property owners to access their property and a staging plan which led to the development of five radiological survey campaigns.

PHAI Cleanup Criteria for Contaminants of Potential Concern (COPCs) in soil have been developed through a co-operative effort involving the PHAI, scientific specialists, federal and provincial government agencies, peer reviewers, the municipalities and members of the public. Principles to guide the clean-up process were built on the statement in the Legal Agreement that:

"Canada shall clean up properties contaminated with historic low-level radioactive waste so that all such properties will be able to be used for all current and foreseeable unrestricted uses."

The intent of the radiological testing (surveys) is to determine which properties have historic low-level radioactive waste and will require remediation. About 90 per cent of properties are not expected to require any cleanup. These property owners will receive a Compliance Letter confirming that the property meets PHAI Clean-up Criteria. For properties requiring remediation, the survey will permit the PHAI to plan the work on a neighbourhood-by-neighbourhood basis. Once a property has been cleaned up, the owner will receive a Compliance Letter.

Port Hope Area Initiative Clean-up Criteria

As studies of contamination progressed, it became apparent that there was a specific chemical signature for the soils contaminated with historic LLRW. This work led to the development of the concept of COPCs specific to Port Hope. Not surprisingly, the historic wastes and associated contaminated soils typically contain a number of contaminants resulting from the past processing of radium and uranium with the most common ones being uranium, arsenic, Th-230 and Ra-226. Moreover, it has been determined that while gamma radiation is an excellent indicator of contamination, removal of soil to the point where the gamma radiation readings are acceptable may not ensure that all of the legacy contaminants have been sufficiently remediated as a consequence of different mobilization rates of the contaminants. Therefore, soil sampling and analysis has become a part of the remediation and verification protocol for the PHAI project.

The current investigation by the PHAI uses different and generally more restrictive clean-up criteria, based on concentrations of COPCs than did the FTPTR, which now results in the identification of historic LLRW soils which did not exceed previous clean-up criteria in both the remediated soils at that time and in properties previously not considered contaminated during the initial program. [1]

Clean-up criteria (CC) developed for the project included soil concentrations for four signature COPCs, namely Ra-226, Th-230, uranium and arsenic. The levels of these COPCs varies depending on the source material, the chemical process and the end product. For example, the waste products from radium refinery from ore will be different than the wastes from processing for uranium from yellowcake. Exceedance of the PHAI CC by any of the four is considered to be indicative of LLRW contamination. Given the presence of non-refinery processes, arsenic is only considered an indicator if background levels by any of uranium, Ra-226 or Th-230 are exceeded. The background levels and the PHAI CCs are included in Table I for varying property uses and for the long-term storage areas. For residentially zoned areas, the Ra-226 PHAI CC is the total of the background plus an incremental concentration estimated to correspond to an incremental (above background) annual dose of 0.3 milli-sievert (mSv). The uranium PHAI CC (23 µg/g) and arsenic PHAI CCs (18 µg/g) were based on chemical toxicity. There were 17 other COPCs that may be present in LLRW due to their presence in the Port Radium ore. These need to be addressed during the remediation plans developed based on the signature COPCs.

A trigger level for indoor radon (Rn-222) exceeding 200 Bq/m^3 was used to determine investigation of above background concentrations of Ra-226 in soils in the perimeter of the buildings. This level of indoor radon is consistent with the Canadian (Health Canada) NORM Guidelines [2]. PHAI CC [1] were provided for the radiological conditions of objects and surfaces: these included gamma radiation exposure rate at distance of 50 cm (80 µR/h), total surface activity averaged over 100 cm^2 (1 Bq/cm^2), removable alpha activity averaged over 300 cm^2 (0.04 Bq/cm^2) and removable beta/gamma averaged over 300 cm^2 (0.40 Bq/cm^2). Separate notification of CNL was required where the measured levels may require immediate consideration.

