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Low Probability Receptor Demonstration Project

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Prepared for:
Petroleum Technology Alliance Canada (PTAC)
and
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1.0 INTRODUCTION

The framework for site remediation generally and the reclamation certification process specifically in western Canada allows for site decisions using prescribed generic approaches or site-specific approaches. The prescriptive generic approach is sometimes best and sometimes the site-specific approach is best, where best is defined as the approach that most aligns with the interests of the stakeholders and provides protection of the environment and human health as required under legislation.

An additional lens that is increasingly important is sustainability of remediation and reclamation.

A significant gap in the ability to optimize the site-specific approaches is the lack of site-specific considerations with respect to on-site and off-site receptors. The current framework largely requires the inclusion of all potential receptors as prescribed as defaults under broad land use categories. The Low Probability Receptor (LPR) initiative is aimed at addressing this gap in the site-specific approach framework.

1.1 Objectives

The goal of inclusion of site-specific receptor considerations in the western Canadian contaminated sites framework, as desired in the LPR initiative, is to allow optimal environmental management decisions which can:

- maintain equivalent levels of protection while reducing impacts on the environment (GHG, NOx, Sox, particulate matter, *etc.*);
- reduce risk of human mortality / health impacts;
- reduce further environmental disturbance;
- reduce costs and accelerate timelines to achieve remediation and reclamation; and
- fully maintain reasonable use of the land.

A successful outcome of the LPR initiative requires meaningful engagement with the Provinces of Saskatchewan, Alberta and British Columbia. Meaningful engagement enables development of optimal approaches to integrate LPR into the contaminated sites framework of each of the provinces. Meaningful engagement also allows for the development of an implementation guide that would form the basis for rolling out LPR concepts into each jurisdiction. The strategy being employed to achieve a successful outcome is a multi-level engagement with each Province and with stakeholders in the provinces that will build on:

- interest and success with other regulatory jurisdictions;
- net environmental benefit, liability reduction outcomes and future economic growth prospects; and
- integration of LPR into existing contaminated site frameworks.

Resolution of concerns on the availability of the land for reasonable future use can be achieved by:

- building on existing experience and acceptance of the implications of past oil & gas activities to reasonable future use;
- options to gain landowner & local government support; and
- options to increase clarity / certainty of desired future land use.

2.0 BACKGROUND

2.1 What is LPR

The Low Probability Receptor (LPR) is an assessment approach allowing for site-specific receptor selection, agreed to by the landowner or agency with control over the land/water use. The site-specific receptor selection is supported by information derived from probability analysis mapping and attenuation modelling tools to validate that this approach is protective of reasonable use of the land. The validation is based on the projected lifetime probability of a receptor occurring relative to potential contaminants of concern on a site.

For example, the domestic use aquifer (DUA) pathway is included at Tier 1 for all land uses. In areas with supplied water, however, the probability that potable water would not be provided through a water supply system is zero over the foreseeable future, and often municipal bylaws prevent the installation of domestic use water wells. Therefore, the lifetime probability of receptor (domestic water well) occurrence relative to contaminants of concern that attenuate is also zero.

Conversely, the population in areas along Highway #2 corridor is increasing in rural subdivisions with groundwater-supplied drinking water. Therefore, probability analysis does not validate the absence of domestic water wells as part of reasonable land use in certain areas along Highway 2.

2.2 Previous Phases

The LPR project was initiated in 2015. Key milestones have included:

- Development of a white paper "Consideration of Low Probability Future Receptors" in January 2016.
- A pilot study including probability mapping of receptors and pilot application at 5 sites in Alberta 2016 and 2017.
- Pilot application at 3 sites in British Columbia in 2017.
- Preparation of a report on regulatory precedent (November 2018).
- Preparation of a report documenting the LPR calculation methodology and probability mapping (February 2019).
- Development of a full Scientific Rationale (September 2019).
- Development of a Net Benefit Analysis approach and accompanying technical report (September 2019).
- Workshops with representatives across multiple sectors of Alberta's economy (2019 – 2020).

Throughout the process, there have been multiple engagements with regulators, particularly EPA and AER, as well as with industry groups including the Canadian Association of Petroleum Producers (CAPP).

3.0 DEMONSTRATION PROJECT

Summary information follows; the details for each of the 3 demonstration projects are provided in Appendices A (Alberta), B (Saskatchewan) and C (British Columbia).

The LPR Demonstration Project is focused demonstrating the integration of LPR into contaminated sites frameworks and the development of implementation guidance documents. As the status of LPR from a regulatory review varies between Provinces, three separate but aligned approaches will be implemented. The overall aim is to lever the progress on issues made within each province to help resolve issues across western Canada.

3.1 Alberta

The Alberta demonstration project is detailed in Appendix A.

LPR technical report submissions and discussions with Alberta Environment and Protected Areas (EPA) and the Alberta Energy Regulator (AER) have occurred. The discussions and technical document review has produced an understanding of the areas of concern to EPA. These areas include items that lie within the mandate of EPA to set guidance on implementation and also include issues affecting Municipal Governments and landowners.

The focus of the LPR Demonstration Project in Alberta is to confirm an ability to resolve the areas of concern identified by EPA. Considerations include but are not necessarily limited to:

1. Municipal Government
    - reasonable land use considerations;
    - mechanisms to establish certainty of LPR approaches;
    - ensuring use of the land is appropriate to site environmental conditions;
    - Landowner interest and concerns; and
    - provision of environmental protection.
2. Landowners / Land Stewards
    - ability to utilize the land for their intended purposes;
    - land value; and
    - consent to reasonable future use.

The intent of the LPR demonstration project is to incorporate the above issues into Alberta's contaminated sites framework and to address possible means of resolving those issues in implementation. The addition of these answers to the current ability to provide guidance on the incorporation of technical issues into the contaminated sites framework would enable a re-engagement with EPA with information and solutions to these issues derived at a demonstration project level.

The approach taken was to identify candidate sites in collaboration with industry representatives and apply the LPR process to the sites, with specific focus on how the application interacted with the issues identified above and how to demonstrate local benefits of an LPR approach.

Only a small number of sites were brought forward by industry. After evaluating candidate sites, only a single Alberta site was determined to be suitable. A former gas plant with multiple areas of potential environmental concern (APECs) and both petroleum hydrocarbon and salinity impacts was selected as a demonstration site for the more detailed evaluation described in Appendix A. This gas plant was intended for commercial/industrial redevelopment, allowing for low probability receptors to be effectively controlled.

The LPR assessment included estimation of remediation volumes and environmental liability based on both conventional (Tier 1/Tier 2) and LPR approaches. Screening-level attenuation modelling was conducted to estimate the length of time required for key chemicals of potential concern (benzene, ethylbenzene, chloride) to attenuate below Tier 1 guidelines. The LPR tool was then applied to estimate the probabilities for sensitive receptors (domestic water wells and livestock dugouts) to occur within a polygon defined by the area of current and predicted future Tier 1 guideline exceedances. Additional scenarios were also evaluated by changing landscape characteristics including distances to roads and topographical slope.

The assessment indicated a reduction in environmental liability of approximately 75% by applying LPR. The probabilities of shallow (<10 m) domestic water wells and livestock dugouts over the lifetime of contaminants above Tier 1 were extremely low (<0.001% for hydrocarbons and <0.1% for salt).

A net benefit analysis (NBA) was conducted comparing remediation based on LPR to remediation to Tier 1/Tier 2 guidelines, considering environmental, economic and social factors. Use of LPR resulted in an approximately 2-fold improvement in overall net benefit.

The demonstration project as well as additional research into mechanisms of control indicated that the potential for low-probability receptors to occur can be effectively controlled with existing mechanisms at many sites. These controls would only be required within a polygon defined by current and potential future concentrations above Tier 1/Tier 2 guidelines. At the demonstration project site, proposed future redevelopment and ongoing control by the current landowner provide an effective mechanism of preventing low-probability receptors; other tools available include land use zoning, water well controls, and landowner commitments. Application of these tools may require demonstration of economic benefit to stakeholders.

The LPR tool applied for the demonstration project is intended to be a web-available standard tool to ensure a consistent approach to LPR application with defined underlying logic. This tool would also provide data that would allow a tracking system such as Abadata to keep a record of the polygons affected by LPR-related controls.

Overall, it is concluded that the Alberta demonstration project shows that LPR can be effectively applied in Alberta without significant legislative change.

3.2 Saskatchewan

Saskatchewan Ministry of Energy and Resources (MER) is interested in investigating whether LPR concepts can improve the outcomes of their risk-based Acknowledgement of Reclamation (AOR) processes; Saskatchewan Ministry of Environment is also supportive. Improvements to the risk-based AOR process would be achieved with inclusion of LPR as an acceptable (no Ministry review required) risk-based closure process and for inclusion of LPR into alternative (Ministry review and acceptance required) risk-based closure approaches as established in the Saskatchewan Environmental Code. The overall goal of MER is to achieve a substantial reduction in the risk of O&G sites being orphaned.

To explore potential applications of LPR, the Saskatchewan component of demonstration project must give consideration to the approach to incorporate a wide range of impacted sites into the contaminated sites framework including varying COPCs, varying size of liability and some geographic distribution. The issues to include in the demonstration project would incorporate both salt and hydrocarbon impacted sites, with consideration to both industry-owned and orphaned sites.

Initial meetings were held with MER to explore interest in collaboration, provide background information on the science supporting LPR and confirm desired characteristics for sites to be included in the Demonstration Project. There was high interest in also considering economically and environmentally beneficial redevelopment; therefore, the demonstration project examined not only LPR but also potential redevelopment for solar power.

An industry partner was identified, which provided 39 sites for initial evaluation using a screening matrix. Criteria included:

- agricultural land capacity;
- chemicals of potential concern/concentrations; and
- receptor presence.

Based on these screening criteria, 9 sites were selected for further evaluation; 3 sites for LPR only, 3 for solar development only, and 3 for both LPR and solar redevelopment. An initial LPR assessment was conducted. The 9 sites showed promise for closure/redevelopment through LPR, but due to limited assessment data there are outstanding data gaps which would need to be addressed.

3.3 British Columbia

In 2020, MEMS developed a proposal for the BC Oil and Gas Commission (OGC), since renamed as the BC Energy Regulator (BCER) on a pilot program for risk-based closure liability management. Important considerations that were communicated are harmonization and consistency with BC regulations and protocols, and integration of the LPR process into Screening Level Risk Assessment and Detailed Risk Assessment in BC. In brief, the defined generic scenarios of the BC Contaminated Sites Regulation incorporate judgment as to the probability of any given receptor’s presence and the degree of that receptor’s exposure. For example, the vapour inhalation pathway is not considered to be active at remote sites due to the absence of human inhabitation (with some defined exceptions). The LPR assessment uses relatively complex methods in alignment with Detailed Risk Assessment to deliver in an automated manner a relatively simple assessment of exposure pathways and receptors.

Because specific feedback on the application of LPR was limited, the BC demonstration project involved regulatory engagement on the approach and conceptual model for LPR and scoping of the demonstration project. Guiding principles included consistency of the tool with science for risk-based screening and contaminant attenuation and integration with BC regulations.

4.0 CONCLUSIONS

The LPR demonstration project evaluated how LPR could be applied within the existing regulatory frameworks in Alberta, Saskatchewan and British Columbia.

In all 3 provinces there are opportunities to apply LPR within certain constraints:

- In Alberta, the primary constraint appears to be a lack of mechanisms to restrict future receptors *via* land titles or within the Contaminated Sites Framework. However, existing mechanisms including land use zoning and water well controls could enable LPR implementation.
- In Saskatchewan LPR for salt-impacted sites is well aligned with current regulatory policy and there are existing mechanisms to control future sensitive receptors. Implementation for biodegradable petroleum hydrocarbons is expected to be achievable where no human health risk can be demonstrated; extension to other substances would require additional policy development.
- In British Columbia, there is potential to apply LPR for sites regulated by BCER, but it would need to align with existing requirements and restrictions for screening-level risk assessment.

Regardless of the jurisdiction, a consistent approach and framework is required, along with a mechanism to track sites where LPR is being applied. A web-available tool has been developed which satisfies the consistent approach and framework requirement; data from this tool can be integrated into existing public databases (*e.g.,* Abadata) for tracking.

5.0 LIMITATIONS OF LIABILITY AND CLOSURE

This report was prepared by Millennium EMS Solutions Ltd. ("MEMS") for the Petroleum Technology Alliance of Canada ("PTAC") and has been completed in accordance with the terms of reference in the Recipient Agreements for PTAC Project reference 20-RRRC-07. This report does not necessarily represent the views or opinions of PTAC or the PTAC members.

Site assessment, risk assessment and remediation involve a number of uncertainties and limitations. As a consequence, the use of the process presented herein to develop site management strategies may either be overly protective or may not necessarily provide complete protection to human receptors or prevent damage of property in all circumstances. The process presented herein was determined in accordance with generally accepted protocols. Given the assumptions indicated, the process presented herein is expected to provide a conservative estimate of the risks involved. The services performed in the preparation of this report were conducted in a manner consistent with the level of skill and care ordinarily exercised by professional engineers and scientists practising under similar conditions.

While preparing this report, Millennium may use or incorporate Millennium's proprietary algorithms, methods, compilations, processes, designs, formulas, and/or techniques, and may also employ advanced technologies for simulation, information modeling, generative design, and the development of project documentation (the **"Technical Tools"**). The Technical Tools may be further used to create data sets and result in simulations or models (collectively, the **"Datasets"**) that may be included in this report. Both the Technical Tools and the Datasets are by-products of Millennium's internal processes and shall belong solely to Millennium. No unauthorized use of the Technical Tools or Datasets is permitted.

The results and interpretations included in this report do not represent any specific site. Millennium accepts no responsibility for foreseeable or unforeseeable damages, or direct or indirect damages, if any, suffered by any third party as a result of decisions made or actions taken based on the use of this report, including but not limited to damages relating to delay of project commencement or completion, reduction of property value, and/or fear of, or actual, exposure to or release of toxic or hazardous substances.

Attachments:

Appendix A	Alberta
Appendix B	Saskatchewan
Appendix C	British Columbia

APPENDIX A: ALBERTA

Appendix A – Alberta

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1.0 INTRODUCTION

Following is a summary of the Alberta LPR Demonstration Project, focused on demonstrating how LPR can be applied within the Alberta landscape and regulatory framework.

1.1 Objectives

The Alberta LPR Demonstration Project is focused on issues raised in discussions between industry as represented by the Canadian Association of Petroleum Producers (CAPP) and Alberta regulators including Alberta Environment and Protected Areas (EPA) and the Alberta Energy Regulator (AER) as well as technical document review by these organizations.

EPA has not identified technical concerns with the Scientific Rationale for LPR, but have brought forward what they perceive as issues with respect to implementation. Firstly, EPA has raised a requirement for the boundary conditions for LPR to be clear, including any limitations on pathways/receptors, COPCs and landscape conditions that would enable the approach. Secondly, EPA has identified factors that need to be considered in the implementation, including:

- any legislative changes required closure with risk management or financial backstop;
- indigenous and stakeholder consultation;
- a tracking system for regulators, land use planners and landowners; and
- tools and guidance to support effective implementation.

The goal of the Alberta Demonstration Project is to show how EPA's concerns can be addressed through real-world application.

1.2 Scope

The Alberta LPR Demonstration Project is focused on illustrating the application of LPR in a real-world scenario. The scope of work included:

- Collaboration with the Steering Committee and the CAPP Remediation and Reclamation Committee for presentations to and discussions with the Government of Alberta with respect to LPR requirements and implementation.
- Engagement with oil and gas companies to identify candidate sites for the LPR demonstration, including establishing screening criteria to identify sites.
- Review of candidate sites and selection of final demonstration sites.
- Assessment of demonstration sites through the LPR process.
- Discussion of how EPA concerns can be addressed through the process.

This appendix focuses on the final demonstration project.

1.3 Candidate Site Selection

A framework was established to identify candidate sites for the LPR demonstration. Desired attributes are described in Table A-1 below.

Table A-1 LPR Pilot Site Criteria

Item	Requirements
Location	Not in an area undergoing rapid development
Landowner	Not a difficult/adversarial landowner
Substances of potential concern	Petroleum hydrocarbons and salt (other substances including metals can be present above guidelines at some locations so long as they are not driving the remediation requirements)
Investigation/delineation status	Sufficiently delineated to begin remediation planning
Extent of impacts	Impacts extend to depth > 1.5 m > 100 m^3 meeting criteria in Table 2.
Receptors of concern	Remediation driven by protection of exposure pathways other than ecological direct contact or management limits. At least one of benzene and chloride should meet criteria below
Benzene (petroleum hydrocarbon sites)	Exceeds Tier 1 (0.046 mg/kg in fine soil) and DUA cannot be eliminated, **or** exceeds livestock water guideline (0.2 mg/kg) and land use is agricultural At least part of site (>100 m^3) has benzene concentrations less than 18 mg/kg
Chloride (salt sites)	Exceeds 100 mg/L in groundwater, or exceeds 100 mg/L in saturated paste if no groundwater data At least part of site (>100 m^3) has chloride concentrations < 10,000 mg/L

2.0 DEMONSTRATION SITE CSM

Only a small number of sites were brought forward by industry. After review of candidate sites provided by industry partners, a former gas plant was selected as the only suitable LPR demonstration site. This facility operated from the 1960s until 2001; facility and building decommissioning began in 2011 though a flowing gas well remained on-site. The property itself remains industrial but surrounding land use includes agricultural with residences and domestic wells.

Data for the site was imported into MEMS' Asset Information Management (AIM) Suite, including concentrations of petroleum hydrocarbons and salinity. Multiple areas of potential environmental concern (APECs) were identified at the site. For purposes of this assessment, they were combined into 3 areas to illustrate the application of LPR:

1. Compressor and Equipment Buildings.
2. Flow Lines.
3. Flare Pit/Release Area/Above-ground Storage Tanks (ASTs).

The APECs, as well as sampling locations, are illustrated on Figures 1 to 4 in Appendix A. Figures 1 and 2 present the locations where petroleum hydrocarbon (PHC) concentrations meet or exceed Tier 1 guidelines in soil and groundwater, respectively, while Figures 3 and 4 present locations where salinity meets and exceeds Tier 1 guidelines in soil and groundwater.

The data for each APEC were processed using the AIM Suite's Environmental Assessment Screening Tool (EAST) to represent the site data in 3 dimensions, as well as identify which pathway-specific guidelines are exceeded.

3.0 LPR ASSESSMENT RESULTS

3.1 APEC 1 (Compressor and Equipment Buildings)

3.1.1 Description

This APEC includes buildings associated with a compressor station as well as an equipment area. The facilities were decommissioned between 2011 and 2012.

3.1.2 Site Assessment Results

The EAST tool analysis of APEC 1 is presented on Figures 5 through 8. Figure 5 present PHC in soil against Tier 1 guidelines (agricultural land use, coarse soil/subsoil). PHC above Tier 1 guidelines were measured from surface to a depth of approximately 4 m over an area of approximately 13,000 m^2. Figure 6 presents the results for benzene, toluene, ethylbenzene and xylenes (BTEX) only, showing a similar distribution. Figure 7 shows benzene only, exceeding guidelines over an area of approximately 2,800 m^2 at depths of 3 to 4 m. Tier 1 groundwater guideline exceedances are shown on Figure 8; due to the limited data meaningful area estimates are not available from groundwater concentrations.

The AIM Suite's Natural Attenuation Tool was used to conduct a screening-level assessment of benzene migration and transport; Figure 9 shows the results of this assessment at time intervals of 5, 20, 40 and 80 years. The tool predicted that within 29 years the benzene concentrations would meet guidelines.

3.1.3 LPR Analysis Results

The LPR tool was then run for benzene (Figure 10). Within the expected lifetime of the benzene plume, the probability of a dugout or shallow (< 30 m deep) was determined to be < 0.00001%; the probability of a water well at any depth was 0.009%.

A similar evaluation was done for ethylbenzene (Figures 11-13). The ethylbenzene was predicted to attenuate below guidelines over 203 years. The probability of a dugout over this time was 0.003%, and probabilities of a shallow water well ranged from 0.001% at < 10 m to 0.027% for 20 – 30 m.

To illustrate the potential landscape effects, the ethylbenzene calculations were re-run with 3 additional scenarios:

- A road within 50 m of the APEC (increases the probability of a water well) – Figure 14.
- A road within the APEC (further increases the probability of a water well) – Figure 15.
- Topographical slope between 6% and 30% (decreases dugout probability) – Figure 16.

Under the first 2 scenarios, the probability of a shallow water well increased above 0.1% at 20 to 30 m but remained below 0.1% at shallower depths. The 3rd scenario did not appreciably affect the outcomes.

3.2 APEC 2 (Flow Lines)

3.2.1 Description

The second APEC is the area surrounding several historical flow lines and pipeline risers in the northeast part of the Site; 51 flowlines were cut and capped in this area.

3.2.2 Site Assessment Results

The EAST tool analysis of APEC 2 is presented on Figures 17 and 18. PHC impacts, including benzene, toluene and ethylbenzene, were identified at depths of approximately 3 to 4 m below ground surface over an area of approximately 2,080 m^2. Benzene and ethylbenzene also exceeded generic guidelines in groundwater in this area.

The AIM Suite's Natural Attenuation Tool was used to conduct a screening-level assessment of benzene migration and transport; Figure 19 shows the results of this assessment at time intervals of

5, 20, 40 and 80 years. The tool predicted that within 19 years the benzene concentrations would meet guidelines. A similar assessment for ethylbenzene (Figure 20) indicated guidelines would be met in 105 years.

3.2.3 LPR Analysis Results

The LPR tool was then run for benzene (Figure 21). Within the expected lifetime of the benzene plume, the probability of a dugout or shallow (< 30 m deep) was determined to be < 0.00001%; the probability of a water well at any depth was 0.002%. An alternative scenario was also assessed (Figure 22) with a road within 50 m of the APEC, increasing the probability of a water well; the probability of a shallow well remained < 0.00001% while the probability of a well at any depth increased to 0.01%.

A similar evaluation was done for ethylbenzene (Figure 23). The ethylbenzene was predicted to attenuate below guidelines over 105 years. The probability of a dugout over this time was < 0.00001%; as was the probability of a water well < 10 m depth or 10 – 20 m depth. The probability of a well 20 m to < 30 m deep was 0.001% and the total probability of a well at any depth was 0.033%. Changing the distance to the nearest road to < 50 m (Figure 24) increased the probability of a well 20 to < 30 m deep to 0.005% and the probability of a well at any depth to 0.165%.

3.3 APEC 3 (Flare Pit/Release Area/ASTs)

3.3.1 Description

The third APEC includes four buried flare pits as well as several above-ground storage tanks and the location of a historical release northeast of one of the flare pits.

3.3.2 Site Assessment Results

PHC including BTEX and F1-F4 were identified above Tier 1 guidelines in one of the flare pits and the release location; salinity (EC and SAR) was also above Tier 1 guidelines at the release location.

The EAST tool analysis of APEC 3 is presented on Figures 25 through 27. PHC impacts, including ethylbenzene and fractions F1 through F3, were identified from surface to a depth of approximately 2 m (4 m for ethylbenzene). The area affected is approximately 5,300 m^2. Salinity (EC and SAR) was also identified in the release area, with an estimated area of soil impacts of 2,550 m^2, overlapping with the PHC-affected area (Figures 30-32). Chloride was also measured in groundwater at concentrations ranging up to 5,100 mg/L in this APEC (Figure 32).

The AIM Suite's Natural Attenuation Tool was used to conduct a screening-level assessment of ethylbenzene migration and transport; Figure 28 shows the results of this assessment at time intervals of 5, 20, 40 and 80 years. The tool predicted that within 61 years the ethylbenzene concentrations would meet Tier 1 guidelines. A similar assessment of chloride is presented on Figure 33; the screening-level transport model suggested that if concentrations were remediated based on a target of 400 mg/kg in soil that offsite groundwater concentrations would not exceed the drinking water guideline.

3.3.3 LPR Analysis Results

The LPR tool was run for ethylbenzene (Figure 29). Within the expected lifetime of the ethylbenzene plume, the probability of a dugout or shallow (< 30 m deep) was determined to be < 0.00001%; the probability of a water well at any depth was 0.003%.

The tool was also run for chloride (Figure 34). Without remediation, offsite concentrations were expected to exceed guidelines offsite, and therefor the tool was run based on remediation of chloride to a maximum concentration of 400 mg/kg. The probability of a dugout within the affected area was estimated to be 0.088%; the probability of a water well was 0.019% at < 10 m below ground surface, 0.238% at 10 to < 20 m, 0.676% at 20 to < 30 m, and 12.2% at any depth.

3.4 Remediation Volumes

Based on the available data, the volume of soil exceeding Tier 1 guidelines for PHC is approximately 27,500 m^3, while the volume exceeding Tier 1 guidelines for salinity is approximately 16,700 m^3. The associated environmental liability (based on typical remediation costs) would be in the order of $4.1 million.

Restricting the presence of sensitive receptors for the lifespan of the contamination above guidelines would substantially reduce remediation volumes and costs. For this case study, the landowner has proposed a commercial/industrial redevelopment of the site that would result in controls on the land use, including the absence of domestic water wells and livestock dugouts, for the lifespan of the development. This reduction is constrained by:

- Concentrations of heavier (F3 and F4) petroleum hydrocarbons above guidelines, including concentrations exceeding management limits at some locations.
- Long timelines for full attenuation to Tier 1 guidelines at some locations, including an estimated time of 203 years for attenuation of ethylbenzene in the Compressor and Equipment Building area.
- High concentrations of chloride in the Flare Pit/Release Areas potentially leading to offsite concentrations above applicable guidelines.

Based on those constraints, it is anticipated that a soil volume of approximately 7,100 m^3 would require remediation prior to redevelopment, at a cost of approximately $1.1 million.

3.5 LPR Tool Report

The LPR tool produces a standardized report that documents all of the inputs and results. The standardized report allows for consistent presentation of the required information for ease of review. An example of the report is attached as Appendix A1.

3.6 Net Benefit Analysis

3.6.1 Introduction

Net Benefit Analysis (NBA) is intended to provide a simple and reproducible evaluation of whether a plan or activity is of overall benefit, considering environmental, economic, and social criteria. The practice can also be used to compare different plans or approaches in order to maximize benefits and reduce costs.

Guideline-based remediation is often disconnected from actual site receptors; either receptors/pathways are not present/can be controlled, or the site characteristics mitigate risks to these receptors. For example, the likelihood of new drinking water wells being installed within a municipality with supplied domestic water is generally low. Similarly, vegetation grown at a site is affected by ecosite, soil conditions and land use, and may not reflect the full range of species considered in guidelines.

Use of NBA to evaluate remediation programs is recognized in Canada and internationally as part of determining the optimum solution, often termed as "sustainable remediation" or "green remediation." These processes incorporate consideration of ecological and human health, as well as social and economic criteria, to help evaluate remediation solutions (ITRC 2011a).

3.6.2 Methodology

The NBA methodology is based on concepts established in the Federal Contaminated Sites Action Plan (FCSAP) Decision-Making Framework (Government of Canada, 2018) as well as established international NBA methods including Sustainable Remediation Forum (SURF-UK, 2010) and Australia's Cooperative Research Centre for Contaminated Assessment (CRC CARE, 2015).

To support the decision process, inputs or characterization criteria are required to frame the assessment. Scores are assigned to inputs; these may be based on quantitative parameters (*e.g., soil* volume, cost) or based on qualitative parameters (*e.g., public* perception). The determination of inputs and scoring generally followed Government of Canada (2016) approaches.

Two scenarios were assessed:

- Remediation based on conventional Tier 1/Tier 2.
- Remediation based on LPR; specifically with the potential presence of domestic water wells and livestock dugouts excluded from the site.

There are limitations in the site characterization and a detailed remedial plan including actual distances to landfills and local costs has not been prepared. As a result, remediation estimated volumes and the associated costs used for calculations are considered approximate. These are representative of industry experience but may vary and have been applied the purposes of comparative analysis, the results of this assessment are considered to be qualitative/semi-quantitative.

There are hundreds of potential inputs that can be used for an NBA. For purposes of this simple assessment, representative criterion, and sub-input for each of the environmental, economic, and social categories is shown below (Table A-2).

Table A-2 Categories and Input Parameters

Category	Characterization Criteria	Sub-Input
Environmental	Landfill Capacity, Emissions	Remediation Soil Volume, Emissions Produced
Economic	Capital and Resource Use	Project Execution Capacity
Social	Community Traffic Volume, Occupational Health, and Safety	Likelihood of a Traffic Accident, Vehicular Volume, Site Injury Rate

3.6.3 Environmental

The environmental impact of remediation was evaluated through landfill capacity required for excavated soil, recognizing the potential environmental issues associated with decreased landfill capacity. The scoring criteria for landfill capacity, based on previous assessments (*e.g.*, PTAC, 2019), are presented in Table A-3.

Table A-3 Environment - Landfill Capacity			
	Base Case (Conventional)	**Alternative Case (LPR)**	
	Results	**RPD**	**NBA Score**
Base Case (Conventional) Required Landfill Volume (m^3)	27,500	118%	1.00
Alternative Case (LPR) Required Landfill Volume (m^3)	7,100		2.50

Based on these metrics, conventional remediation to Tier 1 results in a net benefit analysis score of 1. The application of LPR results in a score of 2.5 due to the much lower landfill space usage.

Emissions created from required transportation during remediation was evaluated for excavated soil volumes for each remediation method. Emissions were calculated EPA (2008) measurements of emissions for associated trucks and equipment required to complete remediation.

Table A-4 Environment - Emissions			
Emission Type (kilograms)	**Base Case (Conventional)**	**Alternative Case (LPR)**	
VOC	49	13	
THC	49	13	
CO	260	66	
CO_2	290,000	74,000	
SO_2	18	4.7	
NO_x	980	250	
PM	23	5.9	
Emissions Total	**290,000**	**74,000**	
Results			
	Results	**RPD**	**NBA Score**
Base Case (Conventional) Emissions Total (kg)	290,000	118%	1.00
Alternative Case (Salt Tolerant Plant Criteria) Emissions Total (kg)	74,000		2.50

More than an order of magnitude in emissions are created using LPR methods, resulting in a higher net benefit score of 2.50 for LPR *versus* conventional Tier 1/Tier 2 remediation.

3.6.4 Economic

The economic impact of each scenario was evaluated based on the estimated costs. The costs of remediation projects can be economically beneficial (*e.g.*, through job creation). However similar benefits can be achieved through alternative application of the same funds including using it to increase the number of sites remediated/reclaimed or for activities that benefit the local community (economic development or land improvement). The results from the economic net benefit analysis can be seen below in Table A-5.

Table A-5 Economic - Remediation and Reclamation Cost Estimates

Cost Estimate	Base Case (Conventional)	Alternative Case (Salt Tolerant Plant Criteria)	
	Results	RPD	NBA Score
Base Case (Conventional) Total Cost ($)	4,100,000	115%	1.0
Alternative Case (LPR) Total Cost ($)	1,100,000		2.5

The cost of conventional Tier 1 remediation is given a score of one, while the alternative case remediation is approximately 115% lower and is given a relative score of 2.5.

3.6.5 Social

The social impact of remediation was evaluated based on the increase in project-related traffic volume, percent likelihood of a traffic accident (causing injury), and the increase of occupational health and safety site injury rates. The injury rate (per billion vehicle kilometres) in Alberta was retrieved from the Canadian Motor Vehicle Traffic Collisions Statistics: 2017 (Government of Canada, 2019). The required truck trips required to complete remediation was calculated assuming that each truck has a payload of 16 m^3, six trucks would be on-site, each truck could complete approximately five 1.5-hour turnaround trips per eight hour work day.

Table A-6 Community Health - Vehicular Volume (noise/odour/traffic)			
	Base Case (Conventional)	**Alternative Case (Salt Tolerant Plant Criteria)**	
Total Remediation + Backfill Volume	55,000	14,200	
Payload / Truck (16 m^3, assumed)	16	16	
Results			
	Results	**RPD**	**NBA Score**
Base Case (Conventional) Total Number of Truck Trips Required	3,438	118%	1.0
Alternative Case (LPR) Total Number of Truck Trips Required	888		2.5

Traditional remediation methods require nearly four times more truck trips, therefore increasing the vehicle volume in the area by four. The base case conventional remediation has a net-benefit analysis score of 1, while the alternative remediation case scored 2.5.

The total kilometers driven were based on the distance between the site and the landfill and the site (assumed to be 50 km for the purposes of these calculations) and the backfill source, multiplied by the number of truck loads required to complete the remediation. Hence, the injury rate is a measure of the probability of injury based on the Motor Vehicle Traffic Collision Statistics (Government of Canada, 2019), adjusted to a per km basis, multiplied by the total kilometers required to complete the project. The results are presented in Table A-7 below.

Table A-7 Community Health – Percent Likelihood of Accident Resulting in Injury

	Base Case (Conventional)	**Alternative Case (LPR)**	
Total km Driven During Project (assuming 50 km to landfill)	170,000	44,000	
Injury Rate (per 10^9 km)	273.1	273.1	
Percent Likelihood of an Accident (%)	4.7	1.2	
Results			
	Results	**RPD**	**NBA Score**
Base Case (Conventional) Percent Likelihood of an Accident (%)	4.7	118%	1.0
Alternative Case (Salt Tolerant Plant Criteria) Percent Likelihood of an Accident (%)	1.2		2.5

The conventional remediation percentage results in more than triple the likelihood of injury compared to alternative LPR remediation. Conventional remediation scored a 1 for net benefit analysis, and alternative remediation scored 2.5.

Based on the number of truckloads, assuming six trucks working regular eight-hour workdays, the total days required for the project were calculated. Using the injury claim rate per day (adapted from Occupational Health and Safety's injury claim rate of cases per 100 person-years [Government of Canada, 2019]), the likelihood of injury during each project was calculated. The results are shown in Table A-8.

Table A-8 Occupational Health and Safety – Site Injury Rate

	Base Case (Conventional)	Alternative Case (LPR)	
Days Required for Project	115	30	
Injury Claim Rate (cases per 100 person-years)	2.62	2.62	
Injury Claim Rate (case per day)	7.18E-05	7.18E-05	
Likelihood of an Injury During Project (%)	0.82	0.21	
Results			
	Results	**RPD**	**Score**
Base Case (Conventional) Likelihood of an Injury (%)	0.82	118%	1.0
Alternative Case (Salt Tolerant Plant Criteria) Likelihood of an Injury (%)	0.21		2.5

Conventional remediation results in over three times greater likelihood of injury on the work site, and thus scored 1 in the net benefit analysis. Alternative LPR remediation methods scored 2.5.

3.6.6 Conclusions

Based on the criteria evaluated, the resulting NBA scores are presented in Table A-9:

Table A-9 Results Summary

Grouping	INPUT	Comparison	
		Conventional	**Alternative**
Environment	Landfill Capacity	1.0	2.5
	Emissions	1.0	2.5
Economics	Economics (cost)	1.0	2.5
	Community Health	1.0	2.5
Community Health	Vehicular Volume	1.0	2.5
	Occupational Health	1.0	2.5
	TOTAL	**6.0**	**15**
	Net Benefit Quotient (NBQ)	**0.4**	

The conclusion of this comparison demonstrates a greater than two fold benefit of the LPR solution. The metrics evaluated support LPR as the preferred remediation option. This analysis is contingent on the LPR approach to complying with the objectives of protecting human health and existing environmental receptors.

There are considerable uncertainties in costs and assumptions applied for the illustrative net benefit analysis. The resulting measures reflect a relative semi-quantitative assessment of net benefit for the purposes of qualitative discussion.

4.0 DISCUSSION

The Alberta demonstration project uses a case study with multiple APECs to present the application of LPR under real-world conditions.

Specific areas raised by EPA are discussed below.

4.1 Boundary Conditions

Boundary conditions for the application of LPR are established from the 2019 Scientific Rationale report. Fundamental constraints include:

- The COPCs must have a finite duration above Tier 1/Tier 2 guidelines; *i.e.,* they must degrade or attenuate over time.
- The receptors driving remediation must be absent and have a low probability of occurring within the lifespan of COPCs above Tier 1/Tier 2 guidelines.
- The landscape must be stable, *i.e.,* not in a high development area where probability of receptor occurrence is increasing non-linearly.

4.2 Legislative Changes Required

There is a requirement for a mechanism to address the low probability of a sensitive receptor occurring in the future – either to ensure that the receptor does not occur, or to prevent adverse effects if that receptor occurs. There are multiple mechanisms available; while some earlier discussions focused on a financial backstop to fund remediation in the event of a low probability receptor appearing, the current approaches focus on the use of existing mechanisms to control sensitive receptors without impacting the ability of the site owner from using the land for planned or likely purposes. These mechanisms include land use zoning, municipal controls on the installation of water wells, and landowner commitments. These controls utilize existing tools and would not require legislative change.

It is also important to stress that these controls do not need to be applied across an entire property, only within the polygon identified during the LPR assessment (extent of potential impacts above Tier 1 or Tier 2 guidelines).

4.2.1 Land Use Zoning

Land use zoning policies and bylaws frequently impose restrictions on use of land beyond the generic land uses defined in environmental guidelines. In many cases existing restrictions may already prevent sensitive receptors within municipal settings, including placing restrictions on the use or construction of buildings.

For a municipality or another authority with jurisdiction over land use to put in place new zoning restrictions, it is expected that there would need to be a significant benefit to that authority; these benefits could include economic development or financial compensation.

Land use restrictions would not need to extend beyond the polygon defined for the application of LPR. They would also not need to include a blanket prohibition, only a requirement to verify that no adverse effects would occur prior to the use being approved (*e.g.,* as a discretionary land use). Removal of land use zoning requirements would typically require the proponent to demonstrate that the requirement is no longer needed.

4.2.2 Water Well Controls

Many municipalities have mechanisms to control the installation of domestic water wells, including bylaws but also permitting processes. An absolute prohibition on domestic use wells is not required; the controls only need to ensure that wells are not installed within the polygon identified for an LPR site without first ensuring that it will not be impacted by contaminants of potential concern. For example, if a landowner desired to install a water well within the polygon, they could demonstrate that it was not being installed in an affected geological unit or could conduct sampling to confirm that remaining concentrations were no longer an issue. There would be no need to restrict domestic well installation outside of the polygon.

4.2.3 Landowner Commitments

Agreement of landowners to abide by any use restrictions required by an LPR assessment is another feasible mechanism. Unlike some other provinces, Alberta does not currently have a mechanism to place these restrictions on a land title, and therefore this approach may be more appropriate when the current owner intends to maintain long-term care and control of the property.

Landowner agreement is expected to require demonstrated benefit to the landowner, which could be in the form of economic development, other revenue-generating use of the site, or financial compensation.

The case study described in Section 3.0 reflects a landowner agreement scenario where the current landowner intends to maintain care and control of the site and seeks to derive economic benefit from the site with a planned land use aligned with LPR requirements.

4.3 Indigenous and Stakeholder Consultation

Stakeholder buy-in is a critical component for successful LPR implementation. This buy-in is most readily achieved when there is a benefit to that stakeholder. This benefit can take on several forms, including:

- Beneficial use of the land, including economic development supported by the stakeholder or other revenue-generating uses of the land.
- Accelerated site closure.
- Financial compensation for any land use value change due to restrictions.

Recent experience suggests that the same general principles apply when the stakeholders are indigenous groups. In a recent example outside the LPR demonstration project, an Alberta First Nation passed council resolutions to prevent sensitive land uses (including water wells) on multiple former oil and gas sites in order to accelerate remediation/closure and allow redevelopment aligned with the goals of the First Nation.

4.4 Tracking System

The ability to track the application, and particularly the polygons within which land use restrictions would apply, has been identified as an important component of LPR application since there is no mechanism to register restrictions on land titles.

Preliminary discussions with Abadata indicate that they would be willing to pull data from the LPR tool's database to facilitate this tracking.

4.5 Tools and Guidance to Support Effective Implementation

The LPR tool applied in Section 3.0 is intended as a web-available standard tool for application of LPR. Use of this tool ensures a consistent approach with defined underlying logic.

5.0 SUMMARY/CONCLUSIONS

The Alberta demonstration project focused on a large facility with multiple distinct APECs; functionally it exhibits characteristics of multiple sites due to differing contaminant characteristics between the different APECs.

The LPR analysis indicated low probabilities of shallow (< 10 m) domestic wells or livestock dugouts within the anticipated lifespan of light end hydrocarbon and salinity concentrations above guidelines. Based on the planned redevelopment of the site and existing control mechanisms, this low probability can be effectively managed.

Some remediation remained necessary due to heavier hydrocarbons including concentrations above management limits, the length of time required for ethylbenzene to attenuate at one APEC, and the potential for chloride to migrate offsite. However, the anticipated remediation costs would be reduced by approximately 75%.

A net benefit analysis was conducted. This analysis indicated a greater than two-fold net benefit associated with the application of LPR compared to remediation conducted without LPR (*i.e.,* assuming that domestic wells and livestock dugouts could be present).

Attachment:

LPR Report Figures 2023
Appendix A1 LPR Report

LEGEND

- All PHC concentrations meet Tier 1 guidelines
- One or more PHC concentrations exceed Tier 1 guidelines

PTAC

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Petroleum Hydrocarbons APECs (Soil)

MEMS, 2023

SCALE NA

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FIGURE
1

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LEGEND

- (green) All PHC concentrations meet Tier 1 guidelines
- (red) One or more PHC concentrations exceed Tier 1 guidelines

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Petroleum Hydrocarbons APECs (Groundwater)

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FIGURE
2

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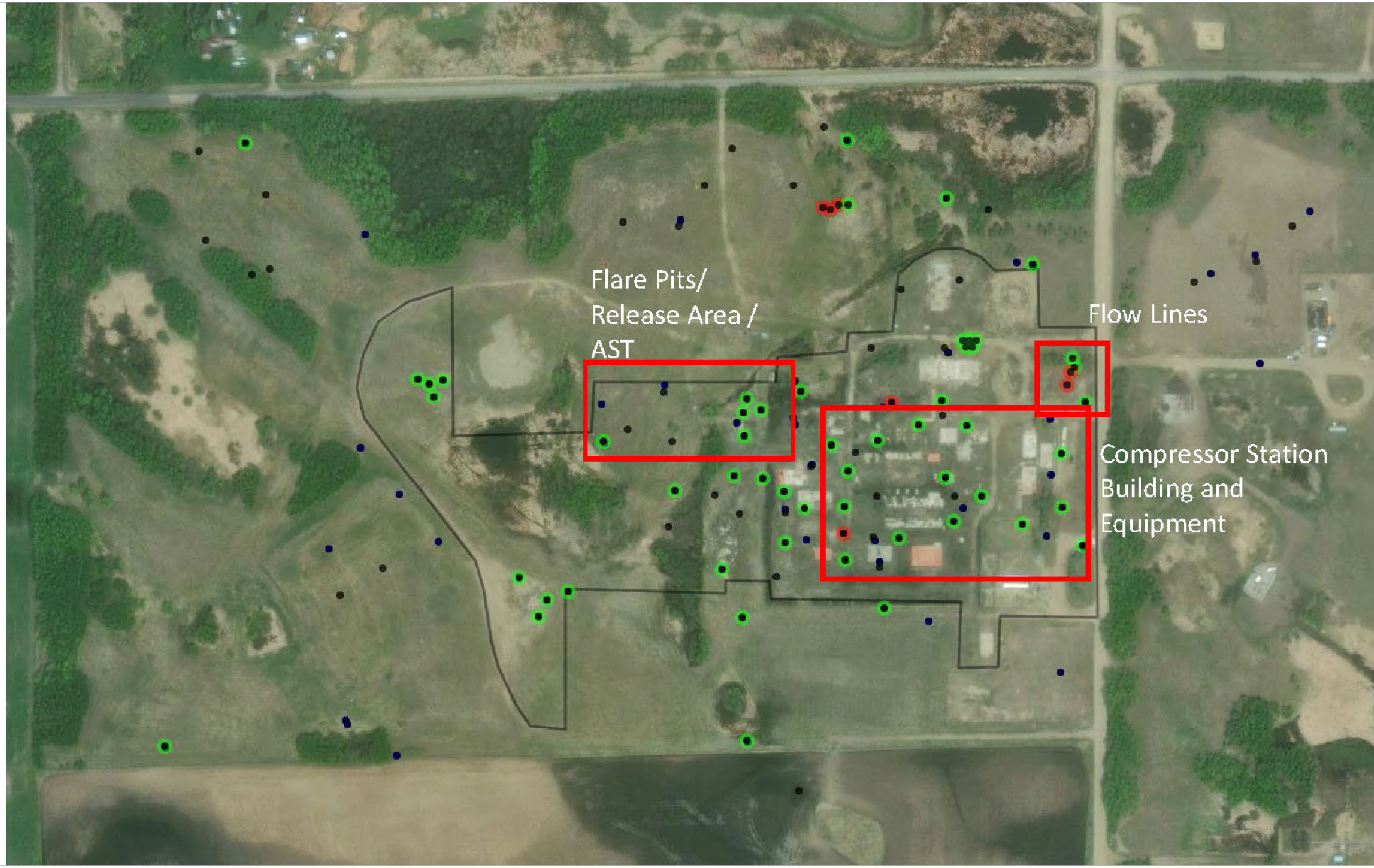

LEGEND

- All PHC concentrations meet Tier 1 guidelines
- One or more PHC concentrations exceed Tier 1 guidelines

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Salinity APECs (Soil)

MEMS, 2023

SCALE NA

FIGURE
3

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LEGEND

- All PHC concentrations meet Tier 1 guidelines
- One or more PHC concentrations exceed Tier 1 guidelines

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Salinity APECs (Groundwater)

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FIGURE
4

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COPC Screening Table

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
F3	0.3 - 3	340 - 5600	21	Compressor Station Building and Equipment,Western Infrastructure,Northwest Site,North Tank,APEC 2: Pipeline ROW,APEC 1: Pipeline ROW,AST	EDC,ML
F1-BTEX	1.2 - 4	26 - 430	19	Compressor Station Building and Equipment,103/09-32 Wellsite,Northwest Site,Infrastructure Buildings,APEC 3: Pipeline ROW	EDC,VI_b,VI_s
Ethylbenzene	2 - 4	0.15 - 1	8	103/09-32 Wellsite,Northwest Site,Infrastructure Buildings,Compressor Station Building and Equipment	DUA
F2	0.3 - 3.01	230 - 4500	7	Compressor Station Building and Equipment	EDC,FAL,DUA,VI_b,VI_s,ML
Benzene	3.01 - 4	0.085 - 0.32	6	103/09-32 Wellsite,Compressor Station Building and Equipment,APEC 3: Pipeline ROW	FAL,LW,DUA,VI_b,VI_s
F4	0.3 - 1.2	3800 - 9200	5	Compressor Station Building and Equipment,North Tank	EDC,WSF
Toluene	3.4 - 3.4	0.14 - 0.14	1	APEC 3: Pipeline ROW	FAL

BG = Background, EDC = Ecological Direct Contact, DUA = Domestic Use Aquifer, FAL = Freshwater Aquatic Life, VI_b = Vapour Inhalation (basement), VI_s = Vapour Inhalation (slab on grade), ML = Management Limit, HDC = Human Direct Contact, IW = Irrigation Water, LW = Livestock Water, LSF = Livestock Soil and Food Ingestion, WW = Wildlife Water, NEC = Nutrient Energy Cycling, OMH = Offsite Migration Human, WSF = Wildlife Soil and Food Ingestion, OME = Offsite Migration Ecological, GZML = Green Zone Management Limits

All values are reported in mg/kg unless otherwise stated.

Media: Soil
APEC: Compressor and Equipment Buildings
COPC Group: PHC
Guidelines: Tier 1 - Ag, Coarse Soil/Subsoil
Area = 13,245 m2 inner polygon with exceedances

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EAST Output Soil (APEC 1)

MEMS, 2023

SCALE NA

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FIGURE 5

Criteria Selection

Province: Alberta

Guidelines: Tier 1

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Assessment/Remediation: (•) Assessment ( ) Remediation

Data Filters

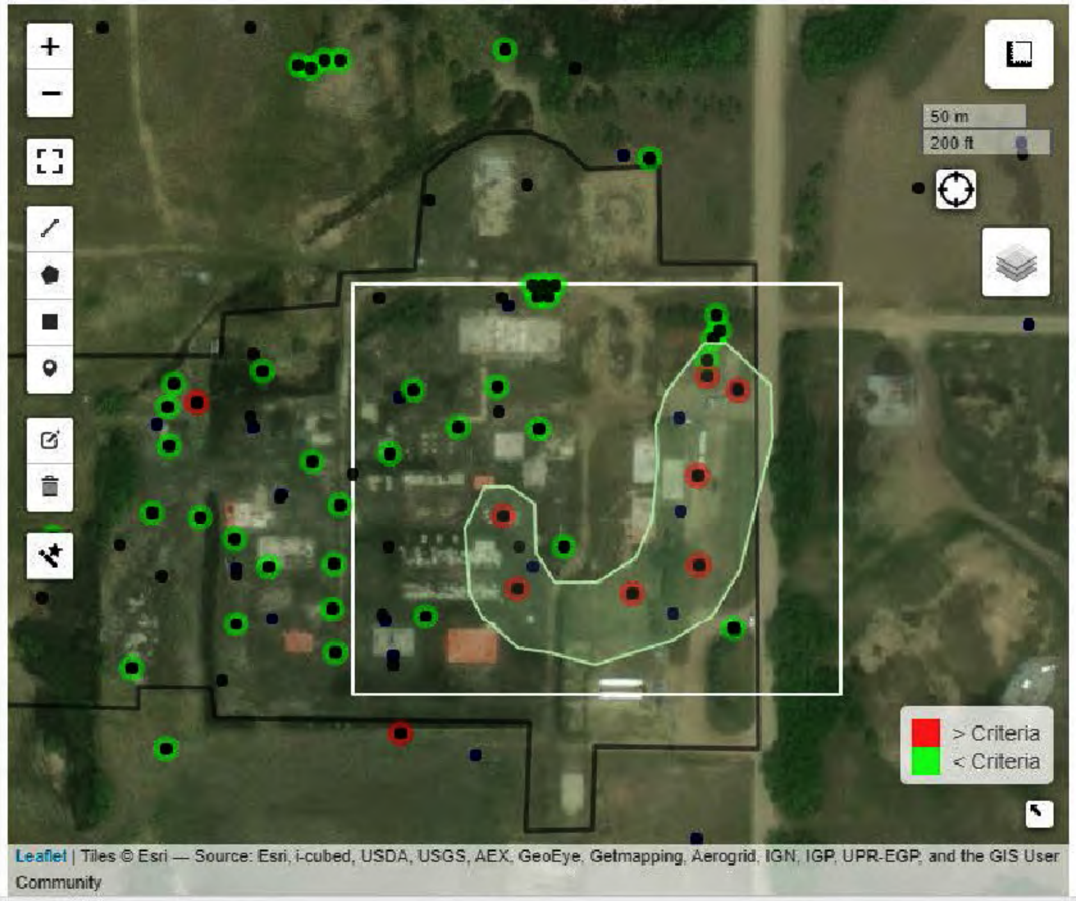
APEC

Sample Point

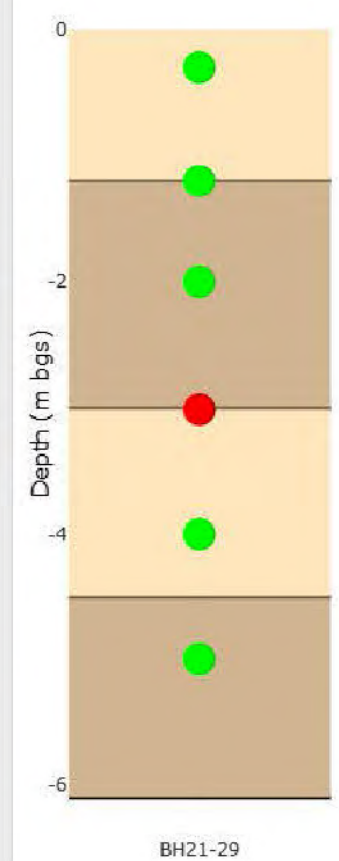
Sample Date: 2003-01-14 to 2023-01-09

Sample Depth (m bgs)

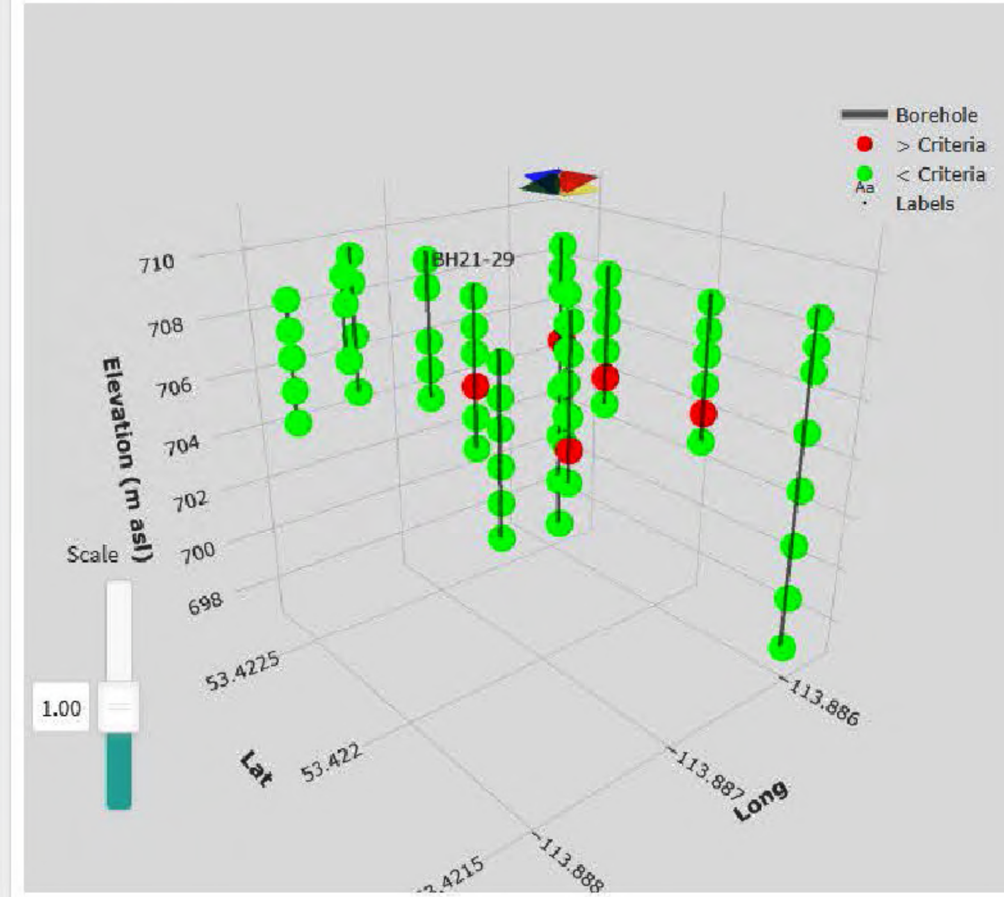
Site Map



Lithology



3D Distribution



COPC Screening Table

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
Ethylbenzene	2 - 4	0.15 - 1	8	103/09-32 Wellsite,Northwest Site,Infrastructure Buildings,Compressor Station Building and Equipment	DUA
Benzene	3.01 - 4	0.085 - 0.32	6	103/09-32 Wellsite,Compressor Station Building and Equipment,APEC 3: Pipeline ROW	FAL,LW,DUA,VI_b,VI_s
Toluene	3.4 - 3.4	0.14 - 0.14	1	APEC 3: Pipeline ROW	FAL

Media: Soil
APEC: Compressor and Equipment Buildings
COPC Group: PHC (BTEX only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Area = 13,245 m2 inner polygon with exceedances

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EAST Output Soil (APEC 1)

MEMS, 2023

SCALE NA

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FIGURE 6

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Criteria Selection

Province: Alberta

Guidelines: Tier 1

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Assessment/Remediation: (●) Assessment ( ) Remediation

Data Filters

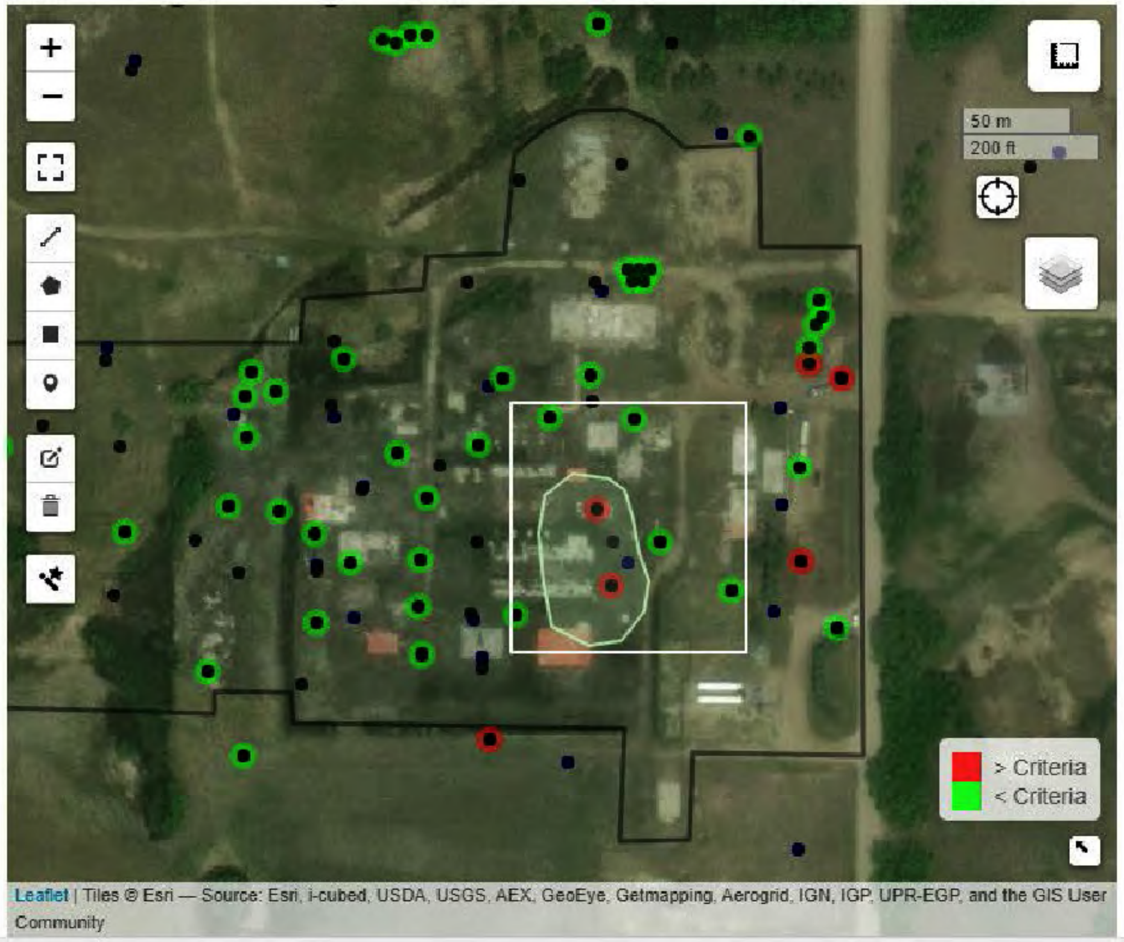
APEC

Sample Point

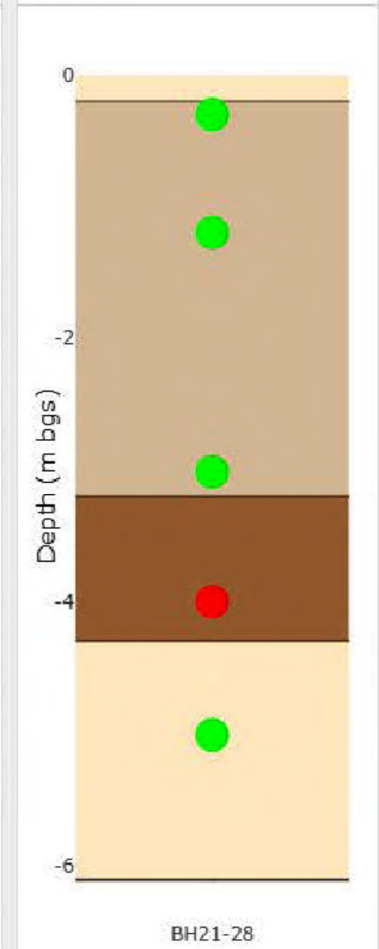
Sample Date: 2003-01-14 to 2023-01-09

Sample Depth (m bgs)

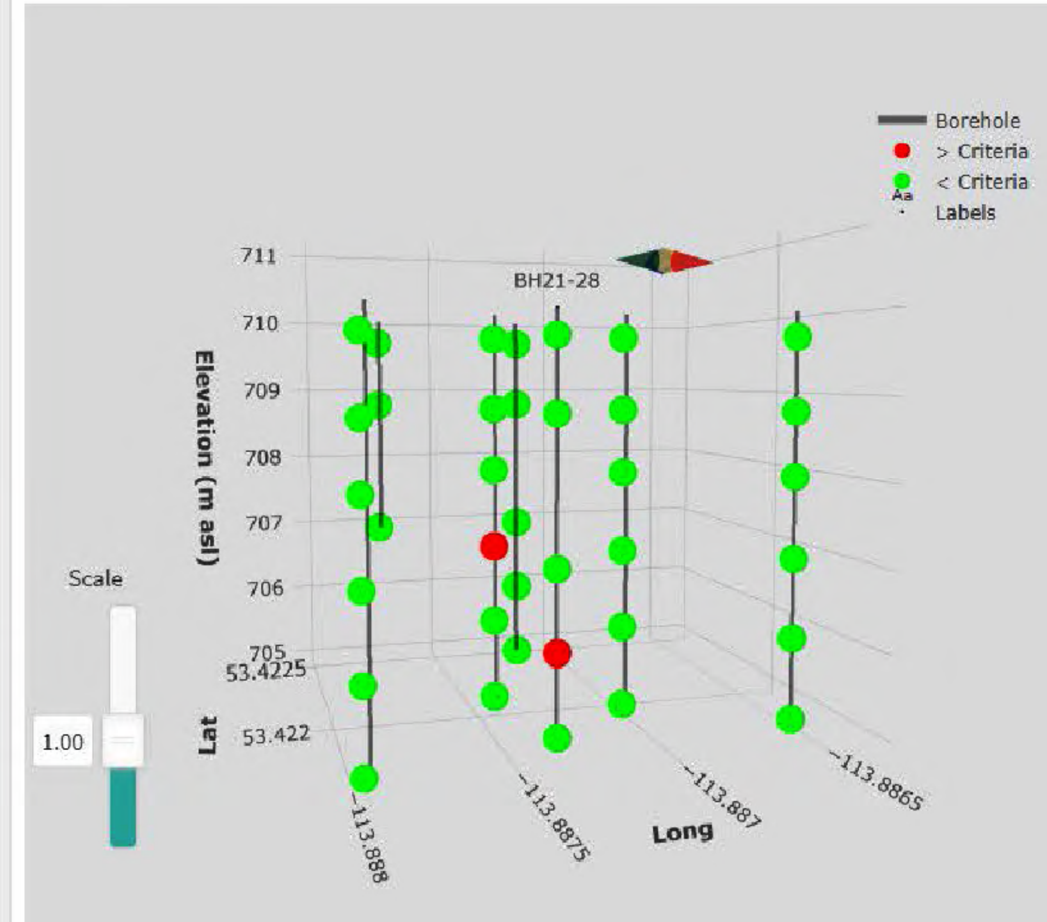
Site Map



Lithology



3D Distribution



COPC Screening Table

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
Benzene	3.01 - 4	0.085 - 0.32	6	103/09-32 Wellsite,Compressor Station Building and Equipment,APEC 3: Pipeline ROW	FAL,LW,DUA,VI_b,VI_s

BG = Background, EDC = Ecological Direct Contact, DUA = Domestic Use Aquifer, FAL = Freshwater Aquatic Life, VI_b = Vapour Inhalation (basement), VI_s = Vapour Inhalation (slab on grade), ML = Management Limit, HDC = Human Direct Contact, IW = Irrigation Water, LW = Livestock Water, LSF = Livestock Soil and Food Ingestion, WW = Wildlife Water, NEC = Nutrient Energy Cycling, OMH = Offsite Migration Human, WSF = Wildlife Soil and Food Ingestion, OME = Offsite Migration Ecological, GZML = Green Zone Management Limits

All values are reported in mg/kg unless otherwise stated.

Media: Groundwater
APEC: Compressor and Equipment Buildings
COPC Group: PHC (BTEX, F1-F2)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil

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EAST Output Soil Benzene Only (APEC 1)

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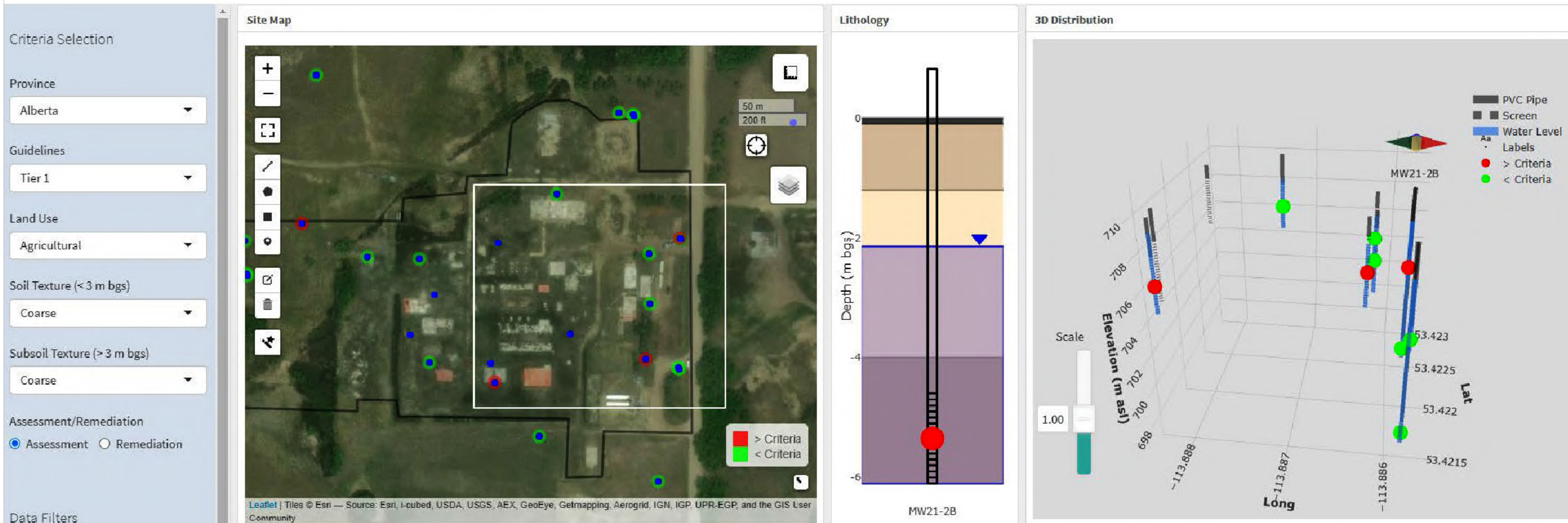
FIGURE 7



COPC Screening Table

Contaminant	Concentration Range	# of Samples	APEC	Pathway
Ethylbenzene	0.0026 - 0.019	4	Compressor Station Building and Equipment	DUA
F1-BTEX	1.3 - 3	4	Compressor Station Building and Equipment	DUA,VI_b
Benzene	0.0061 - 0.0061	1	Compressor Station Building and Equipment	DUA
F2	3.7 - 3.7	1	Flare Pit	EDC,FAL,DUA,VI_b

All values are reported in mg/L, unless otherwise stated.