TABLE I. Clean-up Criteria for the Signature Parameters [3]

Contaminant of Potential Concern	Units	Ontario Background	Port Hope Sites Total Criteria Residential / Parkland / Institutional	Port Hope Sites Total Criteria Industrial / Commercial / Community	Port Hope Sites Total Criteria LTWMFs and Highland Drive Landfill
Uranium (U)	µg/g	2.5	23	33	76
Arsenic (As)	µg/g	18	18	18	40
Ra-226	Bq/g	0.05	0.29	0.97	0.97
Th-230	Bq/g	0.05	1.16	4.67	4.67

THE SURVEY PROCESS

Planning

The PHAI has divided each campaign into priority groups with the schedule concentrating on properties where indoor radon concentration exceed the trigger level or that were located surrounding the large scale properties that require remediation. The drivers for priority grouping from the client were to reduce health risks and to plan efficient area-wide remediation programs.

Information provided by CNL included GIS files showing information including the parcel (i.e. property) boundaries, priority grouping and addresses; historical studies on the property; and, contact information for property owners along with the owners concerns which effect the actual surveys.

The HFRs have been prepared by PHAI for each property to include information on previous investigations and remediation conducted, structures on the sites, correspondence with property owners, etc. Some properties do not have historic files; however, a HFR template was still completed for each property, inputting any information that was available but relying mostly on the geographical location of the site relative to known or likely areas of contamination. Based on the HFR, the properties were given a preliminary classification with respect to potential for LLRW contamination using a decision matrix. Classifications range from Type A to E, with Type A sites indicating no expectation of exceedance of the clean-up criteria, up to Type E sites which indicate the probability of requiring unique remediation. The contractor for the survey was required to consider the HFR in developing a final site survey plan that was in agreement with PHAI in the event additional boreholes or recommendations for more intensive surveys of the property were recommended after review of the HFR data. On a per-property basis, the locations of the boreholes from the preliminary site survey plan may be adjusted based on the exterior gamma radiation survey maps and overall borehole coverage. The need for additional boreholes on a subject property may also be influenced by the results of exterior gamma radiation testing on an adjacent property, and require additional coordination and planning with land owners and drilling teams.

Scheduling

Property owners or residents needed to be scheduled in a manner acceptable to the property owners and recognizing the available survey resource, equipment and, for exterior gamma radiation surveys, the depth of snow on the property which limits the appropriateness of the survey. Documentation of communication is very important since miscommunication can result in adverse public opinion and reduce the efficiency of the field crew. There are multiple visits to each property, beyond those previously conducted by other investigations, ranging from exterior gamma radiation surveys to utility locate visits and soil drilling.

Property Survey Measurements

The survey measurements for each property includes results from the following data collection components to drive the identification of properties with historic LLRW:

- **Interior radon measurements**: Radon testing precedes all other survey components, as it is a long duration test that informs the borehole program whether investigation of soils under or around structures are required. Radon testing is completed using alpha track monitors placed in the basement or the lowest level of a building for a period of six months to span a heating and a cooling season.
- **Exterior gamma radiation surveys:** Gamma radiation measurements are undertaken on a grid pattern and are completed prior to soil sampling, as it informs on borehole locations for the final work plan. Sites are typically assessed using a 1 m x 1 m grid with properties greater than 5,000 m^2 measured with a 1 m x 3 m grid. Measurements are taken at a height of 0.15 m for 1 m x 1 m grids and both 0.15 and 1.0 m heights for properties with the 1 m x 3 m grid requirement. The horizontal positions of the gamma radiation survey measurement points are determined using Global Positioning System (GPS) technology with real-time positional correction.
- **Locates:** Field locates are required prior to the drilling of the planned borehole locations. A combination of information from the HFR, the proposed borehole locations from the client, the exterior gamma radiation levels collected during the campaign and supplemental information such as available infrastructure and field comments on vegetative cover and steepness of slopes was used to develop the planned locations. The process for planned borehole locations are described later in this paper.

- **Soil sampling and analysis**: Boreholes are drilled on properties per the final work plan. Boreholes are advanced to a minimum depth of 1.2 m, with at least 0.5 m into native soil and are sampled continuously with radiological controls based on field measurements. Soil cores are sent to the field laboratory for portioning into 0.20 m increments. Down-hole gamma radiation logging in the field, along with the XRF soil analysis of each increment and lithology investigations at the field office are used to select the soil samples for external laboratory analysis.
- **Interior gamma radiation surveys**: Buildings are surveyed for interior gamma radiation and this includes a visual inspection for the presence of contaminated artefacts, tools and building materials. The interior survey for specified properties includes a scan of floors, walls and ceilings and a gridded scalar survey of interior rooms. The requirement for gamma radiation scans and the density of the measured gamma radiation values are based on the preliminary classification of the property.
- **Objects and surface contamination:** During the interior gamma radiation surveys, contaminated surfaces are identified based on gamma radiation scan indications and visual appearance. The identified points are measured with static measurements of gamma radiation exposure and alpha/beta contamination measurements at the location with the maximum evidence of contamination. The measurements are recorded and descriptions and photographs are collected for these locations. Swipe samples are collected for locations based on the combination of likely causes and the total surface activity. Depending on the initial classification (e.g. age and proximal to the refinery), at least one swipe will be conducted on a property on type C, D and E properties.
- **Properties that fail PHAI CC** with respect to indoor radon trigger levels or exterior soil impacts where the PHAI CC are exceeded have exterior delineation plans developed that describe additional boreholes and sample analysis to define the spatial and vertical extent of contaminated soil requiring removals. This information collected from additional surveys at the property are used to develop a remediation action plan which recommends the removal of soil. A similar process is conducted for properties with interior contamination of surfaces and the presence of contaminated objects.

Reporting

Property characterization reports are required for all properties that include all site-specific survey data and assessments, and indicate the final property classification. Through programmatic data analysis, each property is evaluated on whether it meets the PHAI CC and does not require further actions, or requires a delineation plan. Table II shows a table automatically created and formatted by the IM system showing measured soil concentrations and assessment against PHAI CC with the purpose of the borehole and locations. The property requires some remediation since the PHAI CC is exceeded in a borehole as well as the Ra-226 concentration exceeding background in perimeter holes of a building with indoor radon concentrations exceeding 200 Bq/m^3. A compliance letter is recommended for properties not requiring further work.

Table II. Example of Automated Soil Concentration Table

			As (µg/g)	U (µg/g)	Ra-226 (Bq/g)	Th-230 (Bq/g)
PHAI CC			**18**	**23**	**0.29**	**1.16**
PHAI Background			**18**	**2.5**	**0.05**	**0.05**
Borehole ID	**Depth (m)**	**LLRW (Y/N)**				
Characterization General						
xxxx-BH2	2.20-2.40	N	1.5	1.0	< 0.050	< 0.40
xxxx-BH4	0.20-0.40	Y	**189**	**19.1**	**1.03**	**1.00**
xxxx-BH4	3.00-3.20	N	1.3	0.39	< 0.050	< 0.40
xxxx-BH5	0.00-0.20	N	9.8	1.0	< 0.050	< 0.40
Characterization Perimeter						
xxxx-BH1	0.60-0.80	N	16	2.1	0.050	< 0.40
xxxx-BH3	0.60-0.80	N	6.6	1.2	0.050	< 0.40
xxxx-BH3	2.60-2.80	N	3.2	0.72	< 0.050	< 0.40
xxxx-BH6	1.00-1.20	A	**30**	0.86	< 0.050	0.03
xxxx-BH6	3.00-3.20	N	4.4	0.74	< 0.050	< 0.40
xxxx-BH7	1.40-1.60	N	4.2	0.47	< 0.050	< 0.40
xxxx-BH8	0.20-0.40	N	9.2	0.88	**0.060**	< 0.40
xxxx-BH9	0.80-1.00	N	7.0	0.56	< 0.050	< 0.40
xxxx-BH9	2.00-2.20	N	2.8	0.66	< 0.050	< 0.40
xxxx-BH10	0.00-0.20	N	3.9	0.95	**0.060**	< 0.40
xxxx-BH10	0.80-1.00	N	6.0	0.96	**0.210**	< 0.40

Properties requiring further work to reduce the levels will have two reports. The first report is a Remedial Action Plan (RAP) for the property as required: a web-based application (described later) supports the creation of areas and depths requiring excavation that is shown both visually and in tables using the single common data source. This report incorporates the results of neighbouring properties to address the presence of contamination crossing property boundaries. The second report is the property characterization report which combines the results from the initial characterization and the delineation data with a summary of the RAP. Table III shows an example of summary findings for a property where remediation is required for radon gas and exterior soil impacts but no work required for interior contamination or objects contamination. This property will be reassessed following the remediation. For properties that fail, owners will get a notification letter and phone call.