Media: Soil
APEC: Compressor and Equipment Buildings
COPC Group: PHC (BTEX only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Area = 13,245 m2 inner polygon with exceedances

PTAC
Alberta
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EAST Output BTEX, 1-F2 (APEC 1)

MEMS, 2023

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FIGURE 8

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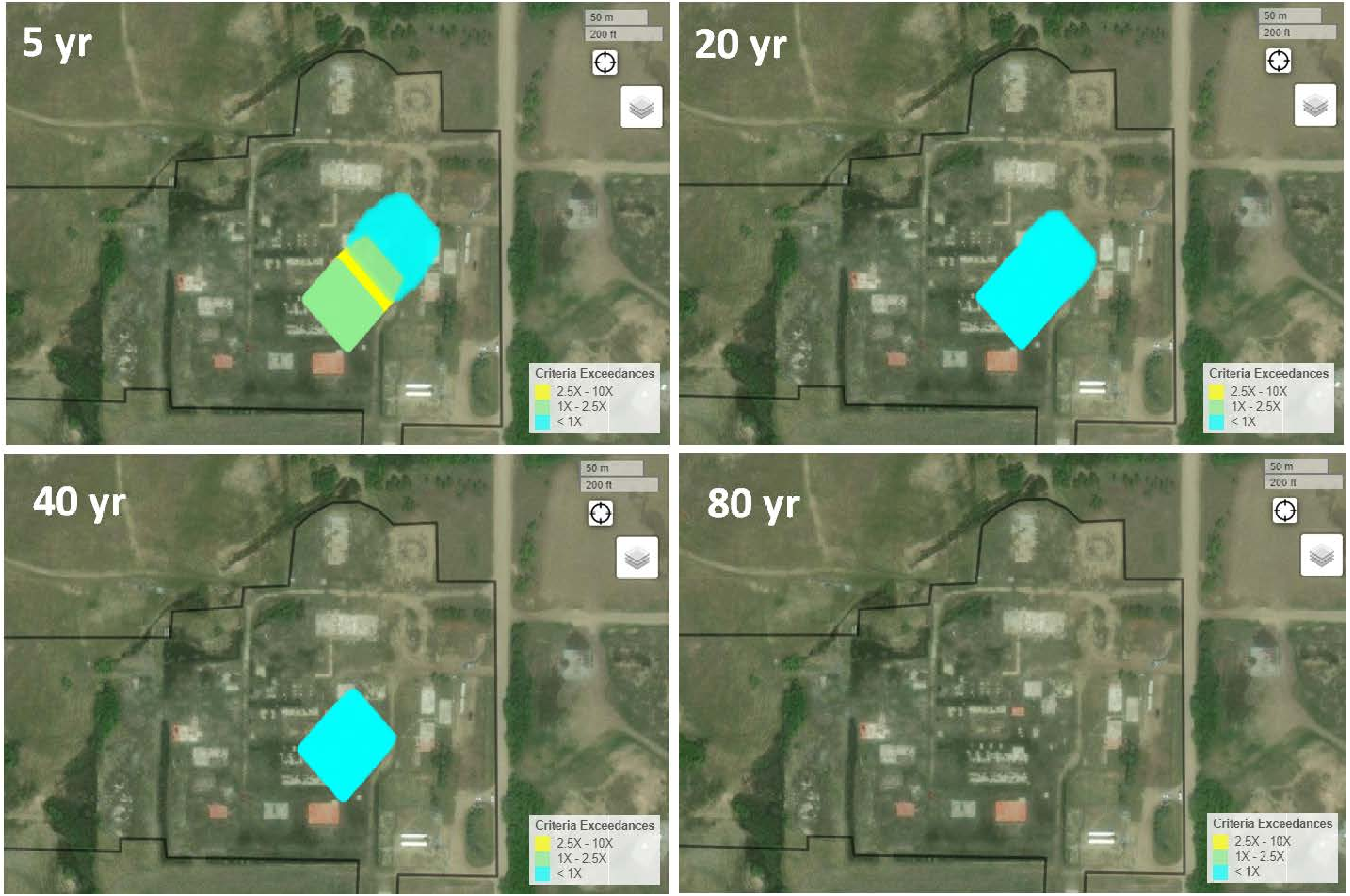

APEC: Compressor and Equipment Buildings
COPC Group: PHC (Benzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.32 mg/kg
Plume Length (25m) > BH to BH range
Source Area = 2,828 m^2
Source thickness = 2 m
GW Flow – SW to NE

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NAT Outputs (APEC 1)

MEMS, 2023

SCALE NA

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FIGURE
9

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0.00000 %	0.00000 %	0.00000 %	0.00000 %	0.00400 %	0.00900 %
Dugout	Water Well (< 10 m bgs)	Water Well (10 to < 20 m bgs)	Water Well (20 to < 30 m bgs)	Water Well (> 30 m bgs)	Water Well (All depths)
Time = 29 yrs	Time = 29 yrs	Time = 29 yrs	Time = 29 yrs	Time = 29 yrs	Time = 29 yrs

Province: Alberta

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Depth to groundwater (m bgs): 2.14

Topographical slope at Site: < 6%

Distance of nearest road to Site: > 50 m

Receptor Evaluation

Is there currently a domestic use water well within the footprint of the Site? No

Is there a dugout within the footprint of the Site? No

Distance to nearest aquatic life

Map

Results

Copy CSV Excel PDF Print

Previous 1 Next

Show 20 entries

Search:

Inputs	User Defined Values
Model run time	29
Maximum Projected Area of Potential Environmental Concern (APEC)	4,932
Land Use Criteria	Alberta
Contaminants of Concern	F2, F3, F4, F1-BTEX, Ethylbenzene, Benzene
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	<6%
What is the distance to the closest road?	>50m

APEC: Compressor and Equipment Buildings
COPC Group: PHC (Benzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.32 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 2828 m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 29 yrs

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Lower Probability Receptor

LPR Outputs (APEC 1)

MEMS, 2023

SCALE NA

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FIGURE 10

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Criteria Selection

Province: Alberta

Guidelines: Tier 1

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Assessment/Remediation: (•) Assessment ( ) Remediation

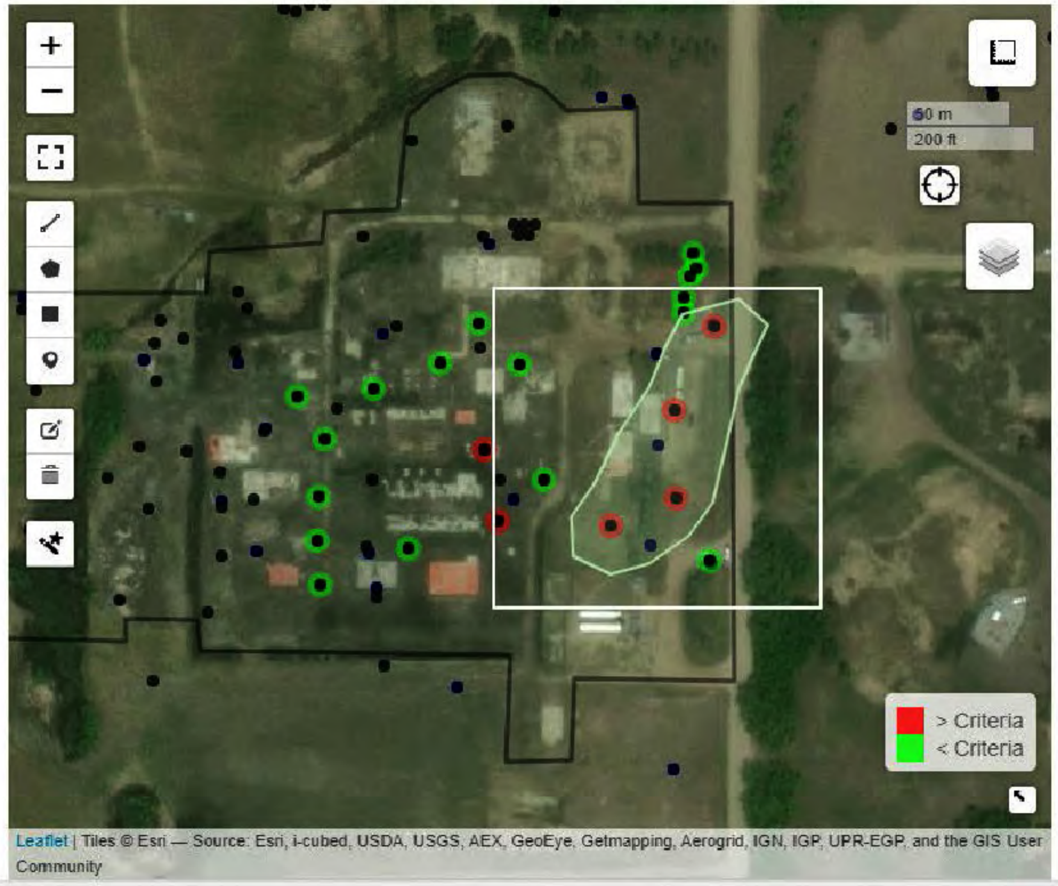
Data Filters

APEC
- Compressor Station Building and Equipment
- APEC 3: Pipeline ROW
- Infrastructure Buildings

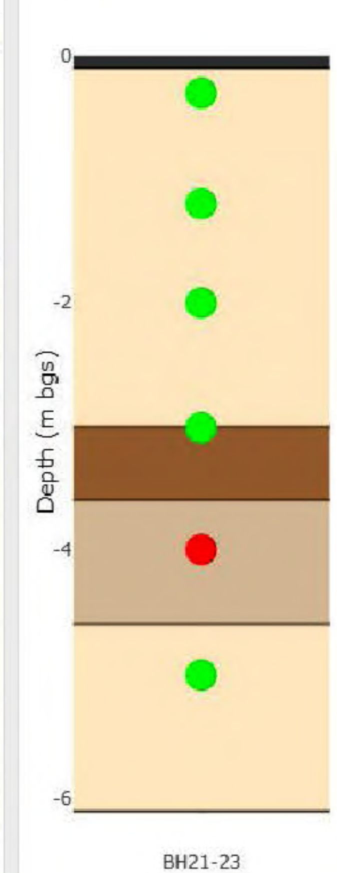
Sample Point

Sample Date

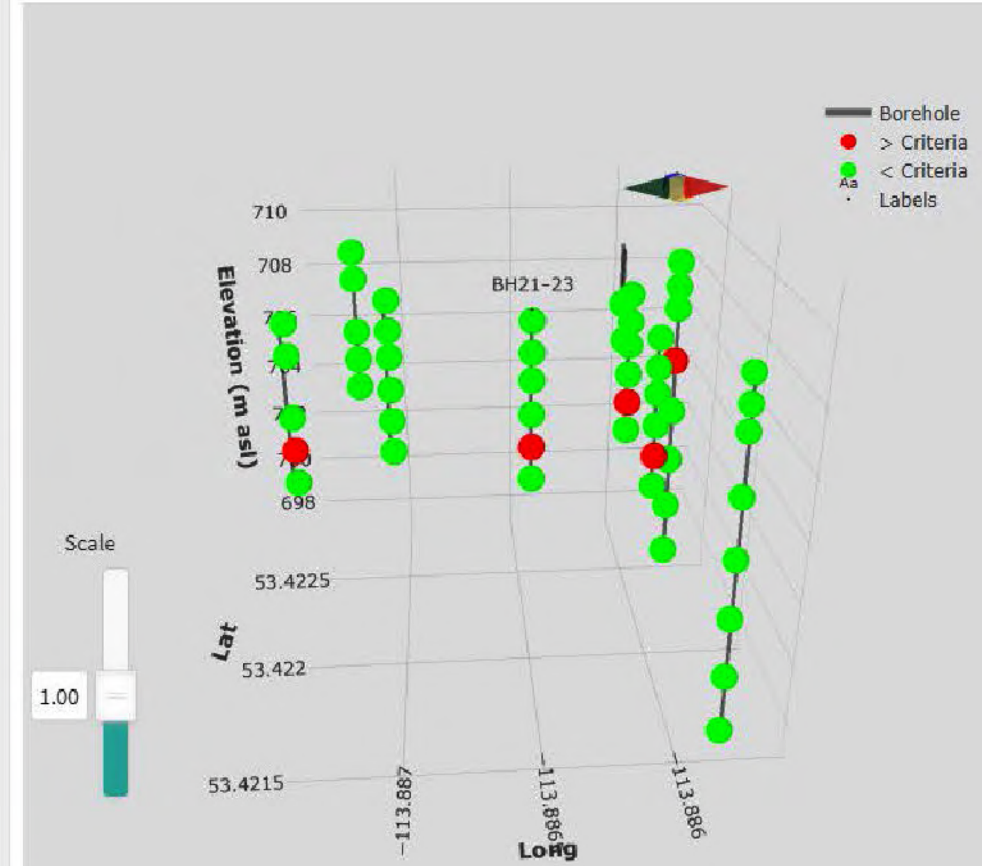
Site Map



Lithology



3D Distribution



COPC Screening Table

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
Ethylbenzene	3.01 - 4	0.17 - 0.88	6	Infrastructure Buildings,Compressor Station Building and Equipment	DUA

BG = Background, EDC = Ecological Direct Contact, DUA = Domestic Use Aquifer, FAL = Freshwater Aquatic Life, VI_b = Vapour Inhalation (basement), VI_s = Vapour Inhalation (slab on grade), ML = Management Limit, HDC = Human Direct Contact, IW = Irrigation Water, LW = Livestock Water, LSF = Livestock Soil and Food Ingestion, WW = Wildlife Water, NEC = Nutrient Energy Cycling, OMH = Offsite Migration Human, WSF = Wildlife Soil and Food Ingestion, OME = Offsite Migration Ecological, GZML = Green Zone Management Limits
All values are reported in mg/kg unless otherwise stated.

Media: Soil
APEC: Compressor and Equipment Buildings
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 - Ag, Coarse Soil/Subsoil
Area - 5,000 m2 inner polygon with exceedances

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

PTAC
Alberta
Lower Probability Receptor

EAST Output Ethylbenzene Only (APEC 1)

MEMS, 2023

SCALE NA

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FIGURE 11

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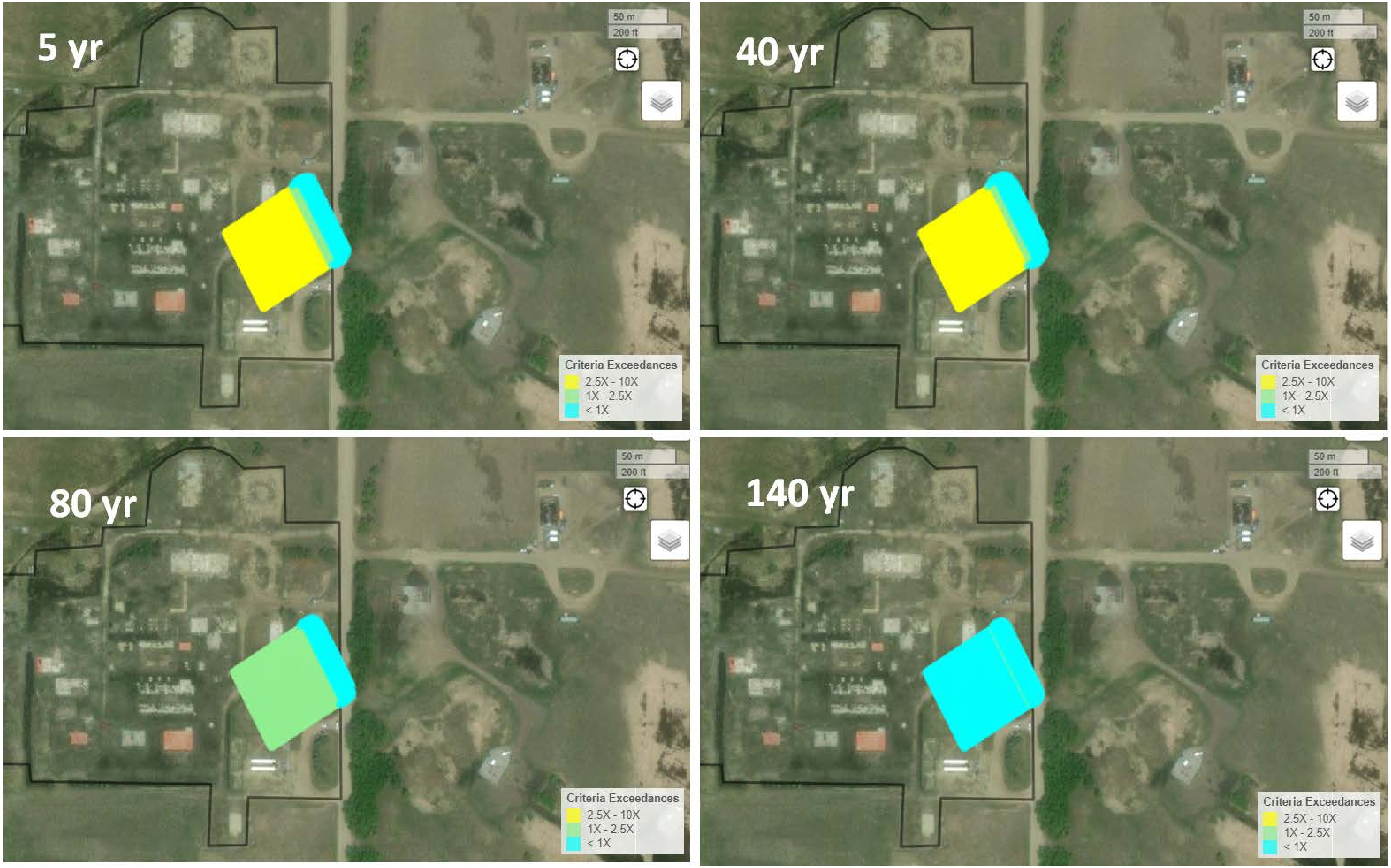

APEC: Compressor and Equipment Buildings
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.88 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 5,000 m2
Source thickness = 2 m
GW Flow – SW to NE

PTAC
Alberta
Lower Probability Receptor

NAT Outputs Ethylbenzene Only (APEC 1)

MEMS, 2023

SCALE NA

MILLENNIUM EMS Solutions Ltd.

PROJECT: 220-00042-00
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FIGURE 12

Province: Alberta

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Depth to groundwater (m bgs): 2.14

Topographical slope at Site: < 6%

Distance of nearest road to Site: > 50 m

Receptor Evaluation

Is there currently a domestic use water well within the footprint of the Site? No

Is there a dugout within the footprint of the Site? No

Distance to nearest aquatic life receptor (m)

0.00300 %	0.00100 %	0.00900 %	0.02700 %	0.26500 %	0.61500 %
Dugout	**Water Well (< 10 m bgs)**	**Water Well (10 to < 20 m bgs)**	**Water Well (20 to < 30 m bgs)**	**Water Well (> 30 m bgs)**	**Water Well (All depths)**
Time = 203 yrs	Time = 203 yrs	Time = 203 yrs	Time = 203 yrs	Time = 203 yrs	Time = 203 yrs

Map

Results

Copy CSV Excel PDF Print

Previous 1 Next

Show 20 entries

Search:

Inputs	User Defined Values
Model run time	203
Maximum Projected Area of Potential Environmental Concern (APEC)	6,038
Land Use Criteria	Alberta
Contaminants of Concern	Ethylbenzene
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	<6%
What is the distance to the closest road?	>50m

-No Site Modification
APEC: Compressor and Equipment Buildings
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.88 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 5,976m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 203 yrs

PTAC
Alberta
Lower Probability Receptor

LPR Outputs Ethylbenzene Only (APEC 1)

MEMS, 2023

SCALE NA

MILLENNIUM EMS Solutions Ltd.

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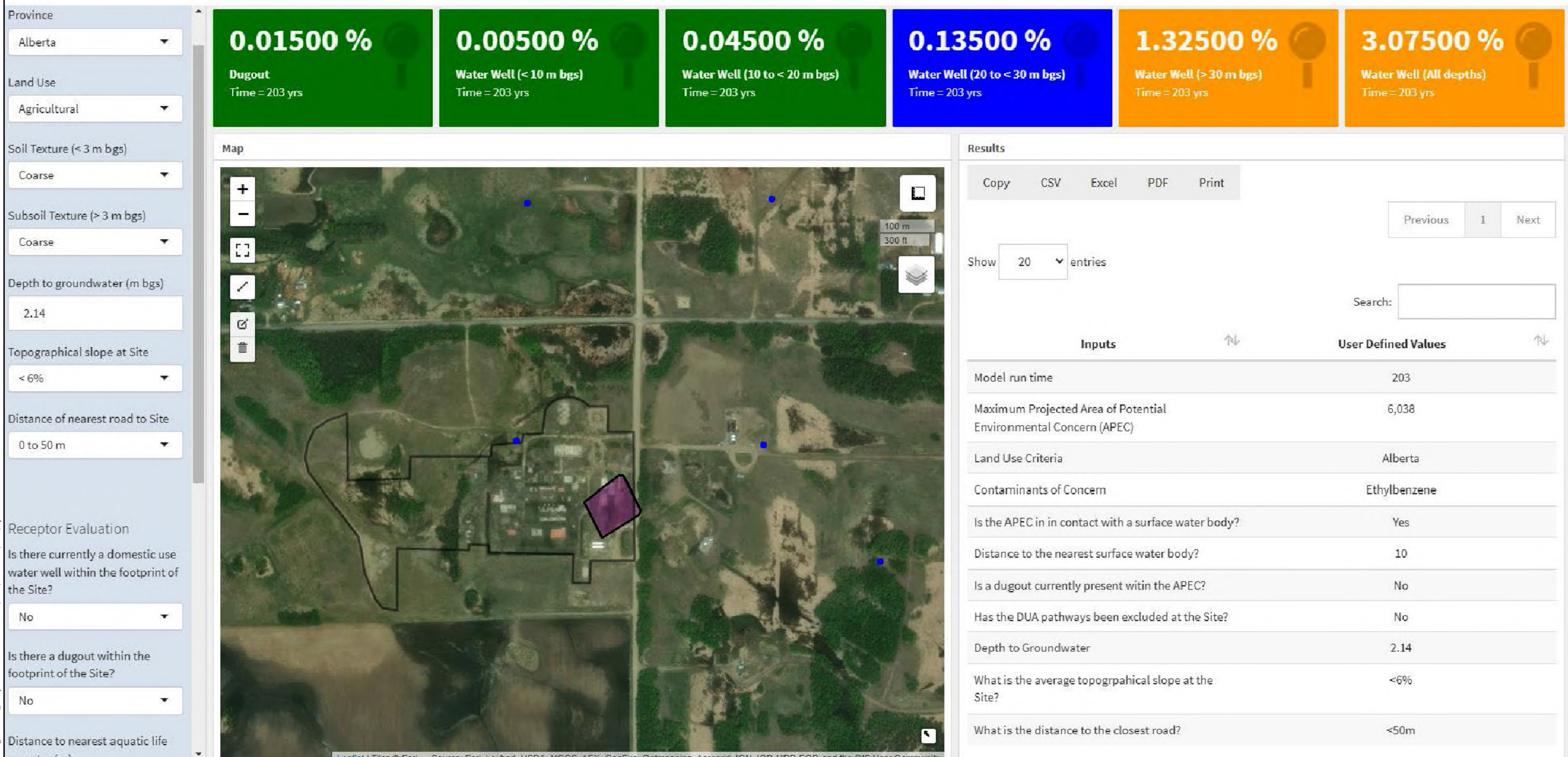
FIGURE 13



-Distance to nearest road modification = 0-50 m (Water well probability increased)
APEC: Compressor and Equipment Buildings
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.88 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 5,976m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 203 yrs

PTAC
Alberta
Lower Probability Receptor

LPR Outputs (APEC 1) (Ethylbenzene only)

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MEMS, 2023

SCALE NA

FIGURE 14

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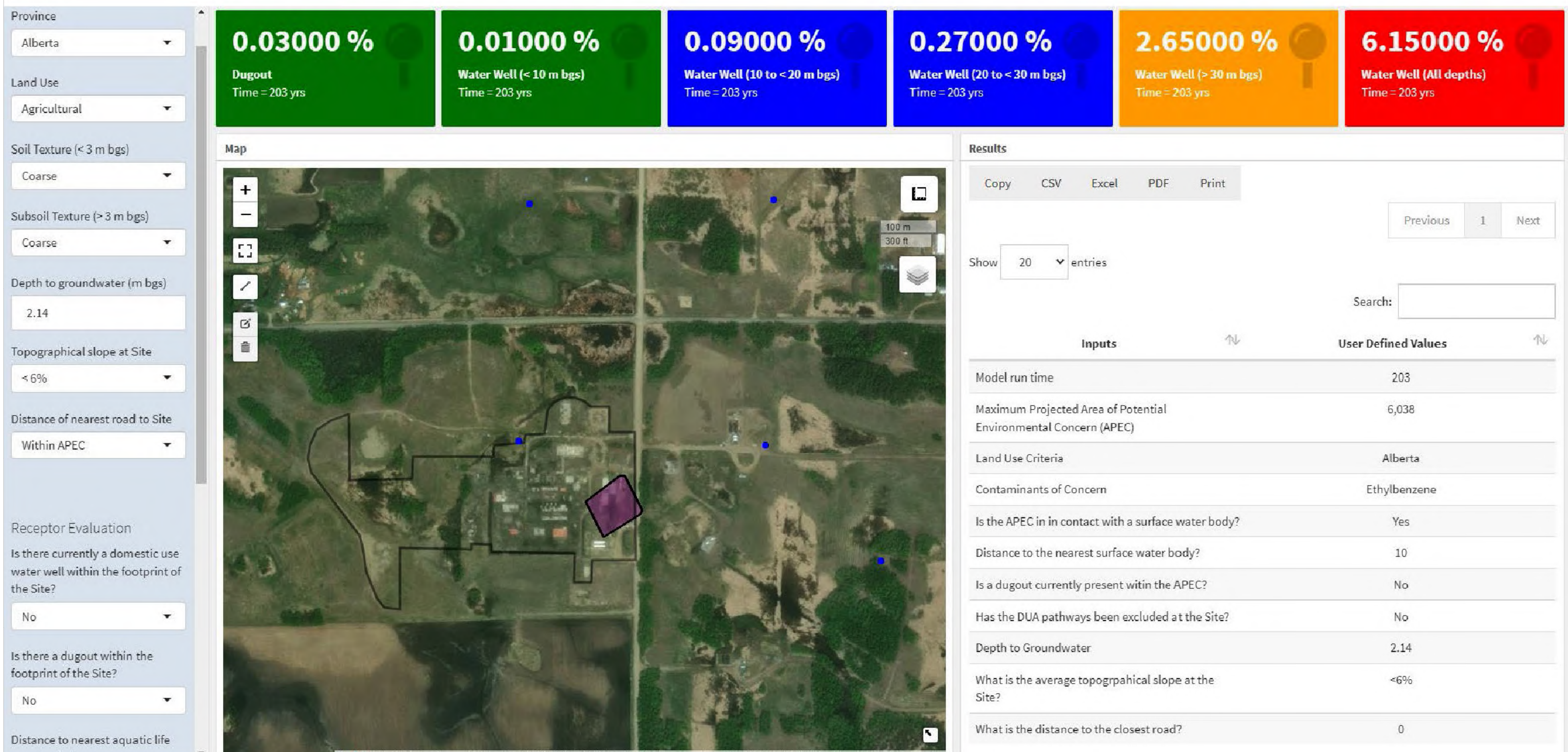

– Distance to nearest road modification = Road within APEC (Water well probability increased)
APEC: Compressor and Equipment Buildings
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.88 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 5,976m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 203 yrs

PTAC
Alberta
Lower Probability Receptor

LPR Outputs (APEC 1) Distance to nearest road modification = Road within APEC (Water well probability increased)

MEMS, 2023

SCALE NA

MILLENNIUM EMS Solutions Ltd.
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FIGURE
15

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Province
Alberta

Land Use
Agricultural

Soil Texture (< 3 m bgs)
Coarse

Subsoil Texture (> 3 m bgs)
Coarse

Depth to groundwater (m bgs)
2.14

Topographical slope at Site
> 6% to < 30%

Distance of nearest road to Site
> 50 m

Receptor Evaluation

Is there currently a domestic use water well within the footprint of the Site?
No

Is there a dugout within the footprint of the Site?
No

Distance to nearest aquatic life receptor (m)

0.0015 %	0.001 %	0.009 %	0.027 %	0.265 %	0.615 %
Dugout	**Water Well (< 10 m bgs)**	**Water Well (10 to < 20 m bgs)**	**Water Well (20 to < 30 m bgs)**	**Water Well (> 30 m bgs)**	**Water Well (All depths)**
Time = 203 yrs	Time = 203 yrs	Time = 203 yrs	Time = 203 yrs	Time = 203 yrs	Time = 203 yrs

Map

Results

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Previous 1 Next

Show 20 entries

Search:

Inputs	User Defined Values
Model run time	203
Maximum Projected Area of Potential Environmental Concern (APEC)	6,038
Land Use Criteria	Alberta
Contaminants of Concern	Ethylbenzene, F2, F3, F4, F1-BTEX, Toluene, Benzene
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	>6-<30%
What is the distance to the closest road?	>50m

– Topographical slope modification= >6 <30% (Dugout probability decreased)
APEC: Compressor and Equipment Buildings
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.88 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 5,976m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 203 yrs

PTAC
Alberta
Lower Probability Receptor

LPR Outputs (APEC 1) – Topographical slope modification= >6 <30% (Dugout probability decreased)

MEMS, 2023

SCALE NA

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FIGURE 16

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Criteria Selection

Province: Alberta

Guidelines: Tier 1

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Assessment/Remediation: (•) Assessment ( ) Remediation

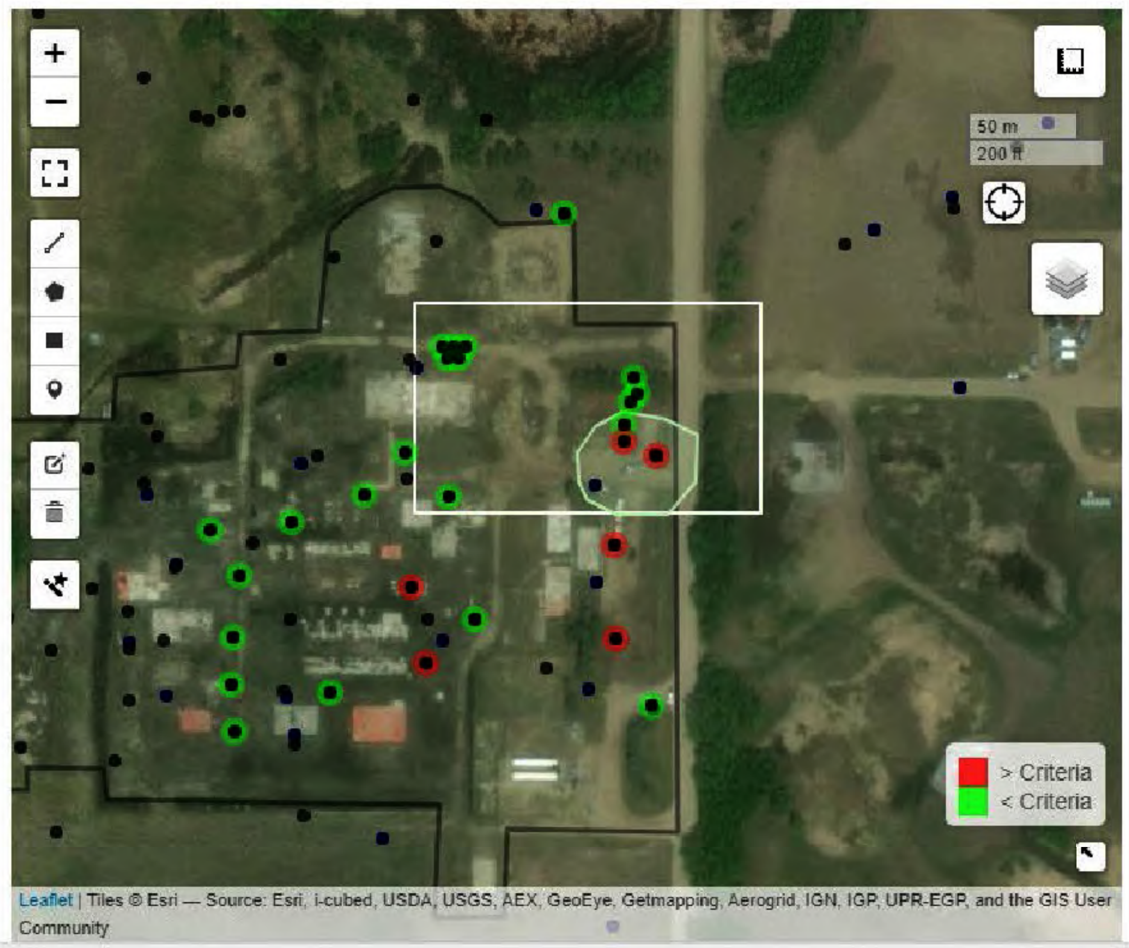
Data Filters

APEC

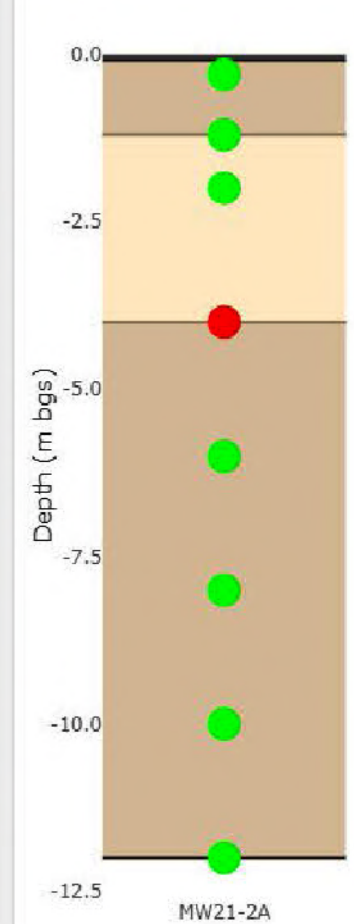
- Compressor Station Building and Equipment
- APEC 3: Pipeline ROW
- APEC 2: Pipeline ROW
- North Tank
- Remote Sump

Sample Point

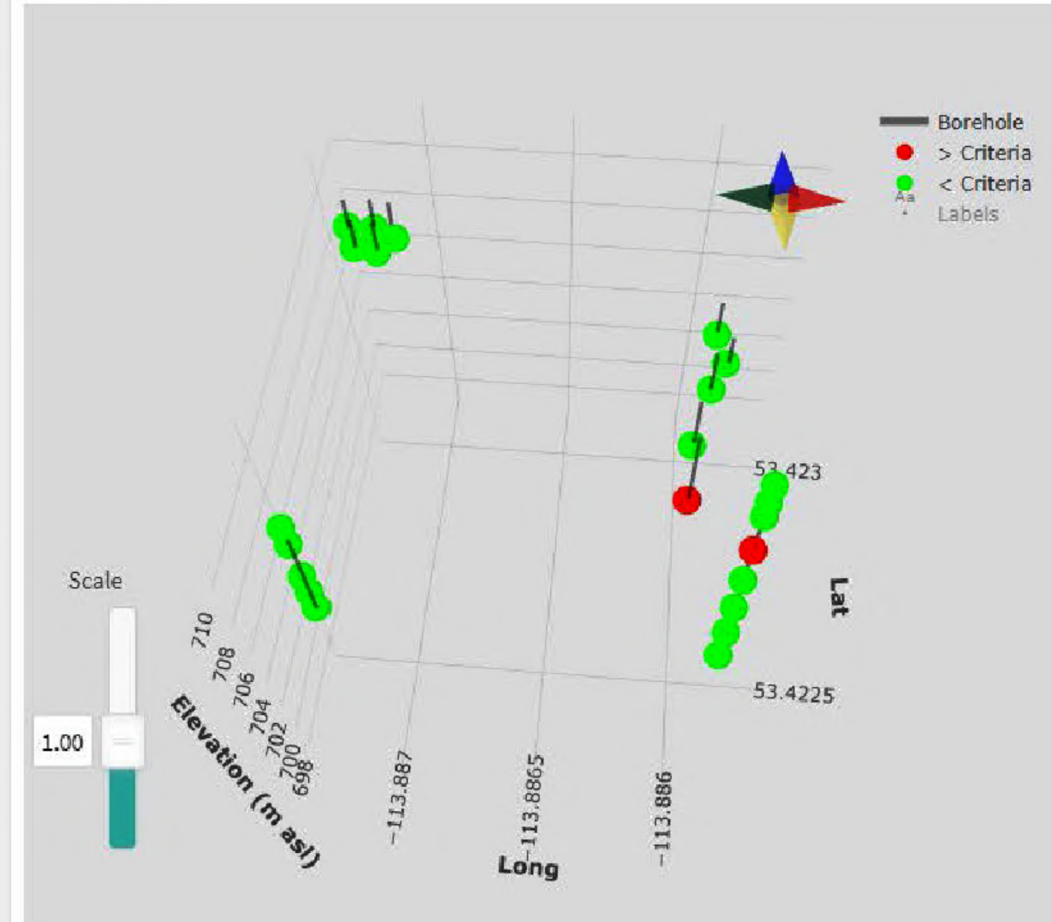
Site Map



Lithology



3D Distribution



COPC Screening Table

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
Ethylbenzene	3.01 - 4	0.17 - 0.88	5	Compressor Station Building and Equipment	DUA
Benzene	3.01 - 4	0.085 - 0.32	5	Compressor Station Building and Equipment,APEC 3: Pipeline ROW	FAL,LW,DUA,VI_b,VI_s
Toluene	3.4 - 3.4	0.14 - 0.14	1	APEC 3: Pipeline ROW	FAL

BG = Background, EDC = Ecological Direct Contact, DUA = Domestic Use Aquifer, FAL = Freshwater Aquatic Life, VI_b = Vapour Inhalation (basement), VI_s = Vapour Inhalation (slab on grade), ML = Management Limit, HDC = Human Direct Contact, IW = Irrigation Water, LW = Livestock Water, LSF = Livestock Soil and Food Ingestion, WW = Wildlife Water, NEC = Nutrient Energy Cycling, OMH = Offsite Migration Human, WSF = Wildlife Soil and Food Ingestion, OME = Offsite Migration Ecological, GZML = Green

– Topographical slope modification= >6 <30% (Dugout probability decreased)
APEC: Compressor and Equipment Buildings
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.88 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 5,976m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 203 yrs

PTAC
Alberta
Lower Probability Receptor

EAST Output (APEC 2) (BTEX)

MEMS, 2023

SCALE NA

MILLENNIUM EMS Solutions Ltd.

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FIGURE 17

Criteria Selection

Province

Alberta

Guidelines

Tier 1

Land Use

Agricultural

Soil Texture (< 3 m bgs)

Coarse

Subsoil Texture (> 3 m bgs)

Coarse

Assessment/Remediation

(•) Assessment ( ) Remediation

Data Filters

APEC

Compressor Station Building and Equipment

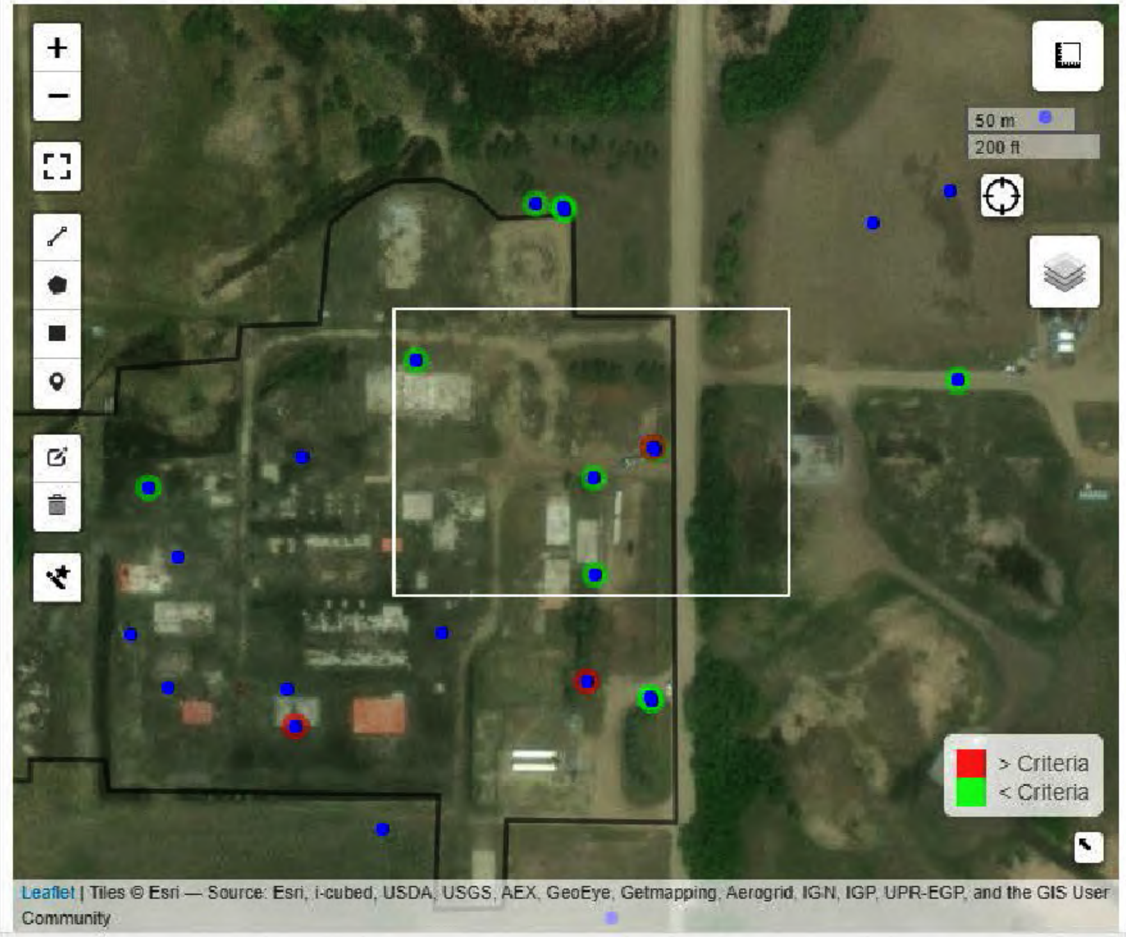
APEC 3: Pipeline ROW

APEC 2: Pipeline ROW

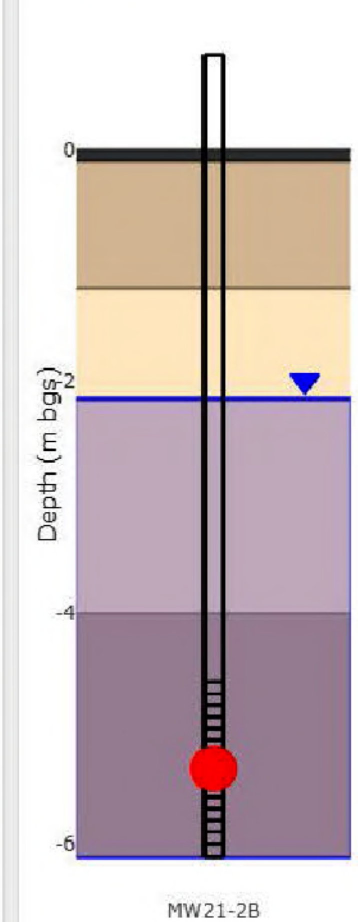
North Tank | Remote Sump

Sample Point

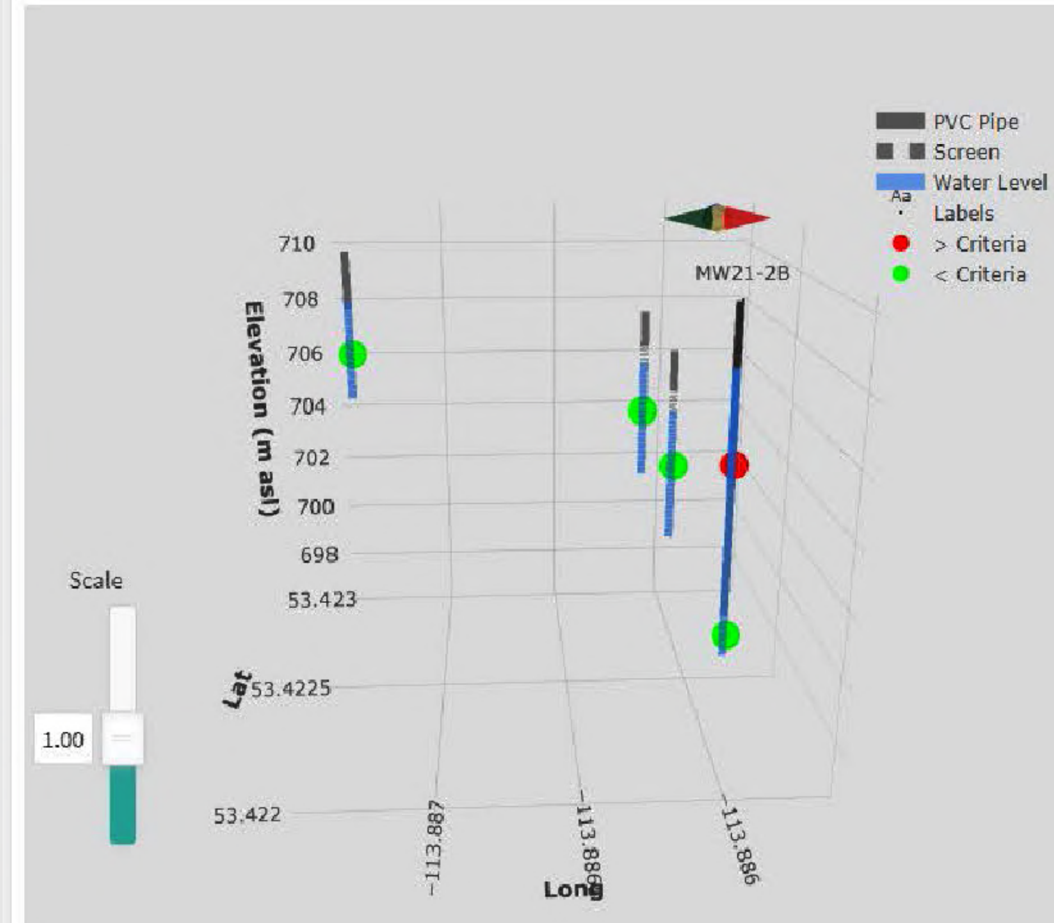
Site Map



Lithology



3D Distribution



COPC Screening Table

Contaminant	Concentration Range	# of Samples	APEC	Pathway
Ethylbenzene	0.0026 - 0.0053	3	Compressor Station Building and Equipment	DUA
Benzene	0.0061 - 0.0061	1	Compressor Station Building and Equipment	DUA

All values are reported in mg/L, unless otherwise stated.

Media: Groundwater
APEC: Flow Lines
COPC Group: PHC (BTEX)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil

PTAC
Alberta
Lower Probability Receptor

EAST Output (APEC 2) (BTEX)

MEMS, 2023

SCALE NA

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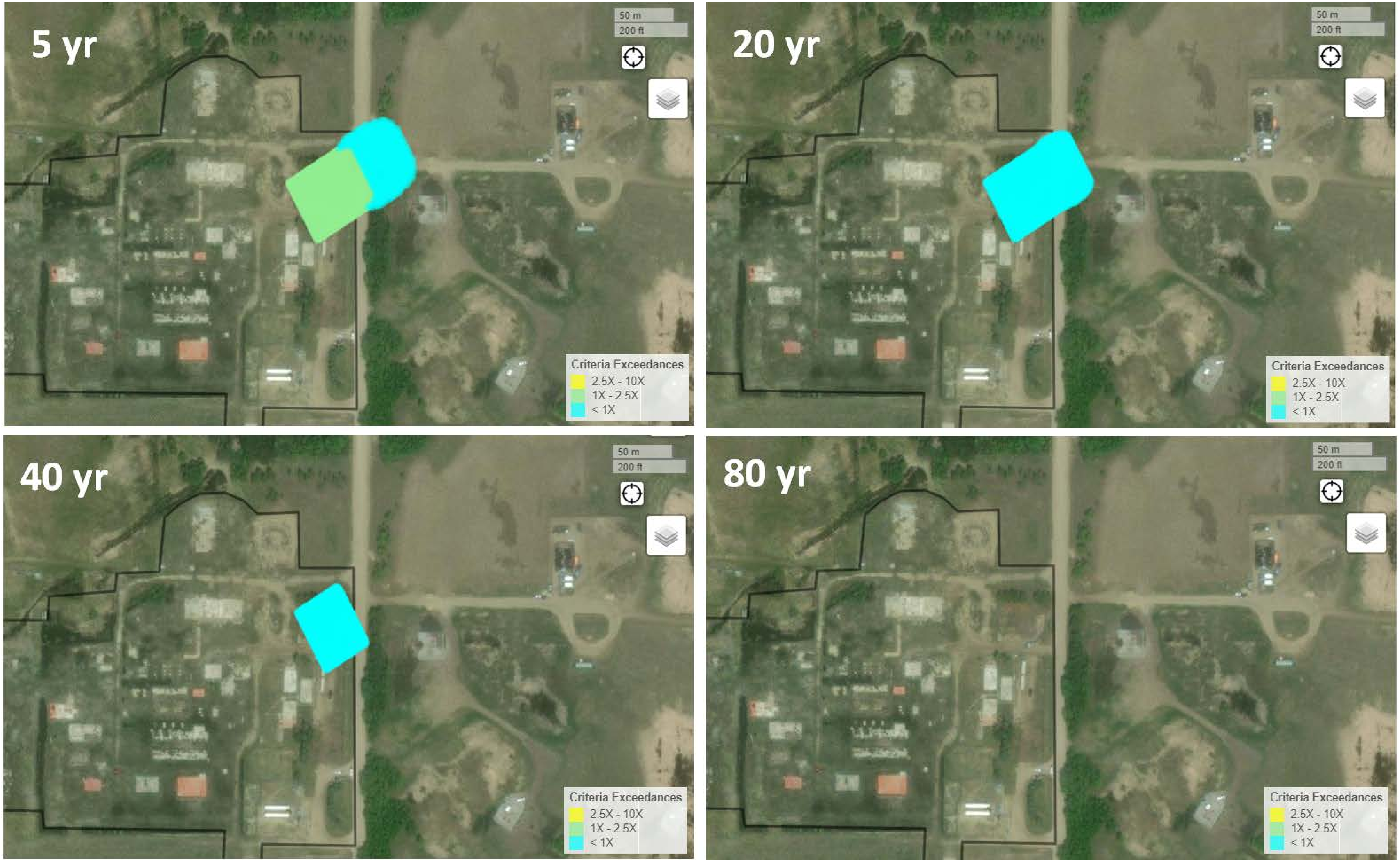
FIGURE 18



APEC: Flow Lines
COPC Group: PHC (Benzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.11 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 2080 m2
Source thickness = 2 m
GW Flow – SW to NE

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

PTAC
Alberta
Lower Probability Receptor

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NAT Outputs (APEC 2) (Benzene only)

MEMS, 2023

SCALE NA

FIGURE
19

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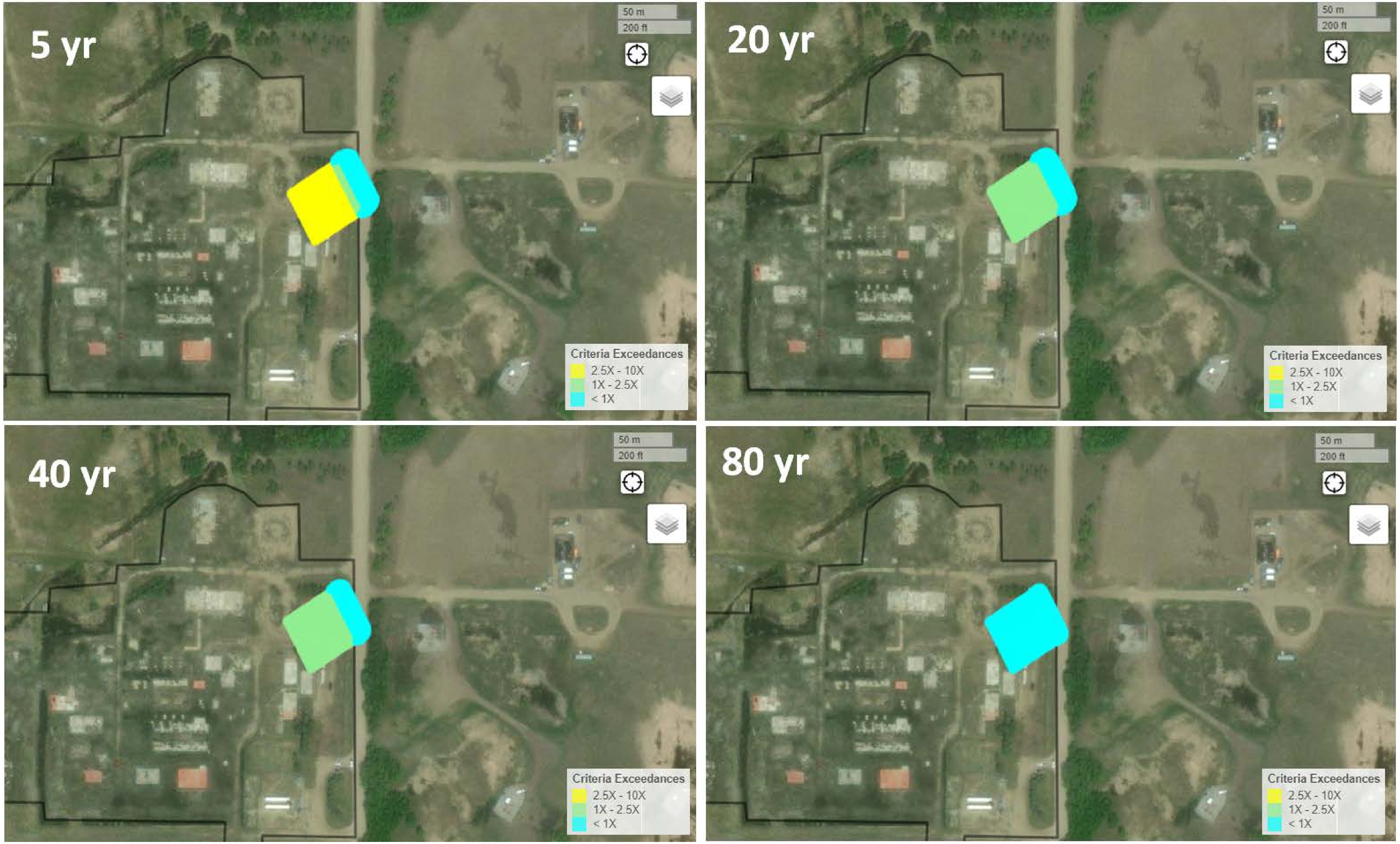

APEC: Flow Lines
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.32 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 2080 m2
Source thickness = 2 m
GW Flow – SW to NE

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

PTAC
Alberta
Lower Probability Receptor

NAT Outputs (APEC 2) (Ethylbenzene only)

MEMS, 2023

SCALE NA

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FIGURE
20

Province: Alberta

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Depth to groundwater (m bgs): 2.14

Topographical slope at Site: < 6%

Distance of nearest road to Site: > 50 m

Receptor Evaluation

Is there currently a domestic use water well within the footprint of the Site? No

Is there a dugout within the footprint of the Site? No

Distance to nearest aquatic life

0 %	0.00000 %	0 %	0 %	0.001 %	0.002 %
Dugout	Water Well (< 10 m bgs)	Water Well (10 to < 20 m bgs)	Water Well (20 to < 30 m bgs)	Water Well (> 30 m bgs)	Water Well (All depths)
Time = 19 yrs	Time = 19 yrs	Time = 19 yrs	Time = 19 yrs	Time = 19 yrs	Time = 19 yrs

Map

Results

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Previous 1 Next

Show 20 entries

Search:

Inputs	User Defined Values
Model run time	19
Maximum Projected Area of Potential Environmental Concern (APEC)	3,420
Land Use Criteria	Alberta
Contaminants of Concern	F2, F3, F4, F1-BTEX, Ethylbenzene, Toluene, Benzene
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	<6%
What is the distance to the closest road?	>50m

-No Site Modification
APEC: Flow Lines
COPC Group: PHC (Benzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.11 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 2080 m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 19 yrs

PTAC
Alberta
Lower Probability Receptor

LPR Outputs (APEC 2) - No Site Modification

MEMS, 2023

SCALE NA

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FIGURE 21

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Province: Alberta

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Depth to groundwater (m bgs): 2.14

Topographical slope at Site: < 6%

Distance of nearest road to Site: 0 to 50 m

Receptor Evaluation

Is there currently a domestic use water well within the footprint of the Site?: No

Is there a dugout within the footprint of the Site?: No

Distance to nearest aquatic life

0 %	0.00000 %	0 %	0 %	0.005 %	0.01 %
Dugout	**Water Well (< 10 m bgs)**	**Water Well (10 to < 20 m bgs)**	**Water Well (20 to < 30 m bgs)**	**Water Well (> 30 m bgs)**	**Water Well (All depths)**
Time = 19 yrs	Time = 19 yrs	Time = 19 yrs	Time = 19 yrs	Time = 19 yrs	Time = 19 yrs

Map

Results

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Previous 1 Next

Show 20 entries

Search:

Inputs	User Defined Values
Model run time	19
Maximum Projected Area of Potential Environmental Concern (APEC)	3,420
Land Use Criteria	Alberta
Contaminants of Concern	F2, F3, F4, F1-BTEX, Ethylbenzene, Toluene, Benzene
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	<6%
What is the distance to the closest road?	<50m

- Distance to nearest road modification = 0 – 50 m (Water well probability increased)
APEC: Flow Lines
COPC Group: PHC (Benzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.11 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 2080 m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 19 yrs

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

PTAC
Alberta
Lower Probability Receptor

LPR Outputs (APEC 2) - Distance to nearest road modification = 0 – 50 m (Water well probability increased)

MEMS, 2023

SCALE NA

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FIGURE 22

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Province

Alberta

Land Use

Agricultural

Soil Texture (< 3 m bgs)

Coarse

Subsoil Texture (> 3 m bgs)

Coarse

Depth to groundwater (m bgs)

2.14

Topographical slope at Site

< 6%

Distance of nearest road to Site

> 50 m

Receptor Evaluation

Is there currently a domestic use water well within the footprint of the Site?

No

Is there a dugout within the footprint of the Site?

No

Distance to nearest aquatic life

0 %	**0.00000 %**	**0 %**	**0.001 %**	**0.014 %**	**0.033 %**
Dugout	**Water Well (< 10 m bgs)**	**Water Well (10 to < 20 m bgs)**	**Water Well (20 to < 30 m bgs)**	**Water Well (> 30 m bgs)**	**Water Well (All depths)**
Time = 105 yrs	Time = 105 yrs	Time = 105 yrs	Time = 105 yrs	Time = 105 yrs	Time = 105 yrs

Map

Results

Copy CSV Excel PDF Print

Previous 1 Next

Show 20 entries

Search:

Inputs	User Defined Values
Model run time	105
Maximum Projected Area of Potential Environmental Concern (APEC)	2,637
Land Use Criteria	Alberta
Contaminants of Concern	F2, F3, F4, F1-BTEX, Ethylbenzene, Toluene, Benzene
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	<6%
What is the distance to the closest road?	>50m

- No Site Modification
APEC: Flow Lines
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.32 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 2080 m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 105 yrs

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

PTAC
Alberta
Lower Probability Receptor

LPR Outputs (APEC 2) - No Site Modification

MEMS, 2023

SCALE NA

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FIGURE
23

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Province

Alberta

Land Use

Agricultural

Soil Texture (< 3 m bgs)

Coarse

Subsoil Texture (> 3 m bgs)

Coarse

Depth to groundwater (m bgs)

2.14

Topographical slope at Site

< 6%

Distance of nearest road to Site

0 to 50 m

Receptor Evaluation

Is there currently a domestic use water well within the footprint of the Site?

No

Is there a dugout within the footprint of the Site?

No

Distance to nearest aquatic life

0 %	0.00000 %	0 %	0.005 %	0.07 %	0.165 %
Dugout	**Water Well (< 10 m bgs)**	**Water Well (10 to < 20 m bgs)**	**Water Well (20 to < 30 m bgs)**	**Water Well (> 30 m bgs)**	**Water Well (All depths)**
Time = 105 yrs	Time = 105 yrs	Time = 105 yrs	Time = 105 yrs	Time = 105 yrs	Time = 105 yrs

Map

Results

Copy CSV Excel PDF Print

Previous 1 Next

Show 20 entries

Search:

Inputs	User Defined Values
Model run time	105
Maximum Projected Area of Potential Environmental Concern (APEC)	2,637
Land Use Criteria	Alberta
Contaminants of Concern	F2, F3, F4, F1-BTEX, Ethylbenzene, Toluene, Benzene
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	<6%
What is the distance to the closest road?	<50m

- Distance to nearest road modification = 0 – 50 m (Water well probability increased)
APEC: Flow Lines
COPC Group: PHC (Ethylbenzene only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.32 mg/kg
Plume Length (25m) @ BH to BH range
Source Area = 2080 m2
Source thickness = 2 m
GW Flow – SW to NE
Time = 105 yrs

PTAC
Alberta
Lower Probability Receptor

LPR Outputs (APEC 2) - Distance to nearest road modification = 0 – 50 m (Water well probability increased)

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FIGURE 24

Criteria Selection

Province: Alberta

Guidelines: Tier 1

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Assessment/Remediation: Assessment / Remediation

Data Filters

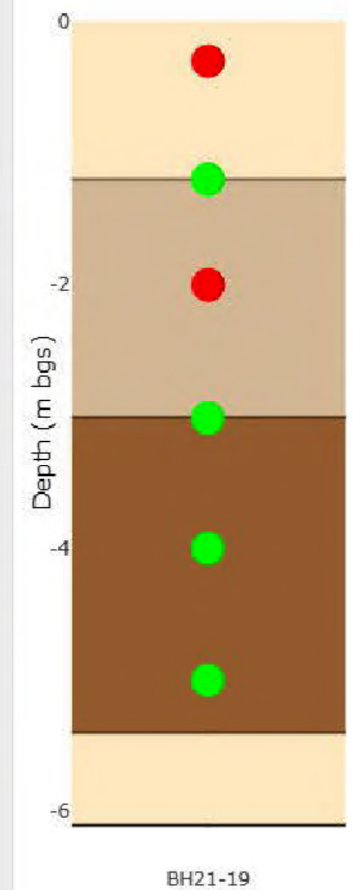
APEC: Western Infrastructure, Western Site, Flare Pit, Northwest Site

Sample Point

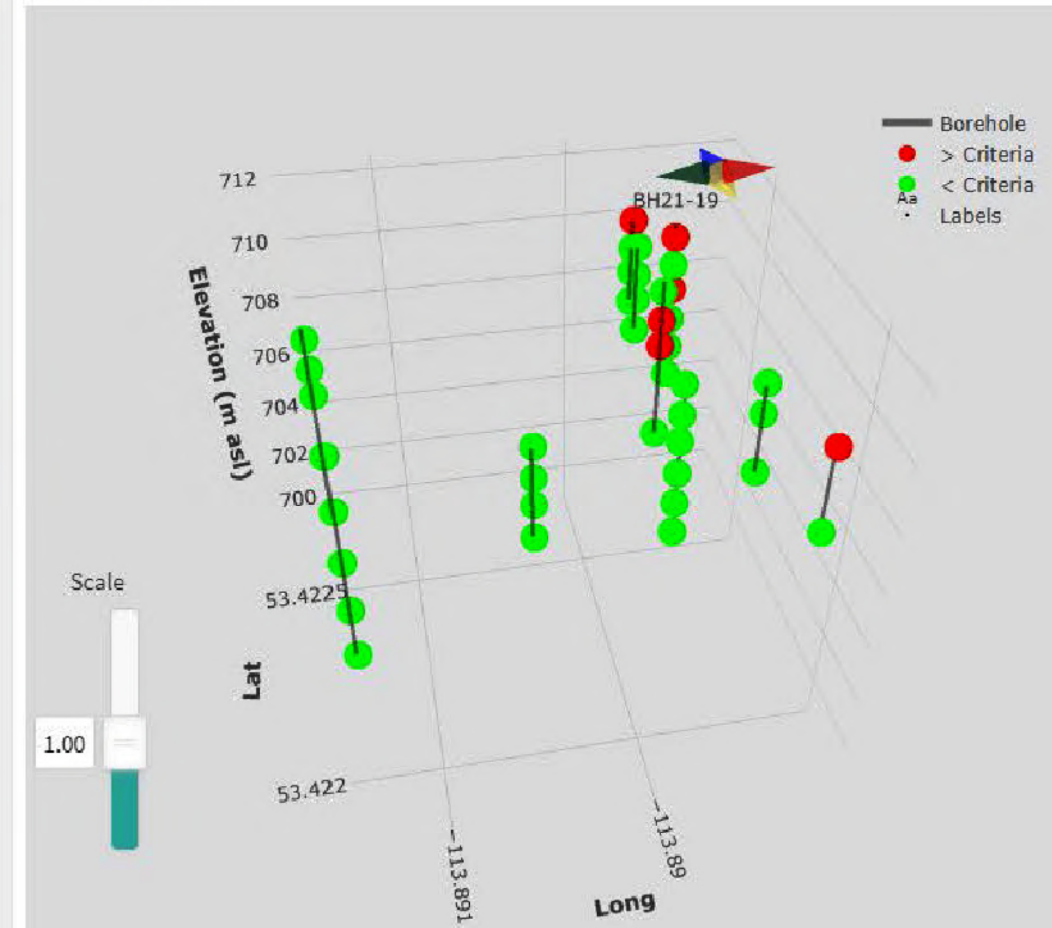
Sample Date: 2003-01-14 to 2023-01-09

Site Map

Lithology



3D Distribution



COPC Screening Table

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
F3	0.3 - 2	350 - 1100	6	Western Infrastructure,Northwest Site	EDC
Ethylbenzene	2 - 2	0.15 - 0.15	1	Northwest Site	DUA
F1-BTEX	2 - 2	170 - 170	1	Northwest Site	VI_b,VI_s

BG = Background, EDC = Ecological Direct Contact, DUA = Domestic Use Aquifer, FAL = Freshwater Aquatic Life, VI_b = Vapour Inhalation (basement), VI_s = Vapour Inhalation (slab on grade), ML = Management Limit, HDC = Human Direct Contact, IW = Irrigation Water, LW = Livestock Water, LSF = Livestock Soil and Food Ingestion, WW = Wildlife Water, NEC = Nutrient Energy Cycling, OMH = Offsite Migration Human, WSF = Wildlife Soil and Food Ingestion, OME = Offsite Migration Ecological, GZML = Green Zone Management Limits

Media: Soil
APEC: Flare Pit/ Release Areas / AST
COPC Group: PHC
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Area = 5,340 m2 inner polygon with exceedances

PTAC
Alberta
Lower Probability Receptor

EAST Output (APEC 3)

MEMS, 2023

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FIGURE
25

Criteria Selection

Province: Alberta

Guidelines: Tier 1

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

Assessment/Remediation: (•) Assessment ( ) Remediation

Data Filters

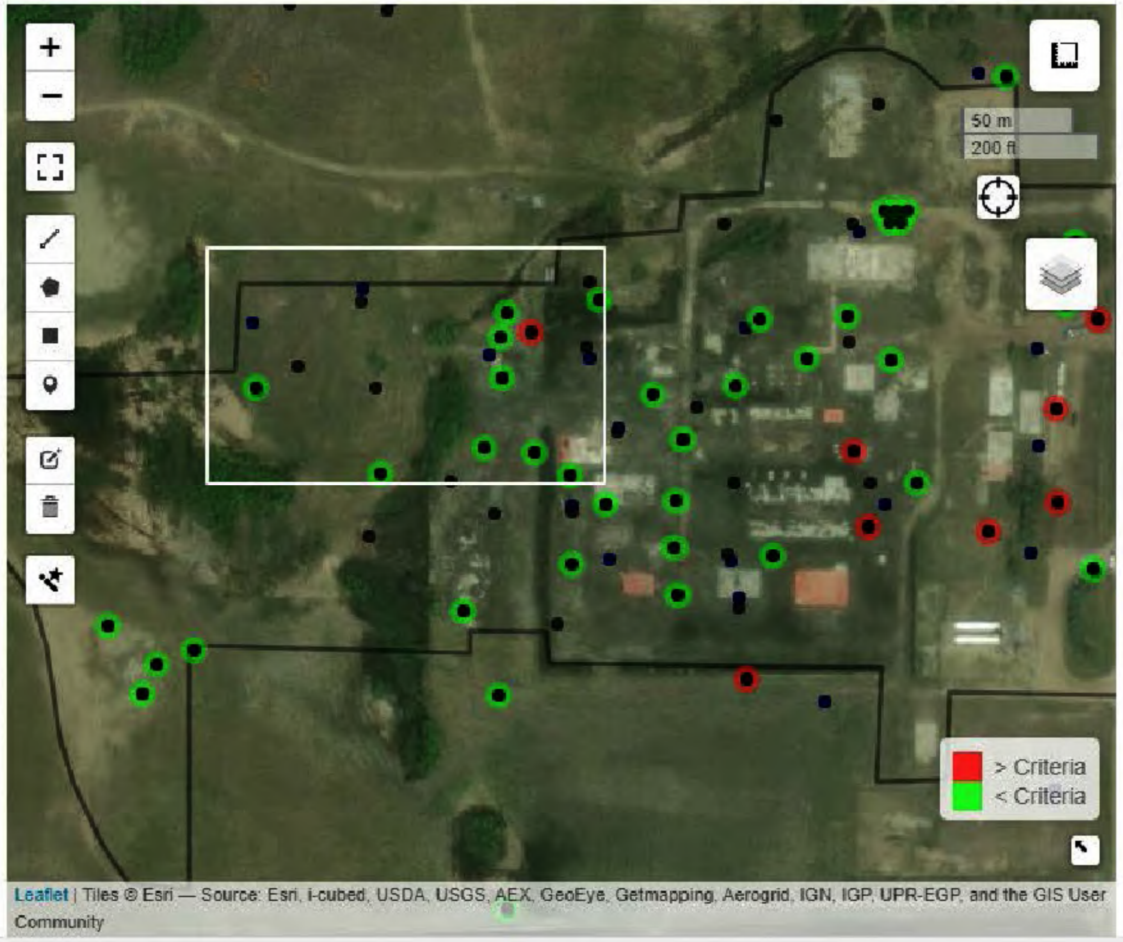
APEC

Sample Point

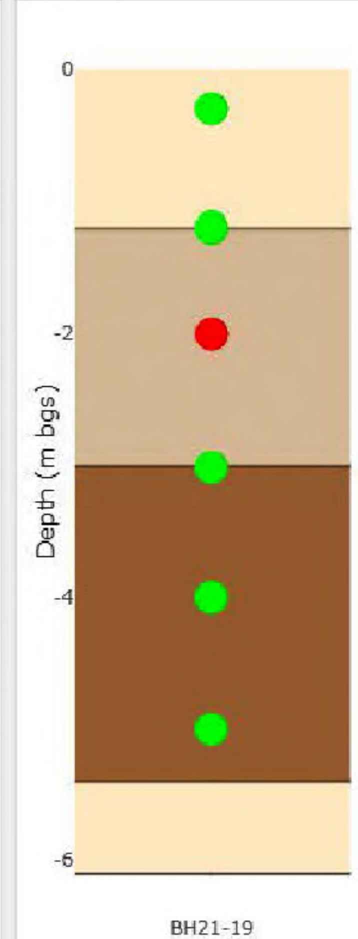
Sample Date: 2003-01-14 to 2023-01-09

Sample Depth (m bgs)

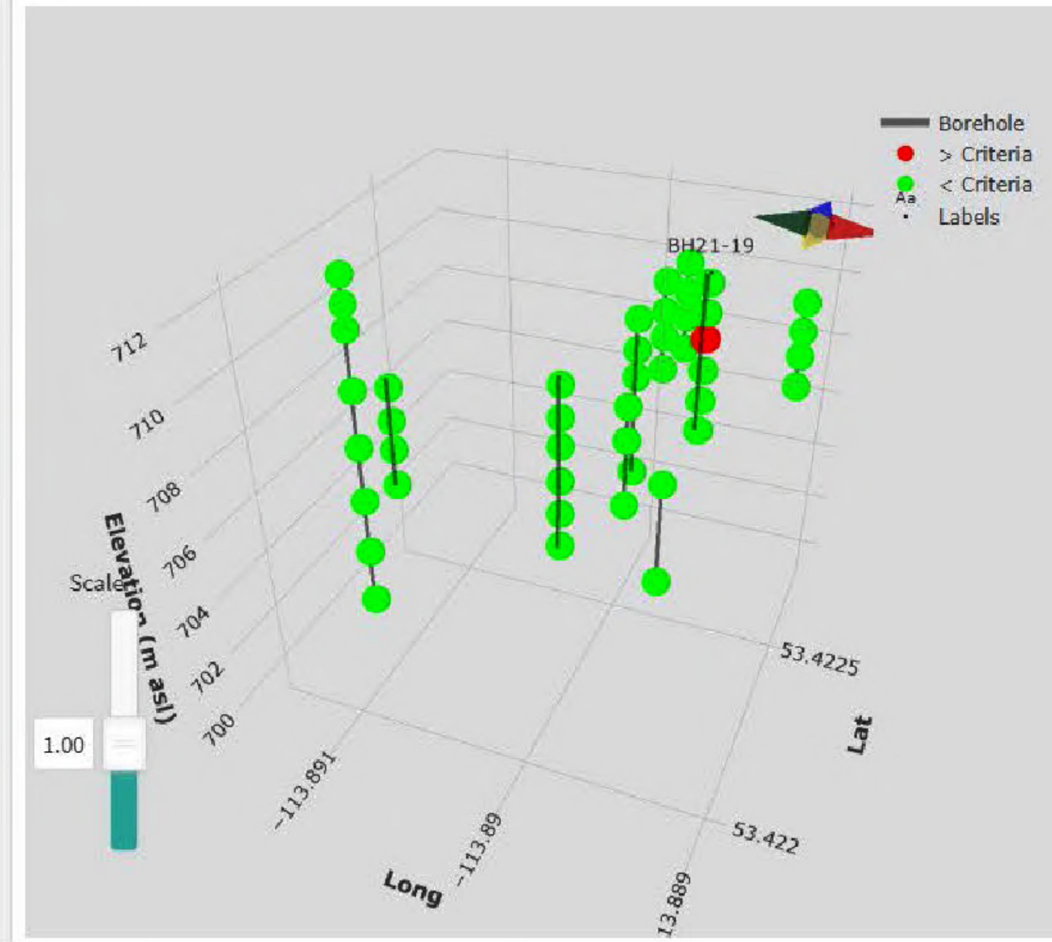
Site Map



Lithology



3D Distribution



COPC Screening Table

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
Ethylbenzene	2 - 4	0.15 - 1	8	103/09-32 Wellsite,Northwest Site,Infrastructure Buildings,Compressor Station Building and Equipment	DUA

BG = Background, EDC = Ecological Direct Contact, DUA = Domestic Use Aquifer, FAL = Freshwater Aquatic Life, VI_b = Vapour Inhalation (basement), VI_s = Vapour Inhalation (slab on grade), ML = Management Limit, HDC = Human Direct Contact, IW = Irrigation Water, LW = Livestock Water, LSF = Livestock Soil and Food Ingestion, WW = Wildlife Water, NEC = Nutrient Energy Cycling, OMH = Offsite Migration Human, WSF = Wildlife Soil and Food Ingestion, OME = Offsite Migration Ecological, GZML = Green Zone Management Limits

All values are reported in mg/kg unless otherwise stated.

Media: Soil
APEC: Flare Pit/ Release Areas / AST
COPC Group: PHC (Ethylbenzene Only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Area = 1020 m2

PTAC
Alberta
Lower Probability Receptor

EAST Output (APEC 3)

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FIGURE 26

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Contaminant	Concentration Range	# of Samples	APEC	Pathway
Ethylbenzene	0.019 - 0.019	1	Flare Pit	DUA
F2	3.7 - 3.7	1	Flare Pit	FAL,DUA,VI_b,EDC

Media: Groundwater
APEC: Flare Pit/ Release Areas / AST
COPC Group: PHC
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil

PTAC
Alberta
Lower Probability Receptor

EAST Output (APEC 3)

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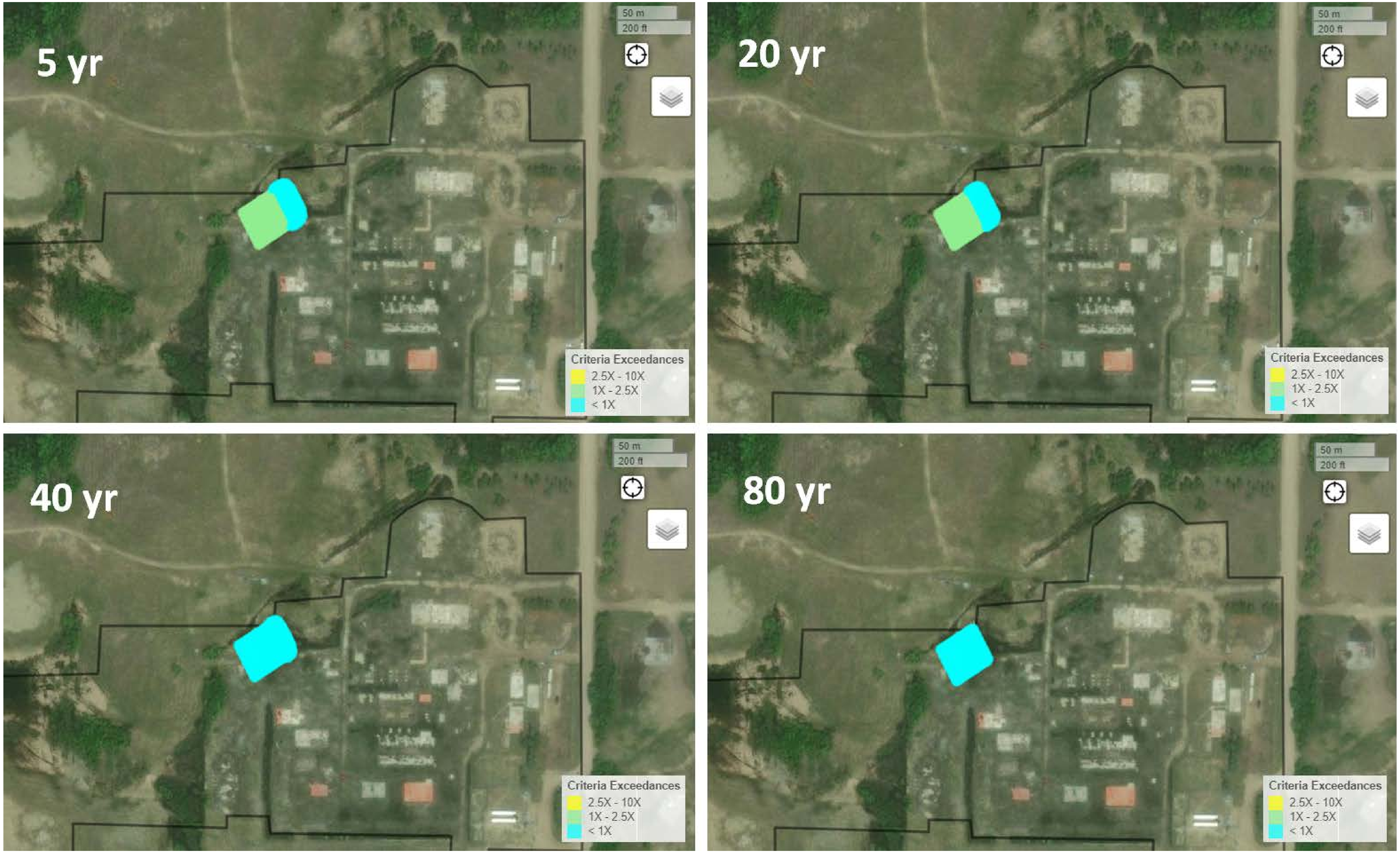
FIGURE 27



APEC: Flare Pit/ Release Areas / AST
COPC Group: PHC (Ethylbenzene Only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.15 mg/kg
Plume Length (25m)
Source Area = 1020 m2
Source thickness = 2 m
GW Flow – SW to NE

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PTAC
Alberta
Lower Probability Receptor

NAT Outputs (APEC 3)

MEMS, 2023

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FIGURE
28

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Province
Alberta

Land Use
Agricultural

Soil Texture (< 3 m bgs)
Coarse

Subsoil Texture (> 3 m bgs)
Coarse

Depth to groundwater (m bgs)
2.14

Topographical slope at Site
< 6%

Distance of nearest road to Site
> 50 m

Receptor Evaluation

Is there currently a domestic use water well within the footprint of the Site?
No

Is there a dugout within the footprint of the Site?
No

Distance to nearest aquatic life receptor (m)

0.00000 %	0.00000 %	0.00000 %	0.00000 %	0.00100 %	0.00300 %
Dugout	**Water Well (< 10 m bgs)**	**Water Well (10 to < 20 m bgs)**	**Water Well (20 to < 30 m bgs)**	**Water Well (> 30 m bgs)**	**Water Well (All depths)**
Time = 61 yrs	Time = 61 yrs	Time = 61 yrs	Time = 61 yrs	Time = 61 yrs	Time = 61 yrs

Map

Results

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Show 20 entries

Search:

Inputs	User Defined Values
Model run time	61
Maximum Projected Area of Potential Environmental Concern (APEC)	1,340
Land Use Criteria	Alberta
Contaminants of Concern	Ethylbenzene, F3, F1-BTEX
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	<6%
What is the distance to the closest road?	>50m

- No Site Modification
APEC: Flare Pit/ Release Areas / AST
COPC Group: PHC (ethylbenzene Only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil
Max Soil Concentration = 0.15 mg/kg
Plume Length (25m)
Source Area = 1020 m2
Source thickness = 2 m

PTAC
Alberta
Lower Probability Receptor

LPR Outputs (APEC 3) - No Site Modification

MEMS, 2023

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FIGURE
29

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Criteria Selection

Province: Alberta

Guidelines: Tier 2A/B

Chloride Screening Value (mg/kg): 100

Land Use: Agricultural

Soil Texture (< 3 m bgs): Coarse

Subsoil Texture (> 3 m bgs): Coarse

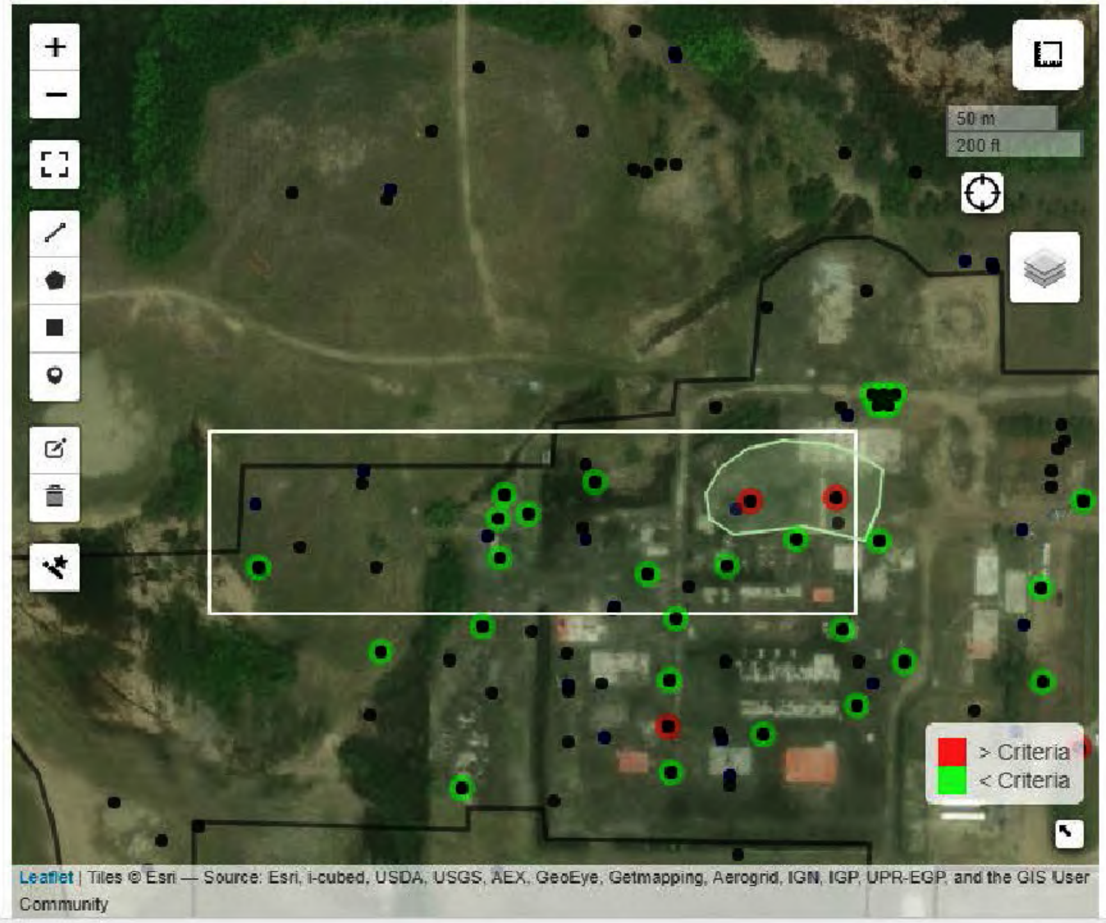
Assessment/Remediation: (●) Assessment ( ) Remediation

Data Filters

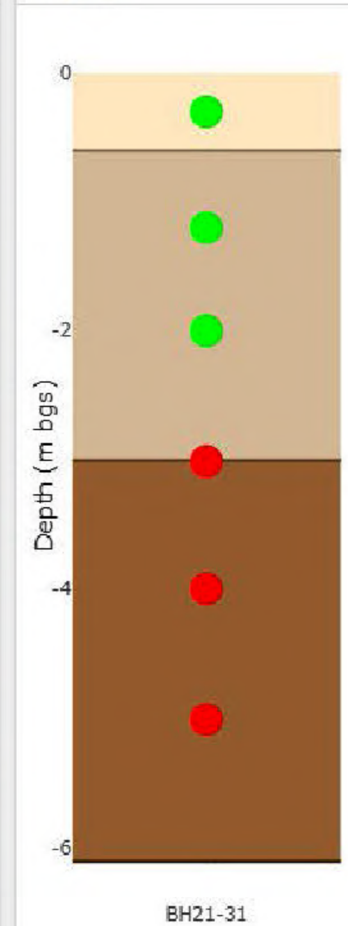
APEC

- APEC 2: Pipeline ROW
- Western Site
- Compressor Station Building and Equipment
- Northwest Site
- Infrastructure - North

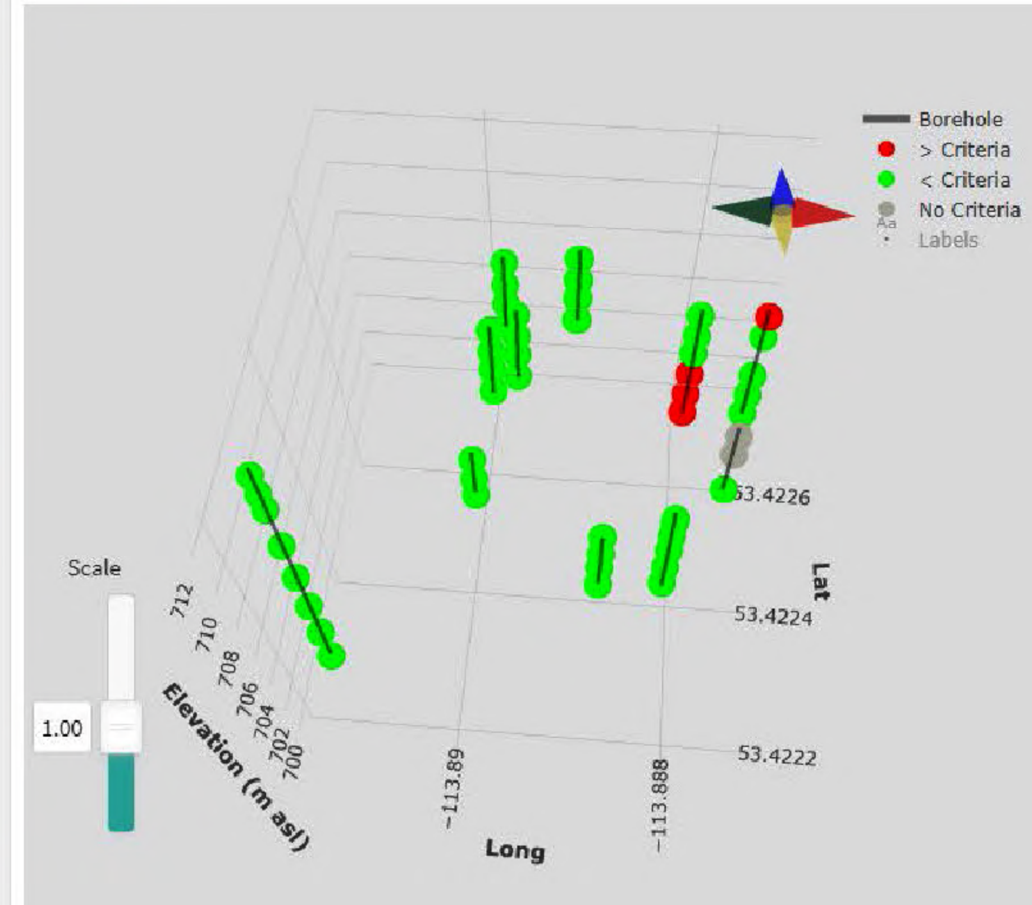
Site Map



Lithology



3D Distribution



COPC Screening Table

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
Chloride	3.01 - 5	110 - 210	4	Compressor Station Building and Equipment,AST	Tier 2A/B
Sodium Adsorption Ratio	0.3 - 1.2	4.8 - 6.3	3	Compressor Station Building and Equipment	Tier 1 (EDC)

BG = Background, EDC = Ecological Direct Contact, DUA = Domestic Use Aquifer, FAL = Freshwater Aquatic Life, VI_b = Vapour Inhalation (basement), VI_s = Vapour Inhalation (slab on grade), ML = Management Limit, HDC = Human Direct Contact, IW = Irrigation Water, LW = Livestock Water, LSF = Livestock Soil and Food Ingestion, WW = Wildlife Water, NEC = Nutrient Energy Cycling, OMH = Offsite Migration Human, WSF = Wildlife Soil and Food Ingestion, OME = Offsite Migration Ecological, GZML = Green Zone Management Limits

All values are reported in mg/kg unless otherwise stated.

Media: Soil
APEC: Flare Pit/ Release Areas / AST
COPC Group: Salinity
Guidelines: Tier 2A – Ag, Coarse Soil/Subsoil – Cl- 100 mg/kg
Area = 2,550 m2 inner polygon with exceedances

PTAC
Alberta
Lower Probability Receptor

EAST Output (APEC 3)

MEMS, 2023

SCALE NA

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FIGURE 30

Contaminant	Depth Range (m bgs)	Concentration Range	# of Samples	APEC	Pathway
Chloride	3.01 - 5	110 - 210	4	Compressor Station Building and Equipment,AST	Tier 2A/B

BG = Background, EDC = Ecological Direct Contact, DUA = Domestic Use Aquifer, FAL = Freshwater Aquatic Life, VI_b = Vapour Inhalation (basement), VI_s = Vapour Inhalation (slab on grade), ML = Management Limit, HDC = Human Direct Contact, IW = Irrigation Water, LW = Livestock Water, LSF = Livestock Soil and Food Ingestion, WW = Wildlife Water, NEC = Nutrient Energy Cycling, OMH = Offsite Migration Human, WSF = Wildlife Soil and Food Ingestion, OME = Offsite Migration Ecological, GZML = Green Zone Management Limits

All values are reported in mg/kg unless otherwise stated.

pH (Lab) has reported units of pH. Sodium Adsorption Ratio has reported units of ---.

Media: Soil
APEC: Flare Pit/ Release Areas / AST
COPC Group: Salinity (Chloride Only)
Guidelines: Tier 2A – Ag, Coarse Soil/Subsoil – Cl- 100 mg/kg
Area = 1,500 m2 inner polygon with exceedances

PTAC
Alberta
Lower Probability Receptor

EAST Output (APEC 3) Salinity (Chloride Only)

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FIGURE 31

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Contaminant	Concentration Range	# of Samples	APEC	Pathway
Chloride	110 - 5100	4	Compressor Station Building and Equipment,Flare Pit	VI_b,EDC,FAL,IW,LW,WW,DUA

All values are reported in mg/L, unless otherwise stated.
pH (Lab) has reported units of pH.

Media: Groundwater
APEC: Flare Pit/ Release Areas / AST
COPC Group: routine (Chloride Only)
Guidelines: Tier 1 – Ag, Coarse Soil/Subsoil – Cl- 100mg/L

PTAC
Alberta
Lower Probability Receptor

EAST Output (APEC 3) routine (Chloride Only)

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FIGURE
32

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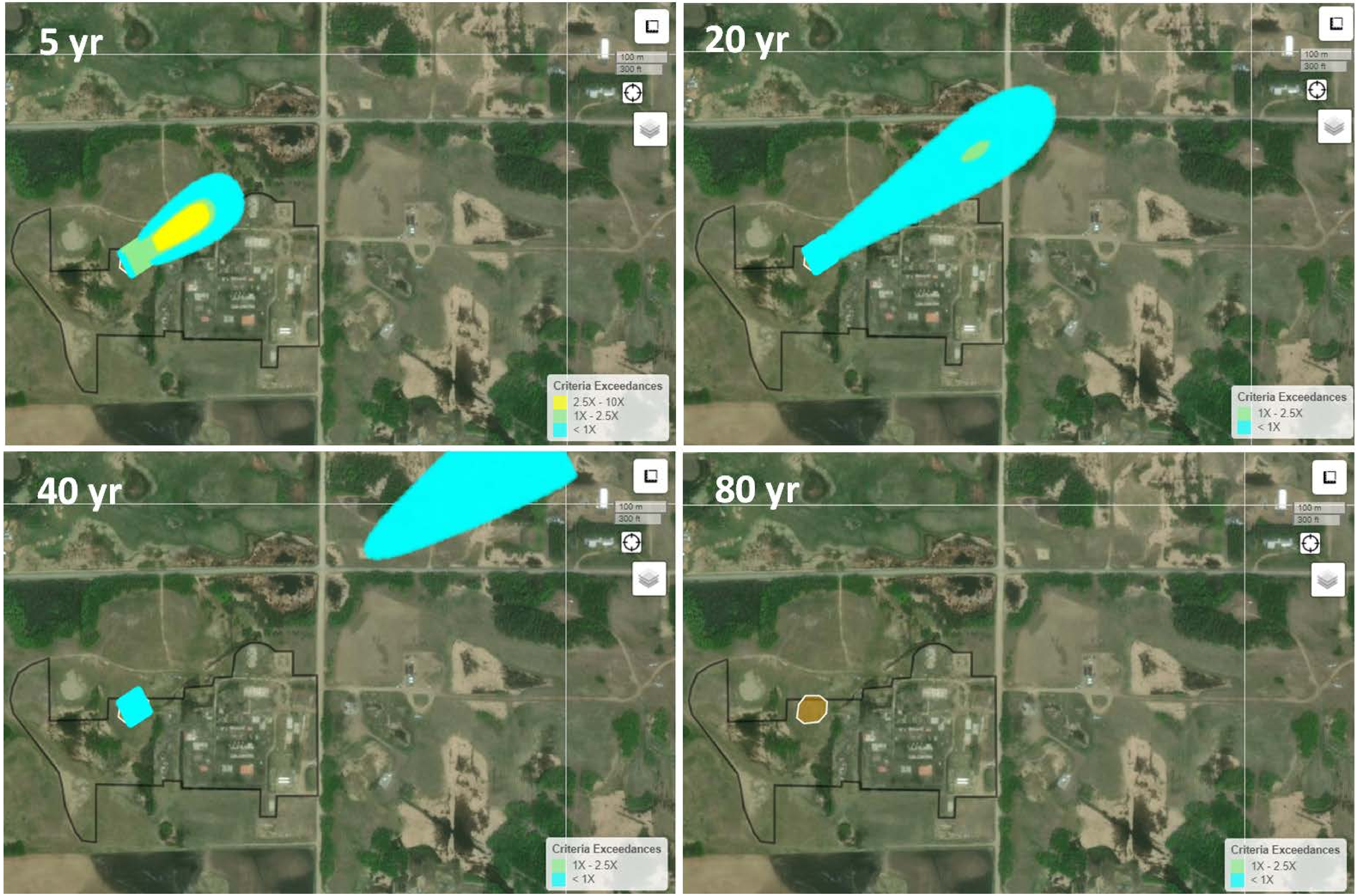

APEC: Flare Pit/ Release Areas / AST -> GW driven APEC delineation
COPC Group: Salinity (Chloride Only)
Guidelines: Tier 2A – Ag, Coarse Soil/Subsoil – Cl- 100 mg/kg
Guidelines: Tier 2B - Ag, Coarse Soil/Subsoil – Cl- 250 mg/L (DUA)
Max Soil Concentration = 400 mg/kg @ Assumed remedial endpoint to ensure 250 mg/L is not exceeded at property boundary in future.
Plume Length (25m)
Source Area = 1,500 m2
Source thickness = 4 m (Screen interval of P02-1A: 3.5 m)
GW Flow – SW to NE

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PTAC
Alberta
Lower Probability Receptor

NAT Outputs (APEC 3)

MEMS, 2023

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FIGURE
33

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Province
Alberta

Land Use
Agricultural

Soil Texture (< 3 m bgs)
Coarse

Subsoil Texture (> 3 m bgs)
Coarse

Depth to groundwater (m bgs)
2.14

Topographical slope at Site
< 6%

Distance of nearest road to Site
> 50 m

Receptor Evaluation

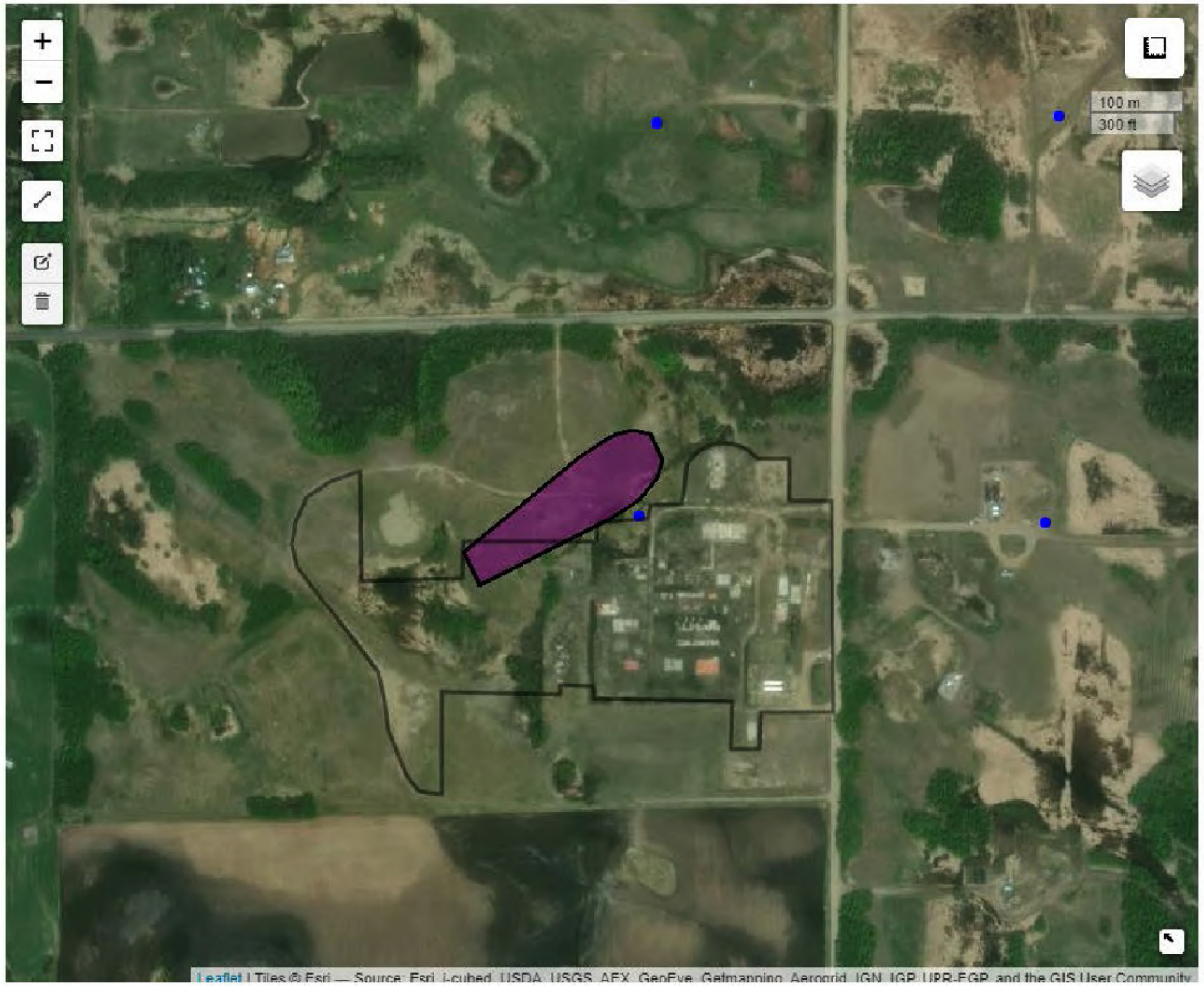
Is there currently a domestic use water well within the footprint of the Site?
No

Is there a dugout within the footprint of the Site?
No

Distance to nearest aquatic life receptor (m)

0.088 %	0.019 %	0.238 %	0.676 %	5.867 %	12.204 %
Dugout	Water Well (< 10 m bgs)	Water Well (10 to < 20 m bgs)	Water Well (20 to < 30 m bgs)	Water Well (> 30 m bgs)	Water Well (All depths)
Time = 500 yrs	Time = 500 yrs	Time = 500 yrs	Time = 500 yrs	Time = 500 yrs	Time = 500 yrs

Map



Results

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Search:

Inputs	User Defined Values
Model run time	500
Maximum Projected Area of Potential Environmental Concern (APEC)	12,750
Land Use Criteria	Alberta
Contaminants of Concern	pH (Lab), Chloride, Sodium Adsorption Ratio
Is the APEC in in contact with a surface water body?	Yes
Distance to the nearest surface water body?	10
Is a dugout currently present witin the APEC?	No
Has the DUA pathways been excluded at the Site?	No
Depth to Groundwater	2.14
What is the average topogrpahical slope at the Site?	<6%
What is the distance to the closest road?	>50m

– Distance to nearest road modification = Road within APEC
APEC: Flare Pit/ Release Areas / AST
COPC Group: Salinity (Chloride Only)
Guidelines: Tier 2A – Ag, Coarse Soil/Subsoil – Cl- 100 mg/kg
Max Soil Concentration = 400 mg/kg ◎ Override to algin with Measured GW of 5,100 mg/L (approx. 1,500 mg/kg)
Plume Length (25m)
Source Area = 1,500 m2
Source thickness = 4 m (Screen interval of P02-1A: 3.5 m)
GW Flow – SW to NE
Time = 500 yrs (conservative solute – AEP)

PTAC
Alberta
Lower Probability Receptor

LPR Outputs – Distance to nearest road modification = Road within APEC

MEMS, 2023

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FIGURE
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APPENDIX A1: LPR REPORT

2022-04-04

Low Probability Receptor Report Summary

LPR Input Prepared by:
Joe Smith

Prepared for:
Client A
Prepared by:
MEMS
Account Number:
1254-451

INTRODUCTION

In most cases, assessment, remediation and subsequent reclamation of contaminated sites in Alberta are driven by the regulatory requirement that contaminated sites meet guidelines that are protective of all receptors and exposure pathways which are linked, by definition, to a given land use. Unless receptors and exposure pathways can be excluded on a site-specific basis, where permitted under the Alberta Environment and Parks (AEP) Tier 2 process, the guidance requires that all receptors associated with the respective land use be considered as being present. There is no ability to adjust the remediation process to account for sites where the receptor or pathway does not exist, and is unlikely to occur in the future (i.e., Low Probability Receptors [LPRs]). Thus, for a certain number of sites in Alberta, remediation criteria are driven by non-existent receptors or pathways (LPRs) which may occur in the future. Examples of LPRs could include a dugout, a residence, a water well, a market garden, cultivated land replacing pasture, or non-present ecological species.

Given the range of geographic settings, physical conditions, development trends and other factors that may differentiate sites classified under a particular land use, the likelihood of a specific default receptor being present, or a related exposure pathway being operative, may be very small in some instances. The potential for a future receptor to be exposed to unacceptable levels of a COPC originating from a site depends on three key factors:

- the likelihood that a receptor/pathway will be constructed in the vicinity of the site at some point in the future (e.g., a dugout or a water well);
- the likelihood that chemicals will still be present when the receptor/pathway is present; and
- the likelihood that chemicals will reach the receptor in the future, at concentrations sufficient to cause an adverse effect.

RESULTS

The location of the Site is LSD: 6 Section: 36 Township: 53 Range: 10 Meridian: W5.

Default LPR values for Dugouts, Waterwells and Urban Areas (as shown in Figures 3 and 4, respectively) are as followed:

Dugouts (%/annum/hectare) = 0.0010%

	0-10 m	10-20 m	20-30 m	>30 m	All Depths
Waterwells (%/annum/hectare) =	0.0004%	0.0032%	0.0084%	0.0138%	0.0258%

Urban Development (%/annum/hectare) = N/A

Maximum Time to Achieve Compliance = 22 yrs

Risk to Aquatic Life Receptors = No antipicipated risk

User defined input parameters were used to refine the LPR prediction on a Site specific bases. These input values are provided in Table A.

Table A: User Defined Input Parameters

Input	*User Defined Value*
Number of Years Run in Model	22
Maximum Predicted Area of Potential Environmental Concern ($APEC_{max}$)	0.20
Land Use Criteria	Agricultural
Secondary Land Use Criteria	N/A
Contaminant(s) of Concern	Hydrocarbons: X; Salts: ; Metals: ; Other:
Is the $APEC_{max}$ in contact with a surface water body?	No
Distance to the nearest surface water body?	150 m
Is a dugout currently present within the $APEC_{max}$?	No
Has the DUA pathway been excluded at the Site?	No
Depth to Groundwater?	2.5 m
What is the average topographic slope at the Site?	< 6%
What is the distance to the closest access road?	0 to 50 m

Attenuation

Based on user input values for maximum concentrations of COPCs, the maximum antpiciated time to which all COPCs will have attenuated to below the applicable soil guidelines is 22 years.

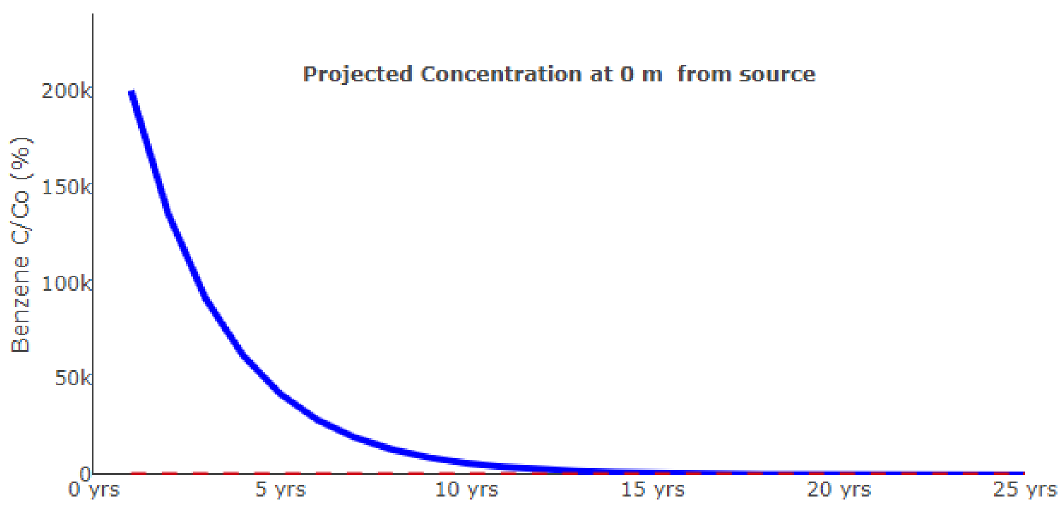

Figure 1. Attenuation Estimates for Chemicals of Potential Concern

Dugouts

Based on user input variables sufficient information is NOT available to eliminate the Protection of Livestock Watering Pathway.

Calculated probability for future dugout in 22 years is **0.00%**

Waterwells

Based on user input variables sufficient information is NOT available to eliminate the Domestic Use Aquifer Pathway.

Calculated probability for future water well in 22 years is **0.11%**

This combined probability is based on the following screening depth interpretations:

Well Interval (m)	Probability (%/annum/hectare)	Probability (%)
0 - 10	0.0004%	0.00%
10 - 20	0.0032%	0.00%
20 - 30	0.0084%	0.00%
> 30	0.0138%	0.00%
All Depths	0.0258%	**0.11%**

Important Considerations:

No comments

Net Environmental Benefit Analysis

KPI Parameter	Conventional Assessment	LPR Assessment
Total Impact Volume	15,000 m^3	2,500 m^3
Total Remedial Cost	$ 3,185,000	$ 1,275,000
Total Fuel Consumed	6,900 L	1,150 L
Total CO_2 Eq Emissions	203 tonnes	33 tonnes
Overall Score	TBD	**TBD**

Note: NEBA is currently in development. Projected values subject to change.

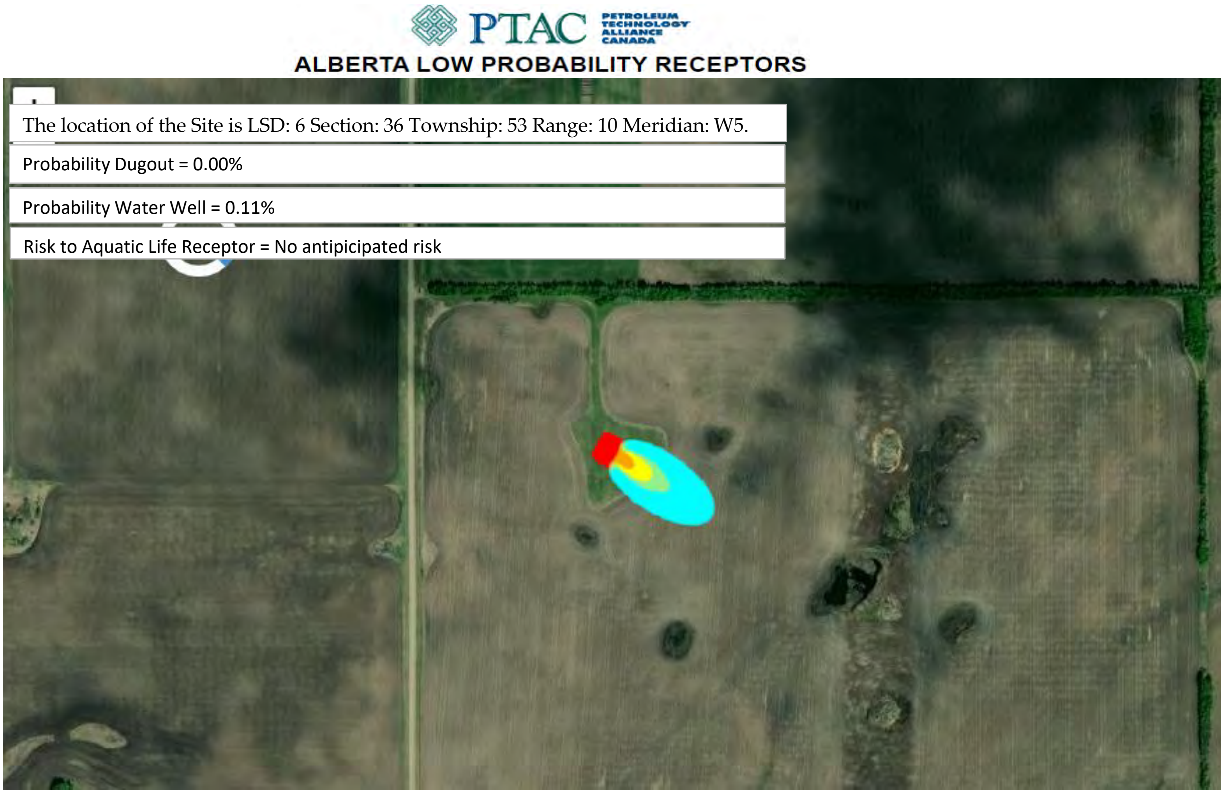

Figure 2. Site Location and Maximum Projected Impact Area

Figure 3. Regional Cross-Section

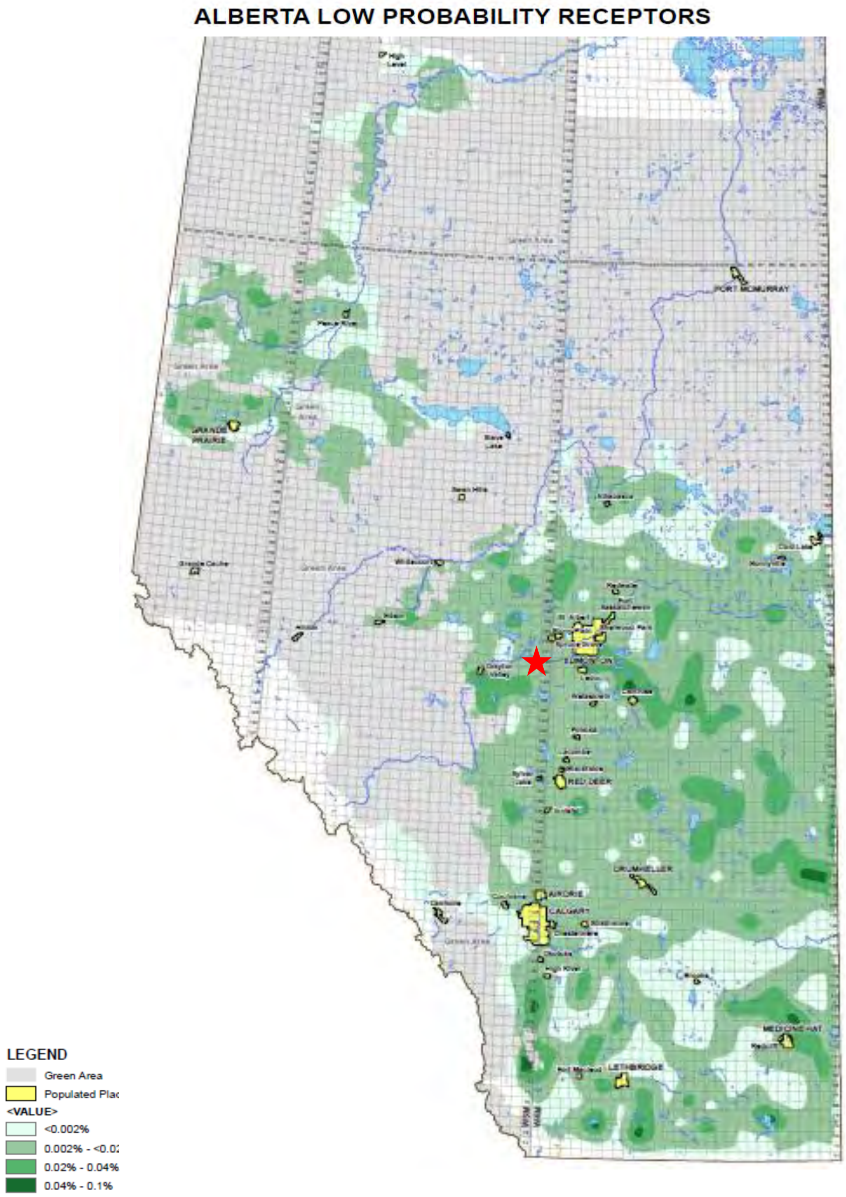

Figure 4. Provincial Level Dugout Probability Map

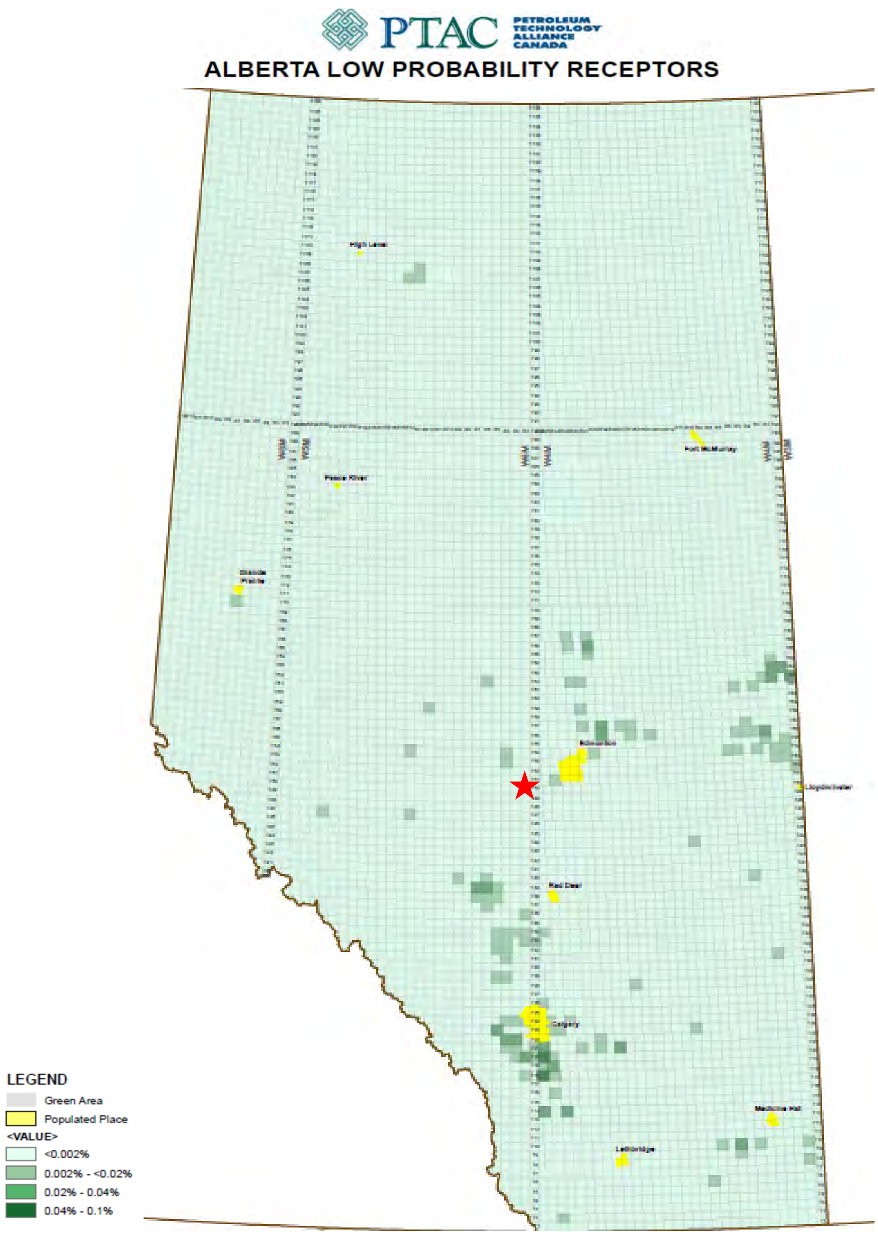

Figure 5a. Provincial Level Water Well Probability Map (0-10m)

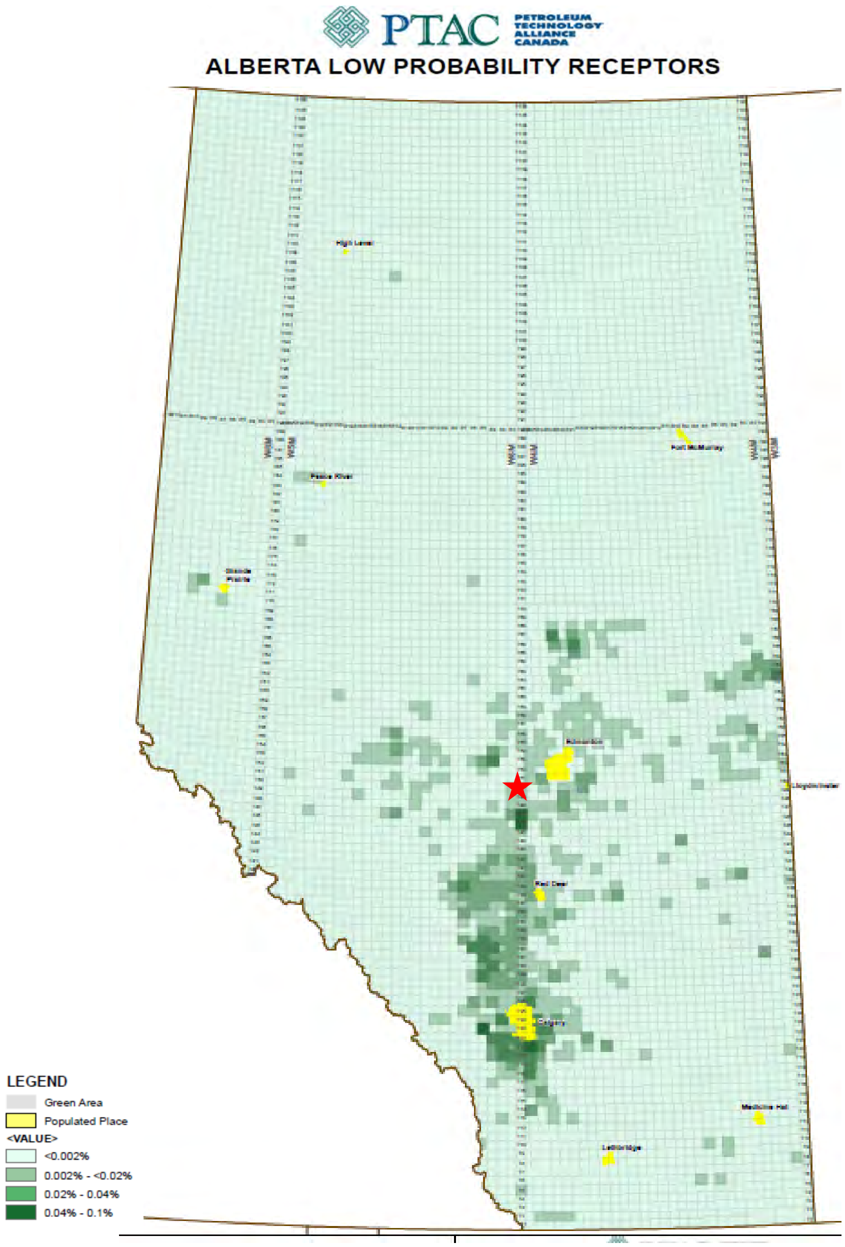

Figure 5b. Provincial Level Water Well Probability Map (10-20m)

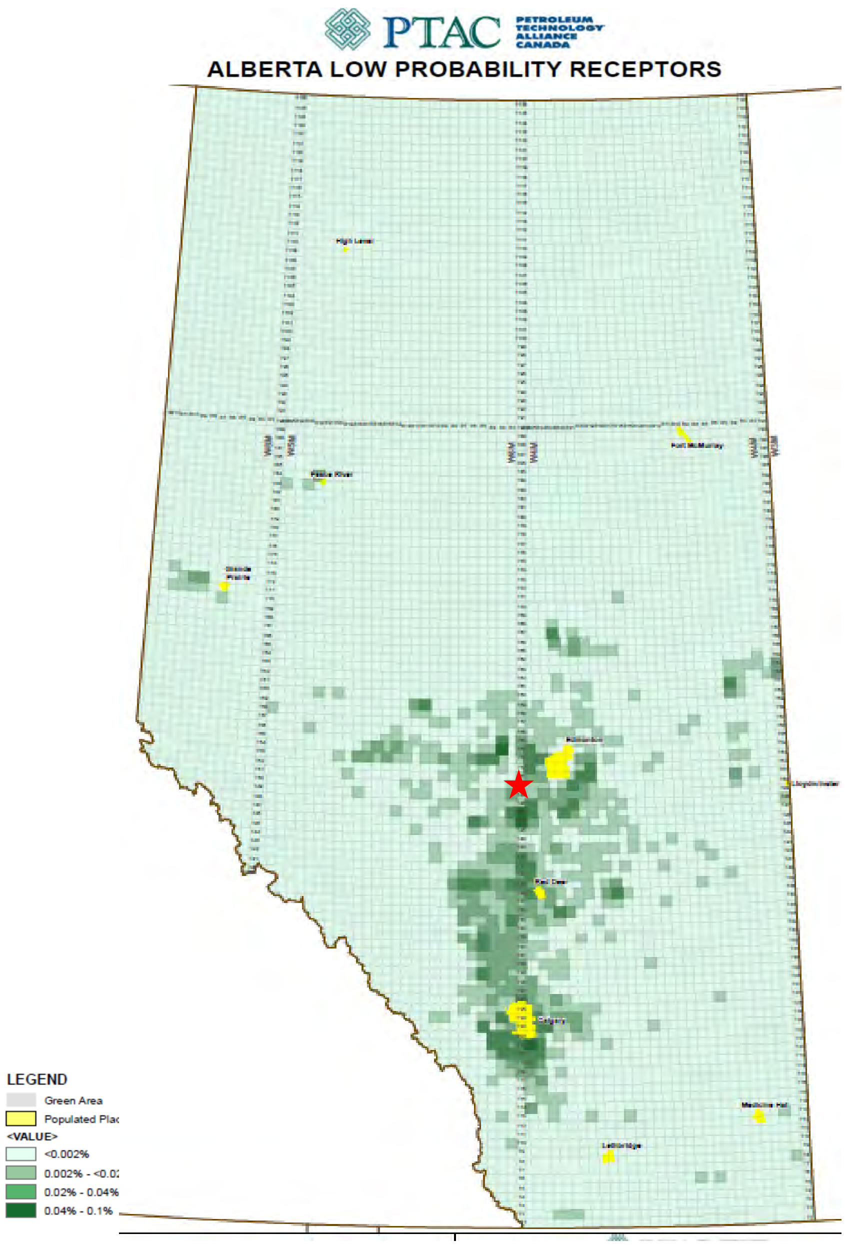

Figure 5c. Provincial Level Water Well Probability Map (20-30m)

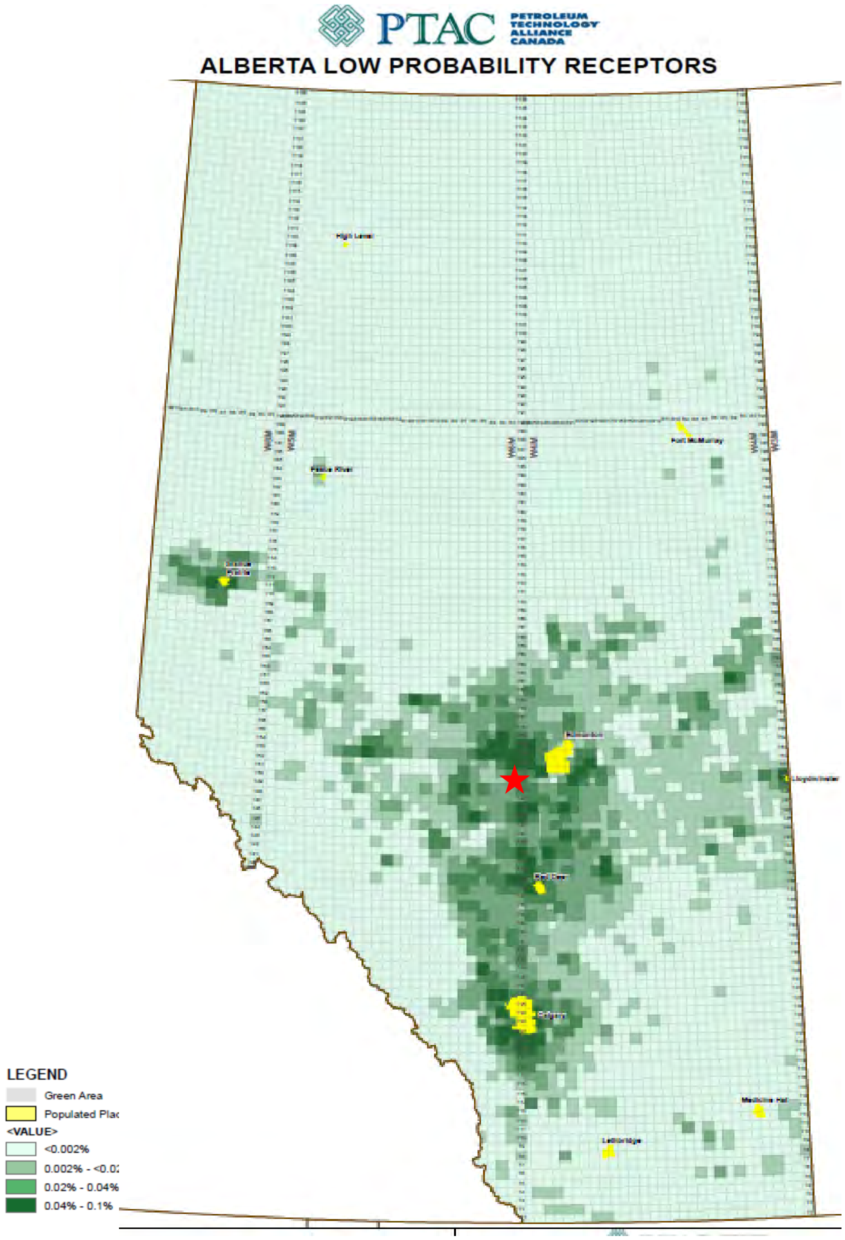

Figure 5d. Provincial Level Water Well Probability Map (>30m)

APPENDIX B: SASKATCHEWAN

Appendix B – Saskatchewan

1.0 INTRODUCTION

The Saskatchewan demonstration project focused on the evaluation of a group of Sites within Weyburn Saskatchewan in order to determine Sites which could be used to demonstrate the feasibility of the application of low probability receptor analysis (LPR) as well as consider the potential for Site-redevelopment towards solar energy production which would provide an additional economic and environmental benefit to the application of LPR.

This document summarizes the selection criteria used to evaluate the 39 Sites and summarizes the potential for LPR at eight key Sites. The potential feasibility of solar integration is also discussed at a regional scale.

Figures are included in Appendix B1, the LPR screening matrix in Appendix B2, pilot Site summaries in Appendix B3 and a solar feasibility analysis in Appendix B4.

1.1 Objectives

The objectives of the Saskatchewan demonstration project were to:

1. Determine criteria which would allow for the screening of Sites in Saskatchewan for the application of LPR.
2. Identify a small number of Sites in the Weyburn area which could be used to demonstrate the application of LPR.
3. Evaluate how solar energy production could be integrated with LPR application.

1.2 Scope of Work

The scope of work for this project includes the following tasks:

- Presentation of LPR concepts to Saskatchewan regulators, including Ministry of Environment (ENV) and Ministry of Energy and Resources (MER).
- Follow-up meetings with ENV and MER to discuss LPR implementation requirements.
- Probability mapping (water wells and dugouts) for key areas of Saskatchewan.
- Collaborating with a Saskatchewan oil & gas operator to identify a portfolio of candidate sites.
- Reviewing historical data available for 39 potential pilot Sites.
- Developing a Site-screening matrix for LPR pilot Site selection.
- Generating applicable figures to support scientific rationale.

- Communicating with RenuWell Energy Solutions to assess the regional feasibility of solar integration.
- Producing a report summarizing the findings of the site screening and potential LPR pilot Site candidates.

2.0 IMPLEMENTATION CONSIDERATIONS

2.1 LPR Implementation

Based on the meetings with ENV and MER, there is high interest in the implementation of LPR. A key goal in Saskatchewan is to achieve pragmatic site closure to ensure that sites are not orphaned, they consider the "risk of inaction" to be potentially greater than the environmental and human health risks from well sites.

In particular, LPR is considered to be strongly aligned with MER approaches for salt contamination as described in *PNG045: Acknowledgement of Reclamation for Sodium Chloride Impacted Sites* (Government of Saskatchewan, 2022). Management of contaminants other than salt, including petroleum hydrocarbons, needs to align with the Saskatchewan Environmental Code, which would require engagement with ENV and potentially some regulatory change; the lifespan/attenuation of hydrocarbons would be an important consideration.

Saskatchewan has existing mechanisms in place to address restrictions on land use within Tier 2 and Tier 3 under the Environmental Code. Stakeholder engagement is of high importance to MER with respect to any land use restrictions; therefore, consideration of landowners and other stakeholders is critical for LPR implementation.

2.2 Solar Integration

There is significant interest in the integration of renewable energy into brownfields as an alternative to the conversion of green spaces or productive agricultural land. Sites at which LPR is applied may be suitable candidates for solar integration as residual Chemicals of Potential Concern (COPCs) are provided an opportunity to degrade or dilute while the land continues to be used for a productive purpose. This may be of particular interest where COPCs are present within the rooting zone or where the presence of solar development could provide assurance against the low probability of a future sensitive receptor (*e.g.*, water well, dugout, residence) on an area of potential environmental concern (APEC) with unmanaged unacceptable incremental risks to human health or the environment.

2.3 Receptor Probability Mapping

To facilitate demonstration of LPR in Saskatchewan, probability mapping was conducted for 2 regions: the area between the Hamlet of Steelman and the Manitoba border, where there are a large number of salt-impacted sites, and the area surrounding the City of Weyburn where a candidate site portfolio was identified.

The mapping was conducted for both water wells and dugouts using the same methodology as previous Alberta probability mapping described in the LPR Scientific Rationale (MEMS, 2019). Some modifications were made to the dugout probability mapping process to account for the data sources available in Saskatchewan:

- Registered dugout data was obtained from the Saskatchewan Water Security Agency; based on an initial review against aerial imagery it was concluded that this data set did not capture all dugouts in the areas.
- Agriculture and Agrifood Canada (AAFC) cropland data for water features was obtained and evaluated for dugouts.
- 2017 or more recent imaging from Esri Canada was used to supplement the database of dugouts in the areas.
- The number of dugouts in each section/township was then determined.
- Other available imagery data was used where necessary to refine estimates of dugout construction time.

2.4 Study Area - Weyburn

The most suitable portfolio of sites identified during consultations with the oil and gas industry was in the vicinity of Weyburn, a regional centre located in southeastern Saskatchewan near the headwater of the Souris River within the Moist Mixed Grassland Ecoregion. The region is host to numerous seasonal water bodies, and flood control programs have also created many dams and reservoirs. The majority of the area is cultivated; natural vegetation is primarily mid- and short grasses with aspen woodlands around sloughs (Acton *et al*., 1998). Oil and gas production has been significant in the area.

3.0 METHODOLOGY

Ideally, an LPR pilot program would include 5 to 10 sites which all have non-adversarial landowners, and have either been evaluated using SST or Tier 2 screening criteria and continue to require remedial activities.

Whitecap Resources Inc. (Whitecap) provided MEMS 39 potential candidate sites. A single Phase 2 Environmental Site Assessment (ESA) report was available for review for each Site. None of the Sites had been evaluated with either SST or Tier 2 options. Completion of SST and Tier 2 guideline recalculations were not within the scope of work for this project. Therefore, screening of the potential candidate sites was completed using professional judgement based on a review of the sites' characteristics.