Table III. Example of Property Findings Table

	Initial Site Classification	C2 Activity (Y/N/NA)	Final Site Classification	Delineation Undertaken (Y/N)	Verification Completed (Y/N)	Remediation Required (Y/N)
Interior Radon Gas	Type A	Y	Type D-F	Y	N	Y
Interior Impacts	Type A	Y	Type A-F	N	Y	N
Contaminated Objects	NA	Y	Type A-F	N	Y	N
Exterior Soil Impacts	Type A	Y	Type C-F	Y	N	Y

Compliance Letter	A compliance letter is not recommended

After completion of remediation, the PHAI provides the property owner with the compliance letter indicating that the property meets the PHAI CC.

INFORMATION MANAGEMENT

The IM system used on this project was initially configured for the Campaign 2 SSS program of 800 properties, and was the system described at the International Radiation Protection Association (IRPA) 2015 conference and published (Radiation Protection and Dosimetry(RPD) 2016). Subsequently, Arcadis was selected to conduct the Campaign 3 survey of 1,250 properties and the Campaign 4 survey of interior radon concentrations. The IM system has evolved to meet the new requirements, in addition to enhancements to improve the process, and from lessons learned during the Campaign 2 survey. New additions to the IM for the current program include the scheduling and tracking of locates for borehole drilling and the support of the collection, management, and reporting of indoor radon concentrations.

The IM system was developed by information management staff from a U.S. division specializing in the information management, mobile data collection and GIS in collaboration with the Canadian division leading and conducting the overall project. There are many approaches to handling information as well as off the shelf customized software applications, and the primary driving force to the system design and integration was based off clear and collaborative definition or requirements for the project, including technology, user interaction, and delivery. Large volumes of information need to be managed for all aspects of the program ranging from incorporating client-provided information, scheduling of multiple survey visits to properties, collection of field data, data management, data analysis and report creation. This section contains an overview of the project needs, the software tools, and discussion of specific functional examples of the IM system.

A specific goal for Campaign 3 is to have completed report sections for survey activities within a month and a half of completion of the specific field activities. For example, an exterior gamma radiation section that included presentation of tables, figures and accompany text would be complete within a month and a half of the survey activities. In effect, the exterior gamma radiation survey could be completed before interior or sub-surface investigations were conducted. These sections completed prior to the other types of survey can be useful to support specific interests by the client or current activities being conducted on the site such as the construction monitoring program (CMP) conducted by a federal department to address works such as additions or new construction occurring in the town.

IM System Goals and Conceptual Design

An effective and efficient means to collect, manage, and analyze the large volumes of data reported for the campaigns is critical to the overall program success, as well as accessibility to the information by the team to make decisions and perform data review.

Two principles of the IM system are to 1) maintain data in a single location to ensure data integrity, accessibility, and QA tracking, and 2) capture the data electronically once and use it for multiple purposes. With the many data streams for each survey and the reporting requirements for the individual properties, the success in meeting the goals of the system and project execution was dependent in part on the electronic collection of data and accessibility for analysis and decision-making. Through this, the teams recorded the multiple surveys and observations, which increased data availability and data quality by reducing transcription errors, supported documentation and analysis, and fed into reporting and significantly reduced the amount of manual tracking and touch points of the data. Electronic data capture also allowed for additional schedule planning and optimization with field staff completing multiple activities in an overall shorter amount of time. Reproducibility of tables and figures used in reports was key as well as providing the client with data collected during the program so it could be integrated with other campaigns or for additional uses.

There are many ways to manage data for this type of project, and the critical element is to define a workflow including the data streams, tasks, and results from beginning to end for a property and the project, as well as the timing and responsibility for each task. The IM system becomes the backbone of the process and enables the completion of the activities. The system leverages industry leading technology integrating Microsoft cloud and server based products, integrated with relational and spatial database using ESRI applications. Arcadis is a global business partner with both ESRI and Microsoft and apply standard and custom applications using these software products for many large-scale programs.