While LPR can easily be applied on a Site-Specific basis, solar redevelopment must first be assessed from a regional perspective as solar panels must be installed in sufficient density within an area to provide optimal energy production for integration into the electrical grid. Additionally, there is a strong desire to prioritize the return of productive agricultural land to this purpose as opposed to less productive agricultural land which may be better suited to solar redevelopment. Agricultural land capacity was therefore used as the first criterion to rank Sites based on their potential as solar *vs* non-solar Sites (Section 3.1). Those Sites which are located within areas of low agricultural productivity were grouped for solar potential and those located in areas with high agricultural productivity were grouped for non-solar. It is understood that several other factors influence the potential for solar integration, and these are discussed in section 3.5 below.

However, LPR may be applicable at both solar and non-solar Sites. The primary function of the LPR tool is to provide options for Sites which cannot be managed through traditional Tier 2 options (Tier 2 guideline recalculations or SST) but present low risk to potential future receptors. Therefore, proximity to receptors and an assessment of COPCs at the Sites was completed to provide a rank with respect to each of these criteria. Those Sites which ranked low with respect to proximity to current receptors (Section 3.3) and had a moderate COPC rank (discussed further in section 3.2 below) were deemed potentially eligible for LPR.

This resulted in four overall groupings:

A. Solar + LPR.
B. Solar only.
C. LPR only.
D. Neither solar nor LPR.

Three Sites from groups A through C were selected as pilot Sites.

3.1 Criterion # 1 – Agricultural Land Capacity

Soil quality data with respect to agricultural capability for the Weyburn area was extracted from the Saskatchewan Soil Information System (SKSIS) and overlayed with the Site locations.

The SKSIS lists the following classes:

1. Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices.
2. Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices.
3. Soils in this class have severe limitations that restrict the range of crops or require special conservation practices, or both.
4. Soils in this class have very severe limitations that restrict their use to the production of native or tame species of perennial forage crops. Improvement practices are feasible.
5. Soils in this class are capable of producing native forage crops only. Improvement practices are not feasible.
6. Soils in this class have no capability for arable agriculture or permanent pasture.

Sites located in areas with a class 4 to 6 were selected as potential solar Sites (Figure 2). These regions are anticipated to be the least productive in terms of agricultural capability.

3.2 Criterion # 2 – COPC Evaluation

In terms of application of LPR, Sites were first screened based on whether the COPCs at the site exceeded Tier 1 guidelines and/or background values. In order to screen COPCs against background values, a regional dataset was generated by compiling the background data for all 39 sites within the Weyburn area, the 95th percentile value was calculated for each parameter and the maximum value reported for COPCs above guidelines for each site was compared to these values. Sites where all COPCs were either within Tier 1 guidelines or below the 95th percentile background values were excluded as potential LPR pilot sites (assigned a rank of 0).

Relevant COPCs at the sites were then summarized and the maximum values noted. LPR is applicable to COPCs which are anticipated to degrade or dilute to within screening values before they would reach a potential receptor (within 500 m). Given that the LPR tool primarily addresses risk with respect to receptors that could potentially be added in the future, it targets the domestic use aquifer (DUA) and livestock watering pathways as the installation of water wells and dugouts are the primary ways that a new receptor would be added to an area. Light-end hydrocarbons (BTEX, F1 and F2) and chloride are COPCs that are frequently limited by these two pathways. Previous LPR evaluations by MEMS have noted that Sites with chloride concentrations above 7,000 mg/kg are often difficult to manage with SST and may be good candidates for LPR. Sites were characterized as either hydrocarbon sites, salinity sites, or hydrocarbon and salinity sites.

The following ranking was used to classify Sites based on observed COPCs:

1. Maximum concentration of COPCs are below Tier 1 guidelines or maximum chloride concentration is within background value (<186 mg/kg).
2. Low concentrations of degradable/dilute COPCs (marginal exceedance from background)
3. Moderate concentration of degradable/dilute COPCs.
4. High concentration of degradable/dilute COPCs, chloride concentrations of >7000 mg/kg, difficult to manage with Tier 2 methods or SST.
5. Likely requires remediation due to the presence of COPCs that do not degrade or dilute.

Sites assigned a Rank of 0 for Criteria 2 do not require further action and therefore would not benefit from the application of LPR. Sites with a Rank of 1 to 3 could potentially benefit from LPR however those Sites with a Rank of 1 or 2 may be addressed through more standard Tier 2 options or risk-based arguments. Those sites assigned a rank of 3 are those most likely to benefit from LPR as standard options may be insufficient to address the COPCs on Site. Sites with a Rank of 4 have COPCs which are not considered to readily degrade or dilute, therefore these Sites would not be addressed through standard application of LPR. LPR may still be used to address other COPCs at these Sites; however, it is anticipated that some other remedial/risk-based activities would be required to address the persistent COPCs at the Sites.

3.3 Criterion # 3 – Receptor Evaluation

LPR is applicable to Sites where risk to receptors is deemed to be low. This is based on both the current absence of sensitive receptors within the affected area and a low probability that a receptor will be added to the affected area. The third criteria of Site screening included an evaluation of receptors present within 500 m of the Site as an initial screen. This focused on permanent freshwater bodies, dugouts, and water wells. Ideal candidates were selected as those with appropriate COPCs and had no or limited receptors within 500 m of the Site.

Sites were assigned a rank of 1 to 4 based on:

1. No receptors within 500 m.
2. One receptor within 500 m.
3. Two receptors within 500 m.
4. Three receptors within 500 m.

Note that while the receptor evaluation considered all types of freshwater bodies, only permanent water bodies were considered for the criteria 2 rank. Ideal LPR candidates would not have any current receptors within 500 m, however sites with a rank of 1 or 2 were retained for potential candidates as further evaluation of the receptor may allow it to be ruled out.

3.4 LPR - Site Characteristics and Refinement

In addition to screening of COPCs and receptors, site characteristics were evaluated to determine if LPR would be applicable at a Site and if it would be beneficial. This included the delineation of COPCs, estimated depth to water table (based on borehole logs), distribution of COPCS, and lithology at the Site. A focus was placed on Sites which were deemed to be potential candidates based on Criteria 2 and 3.

LPR provides an option for Sites which have a low probability of risk but are not able to be managed through standard Tier 2 options. Characteristics that have been flagged as likely to benefit from LPR are Sites with a shallow water table depth relative to the depth of COPCs, Sites with poor vertical delineation, sites driven primarily by risk to groundwater (*i.e.,* drinking water pathways and livestock watering pathways), coarse-grained soils, and Sites with elevated COPC concentrations (a chloride concentration of 7,000 mg/kg has been noted in previous MEMS work as a threshold value which limits the application of SST). Therefore, sites which also had these characteristics were selected as the best candidates for LPR.

The final component of LPR is the evaluation of the probability of future receptor occurrence. MEMS has developed a regression to predict the future construction of water wells and dugouts in a region based on the historical construction dates of these features. MEMS defines "low probability" as a risk of occurrence of less than 0.002% per hectare per annum. With a risk of occurrence below this level, it is highly likely that natural attenuation will reduce any chemical concentrations to levels where they do not pose a hazard to the receptor, should receptor presence arise.

3.5 Solar Integration

In addition to Site-specific classification, a pilot region for potential redevelopment to Solar energy production was selected.

Communications with RenuWell Energy Solutions have indicated that the optimal characteristics of a Site for solar redevelopment would include the following:

- Sites with good access to existing power grids and with opportunities for connections.
- Region with the capacity to produce a minimum of 30 Mega Watts (MW) per year.
  - An area of 5 to 12 acres can typically produce 1 to 2 MW, therefore 10 to 15 locations within a 100 km radius would be required.

RenuWell Energy Solutions provided MEMs with an evaluation of the 39 Sites with respect to their potential for solar integration and is included in Appendix D. Based on the agricultural capability mapping, a pilot region that could produce 30 MW was also selected by MEMS.

It is anticipated that other factors such as geotechnical, landscape and other engineering criteria would be necessary for solar integration however this was not part of the current evaluation.

4.0 RESULTS

A total of nine Sites were selected as potential pilot Sites, three in which both solar and LPR may be applied, three where solar alone may be used, and three where LPR alone may be used based on the criteria discussed in Section 3 (Figure 9). The selected pilot region for solar redevelopment is shown in Figure 10.

While these nine sites were selected as the best candidates out of the 39 sites reviewed, most will likely require additional consideration based on either the co-occurrence of COPCs which are not considered to readily degrade or dilute or the presence of an active potential receptor within 500 m of the Site. Further evaluation of these sites may be necessary upon entry into the LPR tool.

A summary of the risk ranking matrix is included in Appendix B2 and Site profiles are included in Appendix B3. A summary of the solar pilot region and overall potential and for solar integration is included in Appendix B4.

Figure 2 demonstrates agricultural land capability, Figure 3 the COPC ranking, Figures 4 to 6 provide a visual representation of the overlap of the 500 m buffer around sites with pertinent receptors summarized in the site selection matrix. Figures 7 and 8 show mapping of soil salinity and aquifers in the region, respectively.

5.0 SUMMARY AND PATH FORWARD

Phase 2 reports for 39 sites within the Weyburn, Saskatchewan area were reviewed in order to select potential candidate pilot sites for the application of LPR in Saskatchewan. Nine sites were selected as the best candidates of the 39 for solar and/or LPR. None of the sites had previously been evaluated with Tier 2 options, therefore the sites were evaluated based on the COPCs present at the sites, their concentrations and distributions, as well as the current presence of receptors, site characteristics which would promote the application of LPR, and low likelihood of future receptor occurrence.

Based on the initial review, none of the Sites were without flaw in terms of LPR application however these sites showed the most promise. Moving forward on these sites would require complete entry of the potential pilot sites with the fully built out Saskatchewan LPR tool. The LPR model auto-generates a report summarizing the Site in terms of the application of LPR.

Attachments:

Appendix B1	Figures
Appendix B2	Risk Ranking matrix
Appendix B3	Pilot Site Profiles
Appendix B4	Solar Feasibility
Appendix B5	Background Dataset

6.0 REFERENCES

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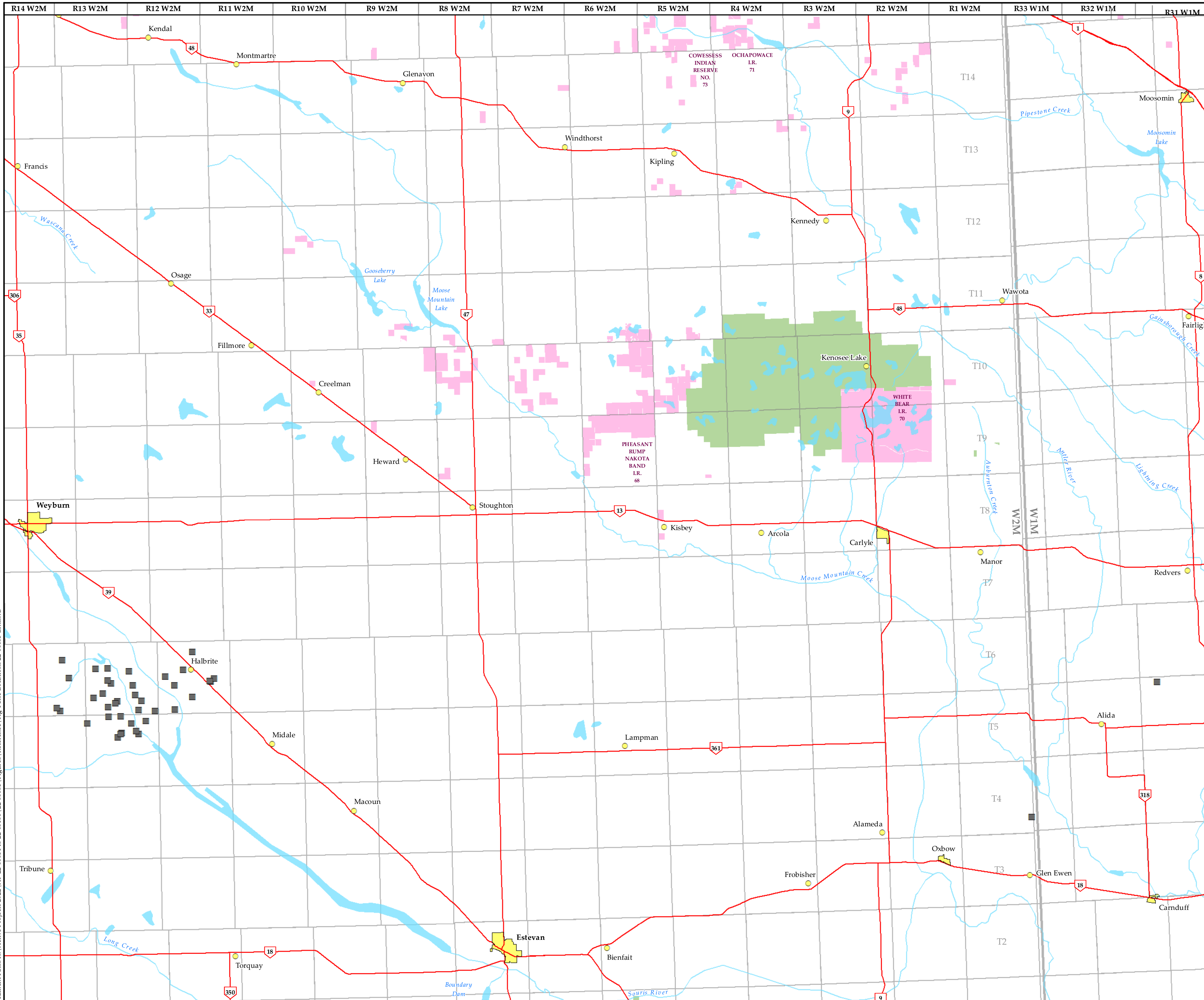
APPENDIX B1: FIGURES



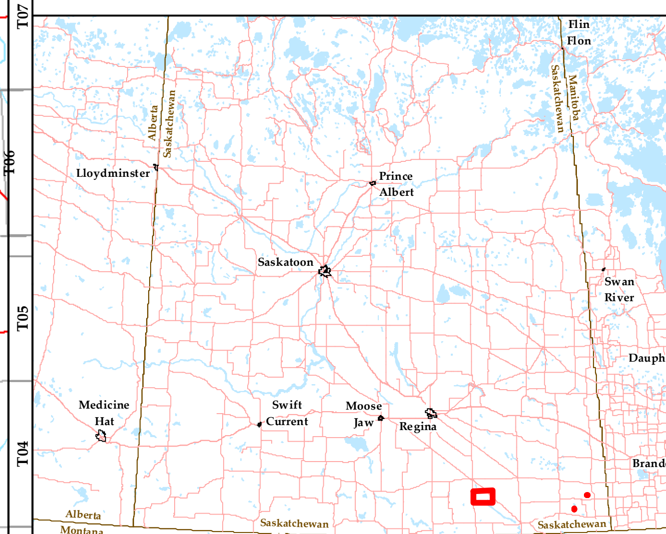
WHITECAP RESOURCES INC

SASKATCHEWAN ALTERNATE CLOSURE / REDEVELOPMENT

SITE LOCATIONS

LEGEND

- Site Locations
- Primary Highway
- Secondary Highway
- Provincial Boundary
- Park/Protected Area
- First Nations Reserve/Metis Settlement
- Populated Place



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Kilometers

Coordinate System: NAD 1983 UTM Zone 13N

ISC, 2019; MEMS, 2022

MILLENNIUM EMS Solutions Ltd.

PROJECT: 22-00083
DRAWN BY: TCHUNG
CHECKED BY: AL
DATE: SEPTEMBER 6, 2022

FIGURE 1

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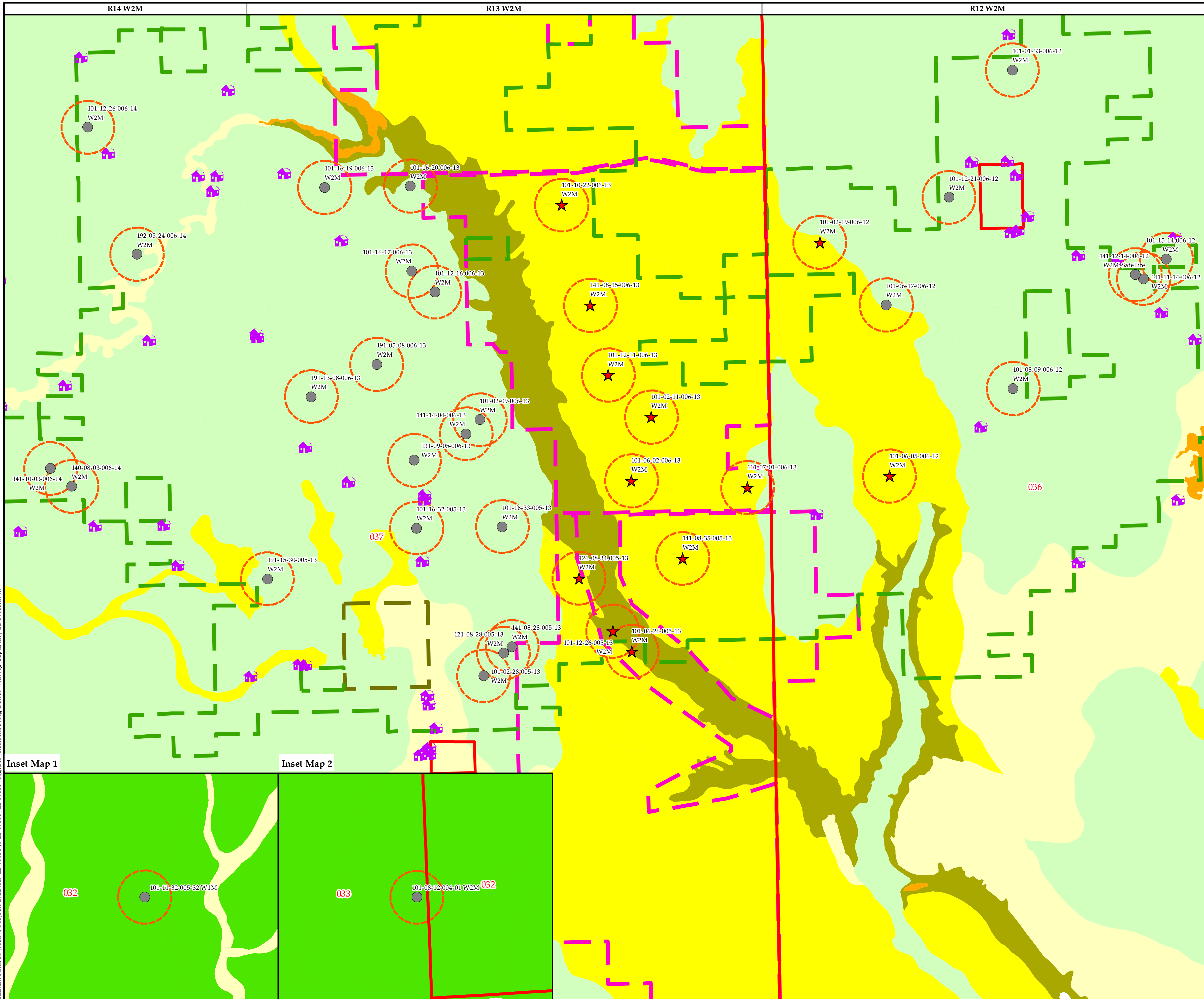
Disclaimer: This figure was derived from multiple data sources and while we make every effort to assure its accuracy, Millennium EMS Solutions Ltd. disclaims any representation or warranty and assumes no liability either for any errors, omission or inaccuracies that may occur.



WHITECAP RESOURCES INC

SASKATCHWEN ALTERNATE CLOSURE / REDEVELOPMENT

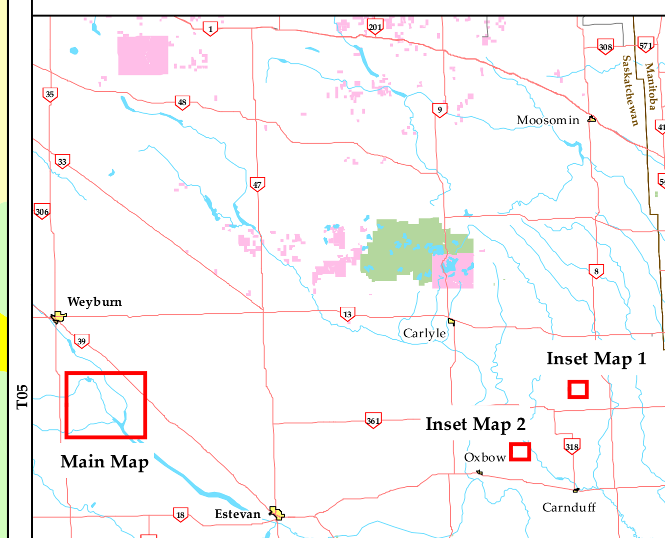
SITES WITH AGRICULTURAL CAPABILITY

LEGEND

- Criteria 1 Rank of 4 or Above
- Criteria 1 Rank of less than 4
- Residence_MidPoints
- 500 m Search Radius
- Rural Municipality
- Whitecap Unit Boundary
- Lomond Grazing Corp Boundary
- WHPA Pasture Boundary

Agricultural Capability (SKSIDv4)

- Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices.
- Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices.
- Soils in this class have severe limitations that restrict the range of crops or require special conservation practices, or both.
- Soils in this class have very severe limitations that restrict their use to the production of native or tame species of perennial forage crops. Improvement practices are feasible.
- Soils in this class are capable of producing native forage crops only. Improvement practices are not feasible.
- Soils in this class have no capability for arable agriculture or permanent pasture.



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DATE: SEPTEMBER 6, 2022

FIGURE 2

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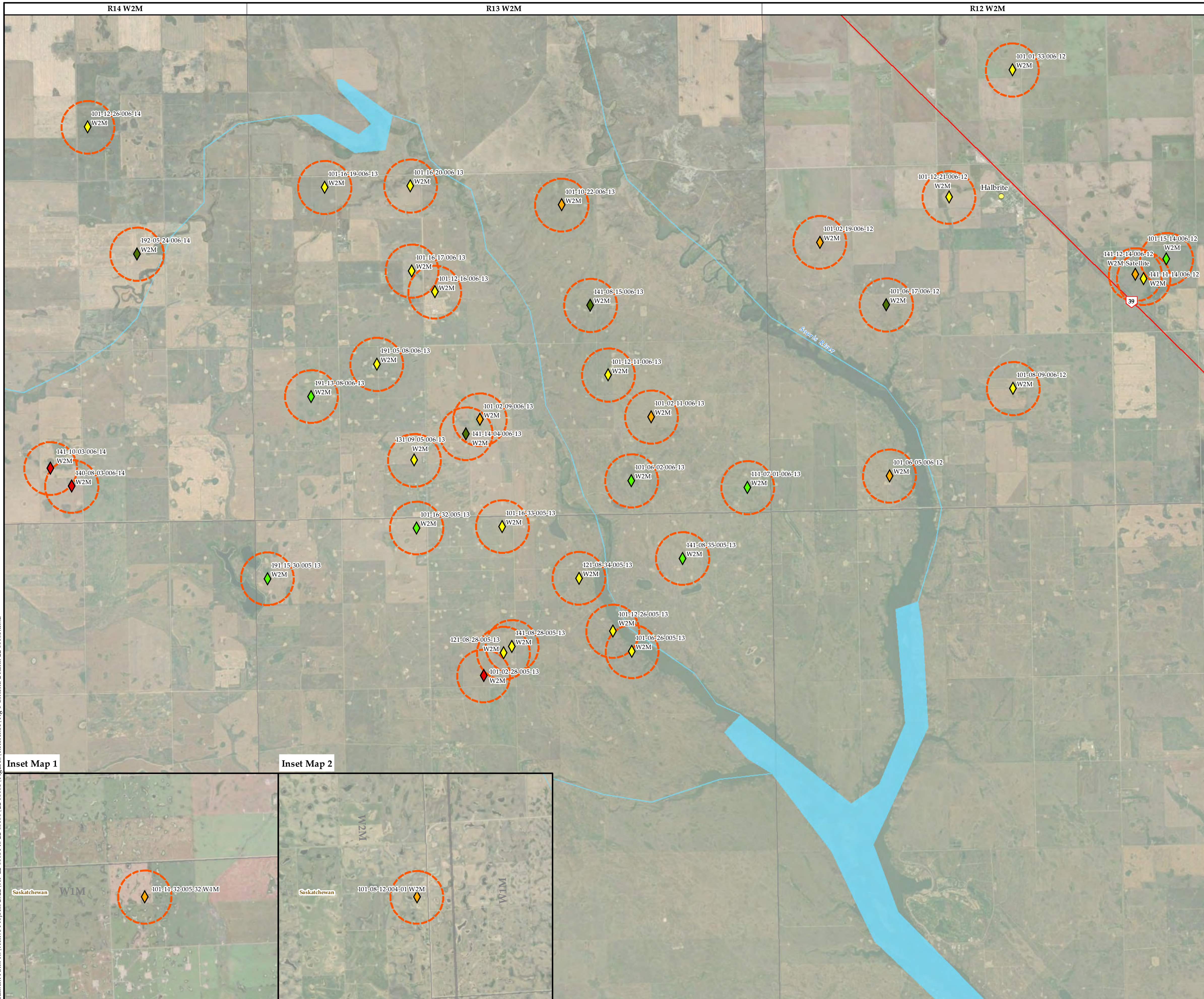

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WHITECAP RESOURCES INC

SASKATCHWEN ALTERNATE CLOSURE / REDEVELOPMENT

CRITERIA 2 RANKING

LEGEND

- Criteria 2 Rank 0
- Criteria 2 Rank 1
- Criteria 2 Rank 2
- Criteria 2 Rank 3
- Criteria 2 Rank 4
- 500 m Search Radius

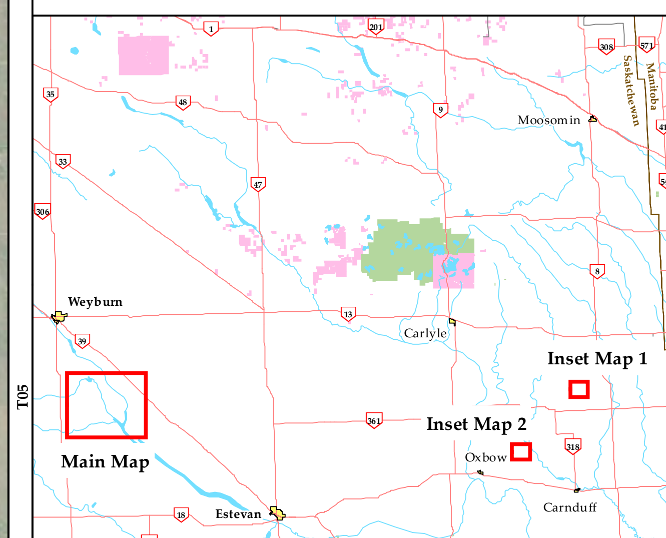

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FIGURE

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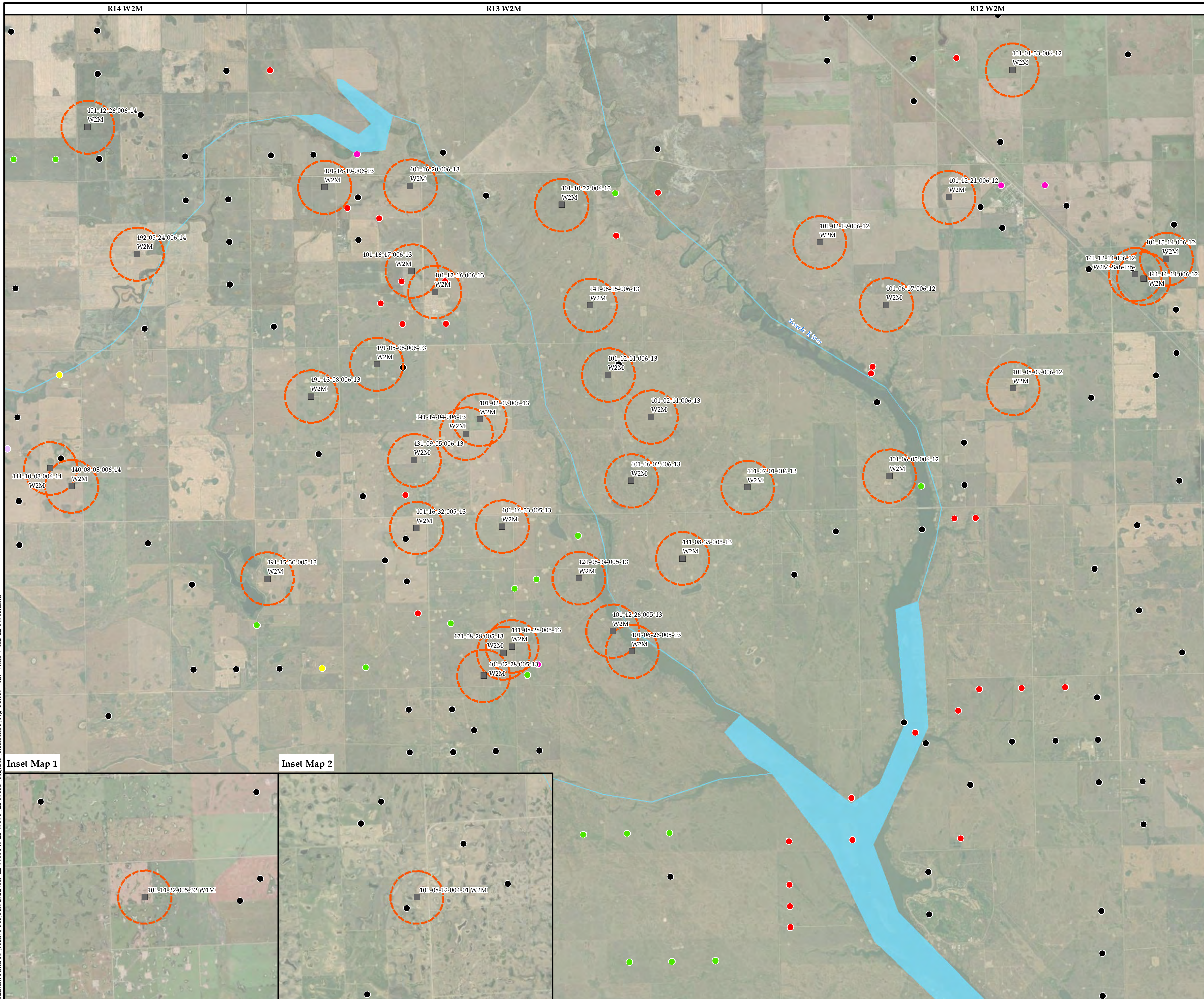


WHITECAP RESOURCES INC

SASKATCHWEN ALTERNATE CLOSURE / REDEVELOPMENT

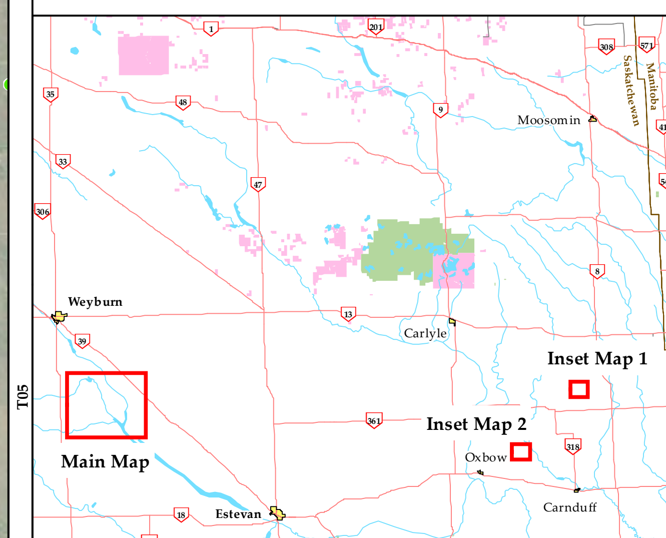
SITES WITH WATER WELLS

LEGEND

- Site Locations
- 500 m Search Radius

Water Wells (Water Use)

- Domestic
- Drainage
- Industrial
- Irrigation
- Mineral Recovery
- Mineral Water
- Multi-purpose
- Municipal
- Other
- Recreation
- Research
- Unknown Well Use



0 1 2
Kilometers

Coordinate System: NAD 1983 UTM Zone 13N

ISC, 2019; MEMS, 2022; Water Security Agency, 2022; ESRI, 2022 (Image Date: 2012-2020)

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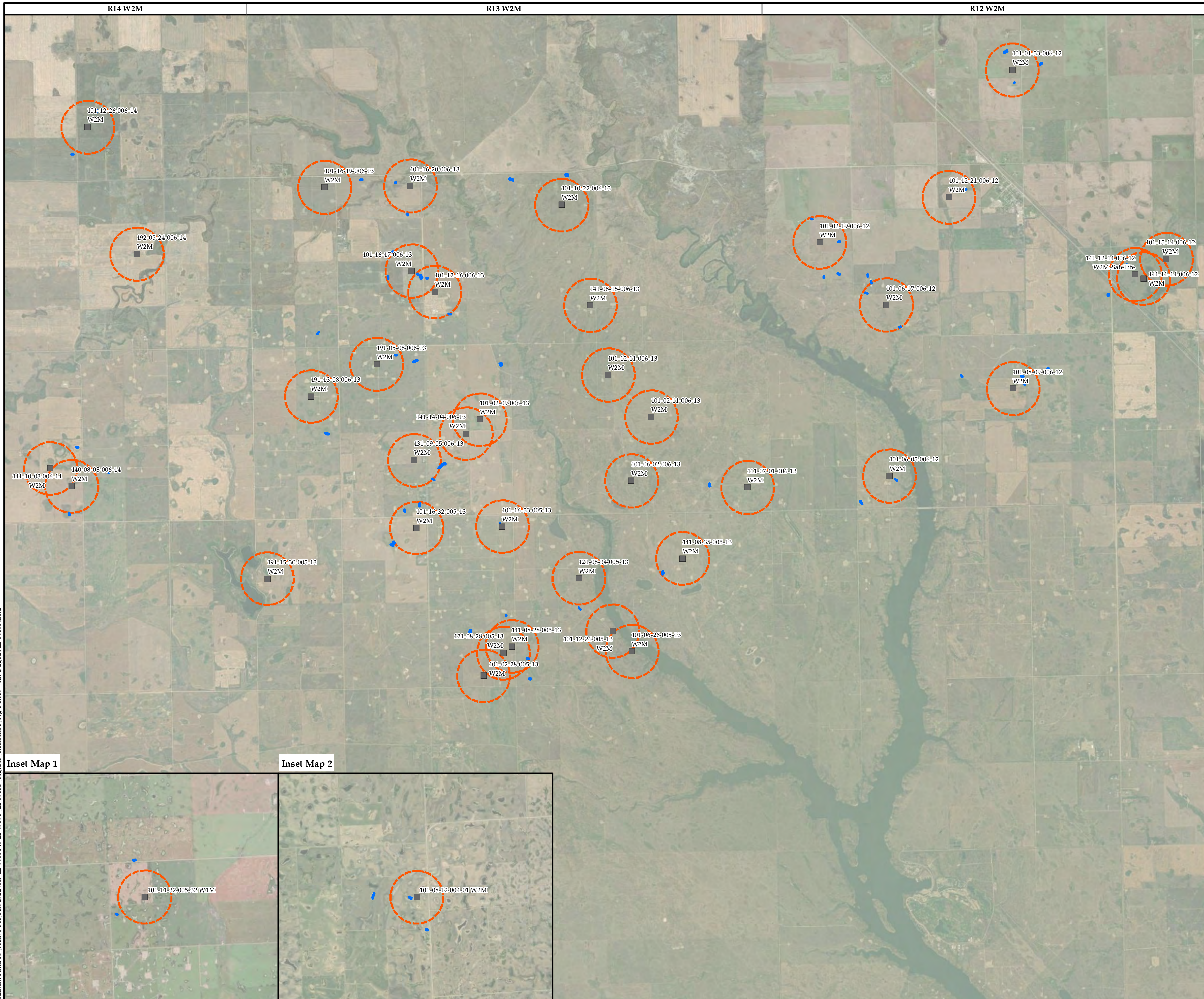
FIGURE 4

Document Path: K:\Active Projects 2022\AP 22-00051 to 22-00100\22-00083\Figures\Reference\Fig 4 Sites with Water Wells 22-00083.mxd



Document Path: K:\Active Projects 2022\AP 22-00051 to 22-00100\22-00083\Figures\Reference\Fig 5 Sites with Dugout 22-00083.mxd

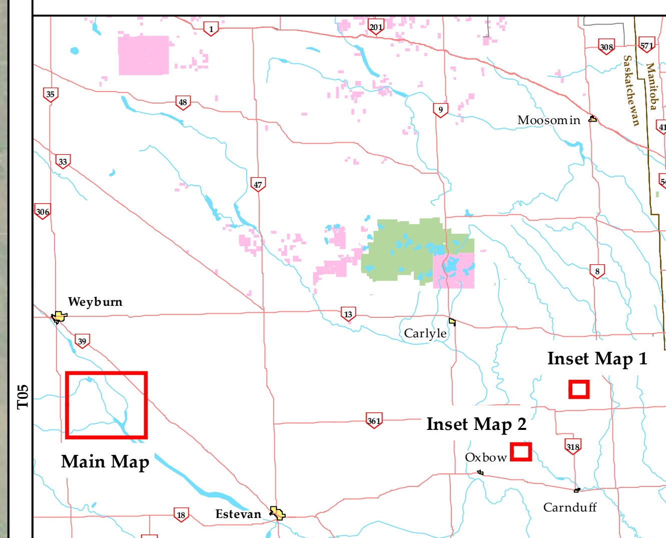
WHITECAP RESOURCES INC

SASKATCHWEN ALTERNATE CLOSURE / REDEVELOPMENT

SITES WITH DUGOUTS

LEGEND

- Site Locations
- 500 m Search Radius
- Dugout Locations



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Coordinate System: NAD 1983 UTM Zone 13N

ISC, 2019; MEMS, 2022; Water Security Agency, 2022; ESRI, 2022 (Image Date: 2012-2020)

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FIGURE

5

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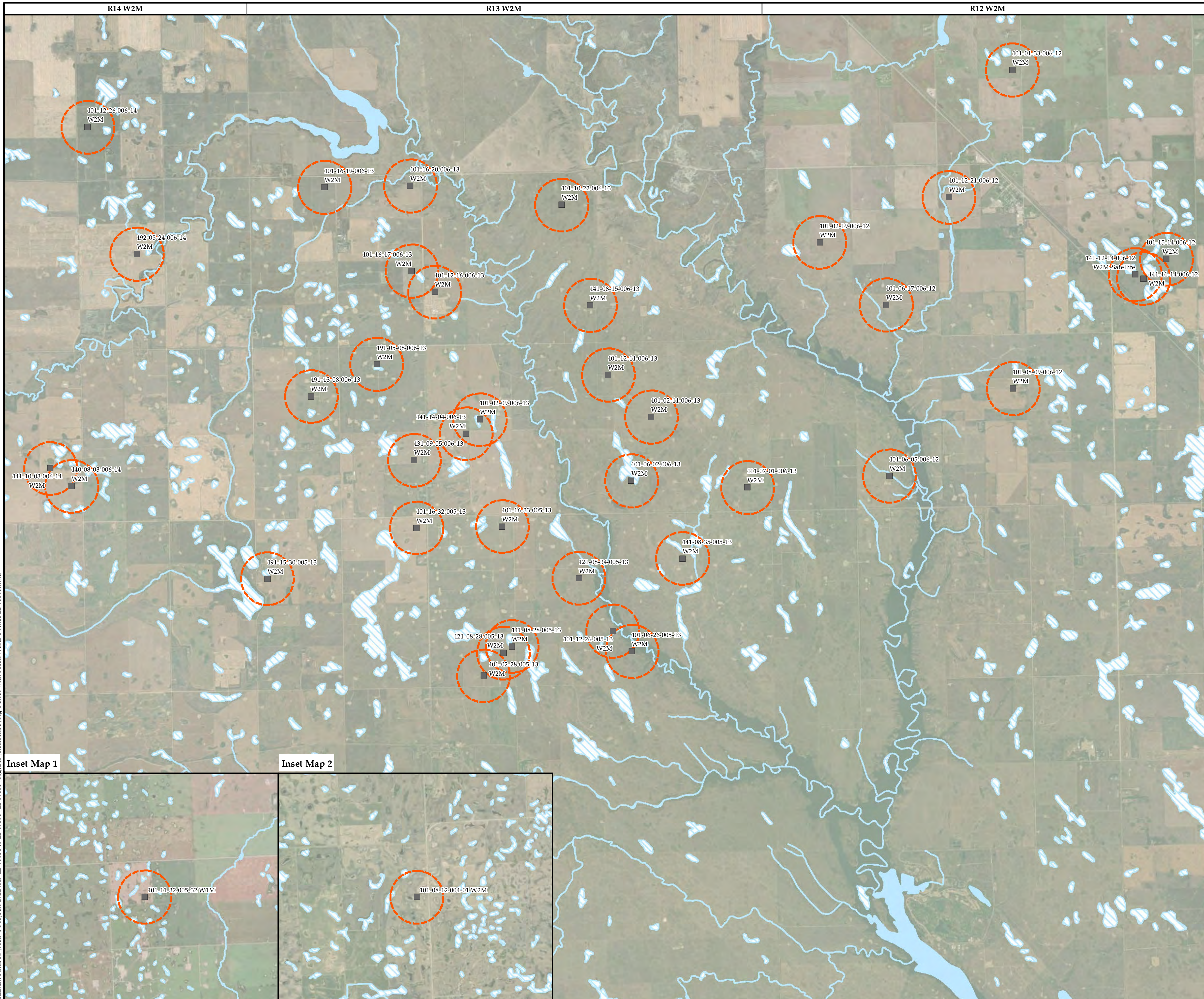
SASKATCHWEN ALTERNATE CLOSURE / REDEVELOPMENT

SITES WITH FRESH WATER BODIES

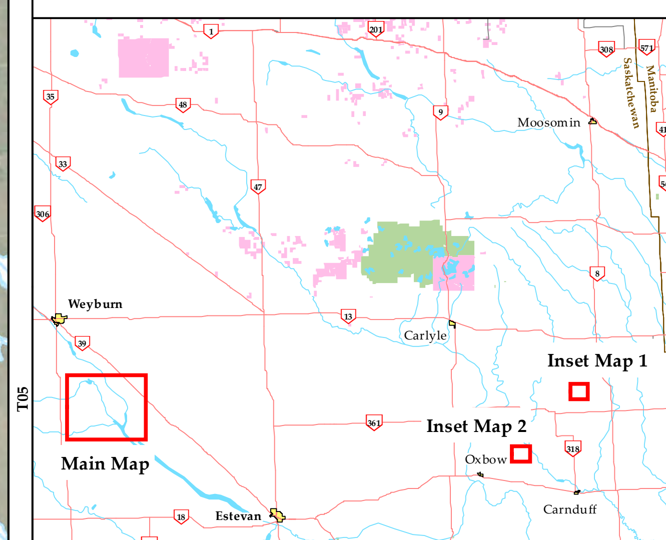


LEGEND

- Site Locations
- 500 m Search Radius

Waterbody

- Permanent
- Intermittent



0 1 2
Kilometers

Coordinate System: NAD 1983 UTM Zone 13N

ISC, 2019; MEMS, 2022; Water Security Agency, 2022; ESRI, 2022 (Image Date: 2012-2020)

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FIGURE

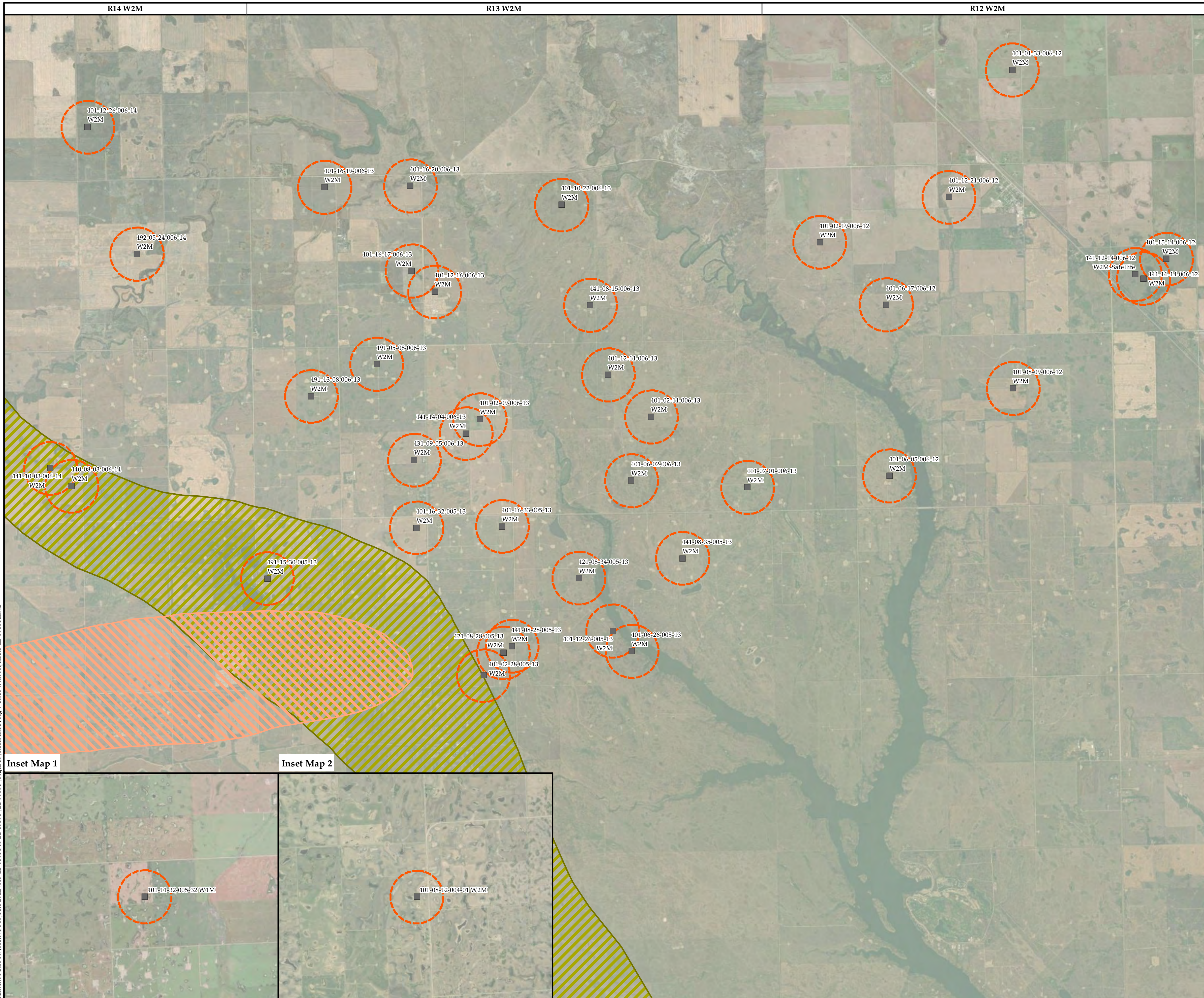
6

Document Path: K:\Active Projects 2022\AP 22-00051 to 22-00100\22-00083\Figures\Reference\Fig 6 Sites with Fresh Water Bodies 22-00083.mxd

WHITECAP RESOURCES INC

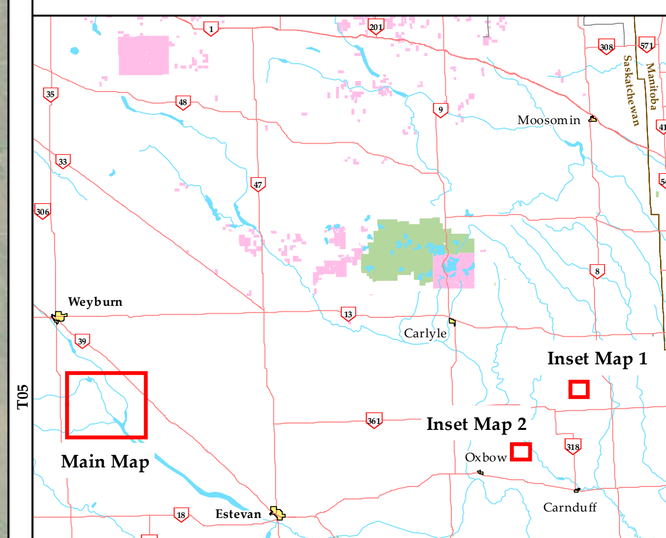
SASKATCHWEN ALTERNATE CLOSURE / REDEVELOPMENT

SITES WITH AQUIFERS



LEGEND

- Site Locations
- 500 m Search Radius
- Intertill Sand and Gravel Aquifers
- Empress Aquifers



0 1 2
Kilometers

Coordinate System: NAD 1983 UTM Zone 13N

ISC, 2019; MEMS, 2022; Water Security Agency, 2022; ESRI, 2022 (Image Date: 2012-2020)

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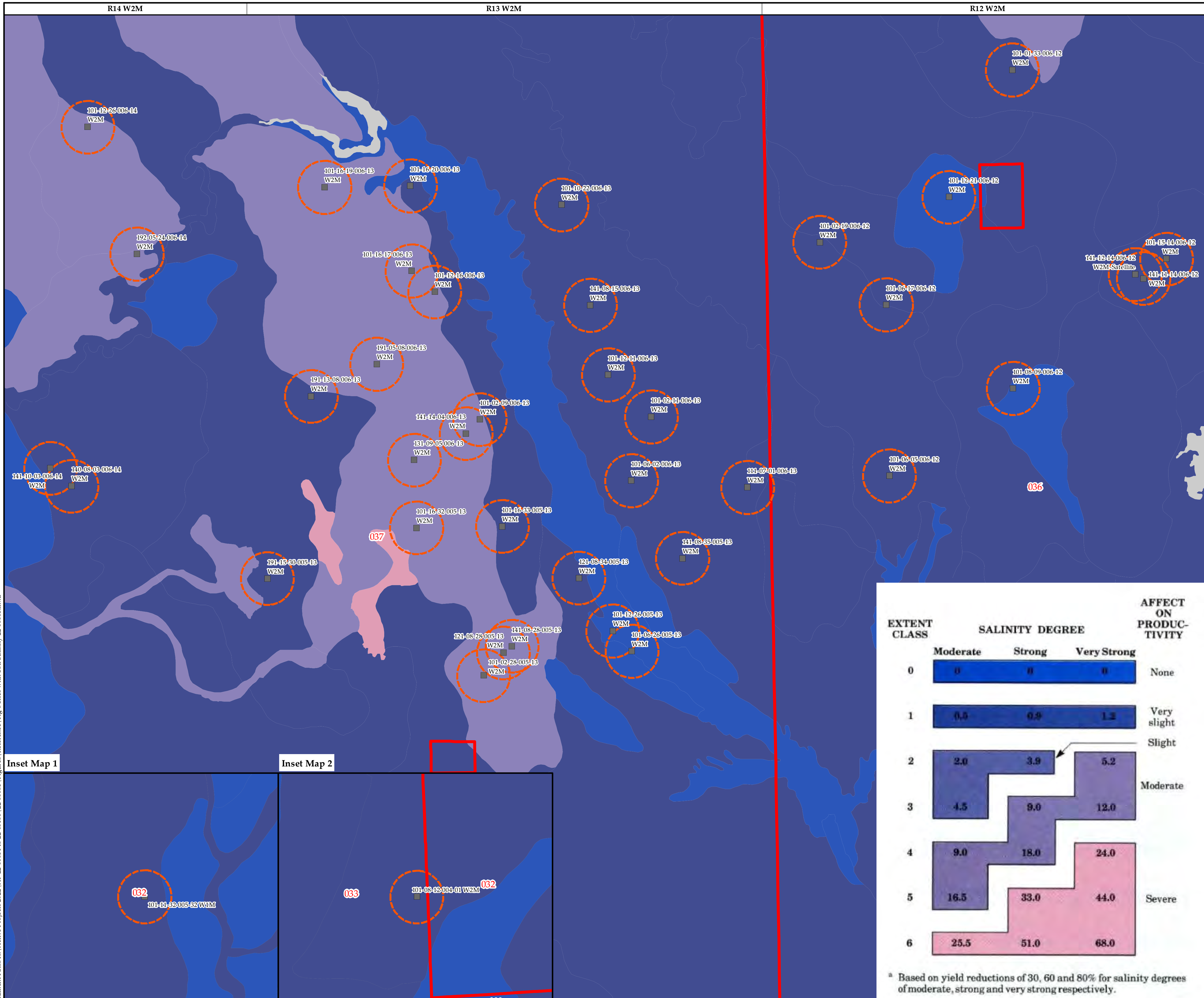
FIGURE

7

Document Path: K:\Active Projects 2022\AP 22-00051 to 22-00100\22-00083\Figures\Reference\Fig 7 Sites with Aquifers 22-00083.mxd



WHITECAP RESOURCES INC

SASKATCHWEN ALTERNATE CLOSURE / REDEVELOPMENT

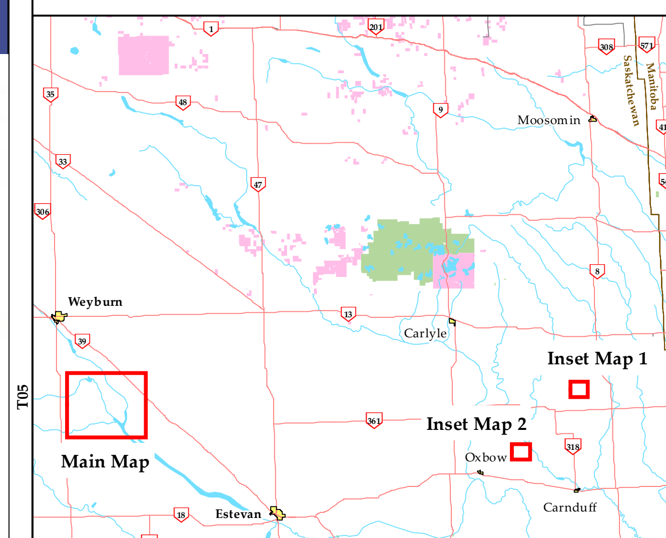
SITES WITH SOIL SALINITY ON PRODUCTIVITY

LEGEND

- Site Locations
- 500 m Search Radius
- Rural Municipality

Salinity Impact on Productivity (SKSIDv4)

- Salinity affect on productivity: Unclassified
- Salinity affect on productivity: Very slight
- Salinity affect on productivity: Slight
- Salinity affect on productivity: Moderate
- Salinity affect on productivity: Severe



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Kilometers

Coordinate System: NAD 1983 UTM Zone 13N

ISC, 2019; MEMS, 2022; Water Security Agency, 2022; ESRI, 2022 (Image Date: 2012-2020)

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FIGURE 8

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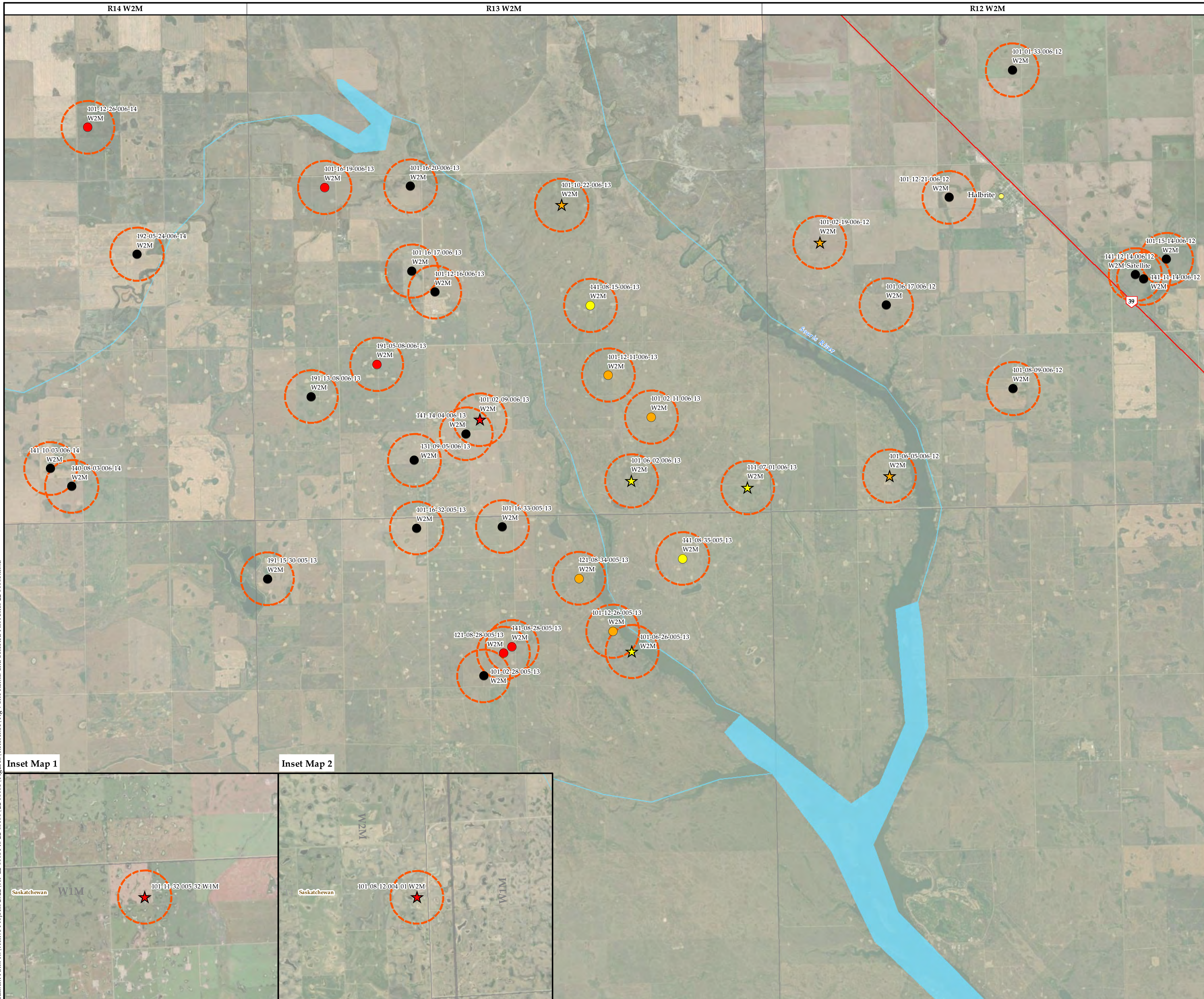


Document Path: K:\Active Projects 2022\AP 22-00051 to 22-00100\22-00083\Figures\Reference\Fig 9 Site Ranks and Selected Pilot Sites 22-00083.mxd

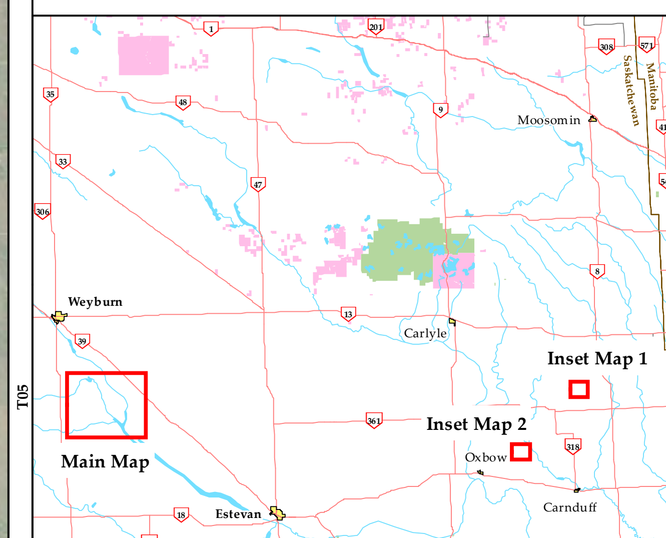
WHITECAP RESOURCES INC

SASKATCHWEN ALTERNATE CLOSURE / REDEVELOPMENT

SITE RANKS AND SELECTED PILOT SITES

LEGEND

- Group A Selected Pilot Site
- Group B Selected Pilot Site
- Group C Selected Pilot Site
- Group A
- Group B
- Group C
- Group D
- 500 m Search Radius



0 1 2
Kilometers

Coordinate System: NAD 1983 UTM Zone 13N

ISC, 2019; MEMS, 2022; Water Security Agency, 2022; ESRI, 2022 (Image Date: 2012-2020)

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FIGURE 9

APPENDIX B2: RISK RANKING MATRIX

Table B2-1: Risk Ranking Matrix

Site Location			Criteria 1 (Agricultural Potential)	Criteria 2 (COPC)							Criteria 2 (Receptors)					Site Characteristics and Refinement							Path Forward Group	Selected Pilot Sites
Site	Latitude	Longitude	Rank	COPCs Assessed				If PHC, light or heavy end	Maximum Chloride Concenration (mg/kg)	Rank	Water Wells within 500 m	Dugouts within 500 m	Freshwater body within 500m	*Type of water body	Rank	Grain size governing transport	AQUIFERS	Depth to Groundwater	Vertical Delineation	Lateral Delineation	Area m2	LPR Notes		Description included in Appendix C
				Detailed Salinity	PHC	PAH	Metals																	
101-02-09-006-13 W2M	49.451791	-103.696289	2	Y	Y	N	N	Both	1440	3	NO	NO	YES*	class 3 wetland immediately west of Site	1	Coarse	NO	3	Y	Y	5400	Good candidate	C	Y
101-02-19-006-12 W2M	49.480924	-103.606825	4	Y	Y	N	Y	Both	3230	3	NO	YES	YES*	several class 3 wetlands	2	fine and coarse	NO	6	N	N	28800	Good candidate for LPR, though distance to dugout will need to be confirmed	A	Y
101-06-05-006-12 W2M	49.440944	-103.589781	4	Y		N	N	-	6030	3	NO	NO	YES	surface water body	2	fine and coarse	NO		N	N	1600	good candidate except for surface water body	A	Y
101-08-12-004-01 W2M	49.280841	-102.00931	1	Y	Y	N	Y	-	10000	3	YES (1)	NO	YES*	seasonal surface water bodies	2	fine	NO	0.5	N	N	75,000	Good candidate for LPR, though water well location will require confirmation	C	Y
101-10-22-006-13 W2M	49.488081	-103.674017	4	Y	Y	N	N	-	5830	3	NO	NO	NO	-	1	fine	NO	1.5	N	N		Good candidate	A	Y
101-11-32-005-32 W1M	49.437646	-101.767758	1	Y	Y	N	N	Both	5860	3	NO	NO	YES*	several seasonal sloughs	1	Fine	NO	5	Y	N	32267	Good candidate	C	Y
140-08-03-006-14 W2M	49.441597	-103.803016	2	Y	Y	Y	Y	Both	3500	4	NO	NO	YES*	class 3 wetland on Site	1	fine and coarse	YES	7.5	N	N	12500	Good candidate	D	N
141-12-14-006-12 W2M-Satel	49.474404	-103.524692	2	Y	Y	Y	Y		12100	3	YES (1)	YES	YES	wetlands adjacent to both sites	4	fine and coarse	NO	5.6	Y	N	150000	Satellite may be a good candidate pending further evaluation fo the water well and dugouts in the area	D	N
101-02-11-006-13 W2M	49.451743	-103.651617	4	Y	Y	Y	N	Both	3030	3	NO	NO	YES*	no permanenet water bodies	1	fine and coarse	NO	1	Y	Y		COPCs can likely be addressed with Tier 2 methods	A	N
101-06-26-005-13 W2M	49.411906	-103.657743	5	Y	Y	N	N	-	2040	2	NO	NO	YES	rafferty reservoir 60 m NE	2	fine and coarse	NO		N	N		within proximity of a sinificant surface water body	B	Y
101-08-09-006-12 W2M	49.455442	-103.557111	2	Y	Y	Y	Y	Both	1740	2	NO	YES	YES	several class 2 wetlands	3	fine and coarse	NO	0.5	Y	Y		COPCs can likely be addressed with Tier 2 methods	D	N
101-12-26-006-14 W2M	49.502657	-103.797317	2	Y	Y	N	N	Heavy	2150	2	NO	YES	YES*	likely seasonal sloughs	2	fine and coarse	NO		Y	Y		heavy-end hydrocarbons and chloride which can likely be managed through Tier 2 options	C	N
101-16-17-006-13 W2M	49.477269	-103.713363	2	Y	Y	N	N	-	3670	2	YES (4)	YES	YES*	dugouts and constructed surface water bodies	4	fine	NO		N	N		within proximity of numerous water wells and dugouts, probability of future occurrence is likely to be higher in this area	D	N
101-16-20-006-13 W2M	49.491738	-103.713381	2	Y	Y	N	N	-	4580	2	NO	YES	YES	creek to the northwest	3	fine	NO	6	Y	N		chloride is predominantly located in the rooting zone and likely limited by this pathway	D	N
191-05-08-006-13 W2M	49.461505	-103.722983	2	Y	Y	N	Y	Both	502	2	NO	NO	YES*	seasonal sloughs	1	Fine	NO		Y	Y		COPCs can likely be addressed with Tier 2 methods	C	N
101-01-33-006-12 W2M	49.509634	-103.555739	2	Y	Y	N	Y	-	972	2	NO	YES	YES	sloughs and a potential creek	3	fine and coarse	NO		N	Y		Limited COPCs can likely be managed through Tier 2 methods	D	N
101-02-28-005-13 W2M	49.408203	-103.696476	2	Y	Y	N	N	Heavy	116	4	NO	NO	YES*	likely seasonal sloughs	1	fine and coarse	YES					COPCs at the Site are not considered to readily degrade or dilute	D	N

Table B2-1: Risk Ranking Matrix

Site Location			Criteria 1 (Agricultural Potential)	Criteria 2 (COPC)							Criteria 2 (Receptors)					Site Characteristics and Refinement							Path Forward Group	Selected Pilot Sites
Site	Latitude	Longitude	Rank	COPCs Assessed				If PHC, light or heavy end	Maximum Chloride Concenration (mg/kg)	Rank	Water Wells within 500 m	Dugouts within 500 m	Freshwater body within 500m	*Type of water body	Rank	Grain size governing transport	AQUIFERS	Depth to Groundwater	Vertical Delineation	Lateral Delineation	Area m2	LPR Notes		Description included in Appendix C
				Detailed Salinity	PHC	PAH	Metals																	
101-12-11-006-13 W2M	49.458999	-103.662633	4	Y	Y	N	N	-	657	2	YES (1)	NO	YES*	likely seasonal sloughs	2	fine	NO		N	N		Limited COPCs can likely be managed through Tier 2 methods	A	N
101-12-16-006-13 W2M	49.473645	-103.707506	2	Y	Y	N	N	-	1530	2	YES (1)	YES	YES*	dugouts and constructed surface water bodies	3	fine	NO		N	N		Ubiquitous distribution of chlroide in soil suggest that salinity may be naturally elevated at the Site	D	N
101-12-21-006-12 W2M	49.488185	-103.572888	2	Y	Y	N	N	-	1180	2	NO	YES	YES	creek 130 m north and 100 m west	3	fine	NO					permanent freshwater body within proximity of the Site (receptor)	D	N
101-12-26-005-13 W2M	49.41542	-103.662638	5	Y	Y	N	N	-	467	2	NO	NO	YES	rafferty reservoir 70 m east of site	2	fine and coarse	NO		Y	Y		Limited COPCs can likely be managed through Tier 2 methods	A	N
101-16-19-006-13 W2M	49.491748	-103.73577	2	Y	Y	N	N	-	750	2	NO	NO	YES	linear drainage feature 410 m southeast	2	fine and coarse	NO		Y	Y		Limited COPCs can likely be managed through Tier 2 methods	C	N
101-16-33-005-13 W2M	49.433535	-103.690925	2	Y	Y	N	N	-	823	2	NO	YES	YES	pond to the east	3	fine and coarse	NO		N	N		Limited COPCs can likely be managed through Tier 2 methods	D	N
121-08-28-005-13 W2M	49.412004	-103.69124	2	Y	Y	N	N	-	808	2	NO	YES	YES*	likely seasonal sloughs	2	fine and coarse	NO		Y	Y		Limited COPCs can likely be managed through Tier 2 methods	C	N
121-08-34-005-13 W2M	49.424504	-103.671223	4	Y	Y	N	N	-	556	2	NO	NO	YES	rafferty reservoir 240 m east	2	fine and coarse	NO		Y	Y		Limited COPCs can likely be managed through Tier 2 methods, significant water body within proximity	A	N
131-09-05-006-13 W2M	49.445094	-103.713593	2	Y	Y	N	Y	-	1520	2	NO	YES	YES	permanent surface water body 300 m northwest	3	fine and coarse	NO		Y	Y		COPCs an likely be managed through Tier 2 options, permanent freshwater body within 500m of Site.	D	N
141-08-28-005-13 W2M	49.413108	-103.688951	2	Y	Y	N	N	-	906	2	NO	YES	YES*	class 3 wetland immediately northwest of site	2	fine and coarse	NO		Y	Y		Localized chloride exceedance in the rooting zone is likely not governed by DUA or livestock watering pathways	C	N
141-10-03-006-14 W2M	49.444715	-103.808461	2	Y	Y	N	Y	-	595	4	YES (3)	NO	YES*	several class 3 wetlands	2	fine	YES		Y	Y		COPCs at the Site are not considered to readily degrade or dilute, those that can can likely be managed through Tier 2 options	D	N
141-11-14-006-12 W2M	49.473699	-103.522552	2	Y	Y	Y	Y	Heavy	627	2	YES (1)	YES	YES	wetlands adjacent to both sites	4	fine and coarse	NO		Y	Y		COPCs can likely be managed through Tier 2 options	D	N
191-13-08-006-13 W2M	49.456222	-103.740167	2	Y	Y	N	Y	-	381	1	NO	NO	YES*	likely seasonal sloughs	1	fine and coarse	NO		N	N		Ubiquitous distribution of chlroide in soil suggest that salinity may be naturally elevated at the Site	D	N
101-06-02-006-13 W2M	49.440949	-103.657079	4	Y	Y	N	N	-	206	1	NO	NO	YES	surface water body along north/east boundary	2	fine	NO					marginal chloirde exceedance	B	Y
101-06-17-006-12 W2M	49.470088	-103.589801	2	Y	Y	N	N	-	78	0	NO	YES	YES	creek to the east	3	fine and coarse	NO					within background values	D	N
101-15-14-006-12 W2M	49.476934	-103.516475	2	Y	Y	N	N	-	214	1	NO	NO	YES	water body 155 m west fo Site	2	fine and coarse	NO					marginal chloirde exceedance	D	N
101-16-32-005-13 W2M	49.433536	-103.713331	2	Y	Y	N	N	-	267	1	YES (2)	YES	YES	permanent surface water body 430 m	4	fine	NO					marginal chloirde exceedance	D	N

Table B2-1: Risk Ranking Matrix

Site Location			Criteria 1 (Agricultural Potential)	Criteria 2 (COPC)							Criteria 2 (Receptors)					Site Characteristics and Refinement							Path Forward Group	Selected Pilot Sites
Site	Latitude	Longitude	Rank	COPCs Assessed				If PHC, light or heavy end	Maximum Chloride Concenration (mg/kg)	Rank	Water Wells within 500 m	Dugouts within 500 m	Freshwater body within 500m	*Type of water body	Rank	Grain size governing transport	AQUIFERS	Depth to Groundwater	Vertical Delineation	Lateral Delineation	Area m2	LPR Notes		Description included in Appendix C
				Detailed Salinity	PHC	PAH	Metals																	
111-07-01-006-13 W2M	49.439422	-103.626818	**4**	Y	Y	N	N	-	279	**1**	NO	NO	YES*	likely seasonal sloughs	**1**	fine and coarse	NO					marginal chloirde exceedance	B	Y
141-08-15-006-13 W2M	49.470922	-103.666995	**4**	Y	Y	N	N	-		**0**	NO	NO	YES	creek to the west	**2**	fine and coarse	NO					within background values	B	N
141-08-35-005-13 W2M	49.427558	-103.644089	**4**	Y	Y	N	N	-	272	**1**	NO	YES	YES	creek to the west	**3**	fine and coarse	NO					marginal chloirde exceedance	B	N
141-14-04-006-13 W2M	49.449444	-103.7	**2**	Y	Y	N	N	-	120	**0**	NO	NO	YES	2 ponds 280 m northeast	**2**	fine and coarse	NO					within background values	D	N
191-15-30-005-13 W2M	49.425333	-103.752417	**2**	Y	Y	N	Y	-	256	**1**	NO	NO	YES*	class 3 wetland immediately north of site	**1**	fine	YES					marginal chloirde exceedance	D	N
192-05-24-006-14 W2M	49.480917	-103.785056	**2**	Y	Y	N	N	-	120	**0**	NO	NO	YES	water body 135 m east	**2**	fine	NO					within background values	D	N

Notes:
Indicates COPC above Tier 1/background values

CRITERIA 1

Ranking	Meaning
1	Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices.
2	Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices.
3	Soils in this class have severe limitations that restrict the range of crops or require special conservation practices, or both.
4	Soils in this class have very severe limitations that restrict their use to the production of native or tame species of perennial forage crops. Improvement practices are feasible.
5	Soils in this class are capable of producing native forage crops only. Improvement practices are not feasible.
6	Soils in this class have no capability for arable agriculture or permanent pasture.