The IM system used in this project focuses on centralizing and standardizing information in a secure and integrated database management platform using a Microsoft Office 365 (O365) SharePoint site for the focal point and central portal of access. Figure 1 provides a conceptual illustration of a proven approach for data and workflow use for integrating property survey activities into the database. The decisions driven by the IM system and the resulting data is maintained in the IM system, in addition to reporting on these values. The figure illustrates the logical progressions through each of the survey tasks from the landowner communication and scheduling of the property for a particular survey program, to the decisions that arise following collection of the data including the need for delineation plans and RAPs.

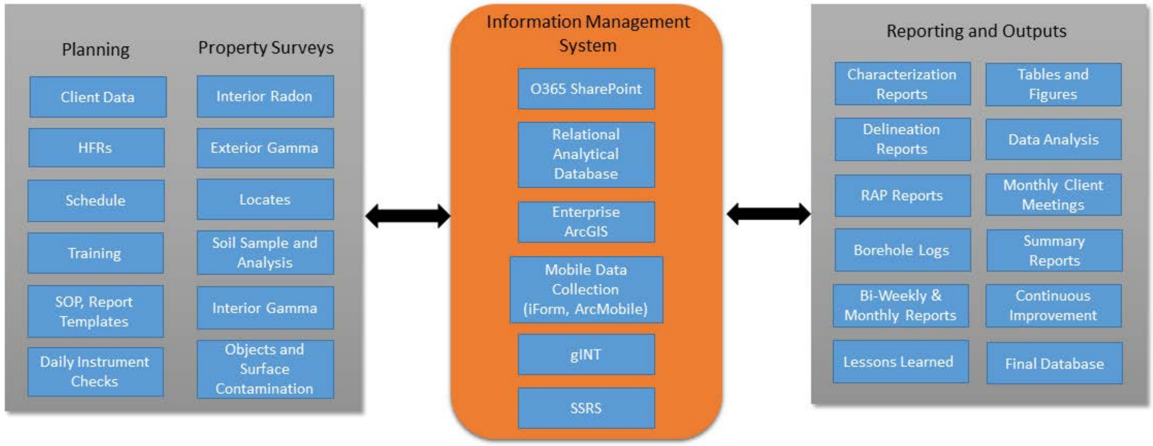

Fig. 1. Conceptual Illustration of Information Management System Related to Project Workflow.

The approach provides a fast and high level of access to the technical team throughout all stages of the project. This approach also reduces the overall cost and time to compile existing data, collect new data, organize information, and prepare project deliverables both in tabular and map formats. Leveraging the IM System benefits the overall progress and outcome by providing the project teams with critical information. Using these tools, Arcadis has improved upon the Campaign 1 approach in Campaign 2 by creating high quality and traceable data flow for PHAI MO through information management, electronic data tracking, and automation of report tasks. Above all else, this approach drives accuracy by reducing the number of "touches" on any given dataset and as a result increases efficiency and confidence in the quality of the data being reported. Additional summary descriptions of the IM components are provided below.

The client provided a large amount of data including HFRs with supplemental information, property master list with contact information, previous survey measurements, and GIS layers including property fabric, proposed borehole locations, previous study information, current infrastructure, and other previously known contamination areas in the town such as road allowances and major waste sites. Arcadis integrated this into a relational database with the individual site identification being the primary identifier for the related data. An enterprise geodatabase and data model was established utilizing ESRI ArcSDE. This also included the previous indoor radon results for the properties along with the historic borehole locations and measurement results.

Project Logistics and Property Activity Scheduling

Once the master property list and HFR information have been uploaded and verified, working through the complex logistics and coordinating the day-to-day scheduling requirements can leverage the custom scheduling tool developed within O365 SharePoint. This application facilitates and documents landowner interactions, survey timing, duration of activities, as well as field crew scheduling and location optimization to help adapt and complete the work with changing weather conditions, equipment needs, and landowner access.

Mobile Data Collection

Field data is collected to the extent possible using mobile devices that facilitated direct electronic capture of information. The systems are menu-driven for the specific applications and sync and store data in electronic format which makes field observations more accessible than written field notes, and removes transcription errors present when field notes are manually transcribed to electronic format. The data is synced with the IM database to ensure functions such as tracking of activities, allowing decision makers immediate access to the information and to allow for real-time review, and multiple uses of the data in various prescribed reports and analysis. An audit trail is built into the process to document data integrity. The two major mobile platforms are:

- **iFORM:** Data collection applications are configured for the tasks and provided to the field teams through use of cellular telephones. The software is programmable to capture field observations, calculations, measurements, and photos, and has been used for real-time collection of interior and contamination radiological surveys, daily equipment checks, borehole drilling and sample collection. These are formulated with pick lists for consistent spelling, increased data quality, reduction of entry time, and ease of use, and include technician names, equipment used, and arrival and departure times. The data is collected along with field comments including the nature of elevated readings and photographs as necessary.
- **ArcGIS:** ArcMobile is used for the data collection, management, and processing for the exterior gamma radiation measurements. Exterior gamma radiation levels are collected using radiation detectors paired with GPS data loggers (i.e. Trimble GeoXH and Geo7) complete with a customized ESRI ArcMobile application. We teamed with a sub-contractor to develop a system of field collection using Trimble GPS and ESRI software in conjunction with custom server-level scripts to process the data. Trimble Positions software was used to ensure high precision GPS coordinates and ArcMobile software was programmed to support numerous field activities and data checks. Base mapping of the property fabric, outlines of buildings and a grid to ensure coverage are included. Both walking surveys and static points with gamma radiation levels and GPS locations are collected. Alarms were established to trigger at user-specified levels that require further field documentation. Obstructed areas where gamma radiation levels could not be collected are electronically mapped in the field along with comments and photographs as needed. The data is uploaded by a syncing method and added to the server level where GIS processing occurs. Additional presentation and visualization of the exterior gamma data that is also integrated with the other data streams were provided through web-based GIS applications allowing for greater access to the information to make decisions supporting the project workflow.

Data Management

To visualize and analyse the vast amount of data collected in the field, Arcadis implemented an electronic data management system (EDMS) in concert with a GIS for integrated data management using ESRI's ArcGIS suite of software as well as EarthSoft's EQuIS environmental database management system with integration of mobile data from iFORM. EQuIS is a centralized database for managing laboratory data, field data, and performing data validation checks, and reporting. ArcGIS provides mapping, spatial analysis, and reporting capabilities. Additionally, we implemented a web-based mapping platform allowing field staff, project teams, and the client to visually see progress on a parcel or portfolio basis:

- **gINT:** Screening information and descriptions of borehole information are initially managed through gINT. QA of the data occurs at this level as well as selection of samples for external laboratory analyses of soil concentrations. Borehole logs are created, reviewed and submitted to the O365 SharePoint site for use by Arcadis and for inclusion into the property reports. The data from gINT is uploaded to the EQuIS database for documentation, QA checks against planned sampling, and delivery to the client.
- **EQuIS:** The database compiles data collected during the program from a variety of sources including iFORM, coordinates from GPS, and electronic data submission from the laboratories. Automated QA checks and data validation are set up and conducted on laboratory data, as well as tracking reports and data integration from multiple sources to support reporting. Types of data managed through EQuIS and that will be sent to CNL at the completion of the project include:
    - **Field Data** – soil lithology, soil sampling, specialty sampling (swipes, material collection), gamma radiation surveys, equipment calibration;
    - **Sample Management** – Project sampling plan that guides the field team and records of samples collected and samples received;
    - **Automated chain-of-custody (COC)** – integrated COC from borehole and swipe sampling and cross-check against data received from laboratories for quality checks as well as status reporting and tracking; and
    - **Efficient Data Sharing** – Synchronize data immediately with data visualization and reporting tools – data mapping, soil boring logs, project management site status tracking and sample with laboratory coordination.
- **ArcGIS:** To maximize data value and provide information to the project teams for rapid evaluation and decision-making, a custom web-based GIS application for this project called ePRISM was developed and accessible through various viewers. This application was developed using ESRI ArcServer and Geocortex Essentials. Primary data layers include aerial photography, parcel boundaries, landowner information, site features, photos and observations, field data collection points, proposed and completed borehole locations. A secondary viewer was established for a limited and focused user base with editing and tracking features to facilitate the evaluation and discussion of potential borehole locations by approved team members. An example of editing tools developed for this secondary viewer showed the exterior gamma radiation levels and the preliminary borehole locations provided by the HFR. Boreholes could be added, removed or moved based on the combination of data accessible sources and would be tracked by date

and reason for change. GIS data also supports the desktop creation of figures for reports and provides a visual representation of the project status for planning and communication.