CRITERIA 2

Rank	Meaning
0	Maximum concentration of COPCs are below Tier 1 guidelines or maximum chloride concentration is within background value (<186 mg/kg)
1	Low concentrations of degradable/dilute COPCs (marginal exceedance from background)
2	Moderate concentration of degradabl/dilute COPCs
3	High concentration of degradable/dilute COPCs, chloride concentrations of >7000 mg/kg, difficult to manage with Tier 2 methods or SST
4	Likely requires remediation due to the presence of COPCs that do not degrade or dilute

CRITERIA 3

Rank	Meaning
1	Site has 0 receptors
2	Site has 1 receptor
3	Site has 2 receptors
4	Site has 3 receptors

GROUP

A	Both Solar and LPR Applicable
B	Only Solar Applicable
C	Only LPR Applicable
D	Neither Solar nor LPR Applicable

Table B2-2: Risk Ranking Matrix for Sites within the Solar Pilot Zone

Site Location			Criteria 1 (Agricultural Potential)	Criteria 2 (COPC)							Criteria 2 (Receptors)					Site Characteristics and Refinement						Path Forward Group
Site	Latitude	Longitude	Rank	COPCs Assessed				If PHC, light or heavy end	Maximum Chloride Concenration (mg/kg)	Rank	Water Wells within 500 m	Dugouts within 500 m	Freshwater body within 500m	*Type of water body	Rank	Grain size governing transport	AQUIFERS	Depth to Groundwater	Vertical Delineation	Lateral Delineation	LPR Notes	
				Detailed Salinity	PHC	PAH	Metals															
101-10-22-006-13 W2M	49.488081	-103.674017	4	Y	Y	N	N	-	5830	3	NO	NO	NO	-	1	fine	NO	1.5	N	N	Good candidate	A
141-08-15-006-13 W2M	49.470922	-103.666995	4	Y	Y	N	N	-		0	NO	NO	YES	creek to the west	2	fine and coarse	NO				within background values	B
101-12-11-006-13 W2M	49.458999	-103.662633	4	Y	Y	N	N	-	657	2	YES (1)	NO	YES*	likely seasonal sloughs	2	fine	NO		N	N	Limited COPCs can likely be managed through Tier 2 methods	A
101-02-11-006-13 W2M	49.451743	-103.651617	4	Y	Y	Y	N	Both	3030	2	NO	NO	YES*	no permanenet water bodies	1	fine and coarse	NO	1	Y	Y	COPCs can likely be addressed with Tier 2 methods	A
101-06-02-006-13 W2M	49.440949	-103.657079	4	Y	Y	N	N	-	206	1	NO	NO	YES	surface water body along north/east boundary	2	fine	NO				marginal chloirde exceedance	B
111-07-01-006-13 W2M	49.439422	-103.626818	4	Y	Y	N	N	-	279	1	NO	NO	YES*	likely seasonal sloughs	1	fine and coarse	NO				marginal chloirde exceedance	A
141-08-35-005-13 W2M	49.427558	-103.644089	4	Y	Y	N	N	-	272	1	NO	YES	YES	creek to the west	3	fine and coarse	NO				marginal chloirde exceedance	B
121-08-34-005-13 W2M	49.424504	-103.671223	4	Y	Y	N	N	-	556	2	NO	NO	YES	rafferty reservoir 240 m east	2	fine and coarse	NO		Y	Y	Limited COPCs can likely be managed through Tier 2 methods, significant water body within proximity	B
101-12-26-005-13 W2M	49.41542	-103.662638	5	Y	Y	N	N	-	467	2	NO	NO	YES	rafferty reservoir 70 m east of site	2	fine and coarse	NO		Y	Y	Limited COPCs can likely be managed through Tier 2 methods	B
101-06-26-005-13 W2M	49.411906	-103.657743	5	Y	Y	N	N	-	2040	3	NO	NO	YES	rafferty reservoir 60 m NE	2	fine and coarse	NO		N	N	within proximity of a sinificant surface water body	B

Notes:
Indicates COPC above Tier 1/background values

CRITERIA 1

Ranking	Meaning
1	Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices.
2	Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices.
3	Soils in this class have severe limitations that restrict the range of crops or require special conservation practices, or both.
4	Soils in this class have very severe limitations that restrict their use to the production of native or tame species of perennial forage crops. Improvement practices are feasible.
5	Soils in this class are capable of producing native forage crops only. Improvement practices are not feasible.
6	Soils in this class have no capability for arable agriculture or permanent pasture.

CRITERIA 2

Rank	Meaning
0	Maximum concentration of degradable/dilute COPCs is below background value (<186
1	Low concentrations of degradable/dilute COPCs (marginal exceedance from background)
2	Moderate concentration of degradabl/dilute COPCs (exceedances can be addressed through
3	High concentration of degradable/dilute COPCs (>7000 mg/kg)
4	Contains COPCs that do not degrade or dilute

CRITERIA 3

Rank	Meaning
1	Site has 0 receptors
2	Site has 1 receptor
3	Site has 2 receptors
4	Site has 3 receptors

GROUP

	Meaning
A	Both Solar and LPR Applicable
B	Only Solar Applicable
C	Only LPR Applicable
D	Neither Solar nor LPR Applicable

Table B2-3: LPR Future Probability Assessment

LPR Township Range	Water Well Probability (%/acre/annum)				Dugout Probability (%/acre/annum)	Sum of probability
	Depth 0m - 10m	Depth 10m - 20m	Depth 20m - 30m	Depth >30 m		
T06R13	9.91456E-06	2.76616E-05	8.33814E-06	3.79331E-05	0.000326858	0.000410705
T06R12	2.08918E-05	9.83554E-06	1.97306E-05	1.77655E-05	0.00000001	6.82335E-05
T06R12	2.08918E-05	9.83554E-06	1.97306E-05	1.77655E-05	0.00000001	6.82335E-05
T04R1					0.00000001	0.00000001
T06R13	9.91456E-06	2.76616E-05	8.33814E-06	3.79331E-05	0.00000001	8.38574E-05
T05R32	1.41388E-05	1.1489E-05	2.47574E-06	6.42146E-06	0.00000001	3.4535E-05
T06R14	5.97482E-05	4.91816E-05	1.35933E-05	2.2213E-05	0.00000001	0.000144746
T06R12	2.08918E-05	9.83554E-06	1.97306E-05	1.77655E-05	0.00000001	6.82335E-05

APPENDIX B3: PILOT SITE PROFILES

Appendix B3

Pilot Sites – Group A Solar and LPR

<u>101-02-19-006-12 W2M</u>

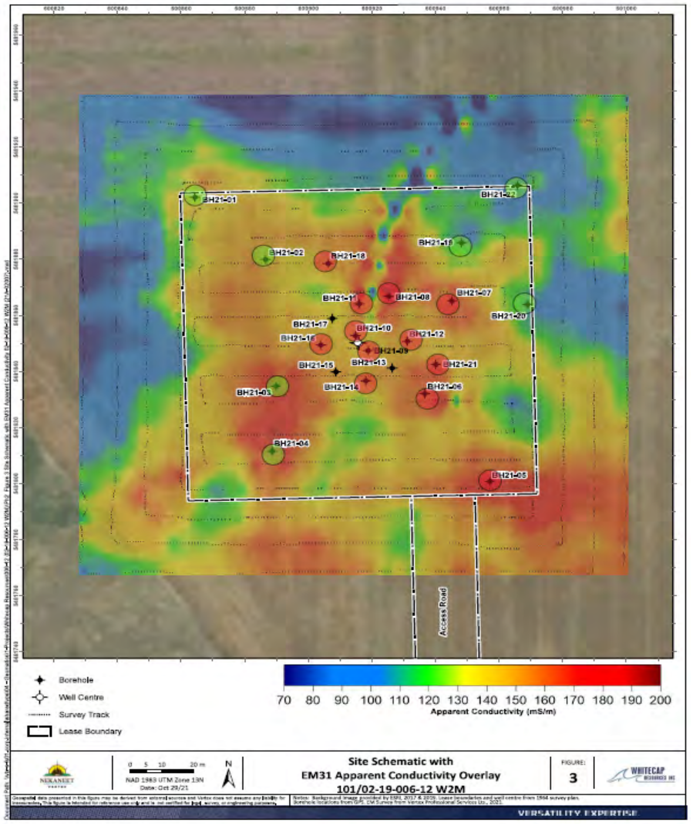
The COPCs driving risk at the Site are petroleum hydrocarbons (benzene (maximum 2.33 mg/g), toluene (maximum 0.66 mg/kg), ethylbenzene (maximum 22.9 mg/kg), F1 (maximum 1,270 mg/kg), F2 (maximum 3,570 mg/kg), F3 (maximum 6,680 mg/kg), and EC (as chloride (maximum 3,230 mg/kg)).

Elevated concentrations of PHCs were encountered between 1.3 and 3.2 m bgs with vertical delineation achieved by 4.3 m bgs. Lateral delineation is generally complete to within 20 m.

Elevated chloride concentrations were reported between surface and 6.0 m bgs, vertical delineation was not achieved. Lateral delineation of chloride in soil is generally complete except towards the southeast. The current remedial volume is estimated to be approximately 28,800 m3.

Lithology was generally described as damp silty clay to 1.5 m bgs overlying sand to 3.0 m bgs overlying sandy silt to 6.0 m bgs (maximum depth of investigation). All units were described as damp.

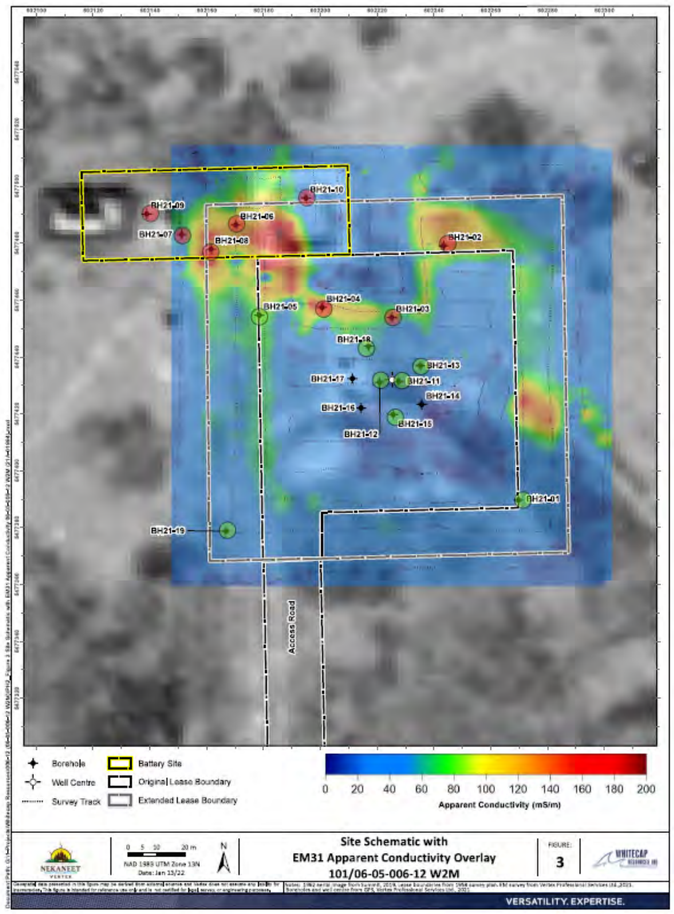
This Site is considered to be a good candidate for LPR as the COPCs identified are above Tier 1/background values, COPCs are anticipated to be limited by DUA pathways and delineation of the chloride is poor which would limit the development of Tier 2 guidelines. No water wells of permanent water bodies were identified within 500 m of the Site however several dugouts are present within 500 m. The probability of either a water well or dugout being constructed was less than 0.002%/annum/hectare and thus represents a low risk of occurrence.



101-06-05-006-12 W2M (Group A)

The primary COPC at the Site is EC as chloride (maximum 6,030 mg/kg at 4.0 to 4.2 m bgs). No vertical or lateral delineation of chloride has been achieved on Site and concentrations are generally observed to increase with depth. Lithology at the site was generally reported as sandy clay with discontinuous sand and silt seams to the maximum depth of investigation at 4.5 m bgs. Some logs however reported gravelly silt and gravelly sand to 3.0 m bgs. All units were generally described as damp.

This Site is considered to be a potential candidate for LPR as the COPCs identified are above Tier 1/background values, COPCs are anticipated to be limited by DUA pathways and delineation of the chloride is poor which would limit the development of Tier 2 guidelines. No water wells or dugouts were identified within 500 m of the Site however a stream is located within 500 m of the Site. Further evaluation of the FAL pathway would likely be necessary in order to apply LPR. The probability of either a water well or dugout being constructed was less than 0.002%/annum/hectare and thus represents a low risk of occurrence.

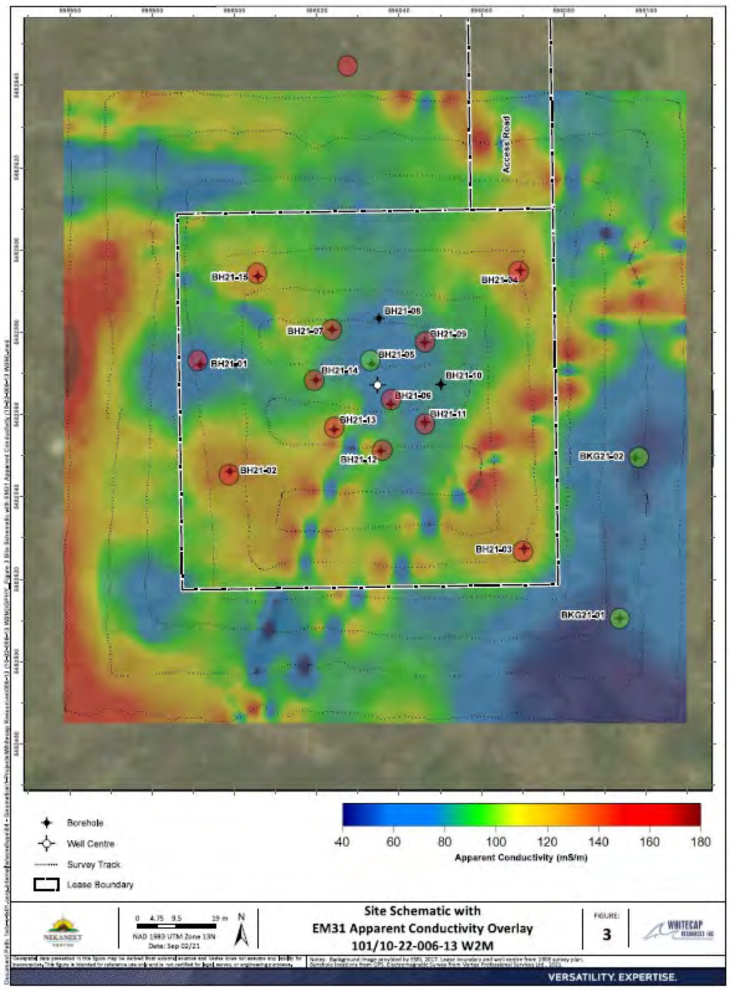


<u>101-10-22-006-13 W2M (Group A)</u>

Elevated salinity parameters are the primary COPCs at the Site as supported by chloride concentrations above background. The maximum reported concentration of chloride was 5,830 mg/kg reported at 4 to 4.2 m bgs however elevated chloride concentrations were reported between 0.4 and 6.0 m bgs (the maximum depth of investigation). No vertical or lateral delineation has been achieved at the Site however concentrations were observed to decrease with depth.

Lithology at the Site was generally described as interbedded sand and sandy clay to the maximum depth of investigation (6.0 m bgs). It is not clear based on the available logs if sand units are continuous across the Site. Clay units were generally described as damp and sand units below 1.5 m bgs as wet. Gleying was also noted on some logs at 1.5 m bgs which suggests that 1.5 m bgs may represent the depth to groundwater.

This Site is considered to be a good candidate for LPR as COPCs exceed Tier 1 guidelines and background concentrations and based on the likely depth to groundwater the DUA and livestock watering pathways are likely to be significant drivers of risk at the Site. No water wells or permanent water bodies have been identified within 500 m of the Site and the closest dugout is located 475 m form the Site. The probability of either a water well or dugout being constructed was less than 0.002%/annum/hectare and thus represents a low risk of occurrence.



Pilot Sites – Group B Solar Alone

101-06-26-005-13 W2M

This Site is located within an area where soils have severe limitations with respect to agricultural productivity. The Site falls within the potential solar pilot region discussed in Appendix D. The COPCs driving risk at the Site are low to moderate concentrations of chloride (maximum 2,040 mg/kg). It is also located within 500 m of the Rafferty reservoir. Given the moderate concentrations of COPCs and proximity to significant receptors, the Site is considered to be plausible for solar redevelopment but is not considered to be an ideal candidate for LPR.

101-06-02-006-13 W2M

This Site is located within an area where soils have severe limitations with respect to agricultural productivity. The Site falls within the potential solar pilot region discussed in Appendix D. It is not considered to be a candidate Site for LPR as COPCs only marginally exceed background concentrations, the maximum chloride concentration reported at the Site was 206 mg/kg. While no water wells or dugouts are present within 500 m of the Site, there is a body of water present along the north/east boundary of the Site.

111-07-01-006-13 W2M

This Site is located within an area where soils have severe limitations with respect to agricultural productivity. The Site falls within the potential solar pilot region discussed in Appendix D. It is not considered to be a candidate Site for LPR as COPCs only marginally exceed background concentrations, the maximum chloride concentration reported at the Site was 279 mg/kg. It is otherwise a good candidate for LPR based on the Site's location with respect to receptors.

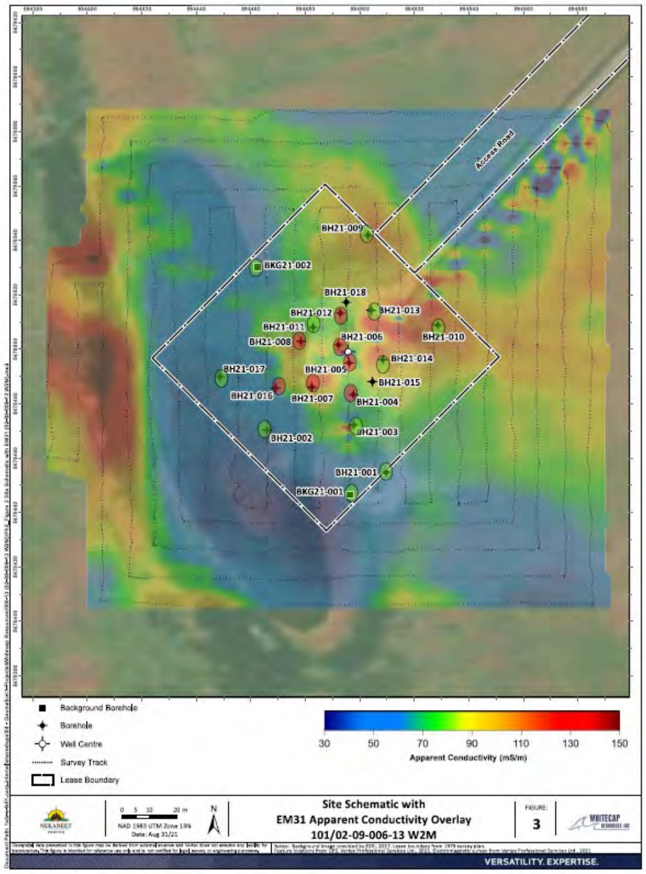
Pilot Sites – Group C LPR Alone

101-02-09-006-13 W2M

The COPCs driving risk at the Site are petroleum hydrocarbons (benzene (maximum 0.076 mg/kg), ethylbenzene (maximum 5.81 mg/kg), xylenes (maximum 1.36 mg/kg), F1 (maximum 350 mg/kg), F2 (maximum 5,470 mg/kg), F3 (maximum 21,400 mg/kg, and F4 (maximum 6,500 mg/kg), EC (as chloride (maximum 1,440 mg/kg), pH, and SAR. Elevated concentrations PHCs were typically reported between 0 and 3 m bgs with vertical delineation achieved by 4 to 4.2 m bgs. Lateral delineation of PHCs was generally achieved within 20 m in all directions. The maximum concentrations of chloride (1,440 mg/kg) were reported at 1.3 to 1.5 m bgs, and vertical delineation was achieved by 4.3 to 4.5 m bgs. Lateral delineation of chloride has been achieved within 20 m in all directions. The total remedial volume estimated for the Site was approximately 5,400 m^3.

Borehole logs indicated that gravelly sand was identified between 1.5 and 4.5 m bgs. By 3.0 m bgs the sand was generally described as wet which suggests that this is the depth to groundwater at the Site.

This Site is considered to be a potential candidate for LPR as COPCs exceed Tier 1 guidelines and background values and COPCs are present on Site which may be driven by DUA and or livestock watering pathways. While Tier 2 guideline recalculations may be possible based the available vertical and lateral delineation, a potential shallow groundwater unit that intersects the COPCs may exist on Site and given its description as both coarse and wet could potentially qualify as a DUA. No water wells and no permanent water bodies have been identified within 500 m of the Site however a class 3 wetland is located immediately west of Site. The probability of either a water well or dugout being constructed was less than 0.002%/annum/hectare and thus represents a low risk of occurrence.

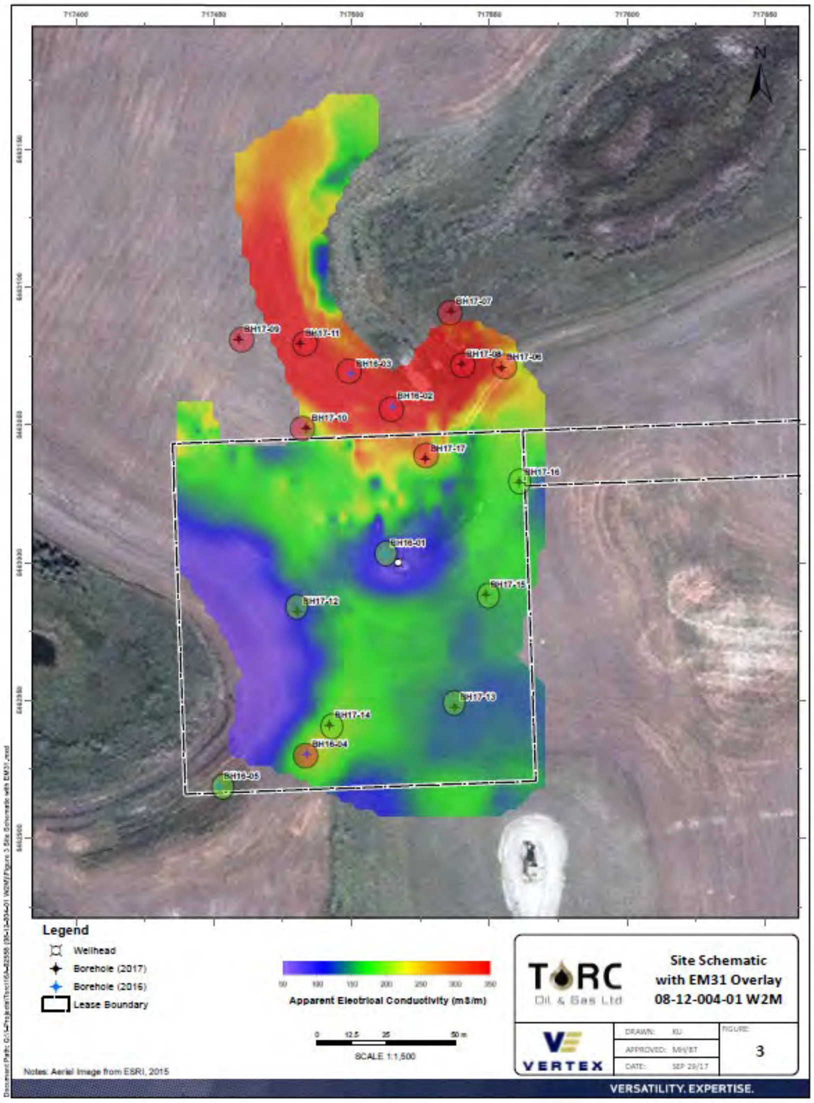


<u>101-08-12-004-01 W2M</u>

Elevated salinity parameters are the primary COPCs at the Site as indicated by chloride concentrations above background (95th percentile) of 186 mg/kg. Elevated chloride concentrations were reported between surface and the maximum depth of investigation at 7.5 m bgs. The maximum reported chloride concentration was 15,300 mg/kg at 4.0 to 4.2 m bgs, no vertical delineation was achieved. Lateral delineation is partially complete with no delineation to the north, east, or west.

One domestic water well was identified within 500 m of the Site and several seasonal surface water bodies are present within 500m of the Site. Lithology at the Site was generally described as damp silty clay from surface to 7.5 m bgs. Mottling was noted from 0.5 m bgs and may be indicative of a shallow groundwater unit.

This Site is considered to be a potential candidate for LPR at the observed chloride concentrations are likely to exceed Tier 2 guidelines and be governed by risk to DUA and livestock watering pathways. While a domestic water well has been identified within 500m of the Site, its exact location could be confirmed to support LPR application. The probability of either a water well or dugout being constructed was less than 0.002%/annum/hectare and thus represents a low risk of occurrence.



<u>101-11-32-005-32 W1M</u>

The COPCs driving risk at the Site are EC (as chloride) and petroleum hydrocarbons (Ethylbenzene, C11 to C22 and C23 to C60 at the former flare pit and wellhead areas. PHCs (ethylbenzene (maximum 8.2 mg/kg), C11 to C22 (4,820 mg/kg), C23 to C60 (7,760mg/kg)) were identified between 1.5 and 4.5 m bgs with vertical delineation achieved by 8.5 to 9.0 m bgs. Lateral delineation of PHCs is generally complete. The maximum chloride concentration of 5,860 mg/kg was reported at 1.5 to 2.0 m bgs, and vertical delineation of chloride was achieved by 7.0 to 7.5 m bgs. Concentrations of chloride above 100 mg/kg were generally reported between 0.25 and 6.0 m bgs. Limited rooting zone characterization was completed, and lateral delineation is incomplete to the southeast. The total remedial volume estimated for the Site was approximately 32,267 m^3.

This Site is considered to be a good candidate for LPR, as COPCs are deemed to be above background/Tier 1 but characterization is incomplete (lateral delineation of chloride) and would likely limit the application of standard Tier 2 tools at this time. Borehole logs indicate that the water table is likely around 5 m bgs which suggests that the DUA pathways could drive remedial decisions. Further, there are no permanent water bodies or water wells currently within 500 m of the Site. The probability of either a water well or dugout being constructed was less than 0.002%/annum/hectare and thus represents a low risk of occurrence.

However, given the presence of heavy end hydrocarbons which are more resistant to degradation than light-end hydrocarbons, restrictions may be necessary to apply LPR. This site may pair well with options such as solar integration.

APPENDIX B4: SOLAR FEASIBILITY

Appendix B4 – Solar Feasibility Analysis

1.0 BACKGROUND

1.1 Repurposing Abandoned Oil and Gas Leases to Solar (the RenuWell Project)

In early 2016, RenuWell Energy Solutions Inc (RESI) began investigating the potential of repurposing abandoned oil and gas leases to small-scale solar generation projects. By re-using the existing oil and gas infrastructure, this initiative offered several advantages over conventional solar development due to easier permitting, faster landowner approvals and the ability to re-purpose the existing roads and powerlines. It also offers the opportunity to rapidly develop a large number of smaller-scale solar generation projects at a cost that is competitive with larger utility-scale projects without requiring large allocations of land that is currently used for agriculture.

While the technical aspects of repurposing existing oil and gas leases to solar generation are straight-forward, the regulatory and logistical elements have proven to be more complex. Through a long process of consultation with the Alberta Energy Regulator, Alberta Environment and Parks and the Alberta Utility Commission, a regulatory framework was proposed for the Province of Alberta. This process was greatly facilitated through partnering with the Municipal District of Taber on a stakeholder consultation and policy development process that was funded by Alberta's Municipal Climate Change Action Centre. This project was completed in 2020 and $2.1 million of additional funding was awarded to enable the construction of the first 2 pilot projects which are scheduled for completion in Q4, 2022[1].

1.2 Integration with Low Probability Receptor Methodology

Based on Alberta's current regulatory framework, oil and gas operators are able to reduce reclamation costs by transferring road reclamation and vegetation management to the solar developers. However, within the current framework, all sites must be remediated to meet Alberta Environments Tier 1 standards before the lease can be used for a solar project. Fortunately, the Low Probability Receptor framework that has been developed by Millennium EMS, has the potential to accelerate the repurposing of contaminated leases that can be safely monitored and remediated *in-situ* during the productive 25-to-40-year life cycle of the solar project. This approach, if fully adopted by landowners and regulators, has the potential to provide significant savings to both sides of the energy industry.

[1] https://mccac.ca/project-showcase/municipal-district-of-taber-renuwell-project/

1.3 Study Area – Weyburn

The Weyburn field is well-known as the site of Canada's first large-scale CO2 sequestration/Enhanced Oil Recovery Project. As noted in MEMs report, several of the 39 sites that were proposed by Whitecap contain elements that may make them suitable candidates for LPR lease closure. Based on information provided for the location of powerlines in the area, together with the LPR analysis and regional information, these sites have been assessed for their solar potential.

2.0 METHODOLOGY

MEMs provided their preliminary analysis of the 39 sites which had been nominated by Whitecap. Based on the coordinate data for the overhead and underground powerline grids, Renuwell analyzed these sites to determine the distance from existing grid tie-in locations.

In addition to this, Renuwell extracted data from the Natural Resources Canada database to assess the solar resource potential for these sites[2]. Based on solar resource data, together with the documented annual performance of active Alberta solar projects in areas with similar solar resources, the potential solar generation potential was estimated. Electricity pricing data was obtained from the SaskPower rate sheet[3] and GHG intensity of the Saskatchewan electricity grid was taken from the Canadian Energy Regulator website[4] Based on this information, a high-level economic analysis was also performed.

3.0 PRELIMINARY RESULTS

RESI has developed software to assess the potential for repurposing abandoned oil and gas lease sites for solar development. This software rates the sites according to the following criteria:

- solar resource potential;
- grid connection: Availability and cost;
  - distance from 3-phase powerlines;
  - cost of additional conductors for grid connection;
  - hosting capacity limitations on available feeder circuits; and
  - conductor size restrictions.
- interested landowners;
- municipal zoning requirements;

[2] https://open.canada.ca/data/en/dataset/8b434ac7-aedb-4698-90df-ba77424a551f/resource/d55995cd-edec-457c-9850-afbd069f880f
[3] https://www.saskpower.com/-/media/SaskPower/Accounts-and-Services/Rates/Service-Rates/Power-Supply-Rates/ServiceRates-OilField.ashx
[4] https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-saskatchewan.html#:~:text=The%20greenhouse%20gas%20intensity%20of,kWh)%20electricity%20generated%20in%202020.

- distance from residences;
- avoidance of irrigated and high-value agricultural lands;
- environmental restrictions;
  - wetlands; and
  - sensitive areas for wildlife and native plants;
- avoidance of important historical resources;
- terrain considerations – avoidance of:
  - complex topography; and
  - shading issues;
- geotechnical considerations:
  - suitable soil profile for solar racking foundations;
- high-Level economic analysis;
  - potential savings in site reclamation;
  - revenue generation potential;
  - estimated costs for solar installation; and
  - high-level estimates of the Levelized Cost of Energy (LCOE).

In the preparation of this report, the solar resource potential, the initial evaluation of the grid connection cost and a high-level economic analysis have been performed. As mentioned in the remainder of the report, almost all of the 39 sites provided by MEMs would be suitable for solar conversion based on the available information. However, additional information and further analysis is required in order to determine which sites are the best candidates for repurposing.

In particular, one of the largest economic factors for this Weyburn pilot is related to the cost-savings potential of the LPR+ alternate closure opportunity. From the solar perspective, the optimum size for Renuwell solar installations ranges from 5 to 20 acres. Based on these criteria, it would be highly beneficial to locate parcels of 15 t0 20 acres that contain more than one LPR lease. This option would optimize both the cost savings related to the LPR closure and the solar installation costs. As noted in other sections of this report, RESI is available to collaborate with MEMs to provide further guidance in solar repurposing for the Weyburn project.

4.0 SOLAR RESOURCE POTENTIAL

According to data gathered by Natural Resources Canada, the Weyburn area of South East Saskatchewan has the best solar resource in Canada and receives solar insolation at an average daily rate of 7.2 kWh/m^2. As expected, this resource varies seasonally from 4.78 kWh/m^2 per day in January to 10.23 kWh/m^2 in July.

In terms of solar PV potential, the area ranks in the top 20 out of 3.508 Canadian municipalities (98^{th} percentile). Based on the average solar insolation values, a 1 kW South-facing standard solar array with a fixed tilt of 45 degrees is expected to generate 1376 kWh of electricity for an average year (1,376 kWh/kWp). Likewise, a 1 MW solar array Is expected to generate 1,376 MWh of electricity and based on the carbon intensity of Saskatchewan's electricity grid (580 g/kWh), and this would displace 798 tonnes CO^2e per year.

In recent years, advances in solar PV technology are providing significant performance improvements that result in improved power generation. Most current projects are being built with bi-facial modules which generate additional power from sunlight that is reflected from the ground surface behind the array. Based on models generated from the National Renewable Energy Laboratory (NREL) System Adviser Modelling software[5], incorporating bifacial modules into a 1 MW array would generate 1,450 MWh annually for a nominal increase in system cost. Incorporating Single Axis Tracking (SAT), which rotates the modules from East to West over the course of the day, results in additional generation capacity at a cost premium of about 10%. Modeling predicts that the combination of SAT and bi-facial modules would generate 1,674 MWh of electricity per year at Weyburn.

5.0 GRID CONNECTION: AVAILABILITY AND COST

Information regarding the network of SaskPower overhead (O/H) powerlines and Whitecap's underground conductors (U/G) was provided by Geoverra to Jonas Fenn in pdf format on August 25. Unfortunately, the RESI software requires the power grid information in kml or shapefile format. MEMs were able to reformat the data into shapfile format and provided the information on August 29.

[5] https://sam.nrel.gov/

The Renuwell software is designed to evaluate the grid connection potential of various lease locations of the basis of several criteria including:

- Distance from the lease to the nearest 3 phase conductor.
- Conductor size.
- Hosting capacity of the nearest conductors.

Unfortunately, the data provided by Geoverra does not include phase information, conductor size and hosting capacity. Therefore, this initial assessment is based on the following assumptions:

- All the O/H and U/G powerlines lines are 3 phases (usually true for oilfield installations).
- All the conductors are adequately sized to be able to connect the solar array.
- There is hosting capacity available on the various feeder circuits.

Provided these assumptions are true, then the major consideration is the distance from the powerlines (it's less costly to connect if the sites are closer to the existing grid).

Based on the information that was provided, it appears that the vast majority of the oilfield facilities in the Weyburn unit are powered by electrical services, and this provides a dense network of SaskPower overhead powerlines throughout the study area. In some cases, where the leases are several hundred meters from the overhead powerlines (which are running along the roads), underground lines have been installed to service the leases. This is ideal for a repurposing exercise. However, in the case of at least one lease (101-02-11-006-13), the data indicated that there is a small segment of the UG line present at the well location and it looks (at least from the digital perspective) that the rest of the line may have been removed. A digital tag for that segment is also marked as ABD so this site, which is 600 meters from the overhead lines, may not be economic for connection unless it is integrated into another site which is closer to the utility connections. Other than this location, all of the other sites are within a reasonable distance from grid connections with the following exceptions:

Distance to Powerlines (m)		
Lease Location	**Overhead**	**Underground**
101-06-26-005-13 W2M	500	400
101-15-14-006-12 W2M	400	500
101-12-21-006-12 W2M	500	500

Over the course of the Renuwell project, grid connection has proven to be the most significant obstacle. This situation is mainly due to long time delays and excessing costs required by the utility companies to assess their hosting capacity and interconnection cost requirements. In Alberta, this has been primarily related to resistance from the private monopolies that control the transmission system, and it seems to be driven by a potential loss in transmission tariffs that would occur with a large network of distribution-connected solar generators. This theory is supported by the fact that very similar solar generation projects can be connected to the grid under the microgeneration regulations, without any resistance from the utility companies, provided they are associated with an electrical load that is owned by the same operator. While SaskPower is a government-owned utility and it operates under a different regulatory environment, it seems that grid-connect remains a fundamental obstacle to the expansion of distribution-connected systems in this province also.

Considering the Whitecap's large number of oilfield facilities associated with the Weyburn unit, combined with Whitecap's extensive network of underground conductors, it's likely that that these small-scale solar projects could be connected directly to Whitecap's facilities to offset power that would otherwise be provided by SaskPower. Provided the generators were connected "behind-the-meter" from SaskPower's perspective, it's likely that the projects could proceed in a time-efficient and cost-effective manner.

However, as mentioned previously, this assessment of the grid-connection options is based on several assumptions that require more thorough analysis. Provided Whitecap is interested in proceeding further, RESI would be available to assist in these regulatory and logistical investigations.

6.0 SOLAR ECONOMICS

6.1 Revenue Potential

The annual revenue generation potential of a solar project is generally based on the value of the electricity sales combined with the environmental credits (either sold as Renewable Energy Credits (RECs) or used to offset GHG emissions). Based on SaskPower's current Oil Field rate class, the energy component of the electricity charges ranges from $80.70 to $67.21 per MWh (depending on demand class, assuming peak time usage and including Federal Carbon Charge). The value of REC credits is indexed against carbon prices and the current value is about $11.00 per MWh. Assuming Carbon prices will increase as scheduled over the coming years, the value of these credits will increase to $62.70 by 2030.

Potential revenue (and costs) varies with the system configuration (Fixed rack or SAT) and the size of the solar array. Average annual revenue projections were made using an estimated value of

$69/MWh for electricity and REC prices ranging from current to 2030 values. The results are presented in the table below for the following configurations:

- 1 MWdc fixed tilt racking (bi-facial modules);
- 1 MWdc Single Axis Tracking (bifacial modules); and
- 30 MWdc Single Axis Tracking (bifacial modules).

	Annual	Annual REC credits		Combined	
Solar Array	**Electricity sales**	**Current**	**2030**	**Current**	**2030**
Fixed Tilt	$ 100,533	$ 16,129	$ 91,354	$ 116,662	$ 191,887
1 MW SAT	$ 115,506	$ 18,531	$ 104,960	$ 134,037	$ 220,466
30 MW SAT	$ 3,465,180	$ 555,935	$3,148,794	$ 4,021,115	$ 6,613,974

7.0 SYSTEM COST

The cost of solar power generation has decreased very rapidly over the past decade, ranging from $5.66/Wattdc in 2010 to $1.01/Wattdc in 2020 for a utility-scale solar installation with Single Axis Tracking in the USA[6]. Costs have followed a similar trend in Canada, however supply chain issues and the high demand for solar components have resulted in considerable instability and somewhat higher prices in 2022. The size of the solar installation can also have a significant impact on the costs, with larger systems benefiting from volume discounts for the major components.

In the case of the Renuwell Project, each individual installation generally occupies between 2.5 and 5 acres with a generation capacity between 800 kW and 1.25 MW. However, since each installation shares the same design parameters and when the converted leases are in the same geographic area, Renuwell model can approach the same cost structure as the larger utility-scale systems. This is due, in part, to advantages in land access, the repurposing of existing roads and powerlines and faster permitting for the smaller installations.

In this case, Canadian Solar Solutions Inc (CSSI - a division of Canadian Solar Inc) has expressed interest in providing project development services provided that Whitecap will proceed with a large-scale pilot project. CSSI has been a partner in the Renuwell project since 2019 and they have developed some draft layouts that could be used in conjunction with an LPR/ solar repurposing project at Weyburn (see figure X). These designs range include Single Axis Tracking and they range in size from 1.2 to 1.4 MWdc (10.4 to 12.7 acres). CSSI, as one of the largest companies in the solar

[6] https://www.nrel.gov/docs/fy21osti/77324.pdf

industry, has significant cost-saving advantages in procuring equipment. However, due to their size, they require project sizes of at least 25 MW in order to operate effectively with their suppliers. In the event that Whitecap would like to proceed with at least 25 MW of combined installations, CSSI would like to discuss options.

In the event that Whitecap would prefer to proceed with a smaller scale solar installation for the pilot project, Renuwell Energy Solutions has strong relationships with a number of smaller solar installation providers. However, in this case, the costs would be significantly more expensive due to the higher equipment prices that these suppliers experience relative to CSSI.

In all cases, the relative value of a solar installation is generally expressed in terms of the Levelized Cost Of Energy (LCOE) which is calculated as the cost of the system installation and associated operating costs divided by the total amount of electricity generated over the system life cycle. For comparison purposes, LCOE, based on CAPEX only and a 25-year lifecycle, for 3 different scenarios is provided in the table below. These include:

- 1 MW system with fixed tilt racking;
- 1 MW system with SAT; and
- 30 MW (30 1 MW systems) with SAT.

Solar Array	Estimated cost $/Wdc	LCOE $/MWh
Fixed Tilt	$ 2.00	$ 54.91
1 MW SAT	$ 2.10	$ 50.18
30 MW SAT	$ 1.45	$ 34.65

8.0 PROJECT OWNERSHIP OPTIONS

In the event that Whitecap would like to proceed with a large-scale pilot project, there are at least 3 ownership options available:

1. Whitecap owns and operates the solar projects.
2. A third-party solar developer sub-leases the land and sells power to Whitecap.
3. A joint partnership is formed between Whitecap and a Solar Developer.

8.1 Additional Economic Incentives

In the cases where Whitecap owns (or partially owns) the solar projects, the CRA offers specific tax incentives under the Canadian Renewable and Conservation Expenses (CRCE) that provides tax savings to cover the cost of start-up expenses such as project feasibility and interconnection studies[7]. If the project proceeds, additional incentives are offered under the Capital Cost Allowance (CCA) Renewable Energy program which allows accelerated depreciation of the capital costs associated with the solar project[8].

8.2 Economic Benefits Associated with the LPR Alternate Closure Program

In the current implementation, the RenuWell solar repurposing project has been shown to reduce reclamation costs by up to 45% through the re-use of existing roads, powerlines and by assuming responsibility for the vegetation monitoring phase of the reclamation program.

Much greater savings, in terms of cost and also in terms of overall environmental impact, are possible through the integration of solar repurposing combined with an LPR-based alternate closure program. In this case, the land can be immediately converted to productive use during the time that is required for the contamination levels to degrade to background levels. The cost savings, compared to the traditional approach, can be directly applied to reduce the cost of the solar project. At the same time, the solar project will generate lease revenue for the landowners and property tax revenue for the Rural Municipalities of Cymri and Lomond.

9.0 NEXT STEPS

9.1 Detailed Site Selection Study

As outlined in the previous sections of this report, more detailed analysis is required to define the optimum sites for solar repurposing. This analysis will require more detailed information about the interconnection options, landowner considerations, specific environmental restrictions, and potential concerns from the Rural Municipalities.

In addition, the greatest benefits will be obtained through a thorough integration of the results from MEM's LPR analysis combined with the solar repurposing analysis.

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[7] https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/CRCE%20Technical%20Guide%202014_en.pdf

[8] https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/funding-grants-incentives/tax-savings-industry/5147

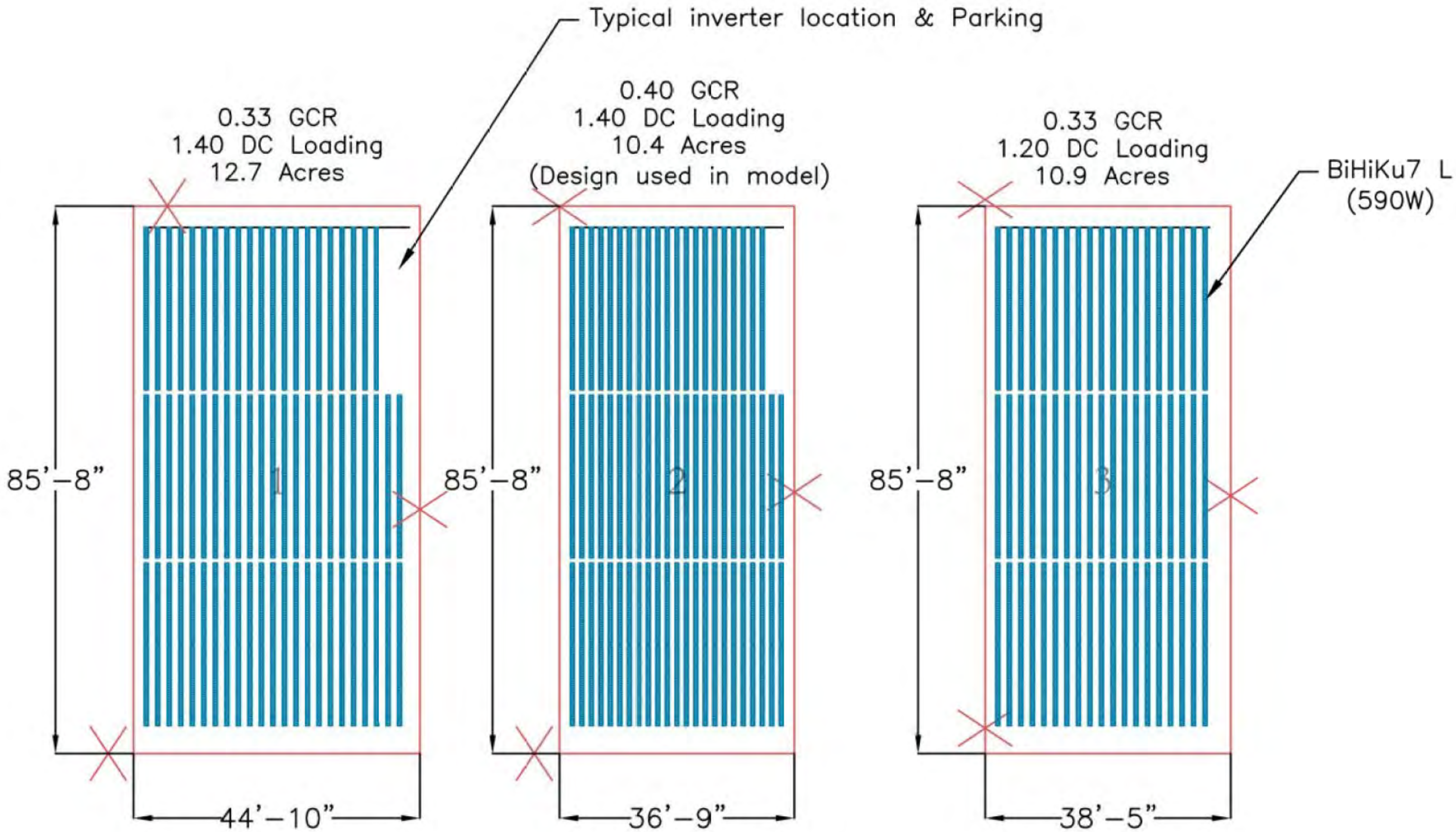

Figure D1. **Draft layouts for Renuwell solar arrays created by Canadian Solar Solutions Inc. for a potential Weyburn LPR/Solar repurposing pilot (for discussion purposes only)**

Site	Distance to Overhead Powerline (m)	Distance to Underground Conductors (m)*
140-08-03-006-14 W2M	300	100
141-10-03-006-14 W2M	630	100
101-06-17-006-12 W2M	0	100
191-05-08-006-13 W2M	100	0
101-02-09-006-13 W2M	600	0^
101-02-28-005-13 W2M	200	0
141-08-28-005-13 W2M	100	100
101-12-16-006-13 W2M	200	0
131-09-05-006-13 W2M	300	100
121-08-28-005-13 W2M	300	100
101-16-17-006-13 W2M	200	0
101-16-19-006-13 W2M	200	100
101-16-32-005-13 W2M	300	100
141-14-04-006-13 W2M	725	100
192-05-24-006-14 W2M	400	100
121-08-34-005-13 W2M	200	100
101-02-11-006-13 W2M	400	100
101-10-22-006-13 W2M	200	400
101-12-11-006-13 W2M	100	0
111-07-01-006-13 W2M	200	100
141-08-35-005-13 W2M	200	100
101-06-02-006-13 W2M	200	100
141-08-15-006-13 W2M	100	0
101-06-26-005-13 W2M	500	400
101-12-26-005-13 W2M	300	100
101-12-26-006-14 W2M	300	0
101-16-20-006-13 W2M	200	100
101-16-33-005-13 W2M	300	100
191-13-08-006-13 W2M	300	0
191-15-30-005-13 W2M	100	100
101-02-19-006-12 W2M	200	500
101-06-05-006-12 W2M	100	100
101-08-09-006-12 W2M	0	100
141-11-14-006-12 W2M	300	100
101-15-14-006-12 W2M	400	500
141-12-14-006-12 W2M-Satellite	200	100
101-12-21-006-12 W2M	0	500
101-01-33-006-12 W2M	0	400

*to the nearest 100 m

^(UG line is marked ABD - is it still useable?)

APPENDIX B5: BACKGROUND DATASET

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BH21-001	0-0.2	12-Sep-21	01-06-05-006-12 W2M	34	4	15	14	11	72	-	11	-	-	-	0.92	6.75	0.61	40
BH21-001	1-1.2	12-Sep-21	01-06-05-006-12 W2M	10	19	7	2	11	20	-	87	-	-	-	0.77	7.88	1.37	22
BH21-001	2-2.2	12-Sep-21	01-06-05-006-12 W2M	10	12	6	3	7	27	-	47	-	-	-	0.56	7.99	0.84	25
BH21-001	2.8-3	12-Sep-21	01-06-05-006-12 W2M	13	19	8	3	12	49	-	82	-	-	-	0.88	8.04	1.29	23
BH21-019	0.4-0.6	14-Sep-21	01-06-05-006-12 W2M	18	9	14	5	10	100	-	21	-	-	-	0.59	6.91	0.63	45
BH21-019	1.3-1.5	14-Sep-21	01-06-05-006-12 W2M	7	9	30	3	34	170	-	22	-	-	-	1.03	7.87	1.95	40
BH21-019	3-3.2	14-Sep-21	01-06-05-006-12 W2M	30	8	18	8	33	187	-	15	-	-	-	0.91	7.67	1.65	50
BH21-019	4.3-4.5	14-Sep-21	01-06-05-006-12 W2M	33	7	16	7	32	205	-	14	-	-	-	1	7.63	1.67	48
BH21-01	0-0.2	09-Sep-21	101-01-33-006-12 W2M	14	2	11	15	5	25	-	5	-	-	-	0.5	6.96	0.36	46
BH21-01	1-1.2	09-Sep-21	101-01-33-006-12 W2M	6	17	11	<2	45	109	-	54	-	-	-	1.06	7.92	4.47	32
BH21-01	2-2.2	09-Sep-21	101-01-33-006-12 W2M	7	4	2	<2	7	24	-	12	-	-	-	0.33	7.84	1	32
BH21-01	2.8-3	09-Sep-21	101-01-33-006-12 W2M	7	3	2	2	7	20	-	9	-	-	-	0.29	7.75	1.03	33
BH21-20	0.4-0.6	09-Sep-21	101-01-33-006-12 W2M	32	9	48	5	312	907	-	25	-	-	-	5.29	7.49	13.6	36
BH21-20	1.3-1.5	09-Sep-21	101-01-33-006-12 W2M	6	13	6	<2	282	512	-	14	-	-	-	1.51	8.22	21.2	92
BH21-20	3-3.2	09-Sep-21	101-01-33-006-12 W2M	15	7	9	6	88	196	-	12	-	-	-	0.92	7.74	5.82	61
BH21-20	4.3-4.5	09-Sep-21	101-01-33-006-12 W2M	30	7	17	8	104	411	-	11	-	-	-	1.35	7.74	4.59	66
BKG21-001	0-0.2	15-Jul-21	101-02-09-006-13 W2M	39	39	123	91	63	647	-	80	-	-	-	3.65	8.01	1.59	49
BKG21-001	1-1.2	15-Jul-21	101-02-09-006-13 W2M	18	16	26	27	8	12	-	33	-	-	-	0.75	7.83	0.39	48
BKG21-001	2-2.2	15-Jul-21	101-02-09-006-13 W2M	42	15	14	11	10	127	-	40	-	-	-	0.86	7.84	0.57	38
BKG21-001	2.8-3	15-Jul-21	101-02-09-006-13 W2M	39	25	13	8	10	113	-	81	-	-	-	1.08	7.75	0.61	31
BKG21-002	0.4-0.6	15-Jul-21	101-02-09-006-13 W2M	223	9	86	23	61	955	-	18	-	-	-	4.15	7.75	1.28	48
BKG21-002	1.3-1.5	15-Jul-21	101-02-09-006-13 W2M	5	37	2	7	136	230	-	48	-	-	-	0.97	8.29	14.7	77
BKG21-002	4-4.2	15-Jul-21	101-02-09-006-13 W2M	36	21	23	16	35	208	-	42	-	-	-	1.19	7.83	1.61	49
BKG21-002	5.8-6	15-Jul-21	101-02-09-006-13 W2M	4	41	1	11	259	274	-	34	-	-	-	1.11	8.32	27.6	120
BKG21-001	0-0.2	27-Jul-21	101-02-11-006-13 W2M	22	5	12	6	11	24	-	11	-	-	-	0.6	7.51	0.73	44
BKG21-001	1-1.2	27-Jul-21	101-02-11-006-13 W2M	2	9	6	<2	37	43	-	31	-	-	-	0.76	8.08	5.48	30
BKG21-001	2-2.2	27-Jul-21	101-02-11-006-13 W2M	2	2	3	<2	14	11	-	9	-	-	-	0.36	7.99	3.14	26
BKG21-001	2.8-3	27-Jul-21	101-02-11-006-13 W2M	2	6	3	<2	18	18	-	27	-	-	-	0.52	8.03	3.97	22

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-002	0.4-0.6	27-Jul-21	101-02-11-006-13 W2M	22	4	11	10	11	40	-	9	-	-	-	0.54	7.43	0.7	49
BKG21-002	1.3-1.5	27-Jul-21	101-02-11-006-13 W2M	2	7	5	2	43	44	-	16	-	-	-	0.59	7.93	5.89	41
BKG21-002	3-3.2	27-Jul-21	101-02-11-006-13 W2M	3	7	2	<2	23	29	-	32	-	-	-	0.68	7.99	5.62	21
BKG21-002	5.8-6	27-Jul-21	101-02-11-006-13 W2M	5	8	3	3	29	45	-	35	-	-	-	0.84	7.94	5.56	23
BH21-001	0-0.2	17-Sep-21	101-02-19-006-12 W2M	200	56	114	4	330	1550	-	105	-	-	-	5.72	7.68	6.33	53
BH21-001	1-1.2	17-Sep-21	101-02-19-006-12 W2M	219	70	218	6	1420	4100	-	82	-	-	-	9.51	8.13	17.6	85
BH21-001	2-2.2	17-Sep-21	101-02-19-006-12 W2M	42	58	62	6	740	1940	-	116	-	-	-	8.33	7.46	24	50
BH21-001	2.8-3	17-Sep-21	101-02-19-006-12 W2M	35	62	45	5	682	1660	-	141	-	-	-	8.4	6.04	27.1	44
BH21-022	0.4-0.6	18-Sep-21	101-02-19-006-12 W2M	249	40	176	11	525	2380	-	60	-	-	-	6.57	8.04	7.62	67
BH21-022	1.3-1.5	18-Sep-21	101-02-19-006-12 W2M	162	25	74	7	445	1680	-	52	-	-	-	6.57	7.85	10.4	49
BH21-022	2.8-3	18-Sep-21	101-02-19-006-12 W2M	42	51	28	6	504	1180	-	99	-	-	-	5.3	6.76	20.5	52
BH21-022	4-4.2	18-Sep-21	101-02-19-006-12 W2M	16	40	9	3	395	1030	-	51	-	-	-	3.11	5.63	22.3	78
BH21-022	5.8-6	18-Sep-21	101-02-19-006-12 W2M	16	40	9	3	486	1050	-	93	-	-	-	5.72	5.61	36.9	43
BKG21-01	0-0.2	13-Jul-21	101-02-28-005-13 W2M	11.6	<10	8.7	6	<5	28.4	-	<20	-	-	-	0.336	7.23	0.25	43.1
BKG21-01	1-1.2	13-Jul-21	101-02-28-005-13 W2M	6.2	<10	6.8	<5	<5	12	-	21	-	-	-	0.41	8.43	0.33	26.5
BKG21-01	1.3-1.5	13-Jul-21	101-02-28-005-13 W2M	6.4	<10	55	<5	<5	18.4	-	<20	-	-	-	0.4	8.34	0.65	25
BKG21-01	3-3.2	13-Jul-21	101-02-28-005-13 W2M	116	12	87.3	6.7	62.5	698	-	31	-	-	-	2.88	8.06	1.71	38.8
BKG21-01	5-5.2	13-Jul-21	101-02-28-005-13 W2M	174	<10	97.5	9	53.8	854	-	24	-	-	-	3.53	7.84	1.37	34.7
BKG21-02	1-1.2	15-Jul-21	101-02-28-005-13 W2M	429	116	558	21	446	3870	-	142	-	-	-	6.66	7.97	3.69	81.9
BKG21-02	2-2.2	15-Jul-21	101-02-28-005-13 W2M	152	37	211	6.4	219	1520	-	97	-	-	-	6.03	8.18	4.36	38.4
BKG21-02	5-5.2	15-Jul-21	101-02-28-005-13 W2M	50.6	18	42.3	<5	58.6	372	-	65	-	-	-	2.48	8.03	2.75	28.6
BKG21-02	7-7.2	15-Jul-21	101-02-28-005-13 W2M	15	<10	9	<5	16.2	87.2	-	27	-	-	-	1.17	8.12	1.91	18.2
BKG21-02	8.8-9	15-Jul-21	101-02-28-005-13 W2M	64.3	<10	29.6	<5	31.6	298	-	38	-	-	-	2.72	7.97	1.84	19.9
BKGG21-001	0-0.2	28-Jul-21	101-06-02-006-13 W2M	10	57	18	10	217	397	-	93	-	-	-	1.96	8.25	12	61
BKGG21-001	1-1.2	28-Jul-21	101-06-02-006-13 W2M	4	29	7	3	172	289	-	43	-	-	-	1.31	8.2	14.9	67
BKGG21-001	2-2.2	28-Jul-21	101-06-02-006-13 W2M	12	19	13	5	111	262	-	28	-	-	-	1	7.8	6.38	69
BKGG21-001	2.8-3	28-Jul-21	101-06-02-006-13 W2M	7	16	7	4	111	199	-	22	-	-	-	0.84	7.9	8.58	73
BKGG21-002	0.4-0.6	28-Jul-21	101-06-02-006-13 W2M	38	100	109	8	1220	3180	-	102	-	-	-	6.26	8.55	22.9	98

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKGG21-002	1.3-1.5	28-Jul-21	101-06-02-006-13 W2M	236	83	359	12	1420	5470	-	138	-	-	-	12.7	8.29	17.6	60
BKGG21-002	3-3.2	28-Jul-21	101-06-02-006-13 W2M	15	42	13	5	270	591	-	54	-	-	-	1.9	7.92	14.1	77
BKGG21-002	4.3-4.5	28-Jul-21	101-06-02-006-13 W2M	13	36	8	6	208	396	-	38	-	-	-	1.16	7.91	11.3	94
BH21-001	0-0.2	16-Aug-21	101-06-17-006-12 W2M	23	3	5	5	3	29	-	7	-	-	-	0.47	7.58	<0.34	42
BH21-001	1-1.2	16-Aug-21	101-06-17-006-12 W2M	4	3	8	2	30	24	-	6	-	-	-	0.49	8.13	3.15	42
BH21-001	2.8-3	16-Aug-21	101-06-17-006-12 W2M	5	8	7	4	33	38	-	20	-	-	-	0.63	7.9	3.54	40
BH21-001	2-22	16-Aug-21	101-06-17-006-12 W2M	2	4	4	2	23	16	-	13	-	-	-	0.59	7.96	4.01	27
BH21-011	0.4-0.6	19-Sep-21	101-06-17-006-12 W2M	3	6	2	<2	169	122	-	6	-	-	-	0.77	8.28	18.5	100
BH21-011	1.3-1.5	19-Sep-21	101-06-17-006-12 W2M	<1	4	<1	<2	55	22	-	21	-	-	-	0.79	8.03	18.4	36
BH21-011	2-2.2	19-Sep-21	101-06-17-006-12 W2M	<1	4	<1	<2	58	41	-	11	-	-	-	0.76	7.99	20.9	40
BH21-011	2.8-3	19-Sep-21	101-06-17-006-12 W2M	4	<2	3	6	226	452	-	<5	-	-	-	1.15	7.94	18.8	111
BKG21-01	0-0.2	18-Jul-21	101-06-26-005-13 W2M	<5	<10	<5	<5	<5	<8	-	21	-	-	-	0.296	8.53	0.49	19.6
BKG21-01	1-1.2	18-Jul-21	101-06-26-005-13 W2M	<5	<10	<5	<5	<5	<8	-	<20	-	-	-	0.254	8.53	0.61	20.1
BKG21-01	2-2.2	18-Jul-21	101-06-26-005-13 W2M	<5	<10	<5	<5	<5	<8	-	<20	-	-	-	0.239	8.6	0.68	24.3
BKG21-01	2.8-3	18-Jul-21	101-06-26-005-13 W2M	<5	<10	<5	<5	<5	<8	-	<20	-	-	-	0.199	8.59	0.48	26.2
BKG21-02	0-0.2	20-Jul-21	101-06-26-005-13 W2M	8.4	<10	<5	<5	<5	8.8	-	<20	-	-	-	0.24	8.25	0.46	45.2
BKG21-02	0.4-0.6	20-Jul-21	101-06-26-005-13 W2M	9.5	<10	12.1	<5	10.2	<8	-	<20	-	-	-	0.401	8.22	0.8	41.6
BKG21-02	1.3-1.5	20-Jul-21	101-06-26-005-13 W2M	<5	<10	13.3	<5	25.8	11.3	-	<20	-	-	-	0.46	8.49	2.08	44.2
BKG21-02	3-3.2	20-Jul-21	101-06-26-005-13 W2M	20.4	<10	21.3	<5	54.7	184	-	<20	-	-	-	1.18	8.15	3.26	38.5
BKG21-02	4-4.2	20-Jul-21	101-06-26-005-13 W2M	18.4	<10	16	6.1	39.6	147	-	25	-	-	-	1.13	8.17	2.86	32.5
BKG21-02	6-6.2	20-Jul-21	101-06-26-005-13 W2M	12.3	<10	<5	<5	6.5	31.5	-	23	-	-	-	0.481	7.99	0.73	29.2
BKG21-02	8-8.2	20-Jul-21	101-06-26-005-13 W2M	15.1	<10	<5	<5	<5	29.2	-	<20	-	-	-	0.426	7.98	0.47	34.5
BKG21-02	8.8-9	20-Jul-21	101-06-26-005-13 W2M	11.7	<10	<5	<5	<5	23.9	-	<20	-	-	-	0.491	8.02	0.59	25
BH21-01	0-0.2	11-Aug-21	101-08-09-006-12 W2M	296	30	297	24.9	124	1980	-	54	-	-	-	4.96	7.97	1.65	54.7
BH21-01	1-1.2	11-Aug-21	101-08-09-006-12 W2M	47.4	<10	30.4	7.6	31.4	250	-	21	-	-	-	1.37	8.06	1.42	382
BH21-01	2-2.2	11-Aug-21	101-08-09-006-12 W2M	34.1	<10	20.4	<5	14.4	160	-	<20	-	-	-	1.12	8.11	0.87	31
BH21-01	2.8-3	11-Aug-21	101-08-09-006-12 W2M	37.4	<10	21.5	<5	14.8	175	-	20	-	-	-	1.22	8.17	0.88	29.9
BH21-14	0-0.2	12-Aug-21	101-08-09-006-12 W2M	32.2	34	28.6	7.1	47.4	191	-	69	-	-	-	1.11	8.16	2.09	49.1