Specific Examples

Scheduling

Scheduling is a complex task since there are about 1,000 properties each year that require multiple visits, scheduling of these activities in the proper order (e.g. exterior gamma radiation prior to drilling), limitations due to meteorological conditions influencing exterior measurements, seasonal occupancy (i.e. many senior citizens travel south) and the staffing of field technicians for the data collection. The IM system was set up to conduct this efficiently with tracking of information provided by the property.

Property activities needed to be scheduled in a manner acceptable to the property owners. Documentation of communication is very important since mis-communication results in adverse public opinion and the efficiency of the field crew. The scheduled timing of field work varied from alerts that activities may be completed within a set time period such as exterior gamma radiation surveys, locates, or door-to-door deployment of radon monitors if the property representative was present. Interior surveys of gamma radiation and contamination surveys required well-defined scheduling since the property owner needed to be inside during the survey and the interior crews were scheduled for other properties during the same day. If requested by the property owner, times could be scheduled for other activities such as exterior gamma radiation surveys or drilling.

Contacting of property owners was conducted by a sub-consultant which had local staff aware of the LLRW history and familiarity with many of the property owners in the community. The property master list on SharePoint integrated events tracking telephone interactions with the property owners where attempts to contact the property, site specific property concerns and scheduled time. The list also helped to determine staff availability and the time required for specific examples. For example, the time required for the survey depended on the type of activity and the HFR classification of the property.

Soil Borehole Web-application

The proposed borehole locations provided by PHAI are considered in the context of the exterior gamma radiation surveys collected during the program to determine changes in the locations or number of boreholes on the property. The planned borehole locations need to be documented with traceability of borehole location names, the reasons for changes in location, or adding boreholes.

A web-mapping application was provided to allow changes in location or adding boreholes based on the exterior gamma radiation to ensure that above background surface radioactivity is incorporated in this decision making. GIS tools allow for an existing borehole location to be moved electronically to the planned location to reflect the exterior gamma radiation levels and for positioning additional delineation boreholes as necessary. The system can be queried for the planned boreholes that can be downloaded and used for way-point files for field locations when the drilling teams are deployed. This process allowed real-time revisions to borehole locations by senior staff without requiring iterative mark-up and revisions by other staff and significantly minimized the time between each phase of a borehole from planning through to completion.

Functionality of the application included:

- Exterior gamma radiation grids and measurements for properties completed up through the previous day;
- Filed obstacle observations, and linked photos;
- Field notes for higher gamma radiation locations;
- Proposed, approved, and advanced boreholes;
- Ability to click and drag editing ability with editor tracking and associated metadata.

Tracking and Client Reporting

The project has time-lines for completion of the activities as other future work (e.g. removal of contaminated soils by potentially other contractors) have already been scheduled; in addition, many of the survey activities are invoiced and tracked on a basis of payment (BOP) approach. These BOP items includes items such as individual soil samples to a survey activity such as an exterior gamma survey. There are sub-divisions of BOPs for field activities that relate to the level of effort required: an interior survey of a school located close to a known waste site requires a much longer survey time than a small residential building located well away from known sites.

Automated reporting was established initially for internal tracking and a number of these have evolved for use by the client through automated E-mail delivery. The system automatically updates the items of interest (e.g. borehole increments, contamination swipes collected) through querying the project database for the daily changes. The mobile apps provide information through iFORM on characteristics such as drilling date, completion of exterior gamma radiation surveys. Other tracking such as submission of soil samples or completion of locates is sourced from the EQuIS data or SharePoint lists.