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BH21-14	0.4-0.6	12-Aug-21	101-08-09-006-12 W2M	25.8	26	18.9	5.5	41.8	149	-	61	-	-	-	1.05	7.99	2.34	42.6
BH21-14	1.3-1.5	12-Aug-21	101-08-09-006-12 W2M	27.7	21	17.8	<5	45.3	158	-	44	-	-	-	0.951	7.93	2.37	48.5
BH21-14	3-3.2	12-Aug-21	101-08-09-006-12 W2M	40.4	36	21.6	7.2	65.7	223	-	65	-	-	-	1.14	7.81	2.79	55.2
BH21-14	4-4.2	12-Aug-21	101-08-09-006-12 W2M	46.1	45	24.1	7.7	68.8	242	-	78	-	-	-	1.19	7.79	2.7	57.3
BH21-14	6-6.2	12-Aug-21	101-08-09-006-12 W2M	63.8	29	29.5	14.8	126	393	-	46	-	-	-	1.6	8.12	4.15	62.5
BH21-14	8-8.2	12-Aug-21	101-08-09-006-12 W2M	68.8	24	32.2	19.5	182	496	-	29	-	-	-	1.56	8.24	5.03	81.2
BH21-14	10-10.2	12-Aug-21	101-08-09-006-12 W2M	57	28	28.8	16.8	200	522	-	42	-	-	-	1.86	8.22	6.56	67.3
BH21-14	11-11.2	12-Aug-21	101-08-09-006-12 W2M	89.8	48	47.8	18.3	229	738	-	69	-	-	-	2.22	8.06	5.82	69.6
BH16-05	0-0.25	18-Nov-16	101-08-12-004-01 W2M	-	180	-	-	-	1300	120	260	310	210	370	4	8.08	4	68
BH16-05	0.25-0.5	18-Nov-16	101-08-12-004-01 W2M	-	460	-	-	-	2200	420	780	370	140	590	7.2	8.01	4.2	59
BH16-05	0.5-1	18-Nov-16	101-08-12-004-01 W2M	-	140	-	-	-	540	250	290	180	27	120	27	7.81	1.4	48
BH16-05	1-1.5	18-Nov-16	101-08-12-004-01 W2M	-	98	-	-	-	520	230	160	110	21	93	2.1	7.85	1.3	61
BH16-05	1.5-2	18-Nov-16	101-08-12-004-01 W2M	-	100	-	-	-	450	240	220	120	23	130	2.3	7.84	1.7	47
BH16-05	2-2.5	18-Nov-16	101-08-12-004-01 W2M	-	160	-	-	-	650	400	330	150	35	150	3	7.79	1.6	48
BH16-05	2.5-3	18-Nov-16	101-08-12-004-01 W2M	-	75	-	-	-	1100	520	150	190	34	160	3.4	7.75	1.6	51
BH16-05	3-3.5	18-Nov-16	101-08-12-004-01 W2M	-	64	-	-	-	1200	520	130	240	34	220	3.9	7.68	2	50
BH16-05	3.5-4	18-Nov-16	101-08-12-004-01 W2M	-	36	-	-	-	1300	500	74	240	33	240	3.8	7.7	2.2	50
BH16-05	4-4.5	18-Nov-16	101-08-12-004-01 W2M	-	26	-	-	-	1300	520	55	250	35	240	3.8	7.68	2.2	48
BH16-05	4.5-5	18-Nov-16	101-08-12-004-01 W2M	-	17	-	-	-	1200	480	35	230	34	240	3.6	47.74	2.3	49
BH16-05	5-5.5	18-Nov-16	101-08-12-004-01 W2M	-	8	-	-	-	1200	480	18	220	33	240	3.7	7.7	2.3	48
BH16-05	5.5-6	18-Nov-16	101-08-12-004-01 W2M	-	10	-	-	-	1200	470	20	220	30	250	3.6	7.69	2.4	50
BH17-16	1-1.2	27-Sep-17	101-08-12-004-01 W2M	-	58	-	-	-	7130	410	93	1830	25	1710	14.2	8.07	8.05	62
BH17-16	2-2.2	27-Sep-17	101-08-12-004-01 W2M	-	36	-	-	-	5980	403	70	1790	35	1760	15.1	8.13	8.38	52
BH17-16	4-4.2	27-Sep-17	101-08-12-004-01 W2M	-	33	-	-	-	5050	424	67	1570	38	1710	12.8	8.18	8.59	49
BH17-16	5.8-6	27-Sep-17	101-08-12-004-01 W2M	-	26	-	-	-	2810	431	50	640	34	950	8.2	8.02	6.79	52
BKG21-001	0.4-0.6	21-Jul-21	101-10-22-006-13 W2M	41	106	111	5	785	2050	-	160	-	-	-	7.06	8.2	17.8	66
BKG21-001	1.3-1.5	21-Jul-21	101-10-22-006-13 W2M	3	18	5	<2	100	160	-	35	-	-	-	1.06	7.697	12	50
BKG21-001	2-2.2	21-Jul-21	101-10-22-006-13 W2M	10	24	11	2	136	297	-	52	-	-	-	1.7	7.8	10.4	47

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-001	2.8-3	21-Jul-21	101-10-22-006-13 W2M	11	20	10	<2	117	260	-	58	-	-	-	1.97	7.83	10.5	35
BKG21-002	0-0.2	21-Jul-21	101-10-22-006-13 W2M	47	19	23	27	19	78	-	37	-	-	-	1.09	6.35	0.78	51
BKG21-002	1-1.2	21-Jul-21	101-10-22-006-13 W2M	6	10	8	<2	19	26	-	28	-	-	-	0.52	7.78	2	35
BKG21-002	4-4.2	21-Jul-21	101-10-22-006-13 W2M	9	33	4	4	197	356	-	28	-	-	-	0.88	7.18	12.8	118
BKG21-002	6-6.2	21-Jul-21	101-10-22-006-13 W2M	13	38	9	6	378	746	-	48	-	-	-	2.39	7.86	22.3	79
BKG21-002	8.8-9	21-Jul-21	101-10-22-006-13 W2M	8	34	5	6	407	801	-	29	-	-	-	1.79	8.18	26	117
BH18-24	0.25-0.5	21-Dec-18	101-11-32-005-32 W1M	-	<5	-	-	-	6.7	13.24	<5	32.82	9.22	6.61	0.27	7.9	0.22	59
BH18-24	0.5-1	21-Dec-18	101-11-32-005-32 W1M	-	<5	-	-	-	324	60.52	7	118.7	15.52	36.56	1.11	7.9	0.63	63
BH18-24	1.5-2	21-Dec-18	101-11-32-005-32 W1M	-	7.6	-	-	-	706	221.4	12	178.2	25.14	39.56	1.9	7.8	0.48	63
BH18-24	3.5-4	21-Dec-18	101-11-32-005-32 W1M	-	12.5	-	-	-	417	191.1	19.6	74.11	22.02	39.55	1.33	7.7	0.53	64
BH18-24	5.5-6	21-Dec-18	101-11-32-005-32 W1M	-	<5	-	-	-	45.4	41.57	<5	11.97	10.49	11.38	0.35	7.7	0.4	58
BH18-24	7.5-8	21-Dec-18	101-11-32-005-32 W1M	-	<5	-	-	-	280	157.3	<5	48.76	34.8	38.34	1.14	7.7	0.68	59
BKG21-001	0-0.2	23-Jul-21	101-12-11-006-13 W2M	52	12	22	32	34	77	-	18	-	-	-	0.94	6.91	1.19	69
BKG21-001	1-1.2	23-Jul-21	101-12-11-006-13 W2M	31	35	99	51	195	870	-	55	-	-	-	2.72	8.32	4.84	64
BKG21-001	2-2.2	23-Jul-21	101-12-11-006-13 W2M	5	17	7	16	170	306	-	20	-	-	-	1.08	8	12.7	84
BKG21-001	2.8-3	23-Jul-21	101-12-11-006-13 W2M	339	26	228	67	544	3010	-	31	-	-	-	5.34	7.93	6.14	83
BKG21-003	0-0.2	24-Jul-21	101-12-11-006-13 W2M	42	24	28	7	250	573	-	40	-	-	-	2.35	7.57	9.53	59
BKG21-003	1-1.2	24-Jul-21	101-12-11-006-13 W2M	288	100	396	10	1790	6430	-	121	-	-	-	12.3	8.57	17.7	83
BKG21-003	2.8-3	24-Jul-21	101-12-11-006-13 W2M	8	20	5	3	176	272	-	27	-	-	-	1.24	8.04	14.2	75
BKG21-003	4-4.2	24-Jul-21	101-12-11-006-13 W2M	9	16	4	4	138	171	-	23	-	-	-	1.03	7.82	11.6	71
BKG21-01	0-0.2	29-Jun-21	101-12-16-006-13 W2M	162	318	74.8	<41.2	857	1880	-	386	-	-	-	5.07	7.89	15.4	82.4
BKG21-01	1-1.2	29-Jun-21	101-12-16-006-13 W2M	<16.6	581	<16.6	<16.6	878	755	-	350	-	-	-	2.36	9.23	<28	166
BKG21-01	2-2.2	29-Jun-21	101-12-16-006-13 W2M	11	144	<9.6	<9.6	473	614	-	150	-	-	-	2.21	8.65	40.1	96.2
BKG21-01	5-5.2	29-Jun-21	101-12-16-006-13 W2M	131	40	47.1	<38.7	1510	3420	-	26	-	-	-	4.31	8.25	23.1	155
BKG21-01	6-6.2	29-Jun-21	101-12-16-006-13 W2M	31.1	63	<19.1	19.3	1070	1880	-	33	-	-	-	2.35	8.56	38.1	191
BKG21-01	8.8-9	29-Jun-21	101-12-16-006-13 W2M	<43.8	485	<43.8	<43.8	1820	3780	-	277	-	-	-	4.2	8.41	<35.2	175
BKG21-02	0.4-0.6	29-Jun-21	101-12-16-006-13 W2M	<178	366	731	<178	3590	10,200	-	516	-	-	-	20.2	8.17	33.8	71
BKG21-02	1-1.2	29-Jun-21	101-12-16-006-13 W2M	369	<300	781	<188	3210	10,500	-	<400	-	-	-	18.6	8.02	25.1	75.1

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-02	2.8-3	29-Jun-21	101-12-16-006-13 W2M	642	310	928	<220	4970	15,600	-	2111	-	-	-	14.7	7.86	24.2	147
BKG21-02	4.3-5	29-Jun-21	101-12-16-006-13 W2M	352	439	583	<171	4770	12,800	-	257	-	-	-	11.8	7.74	27.7	171
BKG21-03	0.4-0.6	29-Jun-21	101-12-16-006-13 W2M	397	1530	339	68	1210	2960	-	2380	-	-	-	12.1	7.97	13.4	64.2
BKG21-03	1-1.2	29-Jun-21	101-12-16-006-13 W2M	492	1260	318	66	940	2730	-	1660	-	-	-	9.44	7.77	9.33	75.8
BKG21-03	2-2.2	29-Jun-21	101-12-16-006-13 W2M	142	712	129	31.2	469	788	-	805	-	-	-	4.12	7.81	7.29	88.5
BKG21-03	2.8-3	29-Jun-21	101-12-16-006-13 W2M	133	559	108	<20.9	364	726	-	1340	-	-	-	6.63	7.86	8.82	41.7
BH21-001	0-0.2	16-Sep-21	101-12-21-006-12 W2M	25	8	15	3	24	109	-	13	-	-	-	0.63	7.51	1.21	60
BH21-001	1-1.2	16-Sep-21	101-12-21-006-12 W2M	317	13	524	8	1350	5520	-	19	-	-	-	11.2	8.02	12.8	71
BH21-001	2-2.2	16-Sep-21	101-12-21-006-12 W2M	130	32	632	11	1650	6630	-	52	-	-	-	14.1	8.14	16.9	62
BH21-012	0.4-0.6	16-Sep-21	101-12-21-006-12 W2M	299	11	226	5	356	2390	-	16	-	-	-	5.33	8.01	4.59	68
BH21-012	1.3-1.5	16-Sep-21	101-12-21-006-12 W2M	266	9	173	6	431	2380	-	15	-	-	-	5.8	7.85	6.37	63
BH21-012	2-2.2	16-Sep-21	101-12-21-006-12 W2M	241	9	231	7	828	3480	-	15	-	-	-	8.45	7.96	11.8	60
BH21-012	2.8-3	16-Sep-21	101-12-21-006-12 W2M	232	8	263	8	897	3700	-	14	-	-	-	9.06	7.94	12.5	59
BH21-013	0-0.2	16-Sep-21	101-12-21-006-12 W2M	47	3	19	5	10	192	-	6	-	-	-	0.94	7.11	0.47	43
BH21-013	1-1.2	16-Sep-21	101-12-21-006-12 W2M	12	2	7	7	5	73	-	5	-	-	-	0.45	7.44	0.5	39
BH21-013	2-2.2	16-Sep-21	101-12-21-006-12 W2M	11	5	12	12	34	74	-	8	-	-	-	0.46	7.7	2.01	68
BH21-013	2.8-3	16-Sep-21	101-12-21-006-12 W2M	11	5	9	9	21	50	-	10	-	-	-	0.51	7.72	1.66	48
BKG21-001	0-0.2	18-Jul-21	101-12-26-005-13 W2M	58	14	22	41	11	126	-	26	-	-	-	1.12	7.08	0.44	54
BKG21-001	1-1.2	18-Jul-21	101-12-26-005-13 W2M	5	5	11	<2	8	20	-	12	-	-	-	0.38	8.16	0.71	41
BKG21-001	2-2.2	18-Jul-21	101-12-26-005-13 W2M	208	5	84	9	67	857	-	12	-	-	-	4.19	7.75	1.54	41
BKG21-001	2.8-3	18-Jul-21	101-12-26-005-13 W2M	217	6	114	9	68	890	-	15	-	-	-	4.43	7.83	1.45	41
BKG21-002	0.4-0.6	18-Jul-21	101-12-26-005-13 W2M	5	17	42	6	35	174	-	29	-	-	-	0.88	8.27	1.48	58
BKG21-002	1.3-1.5	18-Jul-21	101-12-26-005-13 W2M	7	12	50	8	50	178	-	20	-	-	-	0.84	8.17	1.87	62
BKG21-002	2-2.2	18-Jul-21	101-12-26-005-13 W2M	11	9	26	4	19	99	-	24	-	-	-	0.78	7.9	1.17	37
BKG21-002	2.8-3	18-Jul-21	101-12-26-005-13 W2M	11	7	15	4	27	130	-	22	-	-	-	0.93	7.5	2.16	32
BKG21-001	0.4-0.6	18-Jun-21	101-12-26-006-14 W2M	32.5	<10	16.2	<5	<5	118	-	<20	-	-	-	0.719	7.85	0.27	40.3
BKG21-001	1-1.2	18-Jun-21	101-12-26-006-14 W2M	29.2	<10	15	<5	<5	117	-	<20	-	-	-	0.827	7.693	0.33	31.4
BKG21-001	2-2.2	18-Jun-21	101-12-26-006-14 W2M	18.5	18	13.2	<5	19.9	81.2	-	47	-	-	-	0.749	7.9	1.4	38.3

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-001	2.8-3	18-Jun-21	101-12-26-006-14 W2M	21	19	12.3	<5	22.9	78.7	-	30	-	-	-	0.497	7.98	1.24	62
BKG21-002	0.4-0.6	18-Jun-21	101-12-26-006-14 W2M	25.7	21	9.6	<5	10.8	54	-	43	-	-	-	0.517	7.96	0.66	48.47
BKG21-002	1.3-1.5	18-Jun-21	101-12-26-006-14 W2M	17.1	21	6.7	<5	13.6	46.2	-	64	-	-	-	0.634	8.01	1.23	32.5
BKG21-002	4-4.2	18-Jun-21	101-12-26-006-14 W2M	64.1	135	18.2	6.8	28.4	104	-	204	-	-	-	0.961	8.36	0.99	66.1
BKG21-002	7-7.2	18-Jun-21	101-12-26-006-14 W2M	25.6	23	7.5	8.3	21.5	128	-	36	-	-	-	0.486	8.37	1.2	64.5
BKG21-002	9-9.2	18-Jun-21	101-12-26-006-14 W2M	28.3	15	9	10.7	26.1	101	-	33	-	-	-	0.737	8.17	1.63	45.3
BKG21-002	11.8-12	18-Jun-21	101-12-26-006-14 W2M	48.3	59	13.9	5.3	26.3	114	-	118	-	-	-	0.95	8.11	1.21	50.4
BKG21-001	0-0.2	17-Aug-21	101-15-14-006-12 W2M	18	<2	11	3	6	29	-	<5	-	-	-	0.45	7.75	0.39	52
BKG21-001	1-1.2	17-Aug-21	101-15-14-006-12 W2M	151	3	224	9	74	1330	-	7	-	-	-	4.94	7.967	1.35	44
BKG21-001	2-2.2	17-Aug-21	101-15-14-006-12 W2M	23	5	17	4	15	145	-	17	-	-	-	1.07	7.75	1.08	30
BKG21-001	2.8-3	17-Aug-21	101-15-14-006-12 W2M	19	4	10	3	12	113	-	16	-	-	-	0.94	7.78	1.08	26
BKG21-013	0.4-0.6	17-Aug-21	101-15-14-006-12 W2M	9	<2	5	2	3	5	-	<5	-	-	-	0.17	6.66	<0.34	66
BKG21-013	1.3-1.5	17-Aug-21	101-15-14-006-12 W2M	58	9	136	4	71	783	-	20	-	-	-	3.41	8.13	1.76	43
BKG21-013	2-2.2	17-Aug-21	101-15-14-006-12 W2M	103	4	113	6	51	863	-	11	-	-	-	3.73	7.89	1.34	38
BKG21-013	2.8-3	17-Aug-21	101-15-14-006-12 W2M	149	3	103	6	32	832	-	9	-	-	-	4.03	7.81	0.87	33
BKG21-01	0-0.2	09-Jun-21	101-16-17-006-13 W2M	19.5	73	16.9	<11.8	516	922	-	155	-	-	-	4.33	7.78	30	47.3
BKG21-01	1-1.2	09-Jun-21	101-16-17-006-13 W2M	<47.7	149	81.2	<47.7	2580	5120	-	78	-	-	-	5.62	9.09	44.4	191
BKG21-01	3-3.2	09-Jun-21	101-16-17-006-13 W2M	29	109	17.8	<17.6	1180	1970	-	62	-	-	-	3	8.5	32.1	176
BKG21-01	4-4.2	09-Jun-21	101-16-17-006-13 W2M	<45.8	187	<45.8	<45.8	1550	2540	-	102	-	-	-	3.28	8.54	<0.1	183
BKG21-01	4.3-4.5	09-Jun-21	101-16-17-006-13 W2M	25.2	140	19.1	<18	1370	2320	-	78	-	-	-	3.19	8.56	37.3	180
BKG21-02	0-0.2	09-Jun-21	101-16-17-006-13 W2M	68.3	33	29	8.2	287	689	-	52	-	-	-	2.44	7.76	9.14	64.4
BKG21-02	0.4-0.6	09-Jun-21	101-16-17-006-13 W2M	140	275	735	<100	3490	9820	-	412	-	-	-	20.7	8.54	32	66.8
BKG21-02	2-2.2	09-Jun-21	101-16-17-006-13 W2M	176	176	186	<117	4040	8790	-	76	-	-	-	6.79	8.5	33.1	235
BKG21-02	4-4.2	09-Jun-21	101-16-17-006-13 W2M	48.7	338	53.1	<42.1	2840	5290	-	201	-	-	-	6.26	8.64	51.7	168
BKG21-01	0.4-0.6	27-Jun-21	101-16-19-006-13 W2M	73.2	17	86.6	14.2	29.7	543	-	34	-	-	-	1.94	7.96	0.79	49.8
BKG21-01	2-2.2	27-Jun-21	101-16-19-006-13 W2M	41.7	<10	37.9	<5	32.6	268	-	<20	-	-	-	1.41	8.03	1.42	38.3
BKG21-01	3-3.2	27-Jun-21	101-16-19-006-13 W2M	85.8	<11	46	19.6	49	387	-	<20	-	-	-	1.57	7.73	1.44	54.3
BKG21-01	5.8-6	27-Jun-21	101-16-19-006-13 W2M	57.1	<10	29.6	7.5	31.5	256	-	<20	-	-	-	1.17	7.77	1.2	49.2

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-02	0-0.2	27-Jun-21	101-16-19-006-13 W2M	261	31	372	<27.4	452	2940	-	56	-	-	-	7.1	7.92	5.68	54.96
BKG21-02	0.4-0.6	27-Jun-21	101-16-19-006-13 W2M	236	33	324	<25.6	447	2670	-	65	-	-	-	7.06	8.07	6.2	51.3
BKG21-02	1.3-1.5	27-Jun-21	101-16-19-006-13 W2M	260	39	392	<28.6	464	3050	-	68	-	-	-	7.14	7.89	5.61	57.2
BKG21-02	3-3.2	27-Jun-21	101-16-19-006-13 W2M	251	61	389	<26.4	524	3110	-	116	-	-	-	7.89	8.07	6.65	52.7
BKG21-02	5-5.2	27-Jun-21	101-16-19-006-13 W2M	97.5	72	214	19.6	724	2160	-	147	-	-	-	2.92	7.97	7.57	154
BKG21-02	6-6.2	27-Jun-21	101-16-19-006-13 W2M	246	108	436	29.5	718	362	-	92	-	-	-	4.79	8.06	5.89	117
BKG21-02	7-7.2	27-Jun-21	101-16-19-006-13 W2M	258	83	301	38	472	2710	-	112	-	-	-	5.46	8.24	5.5	74
BKG21-02	8.8-9	27-Jun-21	101-16-19-006-13 W2M	99.6	33	114	15.9	292	1180	-	30	-	-	-	2.1	8.31	4.54	109
BKG21-002	0.4-0.6	24-Jul-21	101-16-20-006-13 W2M	294	129	700	13	2030	7890	-	189	-	-	-	14.5	8.56	17.8	68
BKG21-002	1.13-1.5	24-Jul-21	101-16-20-006-13 W2M	270	84	440	11	1450	5690	-	129	-	-	-	12.3	8.18	15.7	65
BKG21-002	3-3.2	24-Jul-21	101-16-20-006-13 W2M	17	49	11	6	363	802	-	53	-	-	-	2.11	8.11	17.7	92
BKG21-002	4.3-4.5	24-Jul-21	101-16-20-006-13 W2M	10	48	7	7	304	549	-	54	-	-	-	1.72	8.1	19.44	88
BKG21-01	0-0.2	23-Jul-21	101-16-20-006-13 W2M	37.8	23	28.4	5.2	22.2	104	-	37	-	-	-	0.74	7.78	0.84	63
BKG21-01	1-1.2	23-Jul-21	101-16-20-006-13 W2M	29.5	46	101	7.3	172	695	-	74	-	-	-	2.29	8.33	4.26	62.6
BKG21-01	1.3-1.5	23-Jul-21	101-16-20-006-13 W2M	37.6	53	108	8.1	262	888	-	76	-	-	-	2.62	8.27	5.89	69.9
BKG21-01	3-3.2	24-Jul-21	101-16-20-006-13 W2M	328	28	209	<15.7	293	2130	-	44	-	-	-	4.78	7.76	3.92	62.9
BKG21-01	4.3-4.5	24-Jul-21	101-16-20-006-13 W2M	265	24	158	<23.5	231	1720	-	51	-	-	-	5.21	7.7	4.04	46.9
BKG21-02	0-0.2	24-Jul-21	101-16-20-006-13 W2M	41.4	35	11.7	7.2	24.3	213	-	58	-	-	-	0.681	8.31	1.1	61.1
BKG21-02	0.4-0.6	24-Jul-21	101-16-20-006-13 W2M	7.8	<14	25.3	11.8	53.7	71.7	-	<20	-	-	-	0.649	8.61	2.52	69.6
BKG21-02	1.3-1.5	24-Jul-21	101-16-20-006-13 W2M	15.8	18	56.6	8.6	79.8	329	-	45	-	-	-	1.86	8.36	3.33	39.9
BKG21-02	3-3.2	24-Jul-21	101-16-20-006-13 W2M	425	24	172	<19.2	262	2110	-	31	-	-	-	3.91	7.65	3.08	77
BKG21-02	4-4.2	24-Jul-21	101-16-20-006-13 W2M	303	22	119	<14.6	210	1520	-	37	-	-	-	4.02	7.66	3.4	58.3
BKG21-02	5.8-6	24-Jul-21	101-16-20-006-13 W2M	392	25	128	<18.3	265	1870	-	34	-	-	-	3.83	7.68	3.47	73.2
BKG21-001	0.4-0.6	12-Jul-21	101-16-32-005-13 W2M	37	11	17	2	10	78	-	26	-	-	-	0.9	6.85	0.54	43
BKG21-001	1-1.2	12-Jul-21	101-16-32-005-13 W2M	265	13	229	7	60	1560	-	21	-	-	-	4.3	7.49	0.84	61
BKG21-001	2-2.2	12-Jul-21	101-16-32-005-13 W2M	60	11	65	8	64	495	-	11	-	-	-	1.22	7.72	1.38	97
BKG21-001	2.8-3	12-Jul-21	101-16-32-005-13 W2M	17	5	14	4	19	82	-	10	-	-	-	0.71	7.68	1.25	45
BKG21-002	0-0.2	12-Jul-21	101-16-32-005-13 W2M	173	15	62	13	22	706	-	32	-	-	-	2.99	7.56	0.52	48

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-002	1.3-1.5	12-Jul-21	101-16-32-005-13 W2M	117	14	205	21	145	1240	-	31	-	-	-	5.14	8.03	2.77	46
BKG21-002	2-2.2	12-Jul-21	101-16-32-005-13 W2M	181	28	193	15	149	1660	-	65	-	-	-	6.44	7.78	2.81	43
BKG21-002	2.8-3	12-Jul-21	101-16-32-005-13 W2M	100	12	40	12	74	500	-	29	-	-	-	2.71	7.7	2.43	42
BKG21-001	0.4-0.6	15-Jul-21	101-16-33-005-13 W2M	421	25	666	17	952	5610	-	46	-	-	-	9.83	7.55	9.07	55
BKG21-001	1.3-1.5	15-Jul-21	101-16-33-005-13 W2M	192	32	617	8	335	3670	-	76	-	-	-	11	7.88	4.1	42
BKG21-001	2-2.2	15-Jul-21	101-16-33-005-13 W2M	171	21	293	9	193	1900	-	57	-	-	-	7.44	7.85	3.46	36
BKG21-001	2.8-3	15-Jul-21	101-16-33-005-13 W2M	185	15	259	10	165	1870	-	39	-	-	-	6.84	7.73	2.99	38
BKG21-002	0-0.2	15-Jul-21	101-16-33-005-13 W2M	86	10	31	22	17	44	-	19	-	-	-	1.34	7.03	0.56	51
BKG21-002	1-1.2	15-Jul-21	101-16-33-005-13 W2M	192	43	480	8	426	3400	-	105	-	-	-	11	8.18	5.85	41
BKG21-002	2-2	15-Jul-21	101-16-33-005-13 W2M	167	41	366	6	370	2520	-	112	-	-	-	10.4	7.99	6.04	37
BKG21-002	2.8-3	15-Jul-21	101-16-33-005-13 W2M	135	42	282	6	292	2170	-	139	-	-	-	10	8.03	6	30
BKG21-002	4-4.2	15-Jul-21	101-16-33-005-13 W2M	167	44	441	11	456	3370	-	112	-	-	-	11.8	7.95	6.74	39
BKG21-002	5.8-6	15-Jul-21	101-16-33-005-13 W2M	200	40	506	20	632	3530	-	65	-	-	-	8.81	8.17	6.88	62
BKG21-001	0-0.2	03-Aug-21	111-07-01-006-13 W2M	12	11	7	26	4	25	-	21	-	-	-	0.42	6.5	<0.34	52
BKG21-001	1-1.2	03-Aug-21	111-07-01-006-13 W2M	28	19	99	32	47	532	-	28	-	-	-	1.55	8.15	1.12	69
BKG21-001	2-2.2	03-Aug-21	111-07-01-006-13 W2M	14	7	16	6	27	134	-	12	-	-	-	0.64	7.81	1.6	56
BKG21-001	2.8-3	03-Aug-21	111-07-01-006-13 W2M	25	6	20	4	35	208	-	14	-	-	-	1.07	7.86	1.96	42
BKG21-002	0.4-0.6	04-Aug-21	111-07-01-006-13 W2M	73	52	120	3	691	1980	-	107	-	-	-	7.8	8.4	16.6	49
BKG21-002	1.3-1.5	04-Aug-21	111-07-01-006-13 W2M	205	53	309	7	1200	4160	-	108	-	-	-	13.4	8.24	17.6	49
BKG21-002	2-2.2	04-Aug-21	111-07-01-006-13 W2M	139	34	124	5	538	1910	-	87	-	-	-	8.41	8.07	12.8	39
BKG21-002	2.8-3	04-Aug-21	111-07-01-006-13 W2M	58	44	67	5	433	1200	-	104	-	-	-	5.89	8.07	14.2	42
BKG21-01	0-0.2	12-Jul-21	121-08-28-005-13 W2M	64.6	19	93	<7.1	100	681	-	66	-	-	-	3.82	8.1	3.49	28.6
BKG21-01	0.4-0.6	12-Jul-21	121-08-28-005-13 W2M	188	<40	307	<20.1	259	2150	-	<100	-	-	-	6.99	8.14	4.27	40.2
BKG21-01	1.3-1.5	12-Jul-21	121-08-28-005-13 W2M	201	31	356	<22.1	300	2460	-	70	-	-	-	7.26	8.07	4.44	44.2
BKG21-01	3-3.2	12-Jul-21	121-08-28-005-13 W2M	43.4	<10	24.9	5.5	54.9	276	-	<20	-	-	-	1.42	7.96	2.56	41.3
BKG21-01	5-5.2	12-Jul-21	121-08-28-005-13 W2M	39.1	<10	14.3	<5	40.4	207	-	<20	-	-	-	1.39	7.92	2.51	31.3
BKG21-02	1-1.2	12-Jul-21	121-08-28-005-13 W2M	206	<10	167	<10.1	54	1260	-	<20	-	-	-	4.18	7.88	1.07	10.3
BKG21-02	1.3-1.5	12-Jul-21	121-08-28-005-13 W2M	188	<16	234	<20.6	127	1640	-	<40	-	-	-	5.27	7.93	2.28	41.1

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-02	2.8-3	12-Jul-21	121-08-28-005-13 W2M	187	42	252	<19.9	193	1810	-	105	-	-	-	6.23	7.9	3.42	39.8
BKG21-03	0-0.2	12-Jul-21	121-08-28-005-13 W2M	137	60	295	<5	369	2110	-	200	-	-	-	10	8.24	7.43	30
BKG21-03	1-1.2	12-Jul-21	121-08-28-005-13 W2M	226	20	562	7	655	3810	-	42	-	-	-	11.6	8.19	7.77	46.8
BKG21-03	1.3-1.5	12-Jul-21	121-08-28-005-13 W2M	201	14	358	6	395	2490	-	32	-	-	-	8.84	8.13	5.93	42.5
BKG21-03	3-3.2	12-Jul-21	121-08-28-005-13 W2M	172	24	110	6.3	117	1020	-	75	-	-	-	4.7	7.83	3	32.5
BKG21-03	5.8-6	12-Jul-21	121-08-28-005-13 W2M	174	68	114	9.6	128	1140	-	200	-	-	-	4.87	7.98	3.17	34.2
BKG21-01	0-0.2	21-Jul-21	121-08-34-005-13 W2M	27.6	11	34	<5	61.8	296	-	26	-	-	-	1.56	8.52	2.83	43.2
BKG21-01	1-1.2	21-Jul-21	121-08-34-005-13 W2M	23.8	<10	20.3	<5	35.2	173	-	<20	-	-	-	0.901	8.53	1.77	52.4
BKG21-01	2-2.2	21-Jul-21	121-08-34-005-13 W2M	11.3	<10	7.5	<5	14	63.4	-	<20	-	-	-	0.591	8.78	1.33	35.2
BKG21-01	2.8-3	21-Jul-21	121-08-34-005-13 W2M	11.3	<10	8	<5	14.7	73.9	-	<20	-	-	-	0.73	8.57	1.52	29.1
BKG21-02	0-0.2	21-Jul-21	121-08-34-005-13 W2M	15	<12	18	<5	33.2	126	-	<20	-	-	-	0.68	8.73	1.74	61.4
BKG21-02	1-1.2	21-Jul-21	121-08-34-005-13 W2M	19.4	<10	24.5	<5	31.1	187	-	<20	-	-	-	0.95	8.53	1.52	52.9
BKG21-02	1.3-1.5	21-Jul-21	121-08-34-005-13 W2M	19.2	12	29.1	<5	35.5	178	-	23	-	-	-	1.02	8.56	1.68	50.1
BKG21-02	3-3.2	21-Jul-21	121-08-34-005-13 W2M	8.2	<10	6.8	<5	7.6	30.3	-	<20	-	-	-	0.423	8.84	0.8	35.7
BKG21-02	4.3-4.5	21-Jul-21	121-08-34-005-13 W2M	9.9	<10	8	<5	6.6	39.8	-	<20	-	-	-	0.38	8.78	0.57	45.3
BKG21-001	1-1.2	17-Jun-21	13-08-006-13 W2M	317	<11	66.2	<5.5	32.3	1060	-	<20	-	-	-	2.92	7.78	0.58	55.2
BKG21-001	1.3-1.5	17-Jun-21	13-08-006-13 W2M	224	<10	40.9	11.8	25.4	726	-	<20	-	-	-	2.8	7.71	0.65	40.1
BKG21-001	2-2.2	17-Jun-21	13-08-006-13 W2M	438	<14	50.3	8.3	29.2	1270	-	<20	-	-	-	2.68	7.65	0.42	70.8
BKG21-001	2.8-3	17-Jun-21	13-08-006-13 W2M	187	<13	32	6.5	24.8	586	-	<20	-	-	-	1.68	7.7	0.55	63.9
BKG21-002	0-0.2	17-Jun-21	13-08-006-13 W2M	310	170	884	<70.7	962	6000	-	241	-	-	-	10.7	8.07	7.49	70.7
BKG21-002	0.4-0.6	17-Jun-21	13-08-006-13 W2M	344	112	851	<68.6	947	6040	-	164	-	-	-	10.7	8	7.53	68.6
BKG21-002	1-1.2	17-Jun-21	13-08-006-13 W2M	290	88	693	<33.3	759	4930	-	132	-	-	-	9.33	7.95	6.77	66.6
BKG21-002	1.3-1.5	17-Jun-21	13-08-006-13 W2M	292	94	693	<31.5	756	4890	-	149	-	-	-	9.74	7.94	6.92	63
BKG21-002	2-2.2	17-Jun-21	13-08-006-13 W2M	157	109	608	<33.7	694	4060	-	162	-	-	-	8.11	8.04	6.84	67.4
BKG21-002	3-3.2	17-Jun-21	13-08-006-13 W2M	282	85	613	<31.8	674	4380	-	134	-	-	-	8.8	7.83	6.47	63.6
BKG21-002	4-4.2	17-Jun-21	13-08-006-13 W2M	200	87	506	<33.1	651	3710	-	131	-	-	-	7.64	7.9	6.86	66.2
BKG21-002	5-5.2	17-Jun-21	13-08-006-13 W2M	224	88	435	<34.9	642	3500	-	126	-	-	-	6.97	7.89	6.89	69.9
BKG21-002	5.8-6	17-Jun-21	13-08-006-13 W2M	80.8	62	166	<14.5	376	1550	-	106	-	-	-	4.44	8.06	7.23	58.1

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-01	0-0.2	29-Jun-21	131-09-05-006-13 W2M	258	<10	286	16.8	92.2	1870	-	20	-	-	-	4.8	7.9	1.33	50.1
BKG21-01	2-2.2	29-Jun-21	131-09-05-006-13 W2M	328	<27	562	<34.1	229	3380	-	<40	-	-	-	6.19	7.9	2.16	68.1
BKG21-01	3-3.2	29-Jun-21	131-09-05-006-13 W2M	147	22	148	15.5	87.8	1050	-	44	-	-	-	3.24	7.75	1.74	49.36
BKG21-01	5-5.2	29-Jun-21	131-09-05-006-13 W2M	155	22	139	13.7	83.8	1020	-	45	-	-	-	3.14	7.78	1.66	50.2
BKG21-01	5.8-6	29-Jun-21	131-09-05-006-13 W2M	272	23	230	17.5	99.9	1700	-	46	-	-	-	4.57	7.72	1.53	49.7
BKG21-02	0-0.2	30-Jun-21	131-09-05-006-13 W2M	26.9	<19	50.7	11.2	56.4	202	-	<20	-	-	-	0.751	8.22	1.51	95.7
BKG21-02	1-1.2	30-Jun-21	131-09-05-006-13 W2M	65.2	<20	119	20.1	83.3	643	-	<20	-	-	-	1.37	8.09	1.42	99.9
BKG21-02	3-3.2	30-Jun-21	131-09-05-006-13 W2M	51.7	<10	48.3	9.2	28.1	316	-	<20	-	-	-	1.48	7.92	1.03	43.1
BKG21-02	4.3-4.5	30-Jun-21	131-09-05-006-13 W2M	63	<10	34.5	8.4	19.4	266	-	<20	-	-	-	1.15	7.83	0.68	50.8
BKG21-01	1.3-1.5	14-Jun-21	140-08-03-006-14 W2M	279	64	237	<24.2	285	2010	-	132	-	-	-	5.97	7.87	4.36	48.4
BKG21-01	2.8-3	14-Jun-21	140-08-03-006-14 W2M	324	68	4444	<27.7	609	3570	-	123	-	-	-	8.54	7.93	6.94	55.4
BKG21-02	0.4-0.6	14-Jun-21	140-08-03-006-14 W2M	93.1	62	89	7.1	39.4	502	-	107	-	-	-	1.96	8.1	0.92	58.2
BKG21-02	1.3-1.5	14-Jun-21	140-08-03-006-14 W2M	84.9	35	33	7.6	11.7	275	-	74	-	-	-	1.38	7.94	0.4	46.9
BKG21-02	8-8.2	14-Jun-21	140-08-03-006-14 W2M	62.6	16	22.2	16.6	87.1	271	-	25	-	-	-	1.19	8.05	2.96	66
BKG21-001	0-0.2	21-Jul-21	141-08-15-006-13 W2M	50	9	19	15	38	74	-	12	-	-	-	0.78	7.14	1.35	73
BKG21-001	1-1.2	21-Jul-21	141-08-15-006-13 W2M	43	61	137	13	902	2490	-	139	-	-	-	10.4	8.76	22.9	44
BKG21-001	2-2.2	21-Jul-21	141-08-15-006-13 W2M	4	14	3	4	194	160	-	13	-	-	-	0.88	8.22	16.9	106
BKG21-001	2.8-3	21-Jul-21	141-08-15-006-13 W2M	6	11	5	6	285	257	-	7	-	-	-	0.9	8.17	17	154
BKG21-002	0.4-0.6	22-Jul-21	141-08-15-006-13 W2M	36	41	89	10	1750	4690	-	38	-	-	-	7.93	8.87	34.4	108
BKG21-002	1.3-1.5	22-Jul-21	141-08-15-006-13 W2M	7	17	6	4	606	1070	-	9	-	-	-	1.66	8.53	30	186
BKG21-002	4-4.2	22-Jul-21	141-08-15-006-13 W2M	8	8	3	3	221	366	-	10	-	-	-	1.38	8.2	19.4	84
BKG21-002	5.8-6	22-Jul-21	141-08-15-006-13 W2M	5	13	3	3	172	129	-	15	-	-	-	0.96	8.35	16.5	87
BH21-006	0.4-0.6	07-Jul-21	141-08-28-005-13 W2M	194	96	670	19	2800	9800	-	192	-	-	-	27.2	8.4	30.2	50
BH21-006	2-2.2	07-Jul-21	141-08-28-005-13 W2M	139	49	385	10	979	4210	-	117	-	-	-	15.7	8.09	15	42
BKG21-001	0.4-0.6	07-Jul-21	141-08-28-005-13 W2M	241	24	94	18	218	1400	-	47	-	-	-	5.05	7.85	4.19	52
BKG21-001	1.3-1.5	07-Jul-21	141-08-28-005-13 W2M	153	26	158	7	167	1420	-	66	-	-	-	6.14	7.84	3.259	40
BKG21-001	2-2.2	07-Jul-21	141-08-28-005-13 W2M	71	43	90	6	130	774	-	135	-	-	-	4.75	7.89	4.27	32
BKG21-001	2.8-3	07-Jul-21	141-08-28-005-13 W2M	23	9	43	6	130	496	-	24	-	-	-	2.88	7.86	6.03	37

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-002	0.4-0.6	07-Jul-21	141-08-28-005-13 W2M	18	3	7	4	22	97	-	8	-	-	-	0.65	7.43	1.77	40
BKG21-002	1.3-1.5	07-Jul-21	141-08-28-005-13 W2M	10	5	6	4	11	49	-	17	-	-	-	0.59	7.61	1.24	29
BKG21-002	3-3.2	07-Jul-21	141-08-28-005-13 W2M	14	8	6	5	15	65	-	23	-	-	-	0.64	7.71	1.46	34
BKG21-002	4.3-4.5	07-Jul-21	141-08-28-005-13 W2M	42	13	18	9	17	209	-	38	-	-	-	1.24	7.91	0.93	35
BH21-17	0-0.2	04-Aug-21	141-08-35-005-13 W2M	192	44	651	57	1280	5430	-	48	-	-	-	8.73	8.26	10.4	90.7
BH21-17	1-1.2	04-Aug-21	141-08-35-005-13 W2M	396	<35	583	53.4	1280	5750	-	<40	-	-	-	9.18	7.98	10.2	87.6
BH21-17	2-2.2	04-Aug-21	141-08-35-005-13 W2M	482	<40	382	41.7	905	4400	-	<40	-	-	-	6.39	7.84	7.47	100
BH21-17	4-4.2	04-Aug-21	141-08-35-005-13 W2M	456	<39	273	53.8	785	3760	-	<40	-	-	-	5.68	7.94	7.28	97.4
BH21-17	5.8-6	04-Aug-21	141-08-35-005-13 W2M	72.6	31	42	29.3	553	1280	-	34	-	-	-	2.92	8.16	13.3	92.6
BH21-19	0-0.2	04-Aug-21	141-08-35-005-13 W2M	45.5	70	128	<23.7	788	2050	-	148	-	-	-	7.43	8.28	19.6	47.5
BH21-19	1-1.2	04-Aug-21	141-08-35-005-13 W2M	286	84	354	<32.5	1200	4340	-	130	-	-	-	9.72	8.12	13.8	65
BH21-19	2-2.2	04-Aug-21	141-08-35-005-13 W2M	357	92	421	<73.2	1460	5310	-	125	-	-	-	10.2	8.08	14.5	73.2
BH21-19	2.8-3	04-Aug-21	141-08-35-005-13 W2M	388	96	458	<41.4	1560	5660	-	116	-	-	-	9.75	8.01	13.9	82.8
BKG21-02	0.4-0.6	14-Jun-21	141-10-03-006-14 W2M	243	<22	344	<27.4	933	3770	-	<40	-	-	-	9.45	8.29	12.2	54.9
BKG21-02	1.3-1.5	14-Jun-21	141-10-03-006-14 W2M	297	<68	441	<67.6	1320	5180	-	<100	-	-	-	10.4	8.1	13.8	67.6
BKG21-02	4.3-4.5	14-Jun-21	141-10-03-006-14 W2M	122	<58	236	<43.1	732	2740	-	<200	-	-	-	12.7	8.1	16.6	28.8
BH21-001	0-0.2	07-Aug-21	141-11-14-006-12 W2M	30	3	17	4	15	38	-	6	-	-	-	0.62	7.16	0.72	54
BH21-001	1-1.2	07-Aug-21	141-11-14-006-12 W2M	214	18	303	16	290	2220	-	35	-	-	-	7.01	8.06	4.19	51
BH21-001	2-2.2	07-Aug-21	141-11-14-006-12 W2M	254	24	96	15	187	1300	-	46	-	-	-	4.46	7.7	3.51	52
BH21-001	2.8-3	07-Aug-21	141-11-14-006-12 W2M	246	19	114	14	183	1310	-	37	-	-	-	4.5	7.72	3.41	50
BH21-007	0.4-0.6	10-Aug-21	141-11-14-006-12 W2M	171	35	438	14	765	3870	-	78	-	-	-	12.9	8.22	10.5	45
BH21-007	2-2.2	10-Aug-21	141-11-14-006-12 W2M	237	62	1290	26	1720	9350	-	110	-	-	-	20.6	8.28	13	56
BH21-018	0.4-0.6	10-Aug-21	141-11-14-006-12 W2M	69	38	43	19	133	550	-	80	-	-	-	2.49	7.95	4.51	47
BH21-018	1.3-1.5	10-Aug-21	141-11-14-006-12 W2M	42	15	32	14	51	312	-	33	-	-	-	1.54	7.89	2.15	45
BH21-018	3-3.2	10-Aug-21	141-11-14-006-12 W2M	52	19	36	14	56	378	-	40	-	-	-	1.6	7.8	2.09	48
BH21-018	4-4.2	10-Aug-21	141-11-14-006-12 W2M	83	16	78	19	142	730	-	25	-	-	-	2.16	8.02	3.37	64
BH21-018	4.3-4.5	10-Aug-21	141-11-14-006-12 W2M	68	18	81	20	126	707	-	34	-	-	-	2.83	8.49	3.4	52
BH21-01a	0-0.2	08-Aug-21	141-11-14-006-12 W2M	257	<21	282	16.4	328	2260	-	<40	-	-	-	6.03	7.9	4.68	54.8

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BH21-01a	1-1.2	08-Aug-21	141-11-14-006-12 W2M	253	<22	312	<27.7	464	2660	-	<40	-	-	-	6.75	7.99	6.2	55.3
BH21-01a	2-2.2	08-Aug-21	141-11-14-006-12 W2M	252	24	341	<27.1	579	3000	-	44	-	-	-	7.65	8	7.59	54.1
BH21-01a	2.8-3	08-Aug-21	141-11-14-006-12 W2M	256	27	346	<27.3	595	3040	-	50	-	-	-	7.64	8.02	7.72	54.6
BKG21-01	0.4-0.6	05-Jul-21	191-05-08-006-13 W2M	154	72	234	10.2	728	2720	-	119	-	-	-	7.29	8.11	11.1	60.7
BKG21-01	1.3-1.5	05-Jul-21	191-05-08-006-13 W2M	154	58	233	9.6	641	2560	-	82	-	-	-	5.91	8.02	9.02	71.2
BKG21-01	3-3.2	05-Jul-21	191-05-08-006-13 W2M	117	60	158	9.8	565	2040	-	73	-	-	-	4.25	8.03	8.84	82.1
BKG21-01	4-4.2	05-Jul-21	191-05-08-006-13 W2M	71.6	44	82.8	6.2	360	1210	-	63	-	-	-	3.21	8.05	8.2	70.2
BKG21-02	0-0.2	05-Jul-21	191-05-08-006-13 W2M	128	403	150	<5	304	1110	-	848	-	-	-	5.28	7.93	6.27	47.5
BKG21-02	0.4-0.6	05-Jul-21	191-05-08-006-13 W2M	129	375	134	<5	291	1020	-	840	-	-	-	5.17	7.94	6.43	44.7
BKG21-02	3-3.2	05-Jul-21	191-05-08-006-13 W2M	94.4	92	163	7	441	1660	-	132	-	-	-	4.23	8.11	7.63	69.9
BKG21-02	4.3-4.5	05-Jul-21	191-05-08-006-13 W2M	145	78	163	6.5	377	1660	-	100	-	-	-	3.72	7.92	5.78	77.8
BKG21-001	0.4-0.6	28-Jun-21	191-15-30-005-13 W2M	304	<12	233	<14.6	128	1890	-	<20	-	-	-	4.35	7.77	1.76	58.4
BKG21-001	1.3-1.5	28-Jun-21	191-15-30-005-13 W2M	265	36	262	18.7	332	2300	-	69	-	-	-	6.07	7.92	4.79	52.2
BKG21-001	3-3.2	28-Jun-21	191-15-30-005-13 W2M	272	45	293	<29	398	2580	-	78	-	-	-	6.32	7.69	5.24	57.9
BKG21-002	0.4-0.6	28-Jun-21	191-15-30-005-13 W2M	170	14	92.6	5.6	86	826	-	30	-	-	-	2.97	7.05	1.91	47.5
BKG21-002	1-1.2	28-Jun-21	191-15-30-005-13 W2M	66.6	12	54.2	<5	83.2	424	-	21	-	-	-	1.69	7.2	2.46	55.5
BKG21-002	2-2.2	28-Jun-21	191-15-30-005-13 W2M	27.2	<10	24.2	<5	57.6	233	-	<20	-	-	-	1.39	7.85	3.21	36.2
BKG21-002	2.8-3	28-Jun-21	191-15-30-005-13 W2M	53.2	12	41.9	<5	54.2	359	-	33	-	-	-	1.94	7.63	2.28	35.2
BKG21-01	0.4-0.6	07-Jun-21	192-05-24-006-14 W2M	122	44	105	<41.1	1810	4010	-	54	-	-	-	8.77	8.56	31.9	82.9
BKG21-01	1.3-1.5	07-Jun-21	192-05-24-006-14 W2M	240	28	301	<30.2	1060	3930	-	47	-	-	-	9.41	8.19	13.9	60.5
BKG21-01	4-4.2	07-Jun-21	192-05-24-006-14 W2M	278	<120	496	<89.9	1400	5490	-	<200	-	-	-	12.4	8.01	15	59.9
BKG21-01	4.3-4.5	07-Jun-21	192-05-24-006-14 W2M	212	<106	567	<79.5	1320	5410	-	<200	-	-	-	13.4	8.59	14.7	53
BKG21-02	0-0.2	07-Jun-21	192-05-24-006-14 W2M	407	<30	250	27.2	626	3000	-	<40	-	-	-	5.97	7.89	6.96	74.9
BKG21-02	1-1.2	07-Jun-21	192-05-24-006-14 W2M	195	120	263	<35.6	1310	4140	-	169	-	-	-	8.965	8.39	17	71.2
BKG21-02	2-2.2	07-Jun-21	192-05-24-006-14 W2M	59.6	68	107	14.4	766	2020	-	143	-	-	-	7.64	8.38	20	47.3
BKG21-02	2.8-3	07-Jun-21	192-05-24-006-14 W2M	270	79	248	<30.2	1070	3650	-	131	-	-	-	9.15	7.97	14.6	60.3
BKG21-001 141/08-15-006-13 W2M	0-0.2	21-Jul-21	101-12-16-006-13 W2M	50	9	19	15	38	74	-	12	-	-	-	0.78	7.14	1.35	73
BKG21-001 141/08-15-006-13 W2M	1-1.2	21-Jul-21	101-12-16-006-13 W2M	43	61	137	13	902	2490	-	139	-	-	-	10.4	8.76	22.9	44

Table B5-1. Soil Detailed Salinity Results

Sample ID	Sample Depth (m)	Sampling Date	LSD	Inorganics											General Chemistry			
				Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Calcium, Soluble	Chloride, Soluble	Magnesium, Soluble	Potassium, Soluble	Sodium, Soluble	EC	pH	SAR	Percent Saturation
				mg/kg						mg/L					dS/m	pH	---	%
BKG21-001 141/08-15-006-13 W2M	2-2.2	21-Jul-21	101-12-16-006-13 W2M	4	14	3	4	194	160	-	13	-	-	-	0.88	8.22	16.9	106
BKG21-001 141/08-15-006-13 W2M	2.8-3	21-Jul-21	101-12-16-006-13 W2M	6	11	5	6	285	257	-	7	-	-	-	0.9	85.17	17	154
BKG21-002 141/08-15-006-13 W2M	0.4-0.6	21-Jul-21	101-12-16-006-13 W2M	36	41	89	10	1750	4690	-	38	-	-	-	7.966	8.87	34.4	108
BKG21-002 141/08-15-006-13 W2M	1.3-1.5	21-Jul-21	101-12-16-006-13 W2M	7	17	6	4	606	1070	-	9	-	-	-	1.66	8.53	30	186
BKG21-002 141/08-15-006-13 W2M	4-4.2	21-Jul-21	101-12-16-006-13 W2M	8	8	3	3	221	366	-	10	-	-	-	1.38	8.2	19.4	84
BKG21-002 141/08-15-006-13 W2M	5.8-6	21-Jul-21	101-12-16-006-13 W2M	5	13	3	3	172	129	-	15	-	-	-	0.96	8.35	16.5	87
BKG21-01 131/09-05-006-13 W2M	0-0.2	29-Jun-21	141-14-04-006-13 W2M	258	<10	286	16.8	92.2	1870	-	<20	-	-	-	4.88	7.9	1.33	50.1
BKG21-01 131/09-05-006-13 W2M	2-2.2	29-Jun-21	141-14-04-006-13 W2M	328	<27	562	<34.1	229	3380	-	<40	-	-	-	6.19	7.9	2.16	68.1
BKG21-01 131/09-05-006-13 W2M	3-3.2	29-Jun-21	141-14-04-006-13 W2M	147	22	148	15.5	87.8	1050	-	44	-	-	-	3.24	7.75	1.74	49.6
BKG21-01 131/09-05-006-13 W2M	5-5.2	29-Jun-21	141-14-04-006-13 W2M	155	22	139	13.7	83.8	1020	-	45	-	-	-	3.14	7.78	1.66	50.2
BKG21-01 131/09-05-006-13 W2M	5.8-6	29-Jun-21	141-14-04-006-13 W2M	272	23	230	17.5	99.9	1700	-	46	-	-	-	4.57	7.72	1.53	49.7
BKG21-02 131/09-05-006-13 W2M	0-0.2	30-Jun-21	141-14-04-006-13 W2M	26.9	<19	50.7	1.2	56.4	202	-	<20	-	-	-	0.751	8.22	1.51	95.7
BKG21-02 131/09-05-006-13 W2M	1-1.2	30-Jun-21	141-14-04-006-13 W2M	65.2	<20	119	20.1	83.3	643	-	<20	-	-	-	1.37	8.09	1.42	99.9
BKG21-02 131/09-05-006-13 W2M	3-3.2	30-Jun-21	141-14-04-006-13 W2M	51.7	<10	48.3	9.2	28.1	316	-	<20	-	-	-	1.48	7.92	1.03	43.1
BKG21-02 131/09-05-006-13 W2M	4.3-4.5	30-Jun-21	141-14-04-006-13 W2M	63	<10	34.5	8.4	19.4	266	-	<20	-	-	-	1.15	7.83	0.68	50.8
95th percentile				**337.4**	**186.3**	**608**	**32**	**1559**	**5551.5**	**520**	**258.1**	**1768**	**129.8**	**1710**	**12.31**	**8.57**	**27.3**	**118.2**

APPENDIX C: BRITISH COLUMBIA

Appendix C – British Columbia

1.0 INTRODUCTION

This appendix provides background information on the demonstration project process for implementation of a Low Probability Receptor (LPR) framework and contaminant attenuation model in British Columbia (BC). The project goal is accelerating closure of sites in northeast BC affected by primarily petroleum hydrocarbon releases. Because of the importance of understanding the BC regulatory process, we summarize regulatory considerations and describe desired outcomes and success factors.

During fall 2020, MEMS presented an approach to the BC Oil and Gas Commission (OGC) for incorporation of LPR in BC regulatory framework. The understanding of OGC's response was that they were supportive of additional information and demonstration of LPR concepts in the BC context. Our comments on regulatory policy in this work plan should be recognized as our best efforts to describe a possible path forward.

Subsequent presentations and meetings were conducted in 2021 and 2022; the results of these discussions are presented herein.

2.0 BACKGROUND

Current Regulatory Framework

Under the BC *Contaminated Sites Regulation* (CSR) and BC ENV *Protocol 21*, the groundwater flow to potential future drinking water wells pathway often applies at sites in northeast BC. The low standards in soil and groundwater for protection of drinking water often drive the site investigation and remediation process.

Under BC ENV *Protocol 13* on Screening Level Risk Assessment (SLRA), when certain conditions are met, a site can be screened out of the remediation process based on acceptable risk. Key conditions that must be met (or precluding factors that must be absent) include non high-risk conditions (including absence of NAPL), concentrations predicted by the BC Groundwater Protection Model (GPM) must be less than the applicable standards at the parcel boundary or at on-site receptors, if present, and no contamination above ecological-based standards within surface soils (within 1 m depth).

At many sites, groundwater concentrations predicted at a parcel boundary exceed standards and consequently SLRA would not apply. There may also be differences in attenuation distances between organic substances and inorganic substances because contaminant degradation is generally not appropriate to include for inorganic substances. While *Protocol 13* is silent on delineation of soil and groundwater, delineation is a requirement under the CSR unless a pre-approval not to delineate is obtained. Because the soil standards for protection of drinking water are low for benzene and toluene, it can be challenging and costly to delineate soil contamination based on the drinking water pathway.

We note there could be benefit from more routine application of *Protocol 13* particularly when contamination is set-back from parcel boundaries as this may provide opportunity for contamination to attenuate before reaching the boundary.

Desired Future State

The desired future state is a framework for excluding a standard based on a very low probability of an on-site or off-site groundwater plume with concentrations above a standard intersecting with a receptor. This framework is intended primarily for the future drinking water pathway but could potentially be applied to other receptors (*e.g.*, dugouts).

Within the BC OGC regulatory framework and specific to sites in northeast BC, we envision modification to *Protocol 21* to determine the applicable water use and modification to *Protocol 13* and BC GPM to include source depletion. The methodology for the LPR would follow the extensive work completed in Alberta on probability-based approach for characterizing the occurrence of wells. The methodology for the groundwater attenuation model would be to adapt the BC GPM to include source depletion as supported by recent science.

Regulatory Policy Considerations

A key policy consideration that underlies the LPR approach is acceptance of groundwater off-site with concentrations above a standard addressed through a probability-based approach to eliminate a receptor when there is very low probability of the receptor existing or being adversely impacted. In BC, there indirectly is precedence for this approach from the Wildlands land use in that the vapour intrusion pathway does not apply based on a low probability of occupied buildings in wildlands.

The current probability-based framework does not address plume migration distance as a decision-criteria but is included in the model output. A distance-based criteria could be evaluated in combination with receptor probability to potentially strengthen the approach. There is precedence for a distance-based approach in US guidance (*e.g.*, California Low-Threat UST closure policy). There are also extensive data on the extent and natural attenuation of dissolved petroleum hydrocarbon plumes that indicate typically relatively short plume lengths.

Technical Considerations

A key technical consideration is inclusion of source depletion in the attenuation model. The source depletion in the model is based on a mass balance approach as hydrocarbons are dissolved in water and then removed *via* infiltration or moving groundwater. While there are different models for mass removal *via* source depletion, the fundamental premise for including depletion is considered reasonable. We note this model does not account for additional mass removed through source zone biodegradation. There are recent data that indicate source zone biodegradation is a significant loss mechanism. A key aspect of our approach will be to explain the basis for the attenuation model.

3.0 OUTCOMES

A detailed analysis of LPR against the BC regulatory framework was conducted; this analysis has been summarized in 3 presentations attached as Appendix C1.

A meeting was conducted with representatives of the BC Oil & Gas Commission (OGC, now the BC Energy Regulator, BCER) along with MEMS and oil and gas producers to identify any barriers to implementation of LPR. Specific issues raised included:

- Ensuring that secondary effects are considered, such as those associated with changed redox from primary contamination impacts; this is considered in the attenuation tool.
- Being able to assess differences in timelines between full natural attenuation against timelines where there is partial or full active remediation to generic criteria; this is considered in the attenuation tool.
- Consideration of consultation requirements with First Nations in BC. With recent regulatory initiatives in BC (*e.g., Declaration Act*), this may become increasingly important and therefore it is recommend that developments in this area be monitored as to potential implications for this project.

There was a general agreement that while, at a high level, there may be concerns with "leaving contamination in the ground", but on the other hand, remediation to generic standards is often not sustainable and does not increase environmental protection (and may have the opposite effect). Communication will be important.

The LPR / attenuation assessment approach was greed to be generally consistent with requirements of a Screening Level Risk Assessment (SLRA) under BC ENV *Protocol 13*. The goal has been to harmonize the assessment with SLRA. Considerable upfront work is done to incorporate knowledge on receptors in the tool. The model tool is flexible and easy to use but use of tool and inputs are constrained (based on SLRA requirements) to enable appropriate predictions of fate and transport.

OGC indicated that LPR and the associated attenuation tool could currently support existing applications as a line of evidence. It would not be appropriate at all sites; SLRA specifies requirements for investigation and has precluding conditions where SLRA should not be used, and the tools will need to be consistent with SLRA. Institutional controls may be needed for some sites assessed with LPR, but SLRA already has some provisions for these types of controls.

4.0 NEXT STEPS

Application of LPR on existing sites would be beneficial to show how LPR and the attenuation tool could be currently used as a line of evidence in a site-specific application under BCER process. Industry and/or BCER sites would need to be provided and funded to progress this demonstration.

Attachment:

Appendix C1 Presentations

APPENDIX C1: PRESENTATIONS

Low Probability Receptor (LPR) Assessment - Update

Millennium EMS Solutions

JANUARY 14, 2022

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Presentation Outline

- What is LPR assessment and why use?
- What's new since 2020 presentations to OGC?
- How does LPR fit into the BC regulatory framework?
- Overview of LPR Process
  - Attenuation Model and initial results
  - Probability Model and initial results
- Benefits of LPR
- Implementation of LPR and proposed next steps?
- Detailed Technical Presentation to follow, if time and interest

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Current Status and Desired Outcome

- Remediation, closure and redevelopment of many sites are stalled (or are cleaned up with negative impacts and at high cost) because of unrealistic exposure and receptor assumptions under generic or screening level approaches.

- More flexible risk-based approaches and incorporation of LPR and sustainability in remediation are needed

- Desired outcome is to work with OGC to develop a path forward to implement LPR process at OGC regulated sites in BC.

Fundamentals

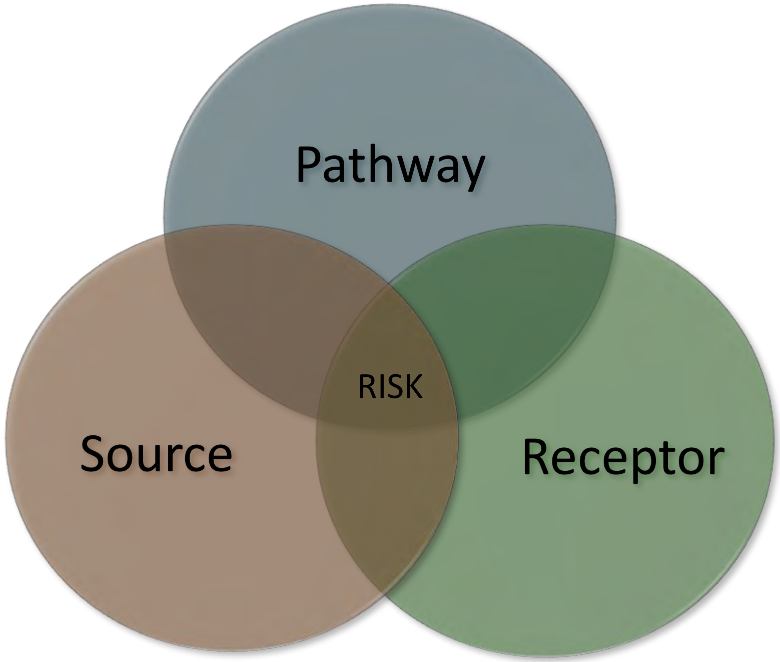
LPR is focused on:

- inclusion of applicable receptors into the Contaminated Sites Frameworks;
- streamlining the ability to modify receptor characteristics; and
- recognition of temporal nature of COPCs that attenuate.

100% Certainty:

- that remediation aimed at protecting a receptor that is not / will not be present creates a negative environmental effect;
- temporal nature of COPCs is an important consideration of environmental protection and economic development planning

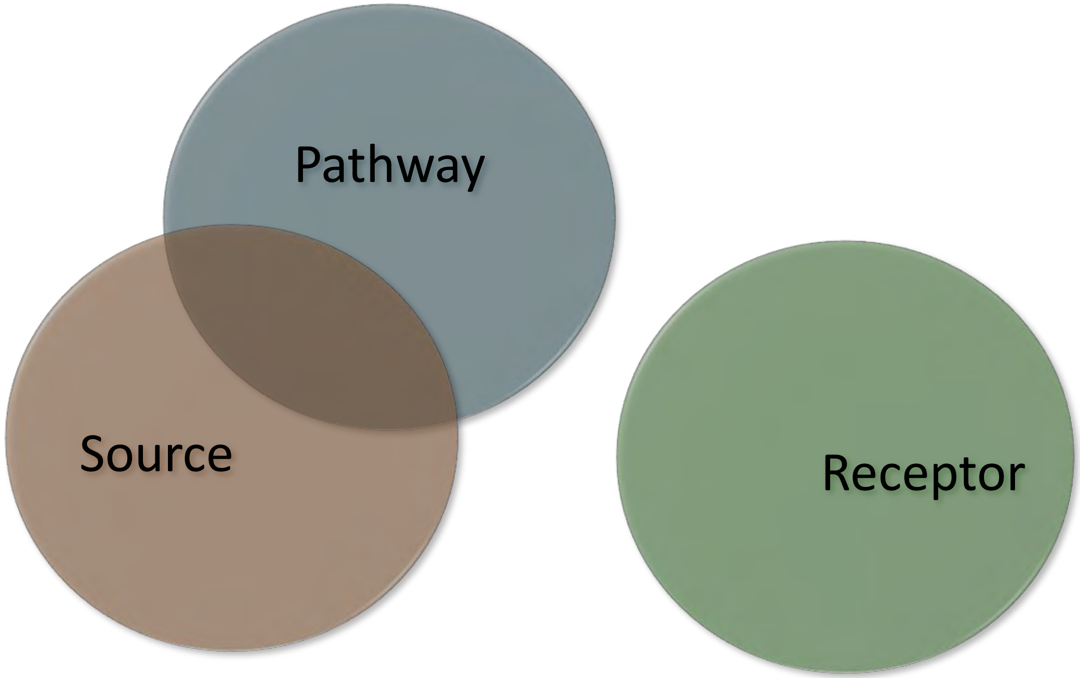
What is LPR Assessment?



Low Probability Receptor Assessment

- Focus on the protection of receptors at risk from source & pathway.

Temporal Impact on Source



No risk if source attenuates prior to receptor occurrence.

Why use an LPR Assessment?

1) Pollution Prevention – accelerate site closure by focusing on mitigating adverse effect to receptors that do or foreseeably will exist thereby reducing liability, and incenting investment

2) Reduce the overall environmental liability while providing the same level of protection as other applicable risk-based options.

3) Increase and accelerate the number of Sites progressing towards closure in northeastern British Columbia, thus returning sites to productive land use.

What's New in LPR Development Process?

1) Framework and rationale presented in September / October 2020.

2) Attenuation tool created that combines source depletion (adapted from BC Groundwater Protection Model, USEPA Bioscreen, USEPA RemFUEL & SourceDK models)

3) Model validation in progress; a) constrained source depletion based on NSZD estimates and b) plume length studies.

4) Harmonization with existing regulations and best practice further considered

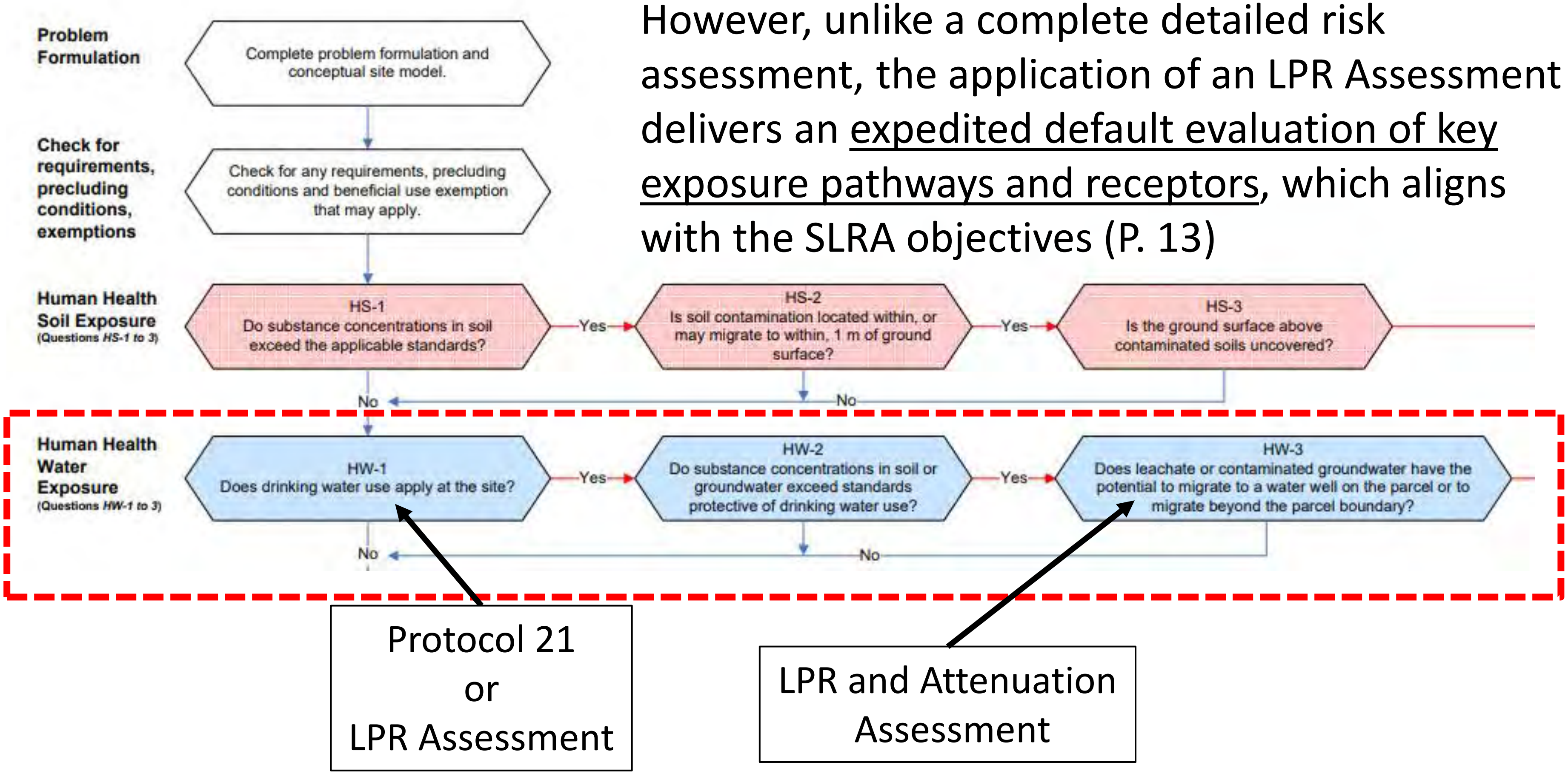
How does LPR fit into the BC Regulatory Framework?

- LPR concepts are consistent with the approaches used in detailed risk assessment.
- LPR aligns with a "*simple assessment of exposure pathways and receptors*", as defined in BC ENV Protocol 13 for Screening Level Risk Assessment (SLRA).
- Acceptance under a SLRA would increase the usability of the approach.
- Consistent with exclusion of vapour pathway for Wildlands Land use

Assess risk to human health and the environment based on the assessment of contaminant concentrations, potential exposure pathways and the presence of receptors (OGC 2020). If there are no unacceptable risks identified the Site is considered to satisfy the risk-based standards of the CSR and eligible for Certificate of Restoration (CoR).

LPR Assessment Methods
Screening Level Risk Assessment

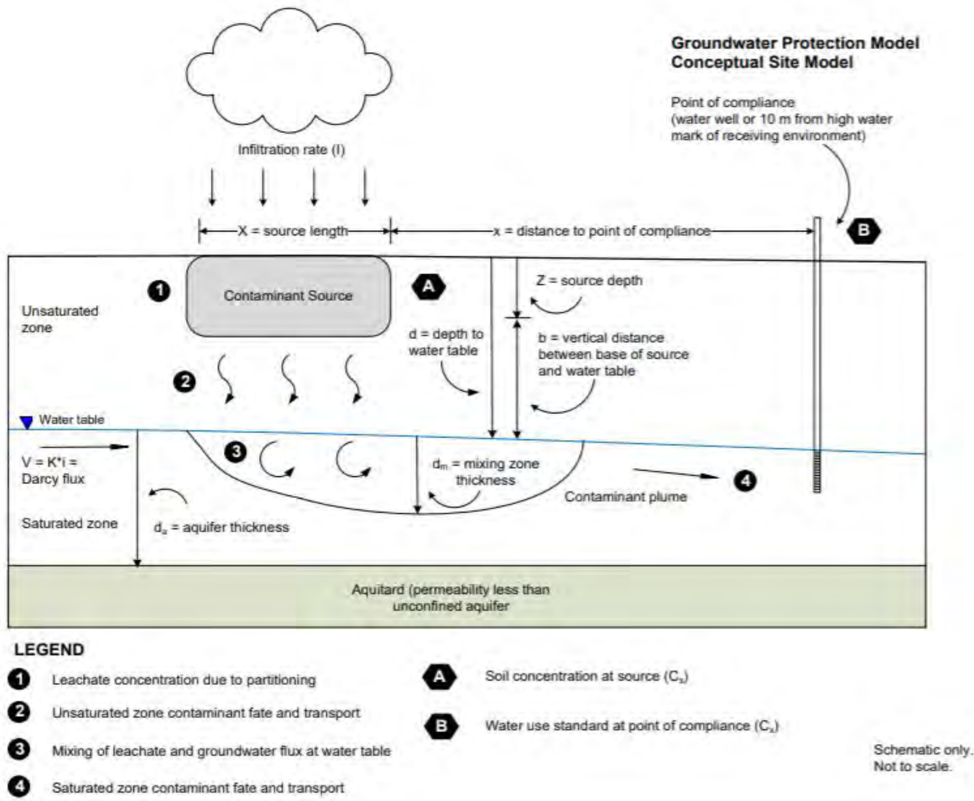
However, unlike a complete detailed risk assessment, the application of an LPR Assessment delivers an <u>expedited default evaluation of key exposure pathways and receptors</u>, which aligns with the SLRA objectives (P. 13)



BC ENV SLRA

BC Groundwater Protection Model

- Proposed modifications:
- If there is an LPR, allow offsite point of compliance, with institutional control (SLRA point of compliance is property boundary, or at receptor if on site)
- Include source depletion in GPM



How does LPR Assessment work?

Two components to the LPR Assessment:

1. Attenuation Model: estimate the maximum time to which impacts will be present within a given area based on conservative assumptions related to contaminant distribution, source depletion & degradation rates (summary follows, details in Technical Module).

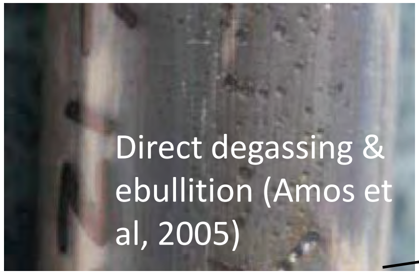
2. Probability Model: estimate the probability of future applicable receptor occurrence based on compiled receptor data. Open-source databases (*i.e.,* water well registry, dugout maps, etc.) are used to derive the rate of change of receptor occurrence over time for local areas.

Therefore, the probability of receptor occurrence is function of both Time and Area.

Natural Attenuation & Source Zone Depletion Processes

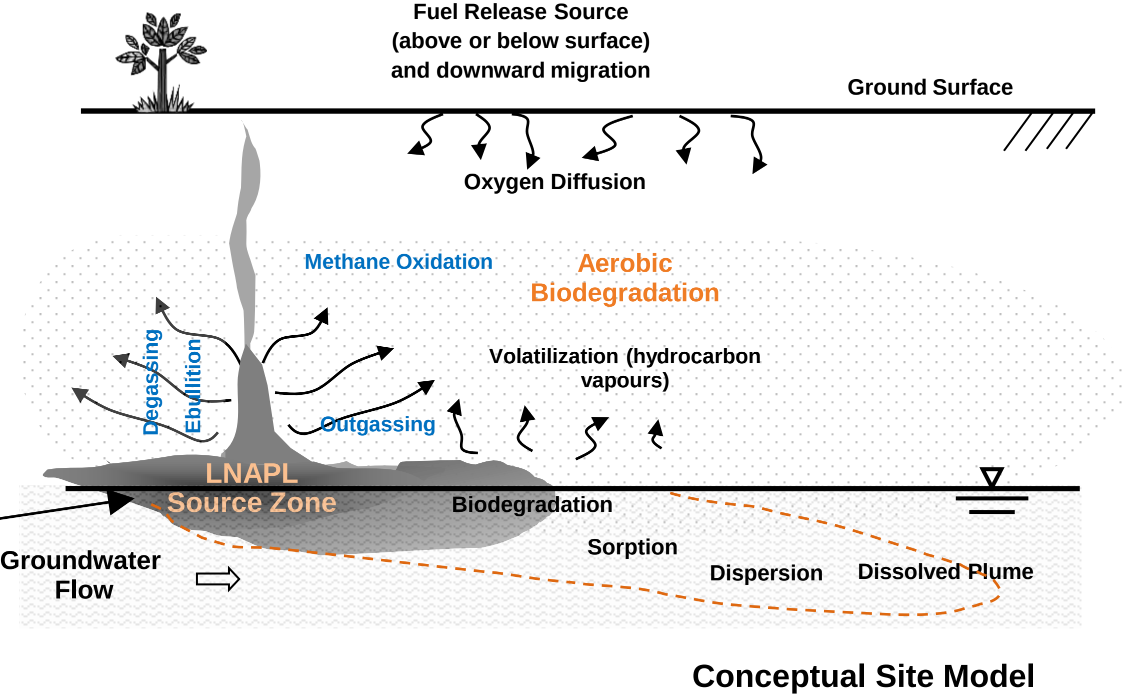
FROM CSAP/SHELL REMEDIATION TOOLKIT #1

Vadose zone rates typically one to two orders of magnitude greater than saturated zone processes



Direct degassing & ebullition (Amos et al, 2005)

Consider dissolved CH_4 analysis (Isoflask)



Photograph from ITRC LNAPL Guidance (2018)

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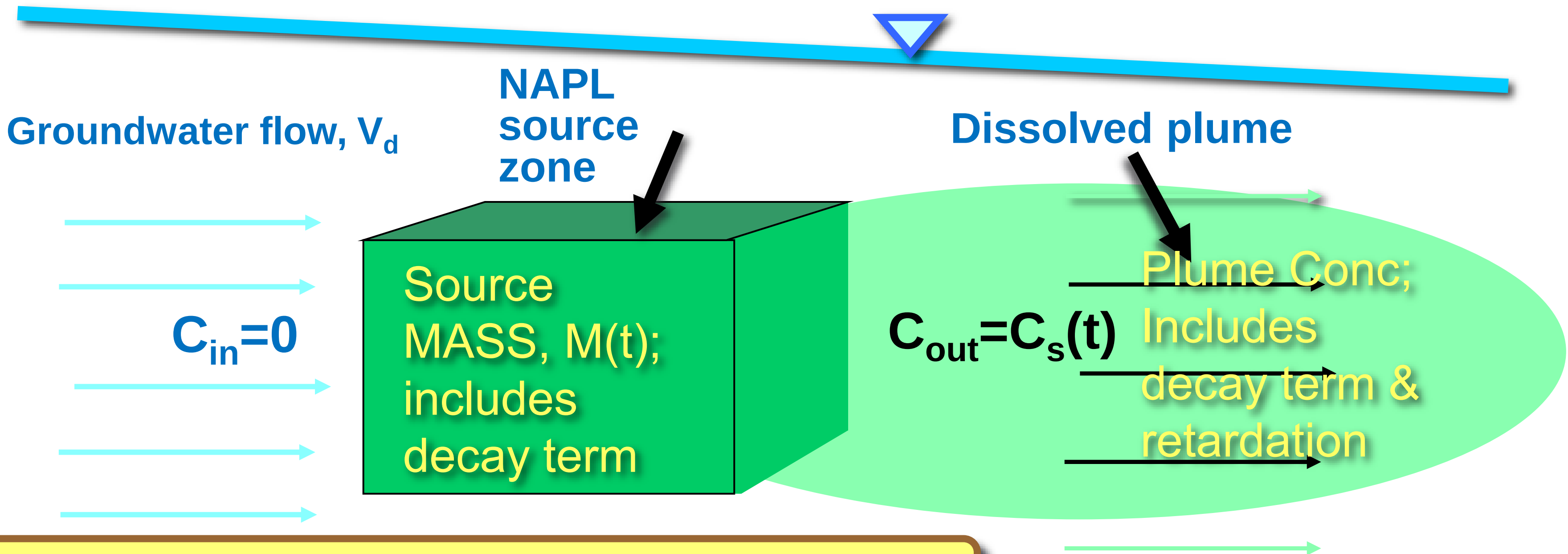
Attenuation Model – Combines Source Depletion & Plume Migration



$$\frac{dM}{dt} = -Q(t)C_s(t) - \lambda_s M \qquad \frac{C_s(t)}{C_0} = \left(\frac{M(t)}{M_0}\right)^{\Gamma}$$

Dissolved concentration (Cs) depends on mass remaining in source zone (M)

$$R\frac{\partial C_i}{\partial t} = -v\frac{\partial C_i}{\partial x} + \alpha_x v\frac{\partial^2 C_i}{\partial x^2} + \alpha_y v\frac{\partial^2 C_i}{\partial y^2} + \alpha_z v\frac{\partial^2 C_i}{\partial z^2} + rxn_i$$

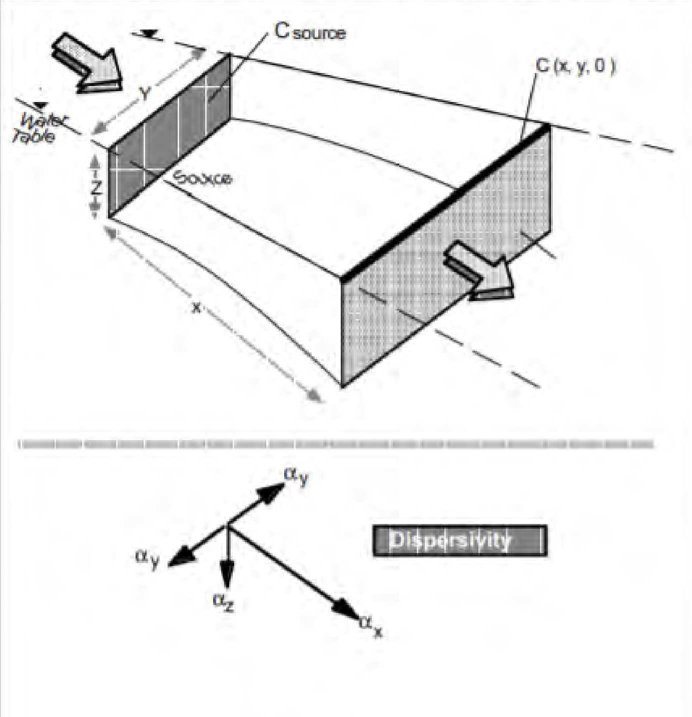
Plume migration estimated using Domenico analytical solution

Adapted from US EPA Bioscreen, US EPA RemFUEL and GSI SourceDK Models

Saturated Groundwater Solute Transport Model

Domenico Transient Model with First Order Plume Decay and Source Attenuation

Domenico Model with First Order Decay Algorithm



$$C(x,y,o,t) = \text{SDM} \times \frac{1}{8}\exp\left[\frac{x}{\alpha_x 2}\left(1-\left(1+4\lambda\alpha_x/v\right)^{1/2}\right)\right] \operatorname{erfc}\left[\frac{\left(x-vt\left(1+4\lambda\alpha_x/v\right)^{1/2}\right)}{2(\alpha_x vt)^{1/2}}\right] \left\{\operatorname{erf}\left[\frac{(y+Y/2)}{2(\alpha_y x)^{1/2}}\right]-\operatorname{erf}\left[\frac{(y-Y/2)}{2(\alpha_y x)^{1/2}}\right]\right\} \left\{\operatorname{erf}\left[\frac{(Z)}{2(\alpha_z x)^{1/2}}\right]-\operatorname{erf}\left[\frac{(-Z)}{2(\alpha_z x)^{1/2}}\right]\right\}$$

where: $v = \frac{K \cdot i}{\theta_e R}$

SDM = Source depletion module

Adapted from BioScreen

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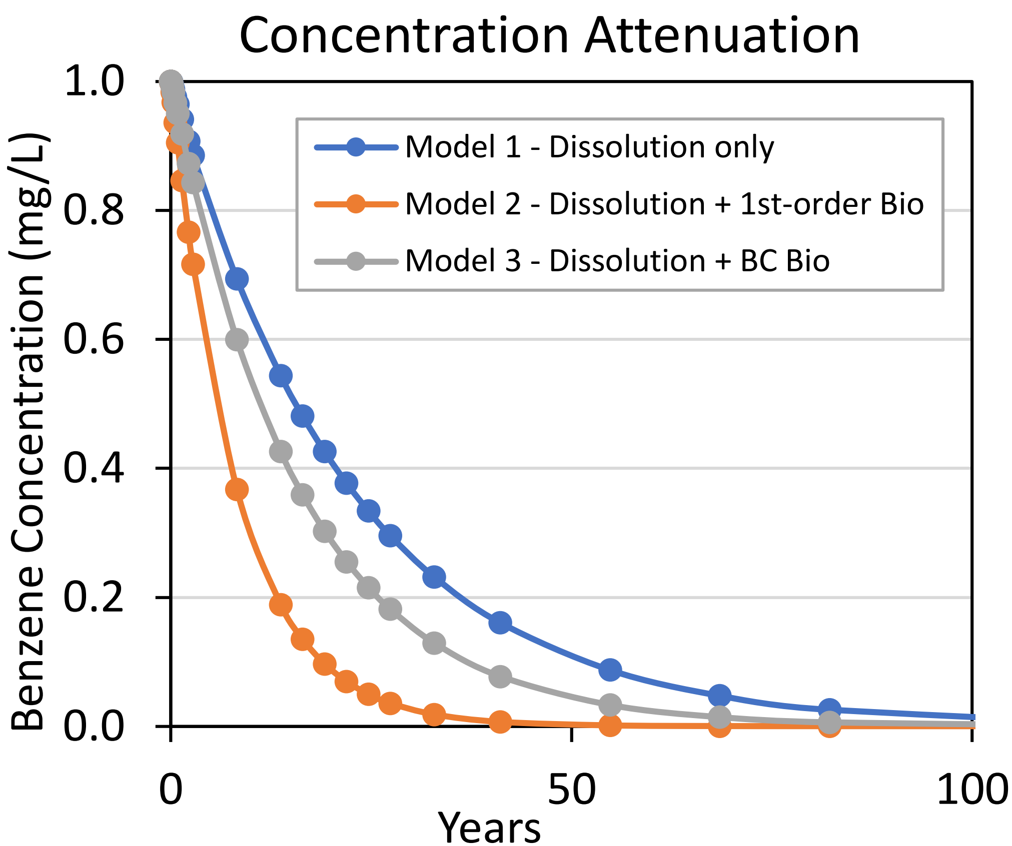
MEMS Attenuation Tool

- US EPA Bioscreen Model + Source Depletion Model (SDM)
- Saturated transport and input parameters <u>same as the BC Groundwater Protection Model (GPM)</u>
- Intended for organic and inorganic substances
- SDM added as supported by recent science
  - Sub-Model 1 (Dissolution only) coding complete
  - Sub-Models 2 and 3 (+Biodegradation for organics) under consideration

Preliminary Results – Source Depletion



Gamma (Γ) = 1 (mass discharge, see RemFUEL)
1st-order biodegradation rate(λ) = 0.01 day^{-1} (Model 2)
Biodegradation Capacity (BC) = 40 mg/L (Model 3)
Biodegradation Factor (mole fraction) (BF) = 0.01 (Model 3)

MEMS Attenuation Tool

Adapts USEPA Bioscreen and USEPA RemFUEL models and adds source depletion (complex math not shown)*

Overview

Model used to simulate source benzene depletion for moderate size release, BC GPM defaults, C_{GW} = 1 mg/L; C_{soil} = 10 mg/kg,

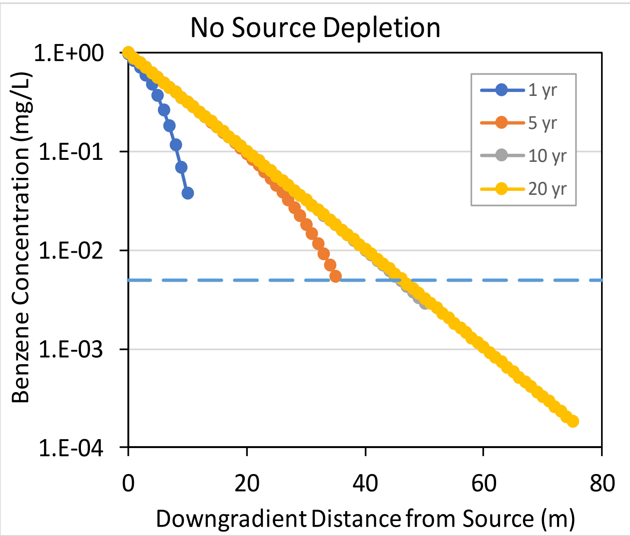
Key Result

Fastest source depletion for Model 2 as it includes biodegradation

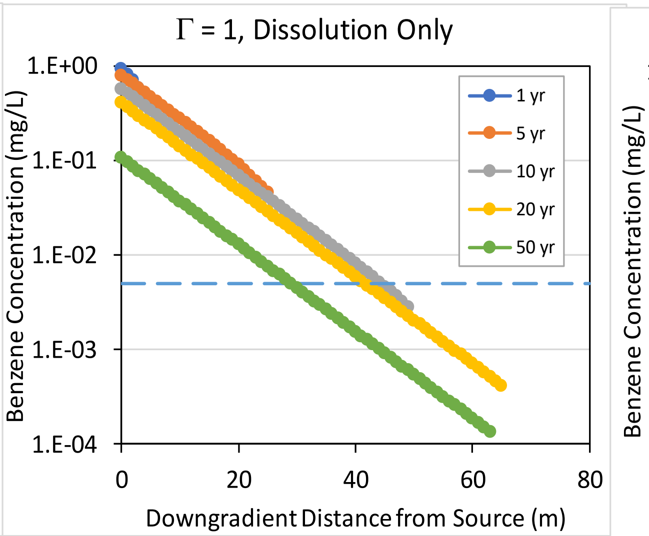
*Default values included in Technical Supplemental Presentation

Preliminary Results – Plume Migration

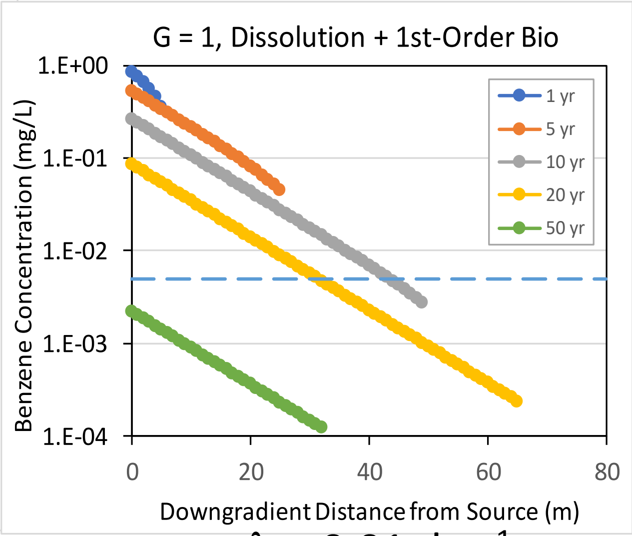
No Depletion (Γ=1)



Model 1 (Γ=1)



Model 2 (Γ=1)



λ = 0.01 day^{-1}

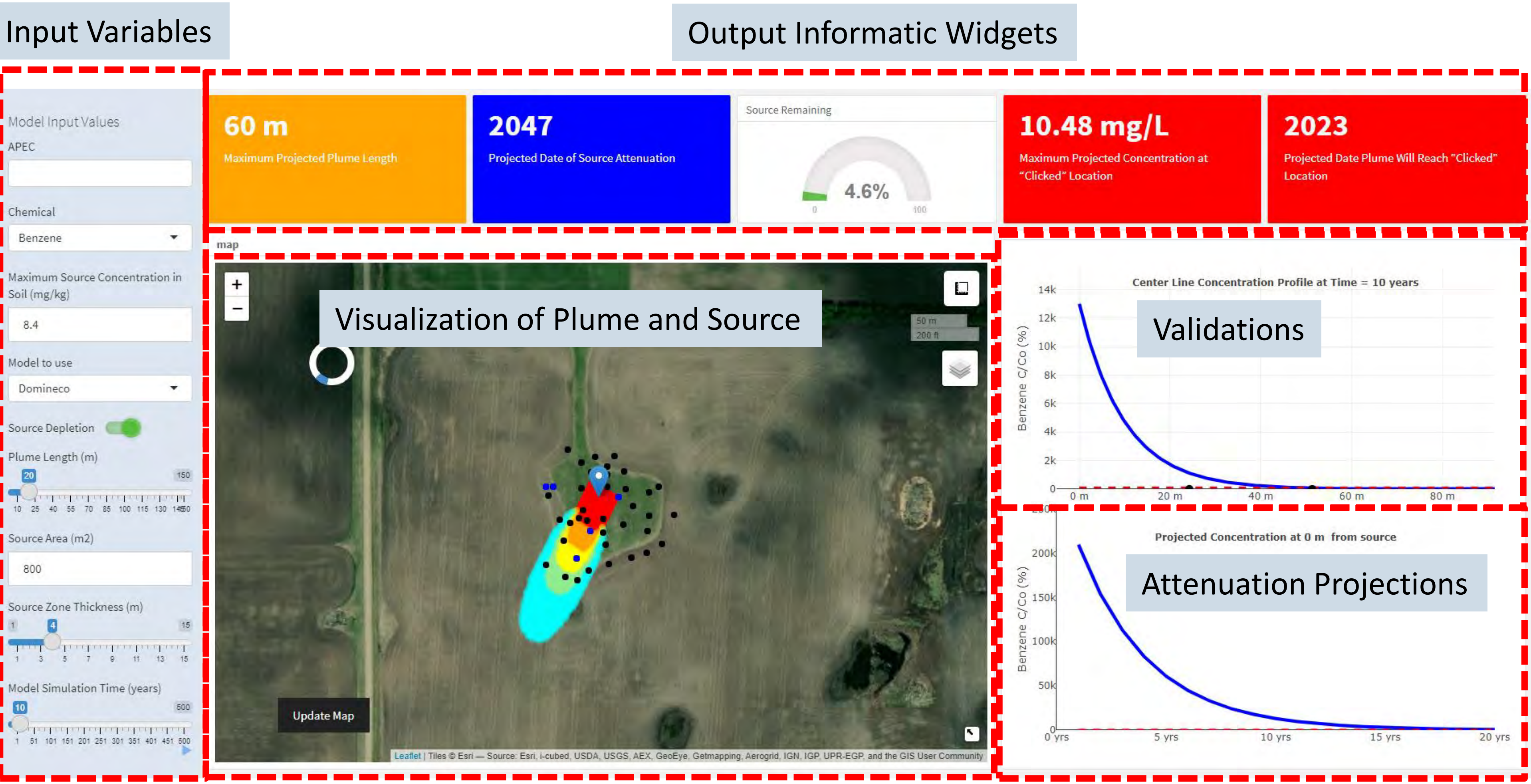
Plume never attenuates

Plume eventually attenuates

Plume attenuates to < Std in < 50 yr

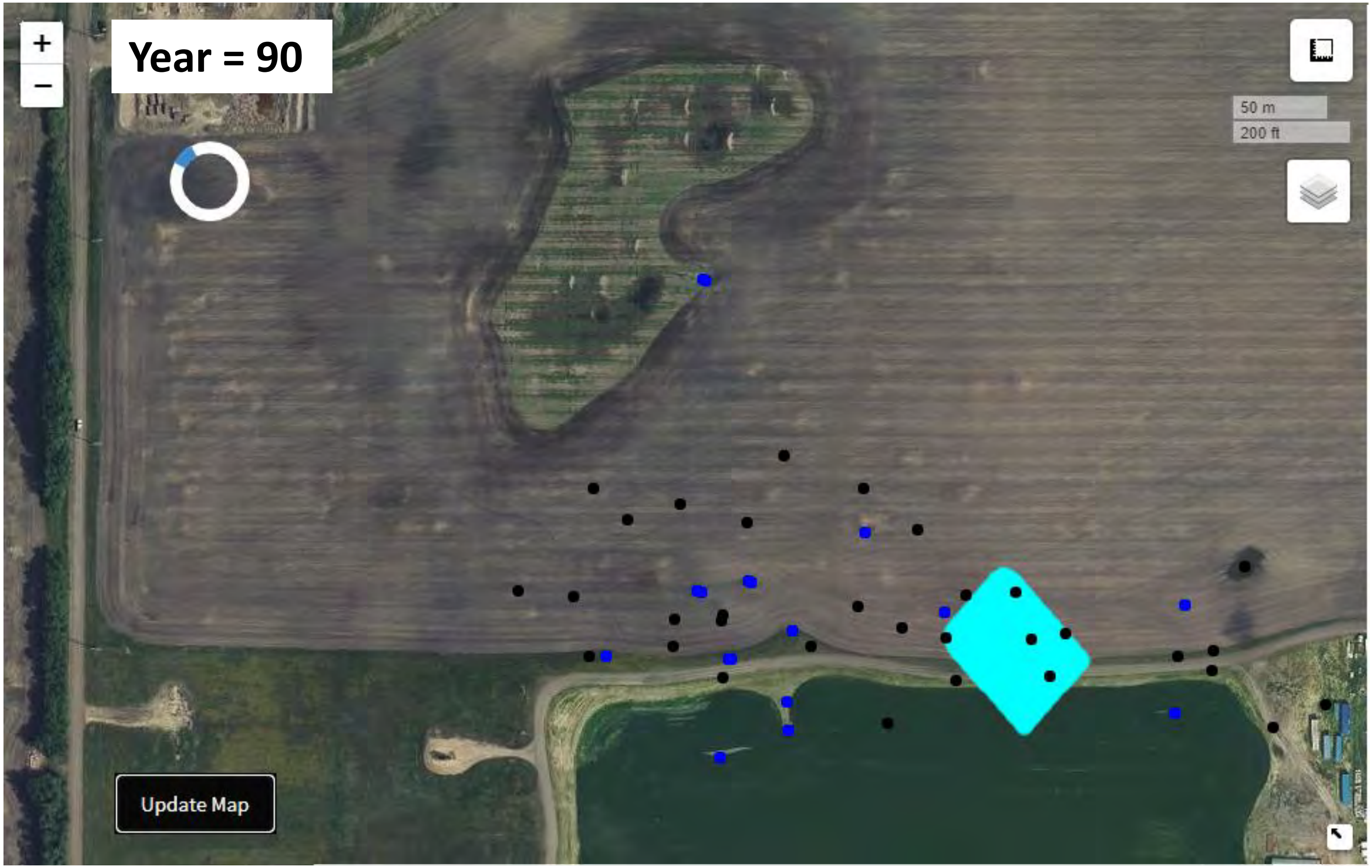
Plume migrates just over 40 m from source (relative to DW std = 0.005 mg/L)

MEMS Attenuation Tool



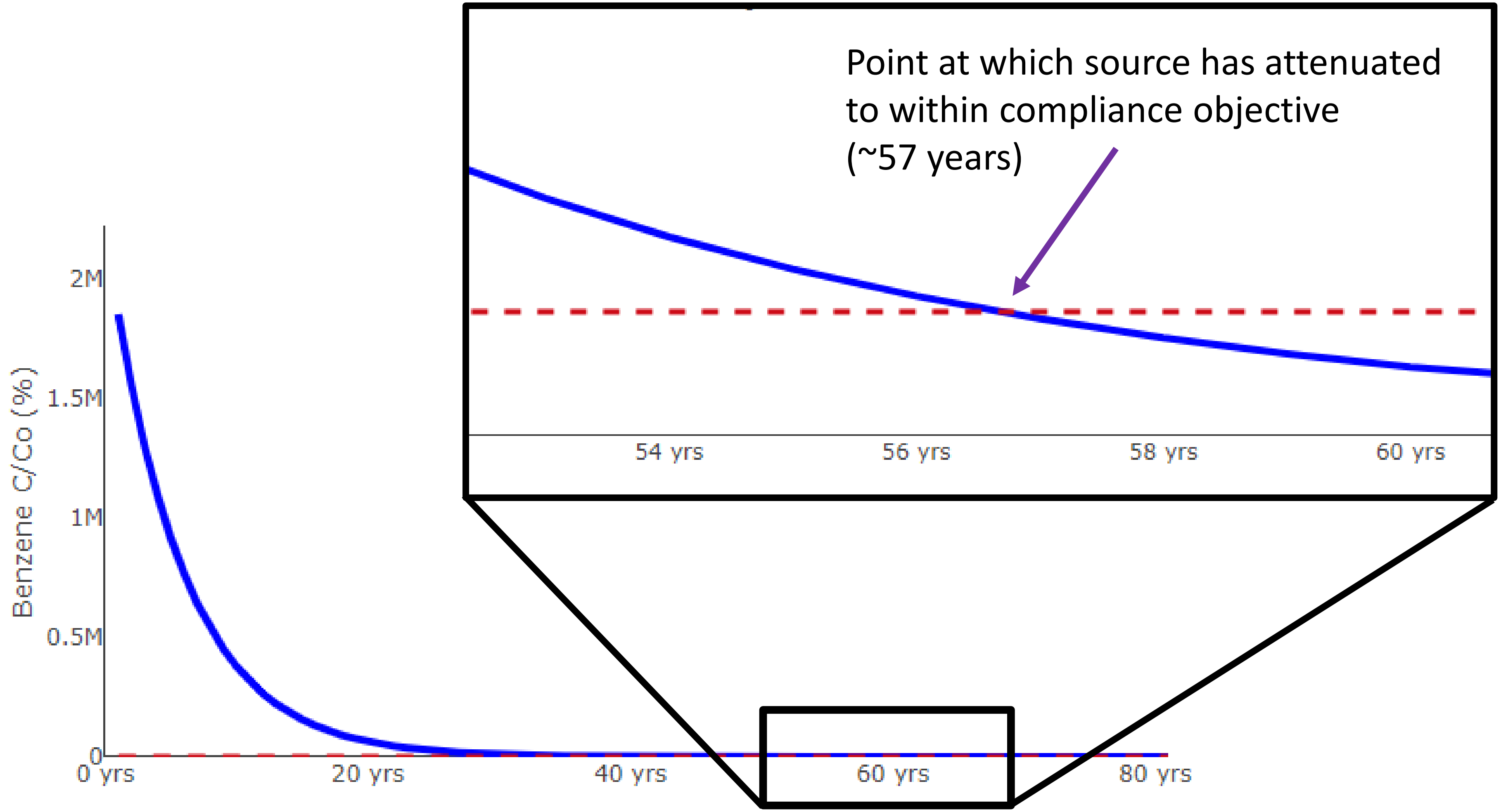
MEMS Attenuation Tool Outputs

Plume Migration / Attenuation



MEMS Attenuation Tool Outputs

Projected Source Attenuation



Model Validation – Source Depletion

Tier 1: Use Literature NSZD Rates

CSAP-Shell Remediation Toolkits (2016) (N = 17) Typical Site average rates = **500-1500** US gal/ac/yr	**Garg et al. 2017** (N=25) 25^{th},50^{th},75^{th} percentiles = **700, 1100, 2800** USgal/ac/yr	**CRC Care 47 2020** (N = 6) Site average rates = **240-9,500** US gal/ac/yr

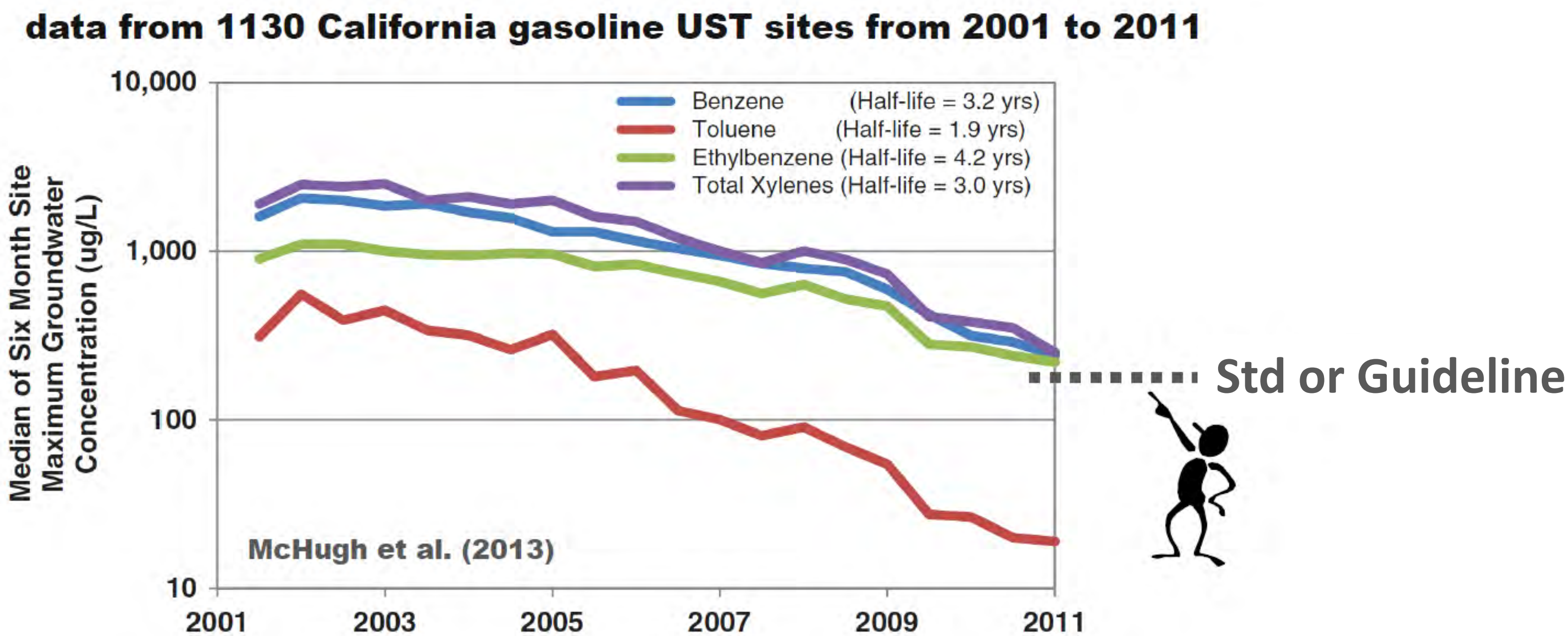
For Sub-model 2 is used, the model will include a mass balance check based on literature NSZD rates (see Technical Appendix)

Tier 2: Measure NSZD Rates

1. CO_2 efflux method
2. Soil gas gradient method
3. Thermal gradient method

Wozney, Hers et al. 202? IOCO site method paper accepted by GWMR
New ASTM Standard being developed

Model Validation – Big Data Analysis Shows Source Attenuation



- Empirical plume length studies also show relatively short BTEX plume lengths, e.g., benzene median plume length = 55 m (O'Conner 2015)
- Available Canadian cold climate data will be summarized

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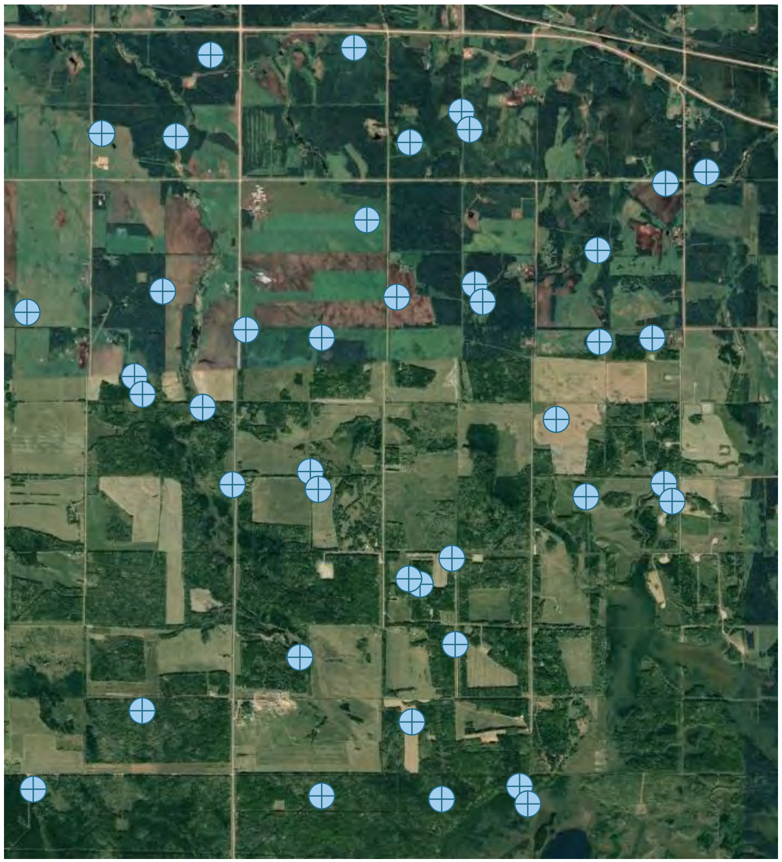
How does LPR Assessment work?

2. Probability Model

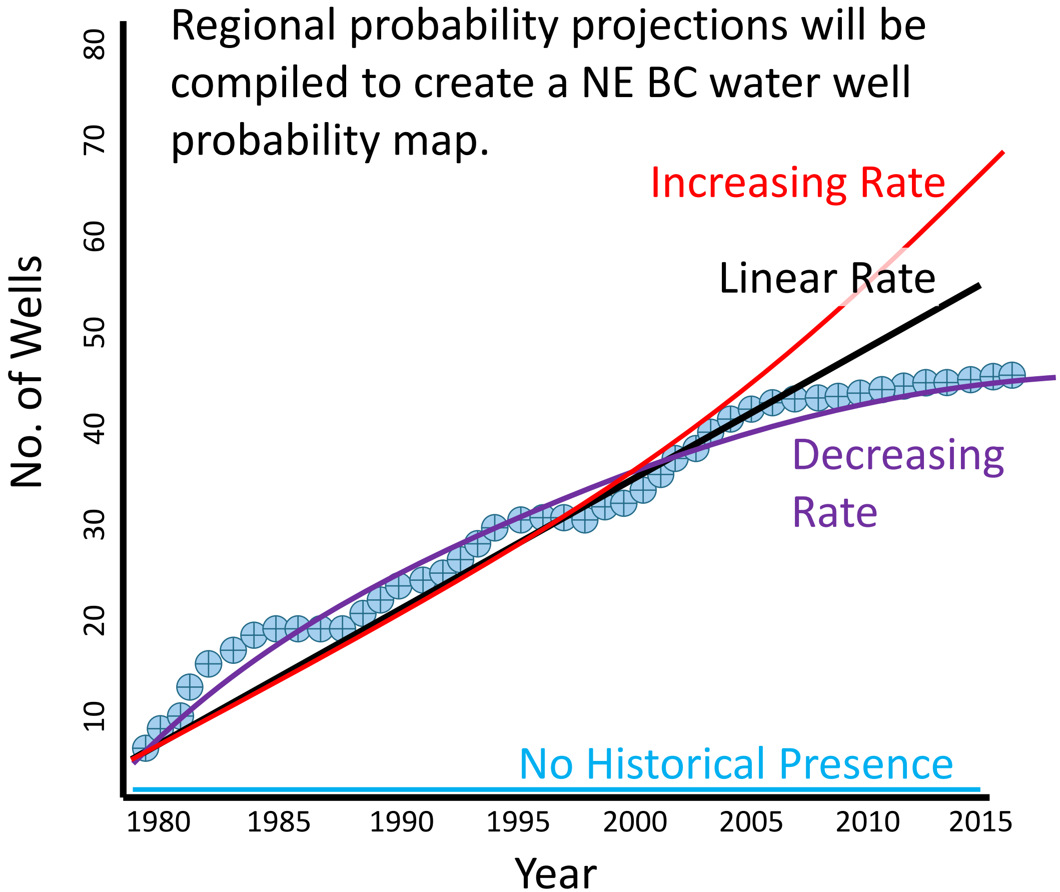
Probability maps are generated for the Province for multiple receptors based on the number of recorded receptor occurrences over time. Open-source databases (*i.e.,* water well registry, dugout maps, etc.) are used to derive the rate of change of receptor occurrence over time for localized areas.

Therefore, the probability of receptor occurrence is function of both Time and Area.

How does LPR Assessment work?
Probability Model

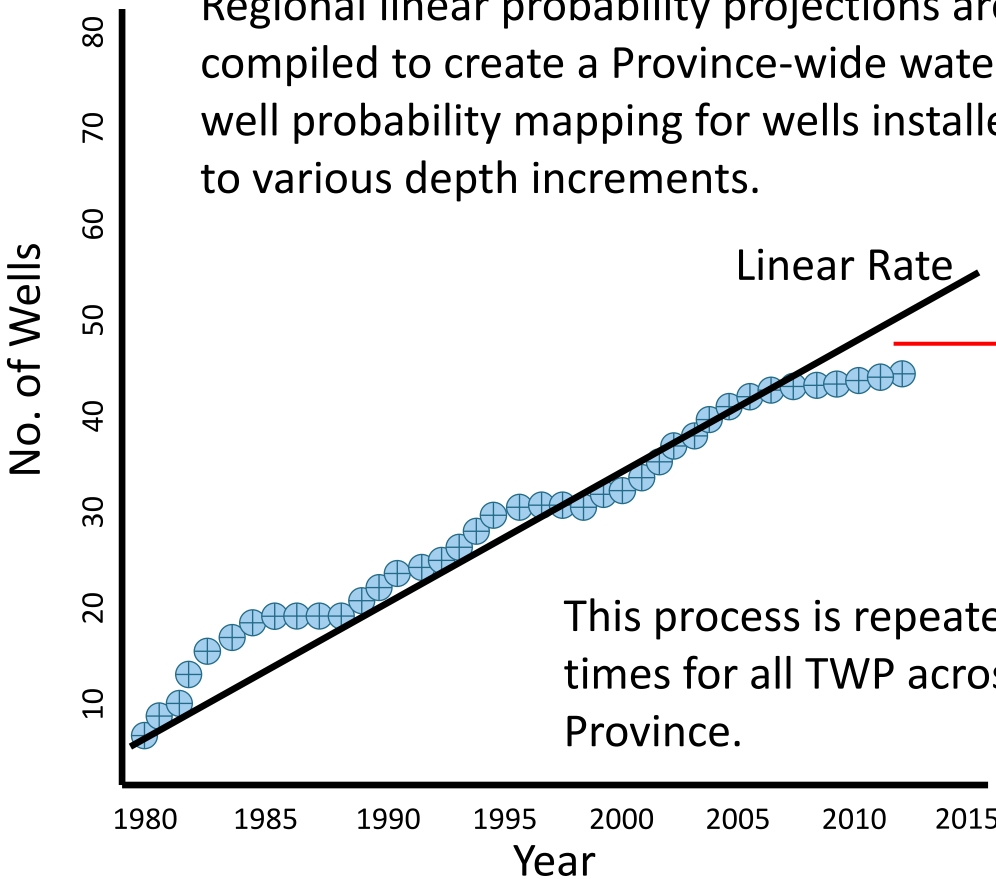


Regional probability projections will be compiled to create a NE BC water well probability map.

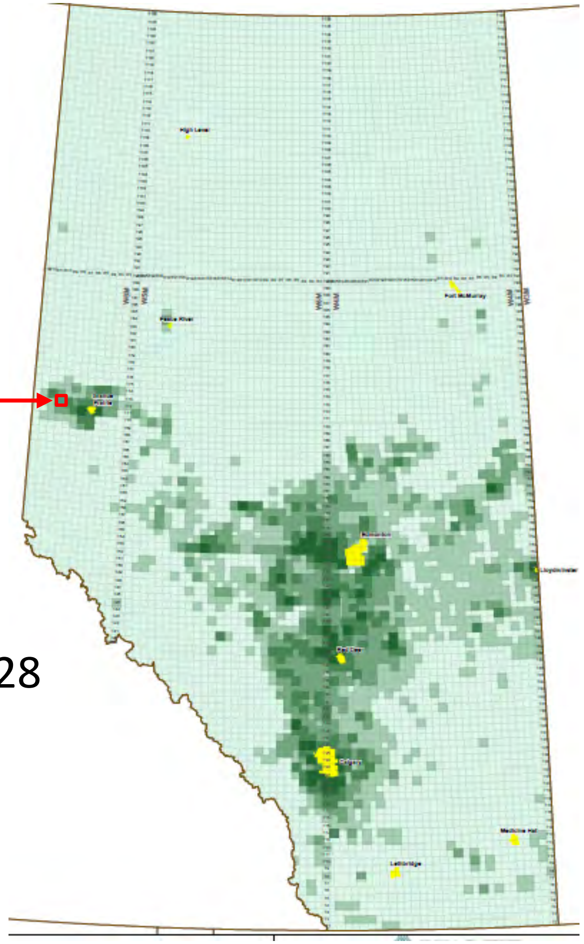


How does LPR Assessment work?
Probability Model

Regional linear probability projections are compiled to create a Province-wide water well probability mapping for wells installed to various depth increments.

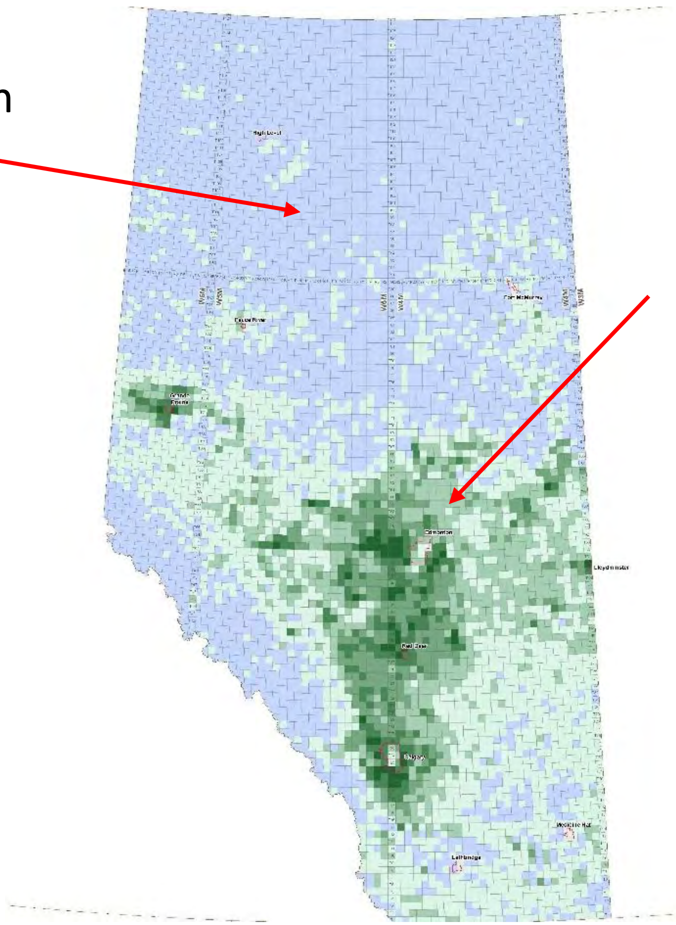


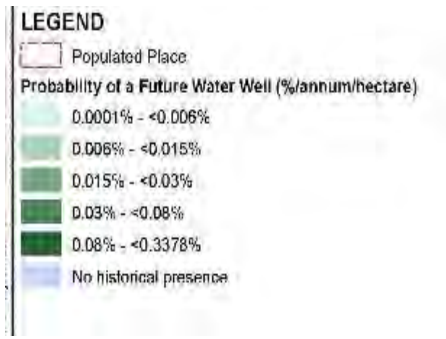
This process is repeated 7,128 times for all TWP across the Province.



Probability Mapping

Regions of the province with
<u>"no historic presence"</u>
of the water wells



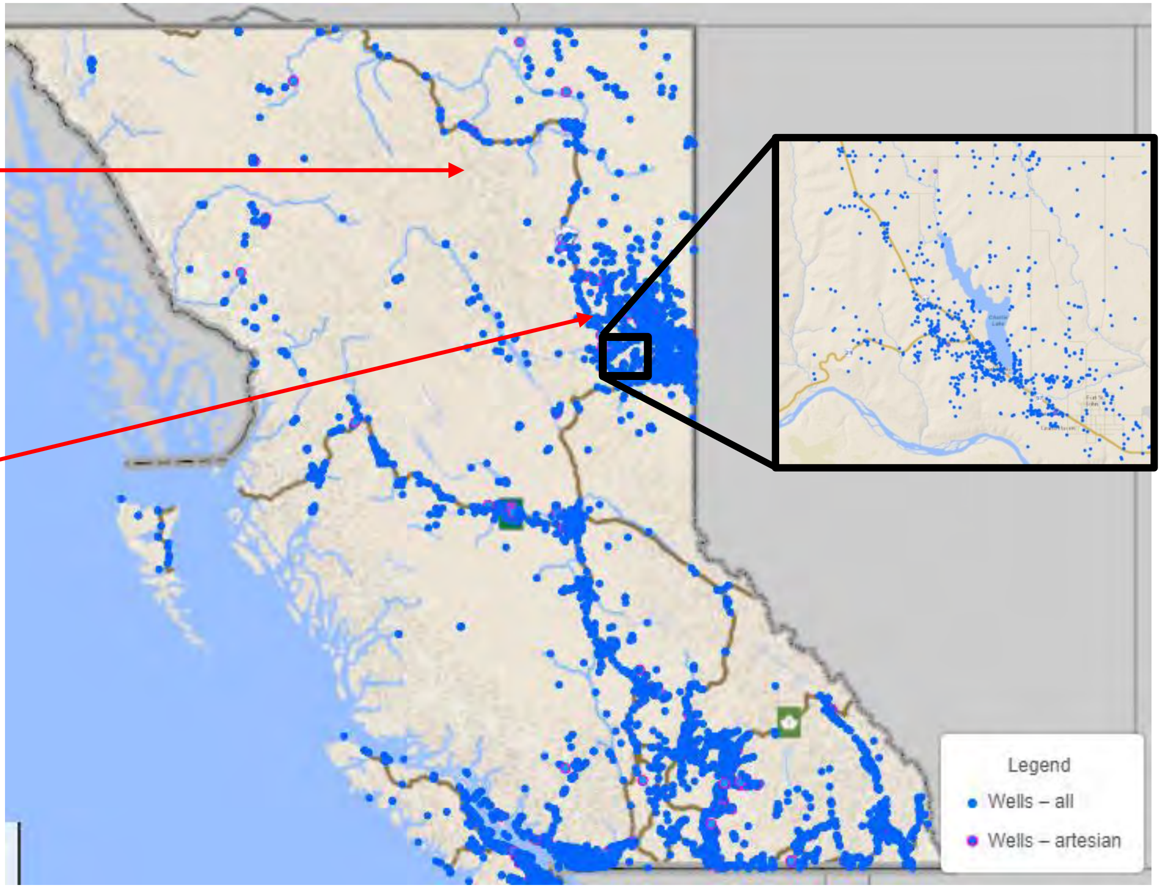


Regions of the province with <u>"historic presence"</u> of the water wells. Used to create probability map

Probability Mapping - BC

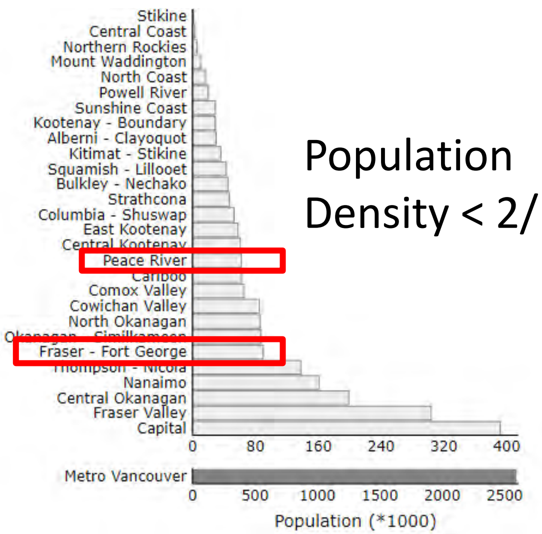
Regions of the province with
<u>"no historic presence"</u>
of the water wells

Regions of the province with
<u>"historic presence"</u> of the water wells. Used to create probability
Map for BC

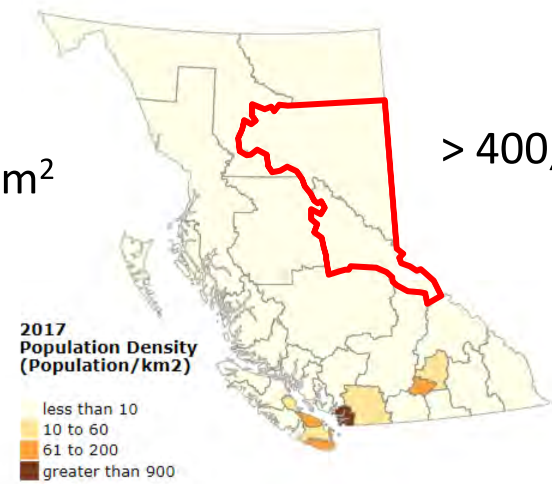


LPR Assessment Probability vs. Density Maps

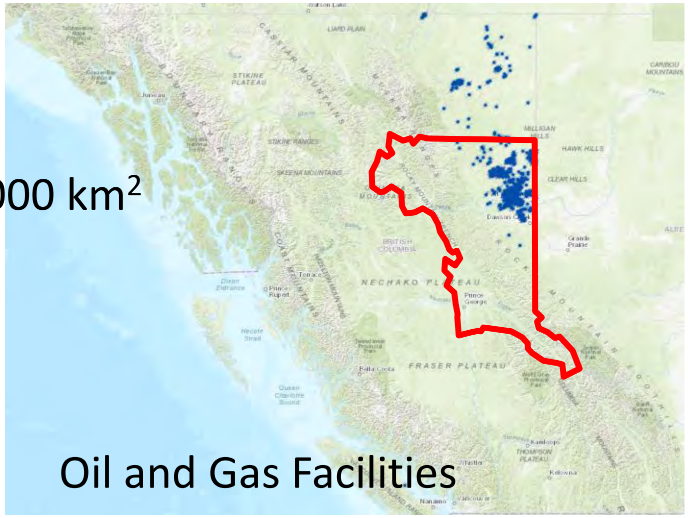
- *Majority of oil & gas site in NE BC are **Remote**, where human inhabitation is unlikely after abandonment.*



Population Density < 2/km^2

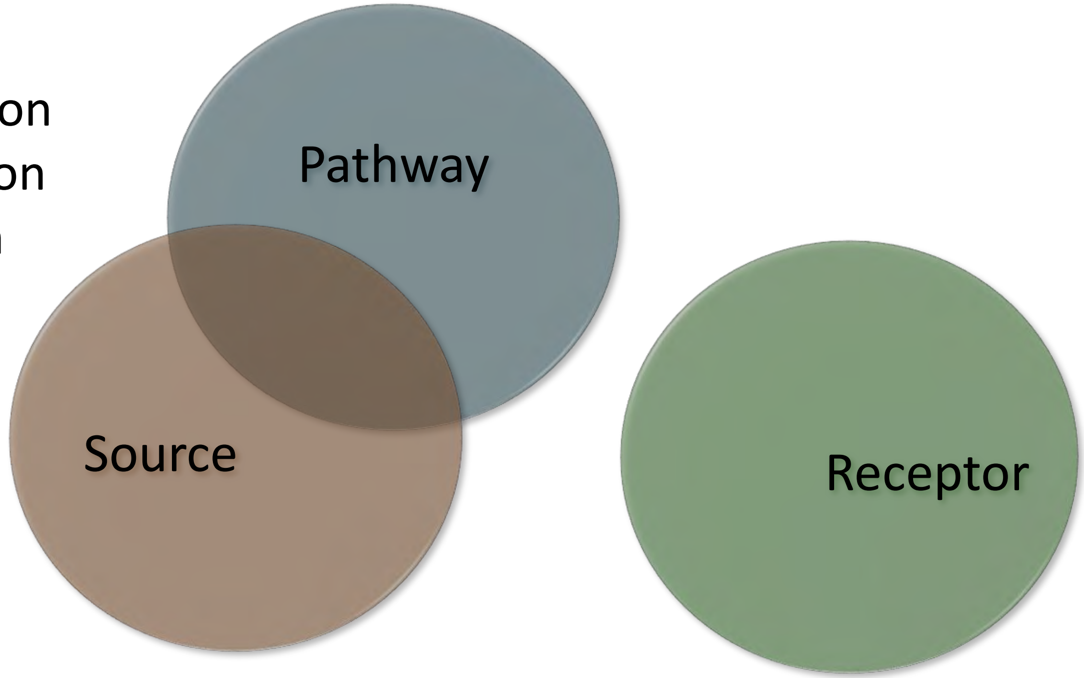


> 400,000 km^2



Low Probability Receptor Assessment

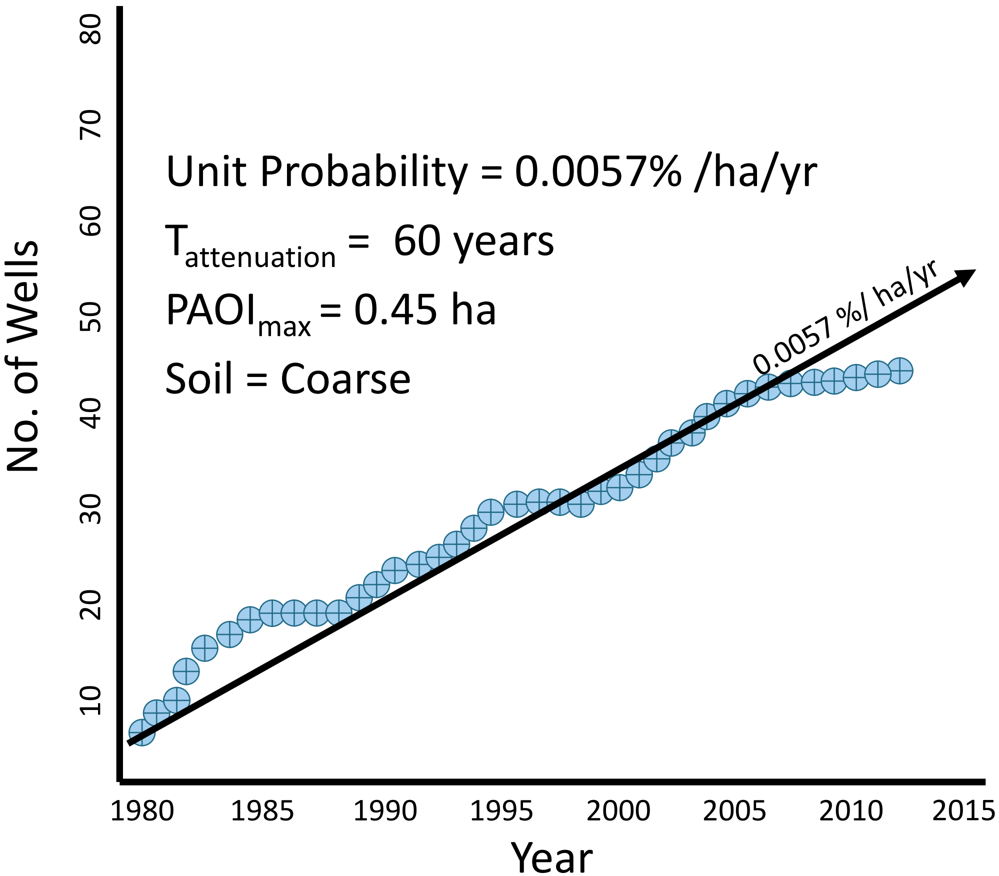
Put together the Probability of Receptor occurrence with the temporal consideration of the plume migration and source depletion

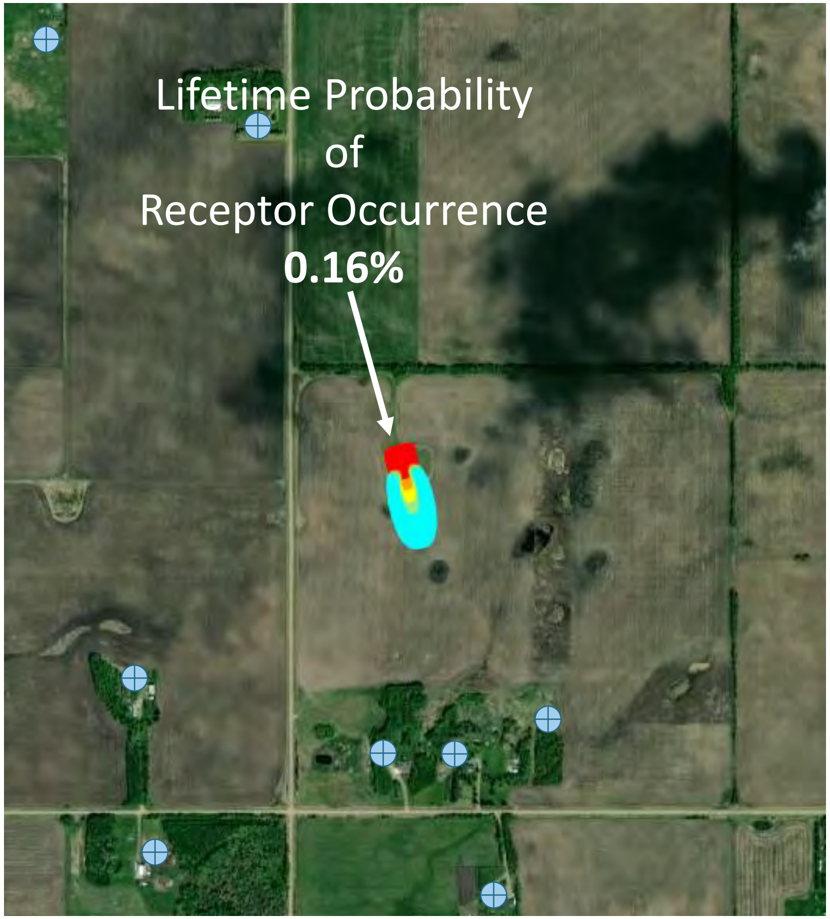


No risk if plume / source attenuates prior to receptor occurrence.