Table IV shows a portion of report of daily activities conducted that is available to team members and the PHAI client. The report is updated automatically each day using data sources such as SharePoint lists and mobile collection device updates. This particular tracking sheet summarizes the progress on each billable item to allow demonstration of progress and work done on a monthly basis. Other tracking reports include documenting the completion of tasks on a property grouping basis.

Table IV. Tracking of Completion of Specific Tasks on Daily Basis

BOP Line Items - Daily		Total To Date	Total To Be Completed	%	2016							
					Nov							
					07						14	
Expand to see priority group detail					M	T	W	T	F	S	M	T
200	Exterior Gamma Surveys	631	1262	50.00%	16	10	12	9	10	12	7	10
201	Exterior surveys for properties (m2): <100	1	13	7.69%								
202	Exterior surveys for properties (m2): 101-300	48	87	55.17%								2
203	Exterior surveys for properties (m2): 301-600	244	451	54.10%	9	4	2	2	4	9		4
204	Exterior surveys for properties (m2): 601-1250	264	472	55.93%	7	3	7	4	4	3	7	2
205	Exterior surveys for properties (m2): 1251-2500	54	129	41.86%		2	3	3	2			1
206	Exterior surveys for properties (m2): 2501-5000	11	51	21.57%		1						1
207	Exterior surveys for properties (m2): 5001-10,000	7	22	31.82%								
208	Exterior surveys for properties (m2): 10,001-20,000	0	19	0.00%								
209	Exterior surveys for properties (m2): 20,001-30,000	0	8	0.00%								
210	Exterior surveys for properties (m2): 30,001-50,000	1	2	50.00%								
212	Exterior surveys for properties (m2): 75,001-100,000	1	3	33.33%								
213	Exterior surveys for properties (m2): 100,001+	0	5	0.00%								
400	Initial Intrusive SubSurface Investigations											
401	Utility Locates for Residential	24	1104	2.17%	2	1		5			6	2
402	Utility Locates for Non-Residential	5	158	3.16%				1			1	3
403	Standard 1.2m BHs	60	4494	1.34%			10	8	12		9	10
404	Additional 1.2 m Increments	20	800	2.50%			1	4	8		2	6
405	T1 - downhole above 16 uR/h (per borehole)	6	925	0.65%				2				1
406	T2 - core above Background (per BH)	0	460	0.00%								
407	T3 - core above 50 uR/h (per borehole)	0	5	0.00%								

Tracking is also visually supported by a web-mapping application where the status of the Campaign shows property status through the completion of varying survey activities. These are tracked by radon placement, radon retrieval, exterior gamma radiation surveys, locates, drilling and interior gamma radiation and contamination surveys. This visually represents the property status and is shared with the client. The client also has access to views showing the exterior gamma radiation and the borehole locations.

Ongoing Improvements

The QA of the raw data is important and efforts are being made to automate logic-based QA prior to the creation of tables or figures. This process reduces the number of steps in the QA process and provides traceability based on the programming approach.

Reporting for the unaffected properties does not require site-specific interpretation as no measurements exceed background and/or PHAI CC. Currently, staff need to compile the various tables and text to make the reports. Methods to automate production of entire reports or sub-sections are being investigated and this will speed up production of the reports and allow staff to address activities where site-specific assessment is required.

Investigations into improvements for the use of XRF and downhole gamma radiation results to support decision making and to reduce the analytical cost for laboratory analyses are being conducted. A multi-variate approach to combining the screening measurements and lithology observed in the field is being investigated.

CONCLUSIONS

A complex program of site characterization, delineation of contamination and remedial action planning is being conducted on multiple properties in a municipality contaminated with LLRW from a historic processing facility. A large amount of property specific data is required to be collected, managed, analysed and tracked: an IM system is crucial to the successful completion of the survey program. Building on experience gained from previously conducting a similar campaign, an IM system has been developed that addresses the project workflow and provides data integrity and accessibility of data to the project team. The systems combine existing software plus new developments in the collection of exterior gamma radiation surveys. Web-enabled field tools and cloud hosted data and applications, provide increased field efficiency, timeliness in reporting, real time QA/QC analysis, and consistency in tracking project advances and changes made to the data. Continuing development of the flexible structure will be implemented during the projects.

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