LPR Assessment Example

Lifetime Probability of Receptor Occurrence





Sustainable Remediation

"More remediation" is not always better

In absence of an adverse effect to human or ecological receptors remediation does not "protect" better and on balance has negative consequences

As part of pilot project, a sustainability evaluation is proposed that includes evaluation of

- Environmental, social and economic indicators
- GHG emissions and other impacts
- Multicriteria analysis (MCA), cost benefit analysis (CBA) or other tools

Recently published CSAP/Shell Toolkits has guidance on conducting sustainability assessments https://csapsociety.bc.ca/csap-toolkits/

Proposed BC Implementation Process – High Level

Develop sustainable and harmonized approach consistent with BC regulatory framework and OGC mission for responsible energy development, protection of public safety, and respect of communities and individuals

- Develop regulatory/stakeholder engagement framework (2022):
  1) Is OGC, in concept, supportive of the LPR approach and progressing project toward trial and implementation phase?
  2) How can we create conditions for success (e.g., panel, workshop?)
- Complete detailed technical studies, conduct pilot (demonstration) project (4-6 case study sites) and assess sustainability of approach (2022-2023)
- Present findings to OGC and refine approach as warranted (2023)
- Prepare implementation guidance (2023)

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Proposed BC Implementation Process - Details

1. Technical Approach
    1. Determine receptors to be considered in LPR approach
    2. Conduct regional probability mapping
    3. Complete development of site-specific attenuation tool – BC GPM saturated transport model + source depletion
    4. Define what represents a LPR, i.e., acceptable probability, and the maximum allowable plume transport distance
    5. Adapt ENV SLRA approach to include LPR (refine point of compliance, add source depletion, identify required source characterization)
    6. Include institutional controls as required (already part of SLRA)
    7. Incorporate sustainability assessment in framework; e.g., environmental, social and environmental indicators and MCA / CBA analysis

Proposed BC Implementation Process – Details (cont.)

2. Conduct pilot demonstration project – does OGC have sites they would like included?
3. Prepare technical report and implementation guidance

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Discussion and Questions

Low Probability Receptor (LPR) Tool

Technical Module

Millennium EMS Solutions

JANUARY 14, 2022

Presentation Outline

- Attenuation Model
  - Models used
  - Assumptions
  - Attenuation Tool Outputs
  - Validation
- Probability Mapping
  - Data sources
  - Receptor occurrence projections
  - Assumptions
- LPR Output

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How does LPR Assessment work?

Two components to the LPR Tool:

1. Attenuation Model: estimates the maximum time to which impacts will be present within a given area based on conservative assumptions related to contaminant distribution, source depletion & degradation rates.

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Therefore, the probability of receptor occurrence is function of both Time and Area.

Millennium Attenuation Tool

Purpose:

- Used to estimate groundwater concentrations at and down-gradient of a source that includes a source depletion term.

Models:

1. Saturated Groundwater Solute Transport Model
2. Four Compartment Transport (Unsat/Sat) Model

Basic Requirements:

- Hydrogeology data
- Source contamination data (dimensions, concentrations)
- Biodegradation rates, for plume and source, source rates are constrained by literature or measured NSZD rates

Millennium Attenuation Tool

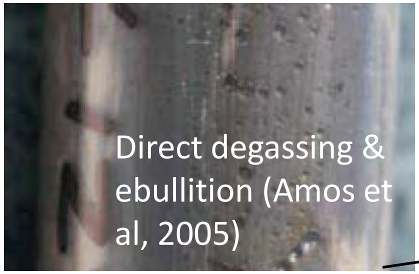
Basis:

- BC GPM (BC ENV Technical Guidance 13, 24, 28)
- US EPA Bioscreen Model
- US EPA RemFUEL Model
- US Air Force Civil Engineering Center (AFCEC) SourceDK Model
- CSAP/Shell BC Remediation Toolkits
- Research on Natural attenuation and Natural Source Zone Depletion (NSZD), e.g., BC Toolkits, USEPA, API, peer reviewed publications

Natural Attenuation & Source Zone Depletion Processes

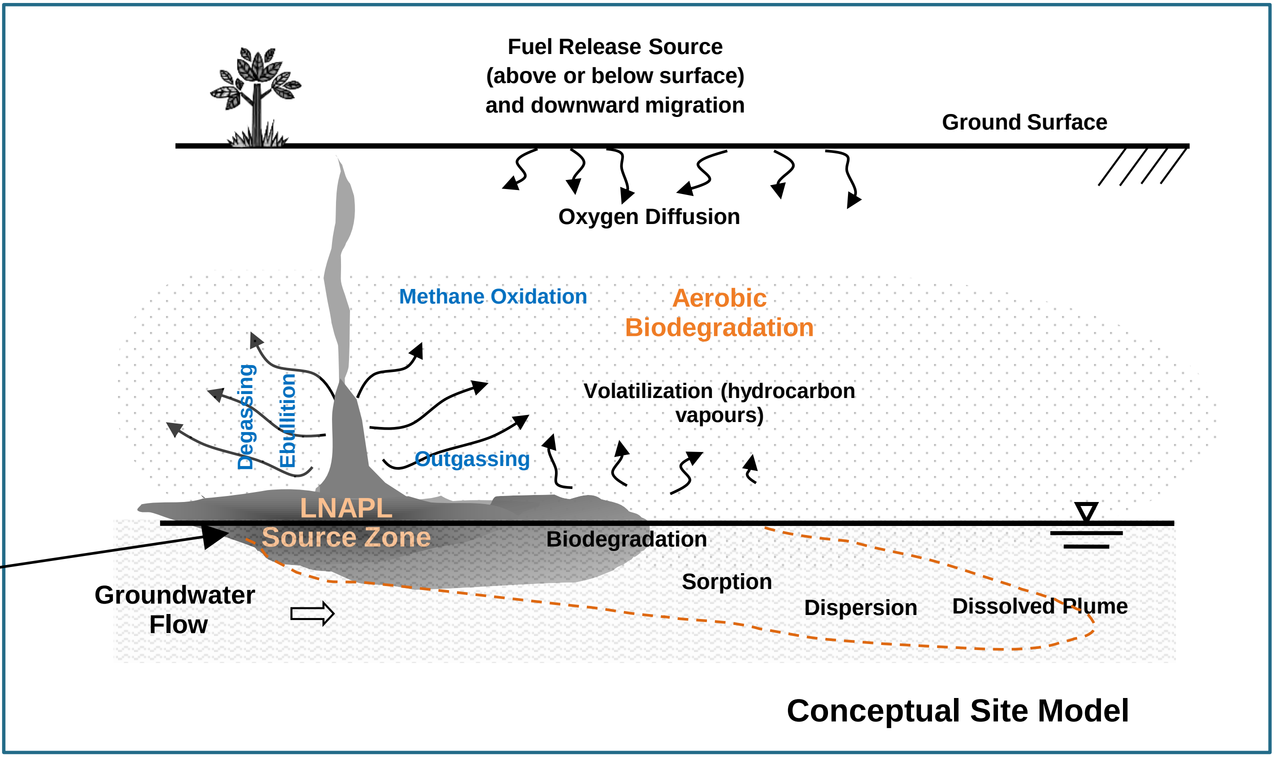
FROM CSAP/SHELL REMEDIATION TOOLKIT #1

Vadose zone rates typically one to two orders of magnitude greater than saturated zone processes



Direct degassing & ebullition (Amos et al, 2005)

Consider dissolved CH_4 analysis (Isoflask)



Photograph from ITRC LNAPL Guidance (2018)

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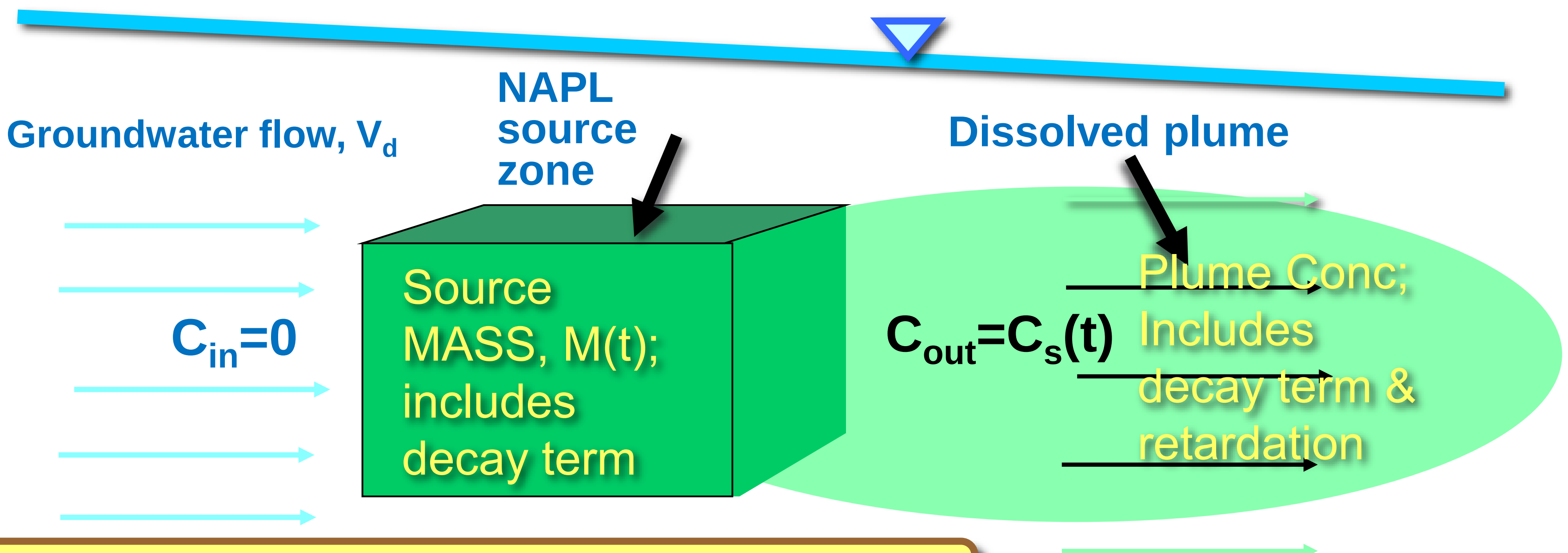
MEMS Attenuation Tool – Saturated Transport

- US EPA Bioscreen Model + Source Depletion Model (SDM)
- Saturated transport and input parameters same as the BC Groundwater Protection Model (GPM)
- Intended for organic and inorganic substances
- SDM added as supported by recent science
  - Sub-Model 1 (Dissolution only) coding complete
  - Sub-Models 2 and 3 (+Biodegradation for organics) under consideration

Attenuation Model – Combines Source Depletion & Plume Migration



$$\frac{dM}{dt} = -Q(t)C_s(t) - \lambda_s M \qquad \frac{C_s(t)}{C_0} = \left(\frac{M(t)}{M_0}\right)^{\Gamma}$$

Dissolved concentration (Cs) depends on mass remaining in source zone (M)

$$R\frac{\partial C_i}{\partial t} = -v\frac{\partial C_i}{\partial x} + \alpha_x v\frac{\partial^2 C_i}{\partial x^2} + \alpha_y v\frac{\partial^2 C_i}{\partial y^2} + \alpha_z v\frac{\partial^2 C_i}{\partial z^2} + rxn_i$$

Plume migration estimated using Domenico analytical solution

Adapted from US EPA Bioscreen, US EPA RemFUEL and GSI SourceDK Models

Saturated Zone Decay Algorithms General Form of Equations

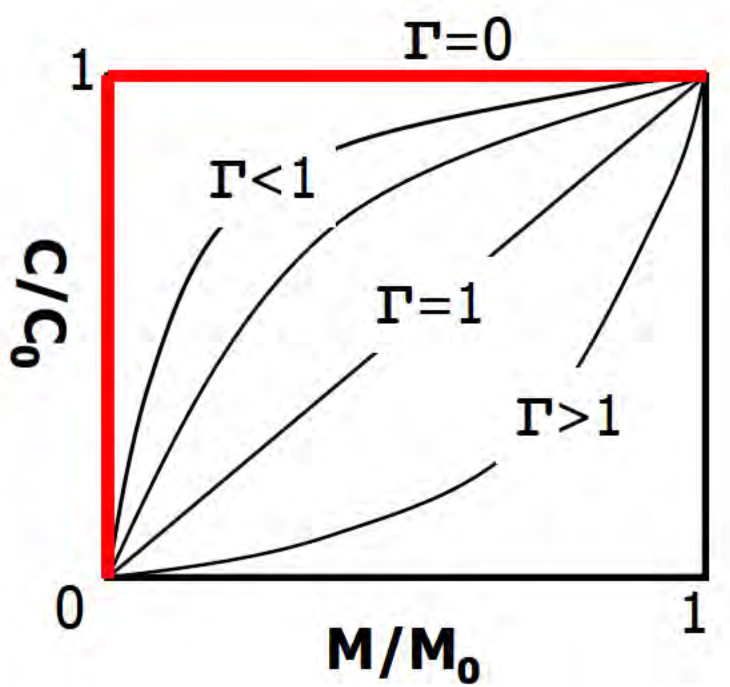
$$C_s = \frac{C_0}{M_0^{\Gamma}} \left\{ \frac{(\Gamma - 1)(Q + \phi \forall \lambda_s) C_0}{M_0^{\Gamma}} t^* + M_0^{1-\Gamma} \right\}^{\frac{\Gamma}{1-\Gamma}}$$

$$M = \left\{ \frac{(\Gamma - 1)(Q + \phi \forall \lambda_s) C_0}{M_0^{\Gamma}} t^* + M_0^{1-\Gamma} \right\}^{\frac{\Gamma}{1-\Gamma}}$$

$$t^* = t - x/v$$

	Description	Unit
Cs	GW Concentration	mg/L
Co	Initial GW Conc.	mg/L
M	Soluble mass	mg
Mo	Initial soluble mass	mg
Γ	Gamma	-
λs	Source decay term	1/day
ϕ	Porosity	-
Q	Flow rate	L/day
$\forall$	Volume source zone	L
x	Distance along flow path	m
v	GW velocity	m/day

Mass vs Concentration Discharge Relationship in Source Zone

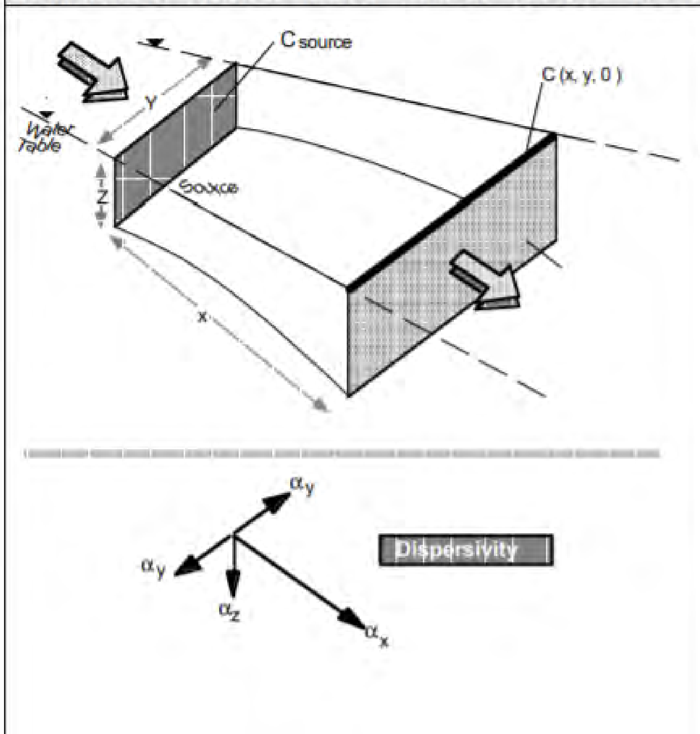


- Current thinking is that G varies from 0.5 to 2.0
- F = 0.5 recommended for sites with relatively extensive LNAPL, including in higher permeability zones
- F = 1.0 recommended for multi-component LNAPL that is more weathered with lower saturations
- F = 2.0 recommended when there is extensive mass diffusion

Saturated Groundwater Solute Transport Model

Domenico Transient Model with First Order Plume Decay and Source Attenuation

Domenico Model with First Order Decay Algorithm



$$C(x,y,o,t) = \text{SDM } x \; \frac{1}{8}\exp\left[\frac{x}{\alpha_x 2}\left(1-\left(1+4\lambda\alpha_x/v\right)^{1/2}\right)\right] \operatorname{erfc}\left[\frac{\left(x-vt\left(1+4\lambda\alpha_x/v\right)^{1/2}\right)}{2(\alpha_x vt)^{1/2}}\right] \left\{\operatorname{erf}\left[\frac{(y+Y/2)}{2(\alpha_y x)^{1/2}}\right]-\operatorname{erf}\left[\frac{(y-Y/2)}{2(\alpha_y x)^{1/2}}\right]\right\} \left\{\operatorname{erf}\left[\frac{(Z)}{2(\alpha_z x)^{1/2}}\right]-\operatorname{erf}\left[\frac{(-Z)}{2(\alpha_z x)^{1/2}}\right]\right\}$$

where: $v = \frac{K \cdot i}{\theta_e R}$

SDM = Source depletion module

Adapted from BioScreen

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Source Zone Depletion Models

Model 1: Dissolution only – based on physical process, considered baseline applicable in all cases

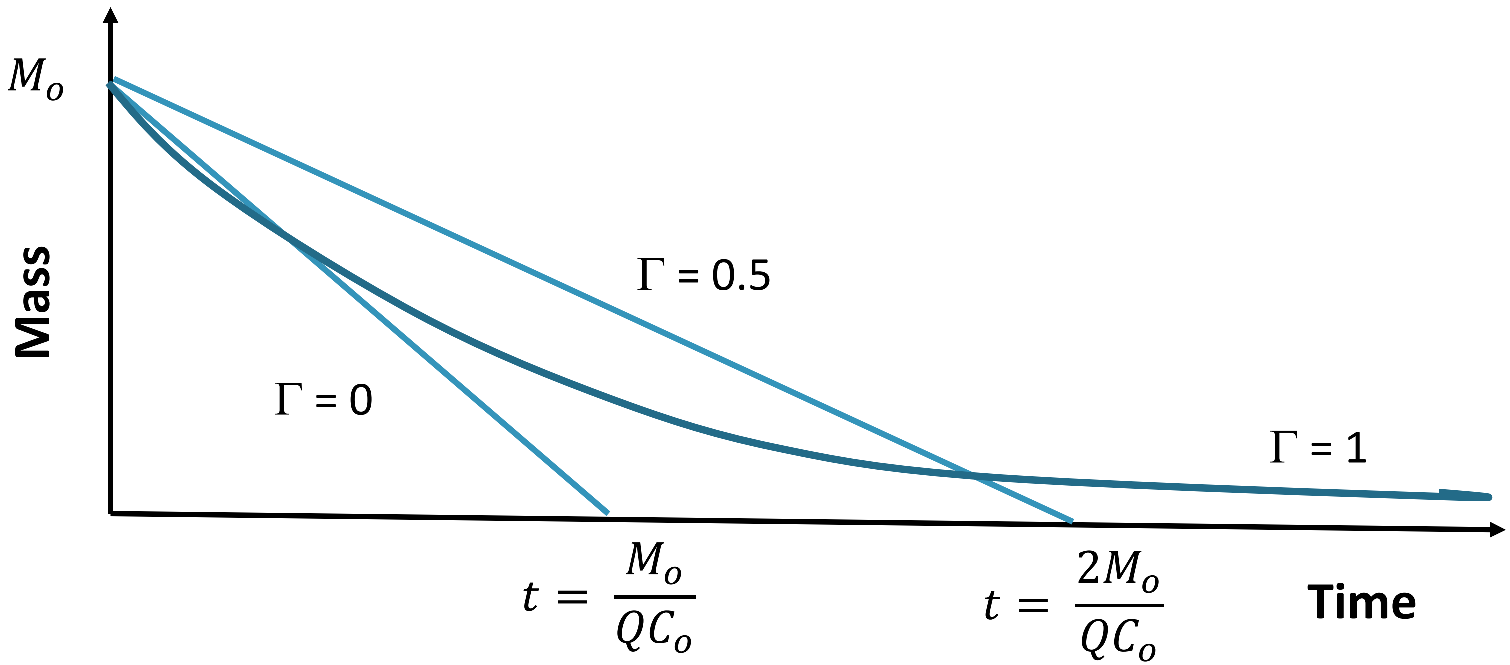
Model 2: Dissolution + Saturated Zone Biodegradation based on 1st-order decay, which is constrained by estimated NSZD rate

Model 3: Dissolution + Saturated Zone Biodegradation based on biodegradation capacity (BC) & geochemical data

Source Zone Mass Depletion

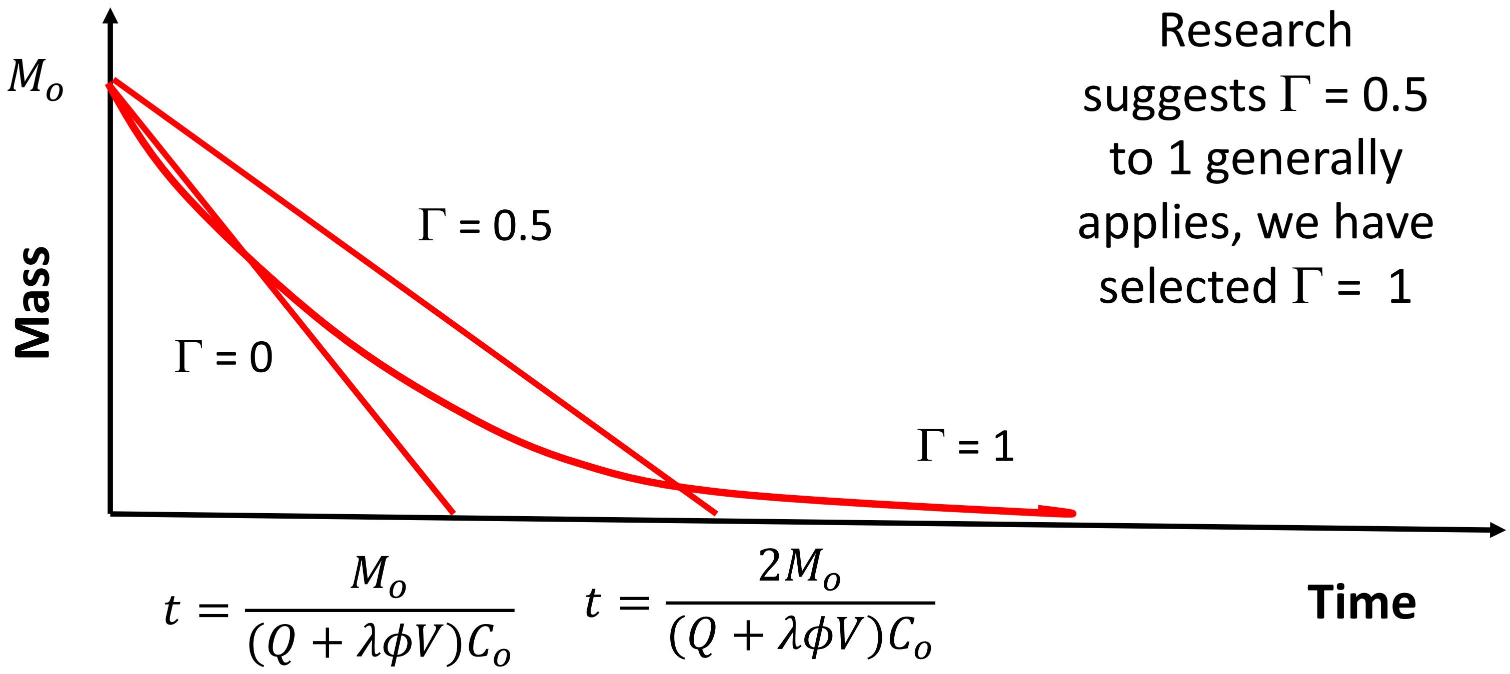
Three sub-models for source depletion developed – details in Technical Appendix including definition Gamma (Γ)

Sub-Model 1: Dissolution only



Source Zone Mass Depletion

Sub-Model 2: Dissolution + 1st-order bio (λ > 0)



Research suggests Γ = 0.5 to 1 generally applies, we have selected Γ = 1

Saturated Zone Decay Algorithms

$\Gamma = 1$ Exponential Decay in Mass Discharge

Model 1

Source dissolution, no bio λs = 0

$$M = M_o\, e^{-\frac{QC_o}{M_o}t}$$

$$C = C_o\, e^{-\frac{QC_o}{M_o}t}$$

$$k_s = \frac{QC_o}{M_o}$$

Model 2

Source dissolution and 1st-order bio, λs > 0

$$M = M_o\, e^{-\frac{(Q+\lambda\theta V)}{M_o}C_o t}$$

$$C = C_o\, e^{-\frac{(Q+\lambda\theta V)}{M_o}C_o t}$$

$$k_s = \frac{(Q+\lambda\phi V)C_o}{M_o}$$

Model 3

Source dissolution and BC bio model

$$M = M_o\, e^{-\frac{Q(C_O+BCxBF)}{M_O}t}$$

$$C = C_o\, e^{-\frac{Q(C_O+BCxBF)}{M_O}t}$$

$$k_s = \frac{Q(C_o+BCxBF)}{M_o}$$

Adapted from RemFUEL & SourceDK

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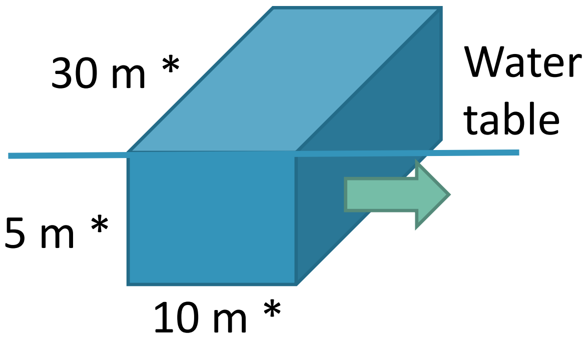
Model Parameters



Flow Rate

$$U = K\ i$$

$$Q = U\ Ac$$

Mass of Contaminant Sorbed on Soil (1) or (2) Predicted from Groundwater

$$1:\ M_o = V\ \rho_b\ C_{soil}$$

$$2:\ M_o = V\ C_s(\phi + K_d \rho_b)\quad K_d = K_{oc} f_{oc}$$

Mass Depletion Rate

$$DR = \frac{(M_{t1} - M_{t2})\ UCF}{1E6\ (t_2 - t_1)\ A_f}$$

	Description	Unit
K	Hydraulic conductivity	m/s
i	Hydraulic gradient	-
U	Darcy velocity	m/yr
Ac	Area perpendicular to flow	m^2
ρ_b	Density of soil	kg/L
ρ_{LNAPL}	Density of LNAPL	kg/L
K_{oc}	Organic carbon partitioning coefficient	L/kg
f_{oc}	Fraction organic carbon	-
K_d	Soil partitioning coefficient	L/kg
A_f	Footprint area	m^2
t	time	yr
M	Mass	mg
UCF	4047 m^2/acre/3.785 USGal/L	

* BC GPM Default

Model Inputs

Model 2: First-order Biodegradation Source Zone

Biodegradation from first-order decay in model should not exceed empirical (literature) or site-specific NSZD rate

Literature vadose zone NSZD rates (which reflect biodegradation in saturated and unsaturated zone) should be adjusted to represent saturated zone rates and scaled when individual substance is modeled

Model 2 Source Biodegradation Rate <= NSZD Rate x MF x Sat Zone Adjust

NSZD Rate = estimated from literature or measured
Mole Fraction = substance-specific mole fraction
Sat Zone Adjust = 0.25 to 0.5 (0.25 if primarily aerobic biodegradation in unsaturated zone; 0.5 if significant anaerobic biodegradation)

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Model Inputs

Model 3: Biodegradation Capacity (mg/L)

Biodegradation Capacity (BC) =

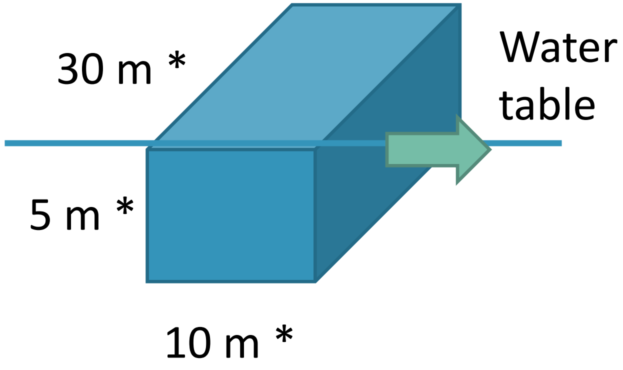
{(Average Upgradient Oxygen Conc.) - (Minimum Source Zone Oxygen Conc)} / 3.14
+{(Average Upgradient Nitrate Conc.) - (Minimum Source Zone Nitrate Conc)} /4.9
+{(Average Upgradient Sulfate Conc.) - (Minimum Source Zone Sulfate Conc)} / 4.7
+{Average Observed Ferrous Iron Conc. in Source Area} / 21.8
+{Average Observed Methane Conc. in Source Area} / 0.78

Biodegradation Factor (BF) =

Substance-specific biodegradation capacity (BC_i) / biodegradation capacity (BC) (total)
BF = substance mole fraction = MF

Saturated Groundwater Solute Transport Model - Example

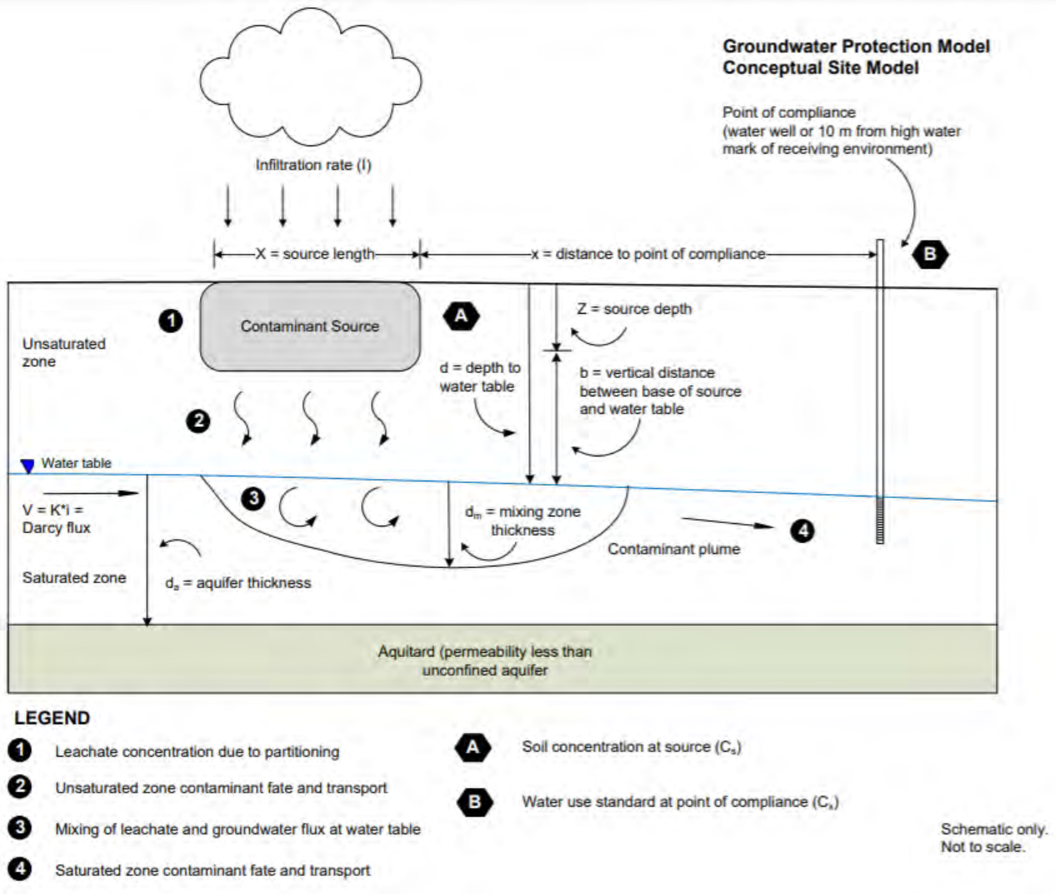
Benzene



BC GPM Defaults used where possible

	Description	Unit	Value	Source
K	Hydraulic conductivity	m/s	3E-5	GPM
I	Hydraulic gradient	-	0.008	GPM
U	Darcy velocity	m/yr	7.57	GPM
L	Source length	m	10	GPM
W	Source width	m	30	GPM
t	Source thickness	m	5	GPM
Ac	Area perpendicular to flow	m^2	150	GPM
ρ_b	Density of soil	kg/L	1.7	GPM
Φ	Total porosity	-	0.36	GPM
f_{oc}	Fraction organic carbon	-	0.005	GPM
K_d	Soil partitioning coefficient	L/kg	146	GPM
C_{soil}	Soil concentration	mg/kg	10	Site
C_o	Initial groundwater conc	mg/L	10	Site
M_o	Initial soluble mass	kg	25.6	Site
BC	Biodegradation capacity	mg/L		Site
BF	Biodegradation factor (mole fraction)	-	0.01	Site
Γ	Gamma	-	0.5-1.0	RemFUEL

Four Compartment Transport Model (BC GPM)



Unsaturated Zone Decay Algorithms

$\Gamma = 1$ Exponential Decay in Mass Discharge

Model 1

Source dissolution, no bio $\lambda s = 0$

$$M_u = M_{ou}\, e^{-\frac{Q_u C_{oL}}{M_{ou}} t}$$

$$C_L = C_{oL}\, e^{-\frac{Q C_{oL}}{M_{ou}} t}$$

$$k_s = \frac{Q C_{oL}}{M_{ou}}$$

Model 2

Source dissolution and zero-order bio, $\lambda s > 0$

$$M_u = M_{ou}\, e^{-Q_u \left(\frac{C_{oL}}{M_{ou}} + k_o\, p_b\right) t}$$

$$C_L = C_{oL}\, e^{-Q_u \left(\frac{C_{oL}}{M_{ou}} + k_o\, p_b\right) t}$$

$$k_s = e^{-Q_u \left(\frac{C_{oL}}{M_{oL}} + k_o\, p_b\right)}$$

Model Parameters

$$Q_{Lu} = A_f I$$

Soil leachate partitioning

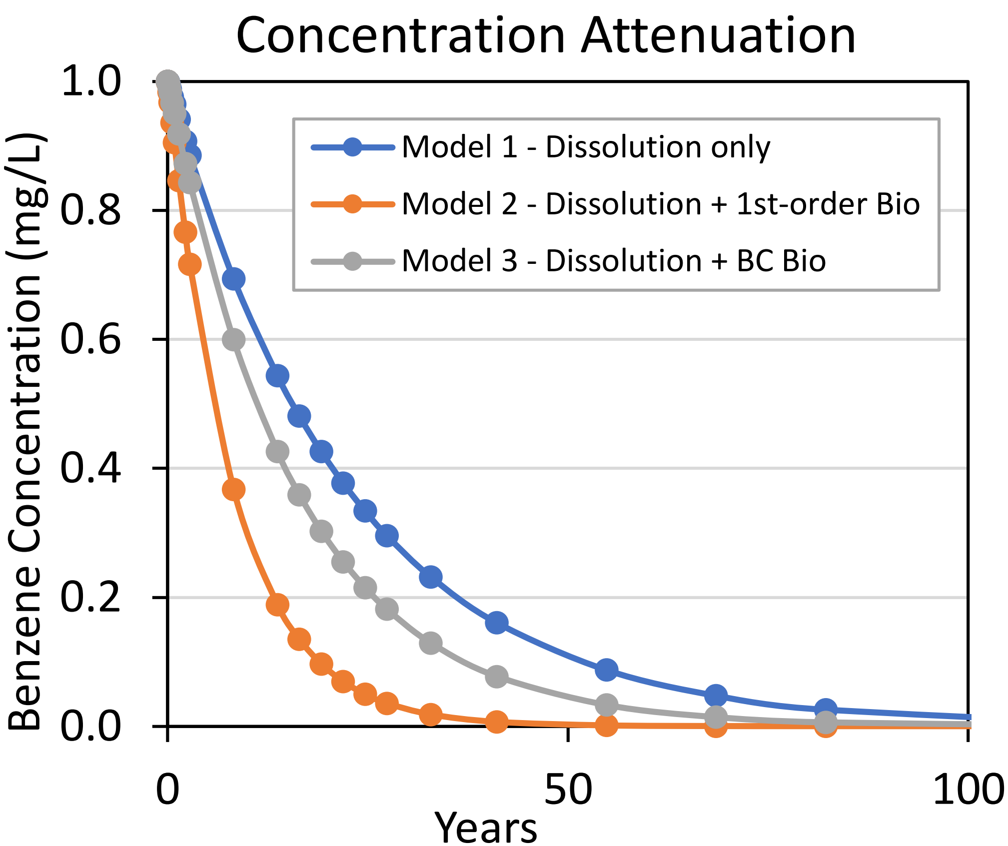
From EPA SSG [1]:

$$C_s = \frac{C_L \left[K_d + \left(\frac{n_w + H' n_a}{\rho_b} \right) \right]}{1000}$$

$$n_a = n - n_w$$

Adapted from RemFUEL & SourceDK

Preliminary Results – Source Depletion – Sat. Model



Gamma (Γ) = 1 (mass discharge, see RemFUEL)
1st-order biodegradation rate(λ) = 0.01 day^{-1} (Model 2)
Biodegradation Capacity (BC) = 40 mg/L (Model 3)
Biodegradation Factor (mole fraction) (BF) = 0.01 (Model 3)

MEMS Attenuation Model

Adapts USEPA Bioscreen and USEPA RemFUEL models and adds source depletion (complex math not shown)

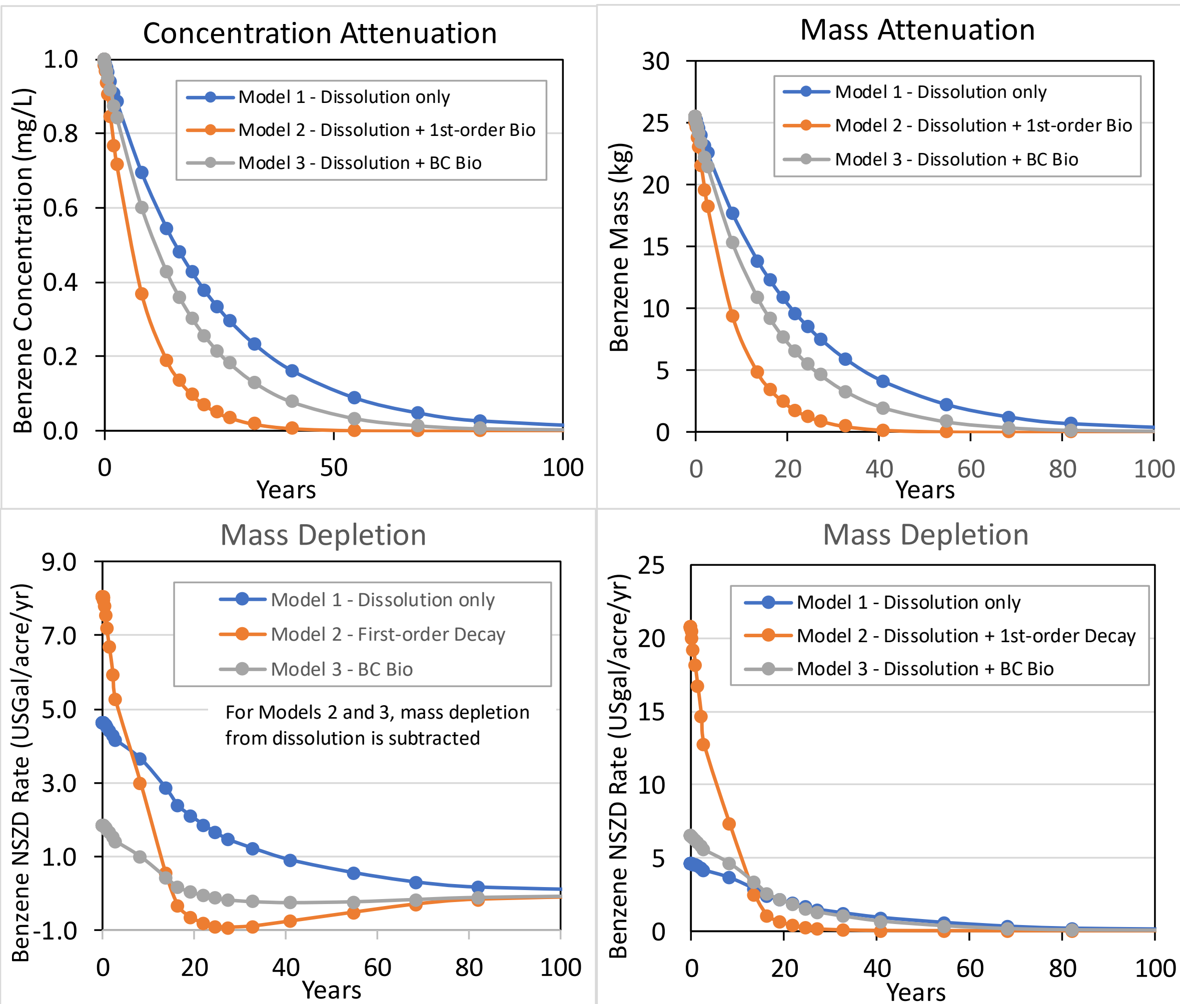
Overview

Model used to simulate source benzene depletion for moderate size release, BC GPM defaults, C_{GW} = 1 mg/L; C_{soil} = 10 mg/kg,

Key Result

Fastest source depletion for Model 2 as it includes biodegradation

Preliminary Results – Source Depletion Examples



Input Parameters

BC GPM Defaults
Co = 1 mg/L
Cs = 10 mg/kg
$\Gamma = 1$
$\lambda = 0.01\ day^{-1}$ (Model 2)
BC = 40 mg/L (Model 3)
BF = 0.01 (Model 3) (mole fraction)

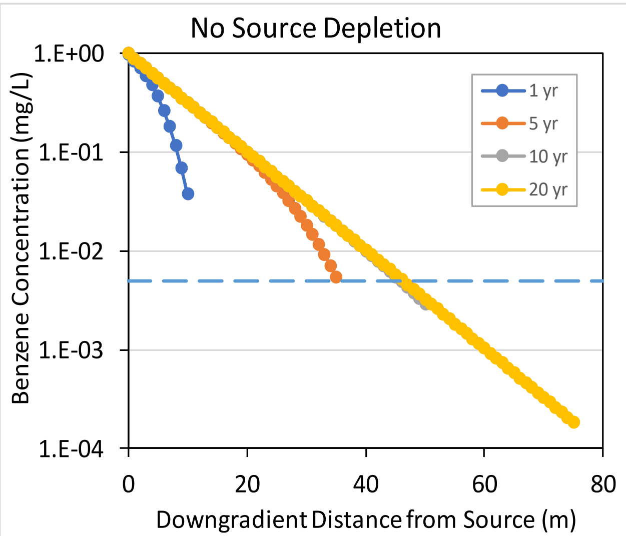
Key Check

For Model 2, the mass depletion rates should be compared to literature rates

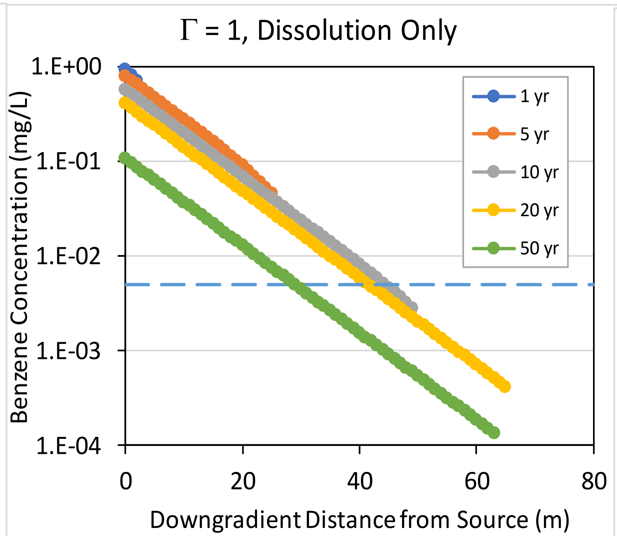
–

Preliminary Results – Plume Migration

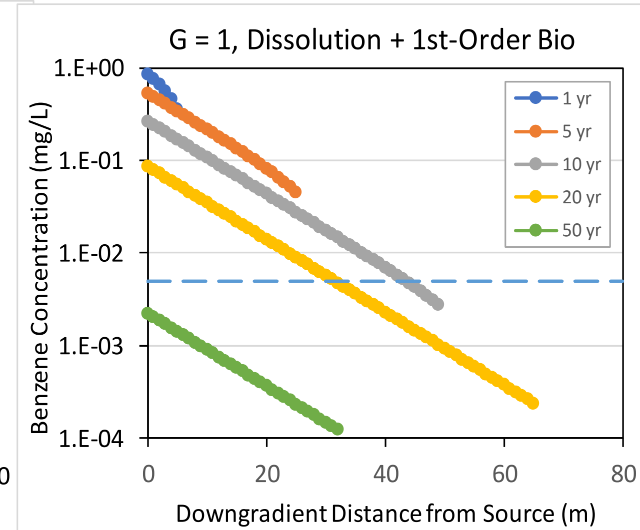
No Depletion (Γ=1)



Model 1 (Γ=1)



Model 2 (Γ=1)



λ = 0.01 day^{-1}

Plume never attenuates

Plume eventually attenuates

Plume attenuates to < Std in < 50 yr

Plume migrates just over 40 m from source (relative to DW std = 0.005 mg/L)

Model Validation – Source Depletion

Tier 1: Use Literature NSZD Rates

CSAP-Shell Remediation Toolkits (2016) (N = 17) Typical Site average rates = **500-1500** US gal/ac/yr	**Garg et al. 2017** (N=25) 25^{th},50^{th},75^{th} percentiles = **700, 1100, 2800** USgal/ac/yr	**CRC Care 47 2020** (N = 6) Site average rates = **240-9,500** US gal/ac/yr

For Sub-model 2 is used, the model will include a mass balance check based on literature NSZD rates (see Technical Appendix)

Tier 2: Measure NSZD Rates

1. CO_2 efflux method
2. Soil gas gradient method
3. Thermal gradient method

Wozney, Hers et al. 202? IOCO site method paper accepted by GWMR
New ASTM Standard being developed

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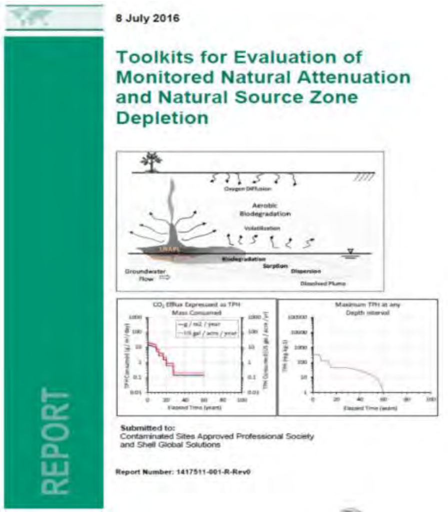
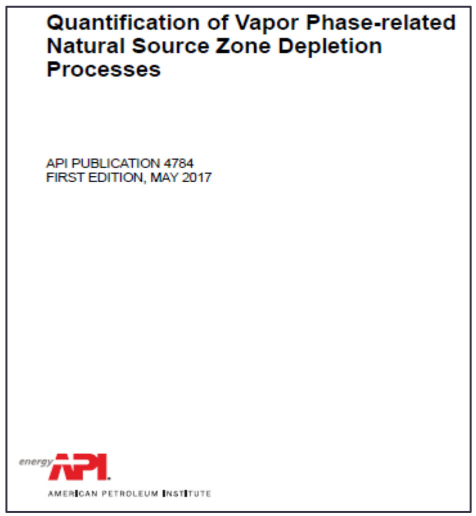
Natural Attenuation and NSZD Guidance

CSAP-Shell-Golder Remediation "Toolkits" 2016 (1&2)



API 2017


Quantification of Vapor Phase-related Natural Source Zone Depletion Processes

API PUBLICATION 4784
FIRST EDITION, MAY 2017

CRC Care 44 2018

CRC Care 47 2020

Garg et al 2017


Groundwater Monitoring&Remediation

Overview of Natural Source Zone Depletion: Processes, Controlling Factors, and Composition Change

by Sanjay Garg, Charles J. Newell, Poonam R. Kulkarni, David C. King, David T. Adamson, Maria Irianni Renno, and Tom Sale

ITRC 2018

REFERENCES ARE PROVIDED AT END OF PRESENTATION

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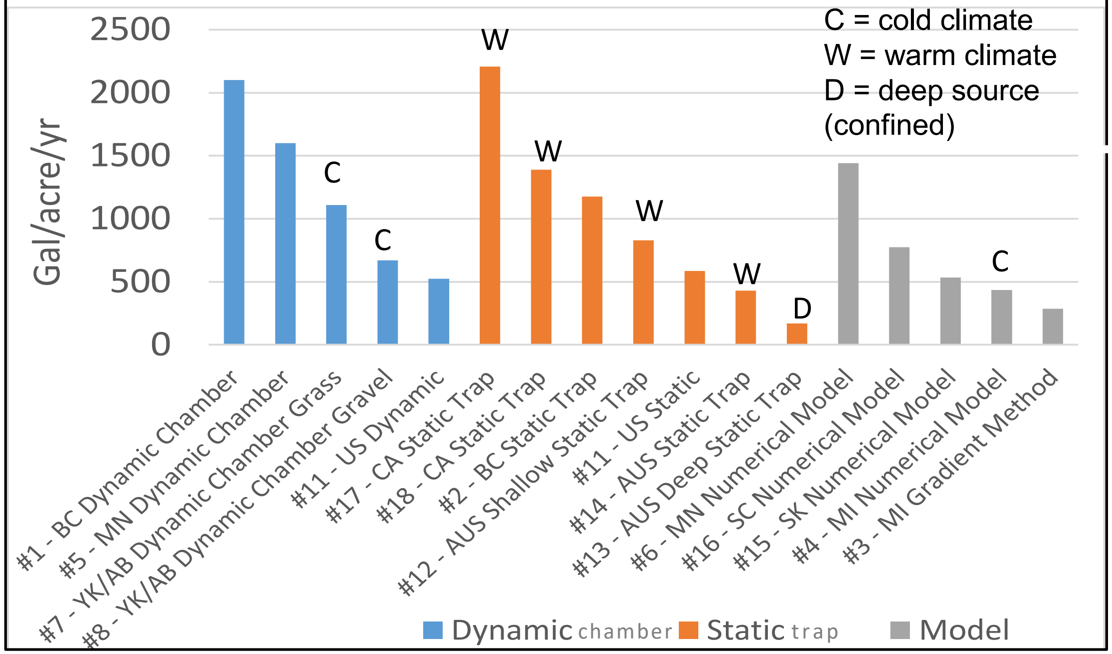
NSZD Rates

PRIMARILY UNSATURATED ZONE

CSAP-Shell-Golder Remediation Toolkits (2016)[1]: N = 17 Typical range site means: **500-1500** US gal/acre/yr



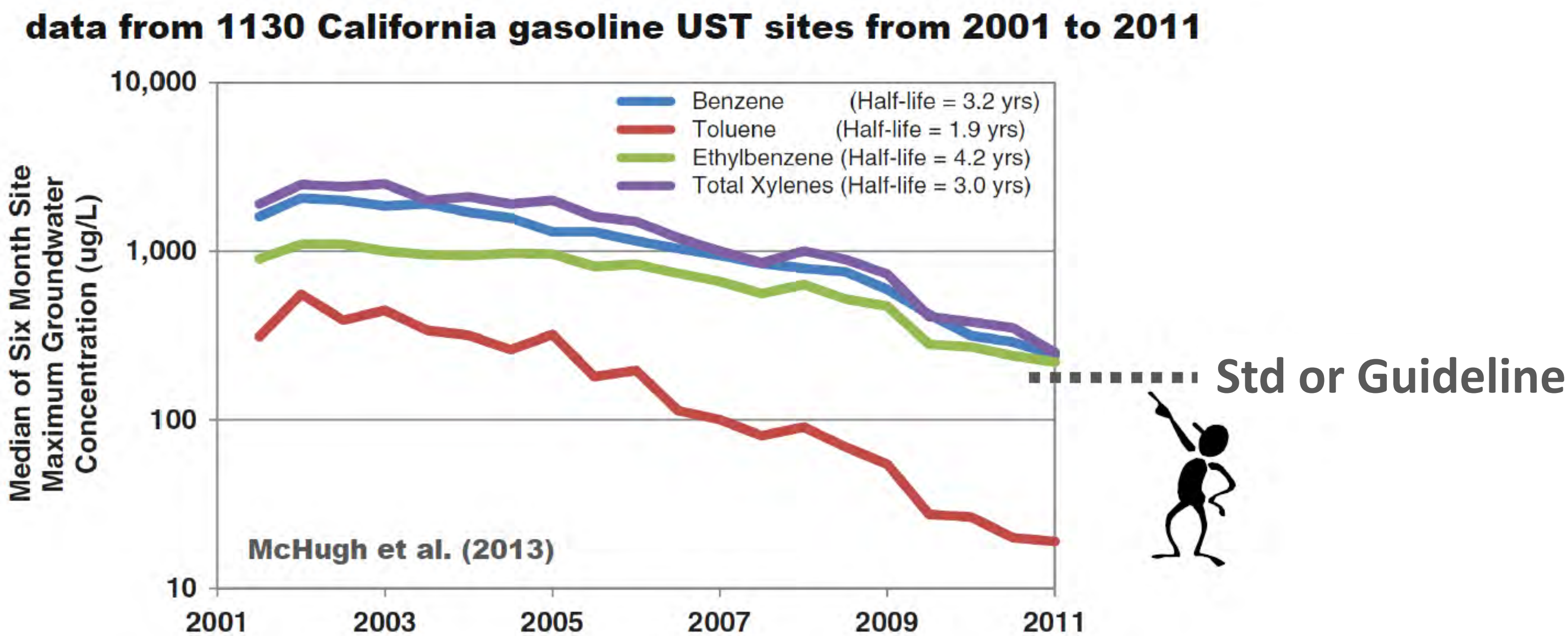
Garg et al. 2017
N = 25 sites
Primarily CO_2 efflux method
25th,50th,75th percentiles =
700, 1100, 2800 US gal/acre/yr

CRC Care 47 2020
N = 6 sites
CO_2 efflux, soil gas gradient & temperature methods
Highly variable site conditions
Range site average =
240-9,500 US gal/acre/yr

1 USgal/acre/yr = 9.35 L/hectare/yr

[1] https://csapsociety.bc.ca/wp-content/uploads/Monitored-Natural-Attenuation-Toolkit-for-Evaluation-1-and-2_combined-FINAL-.pdf CSAP = Contaminated Sites Approved Professional Society of BC

Model Validation – Big Data Analysis Shows Source Attenuation



- Empirical plume length studies also show relatively short BTEX plume lengths, e.g., benzene median plume length = 55 m (O'Conner 2015)
- Available Canadian cold climate data will be summarized

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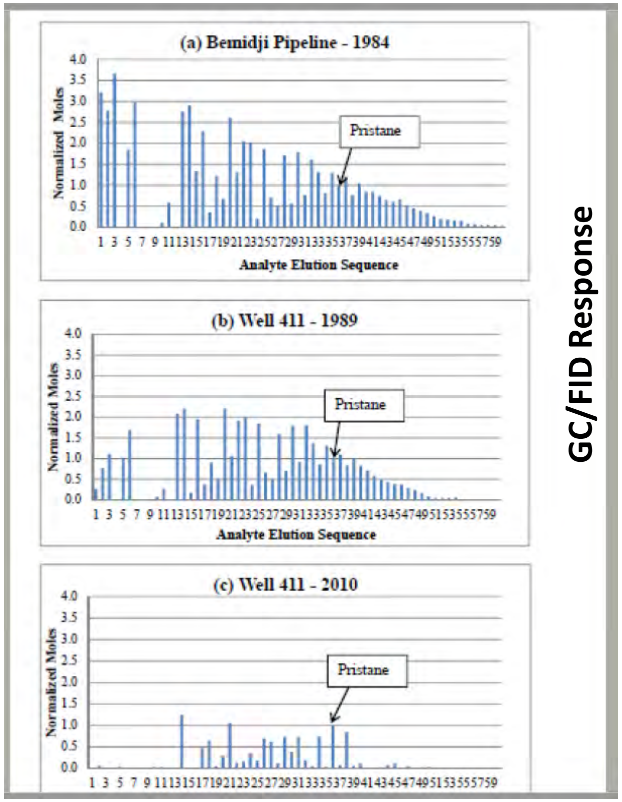
Model Validation – LNAPL Composition Analysis Shows Depletion Over Time

- Time series analysis of LNAPL composition change based on chemical analysis (GG/FID) of oil
- Analysis is performed relative to conservative (recalcitrant) marker chemical (e.g., phytane, pristane) or group of chemicals (Douglas et al. 1996; CRC Care 44 2018)
- Baedecker et al. 2018 Bemidji crude oil: 18–31% depletion in 30 yrs

Promising method as can estimate individual compound and total LNAPL depletion rate and % depleted. Potentially extrapolate using curve-fitting to estimate source depletion time



Bemidji Site (Lundy 2018)

How does LPR Assessment work?

Probability Maps

Probability maps are generated for the Province for multiple receptors based on the number of recorded receptor occurrences over time. Open-source databases (*i.e.,* water well registry, dugout maps, etc.) are used to derive the rate of change of receptor occurrence over time for localized areas.

Therefore, the probability of receptor occurrence is function of both <u>Time</u> and <u>Area</u>.

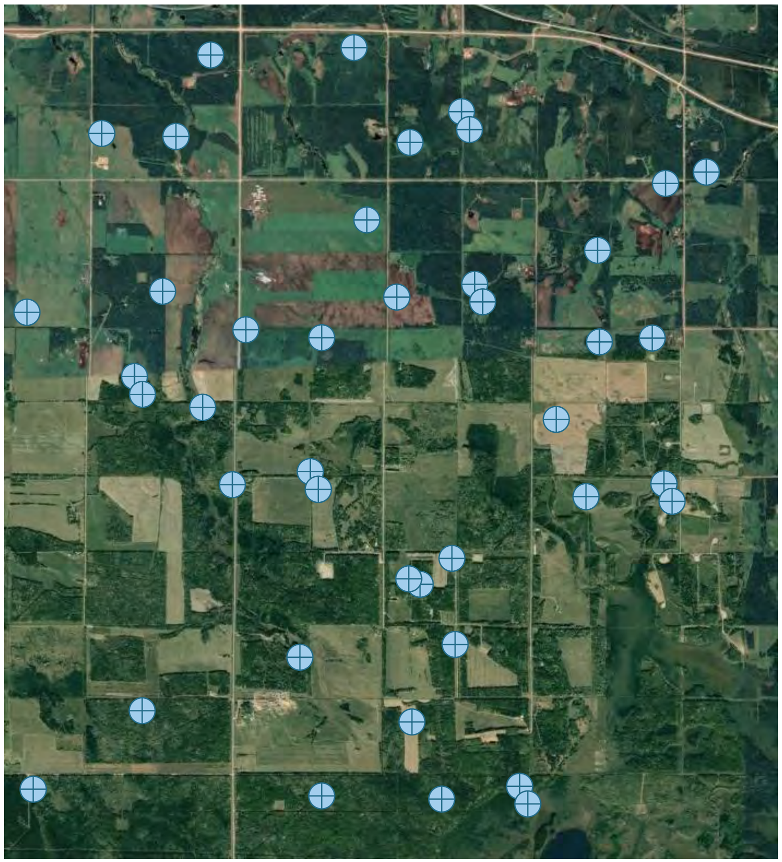
How does LPR Tool work?
Data Sources (AB)

- Water Wells
  - Alberta Water Well Information Database.
  - Water wells drilled since 1980.
- Dugouts
  - Alberta Biodiversity Monitoring Institute (ABMI) 1999-2014.
  - MEMS undertook data validation.

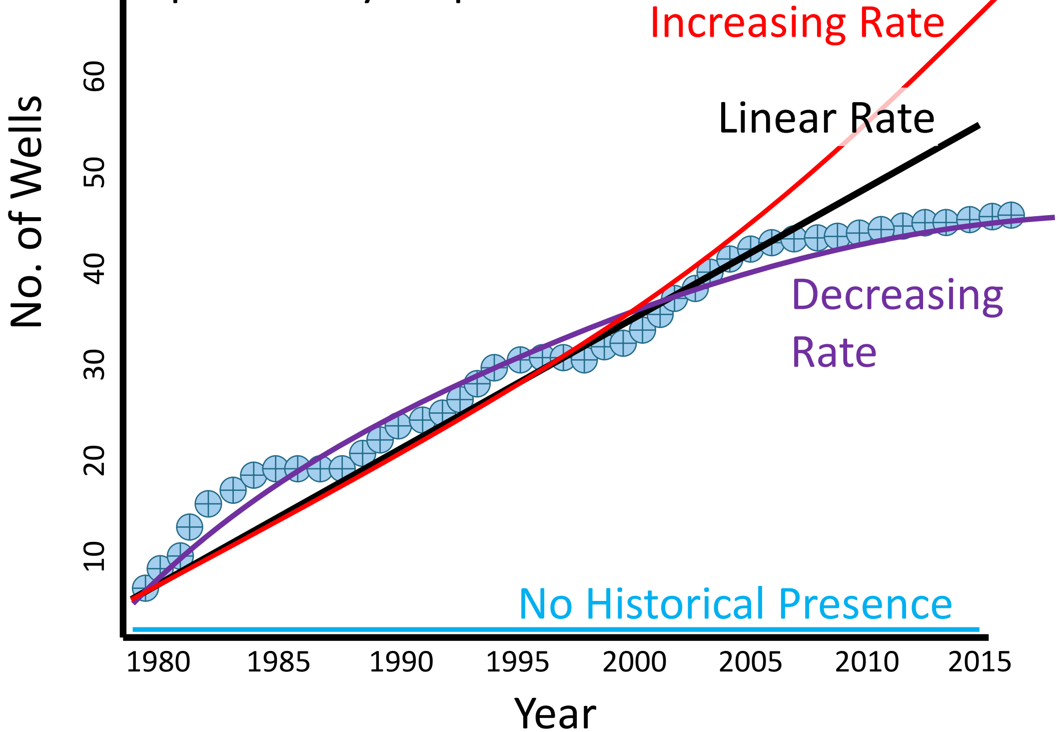
How does LPR Tool work? Calculating Future Probability

- The rate of change in the number of receptor occurrences over <u>time</u> is required to determine the future probability of receptor occurrence and thus risk.

How does LPR Tool work?
Probability Model

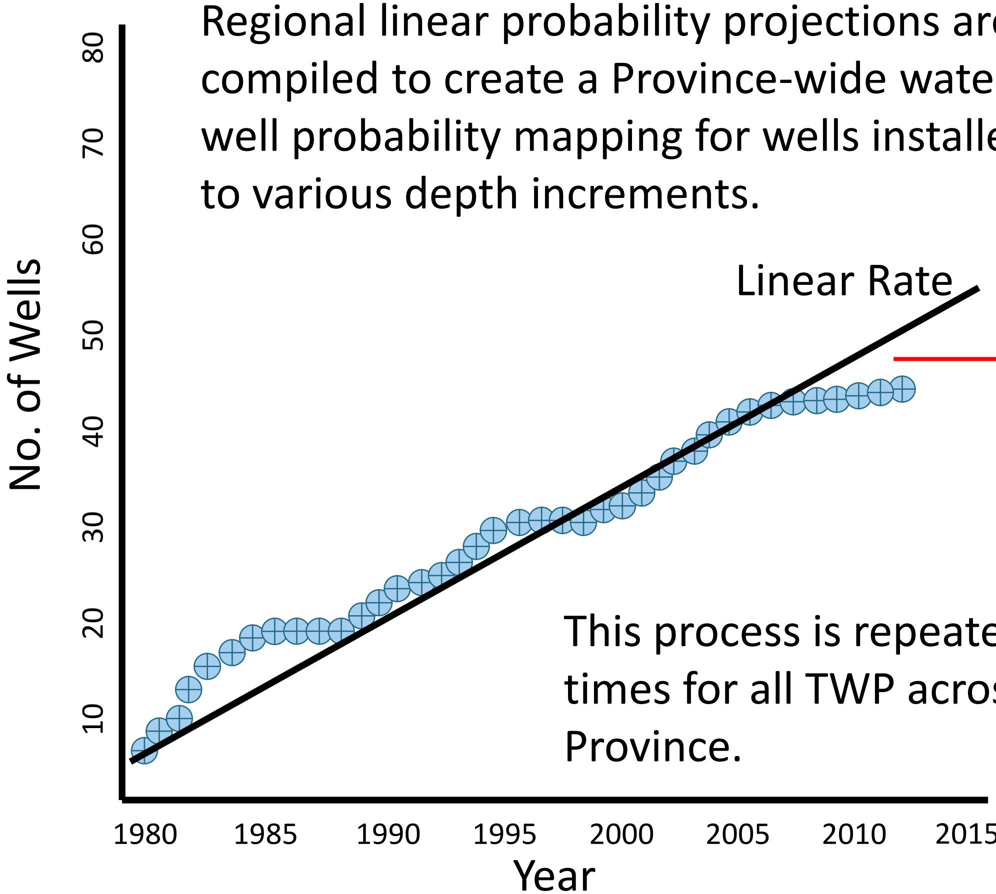


Regional probability projections will be compiled to create a NE BC water well probability map.

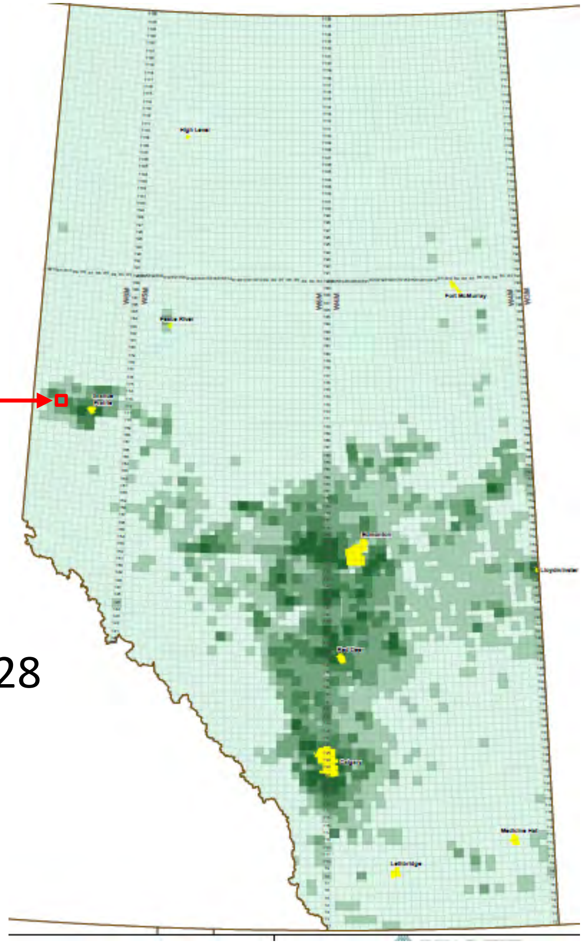


How does LPR Tool work?
Probability Maps

Regional linear probability projections are compiled to create a Province-wide water well probability mapping for wells installed to various depth increments.



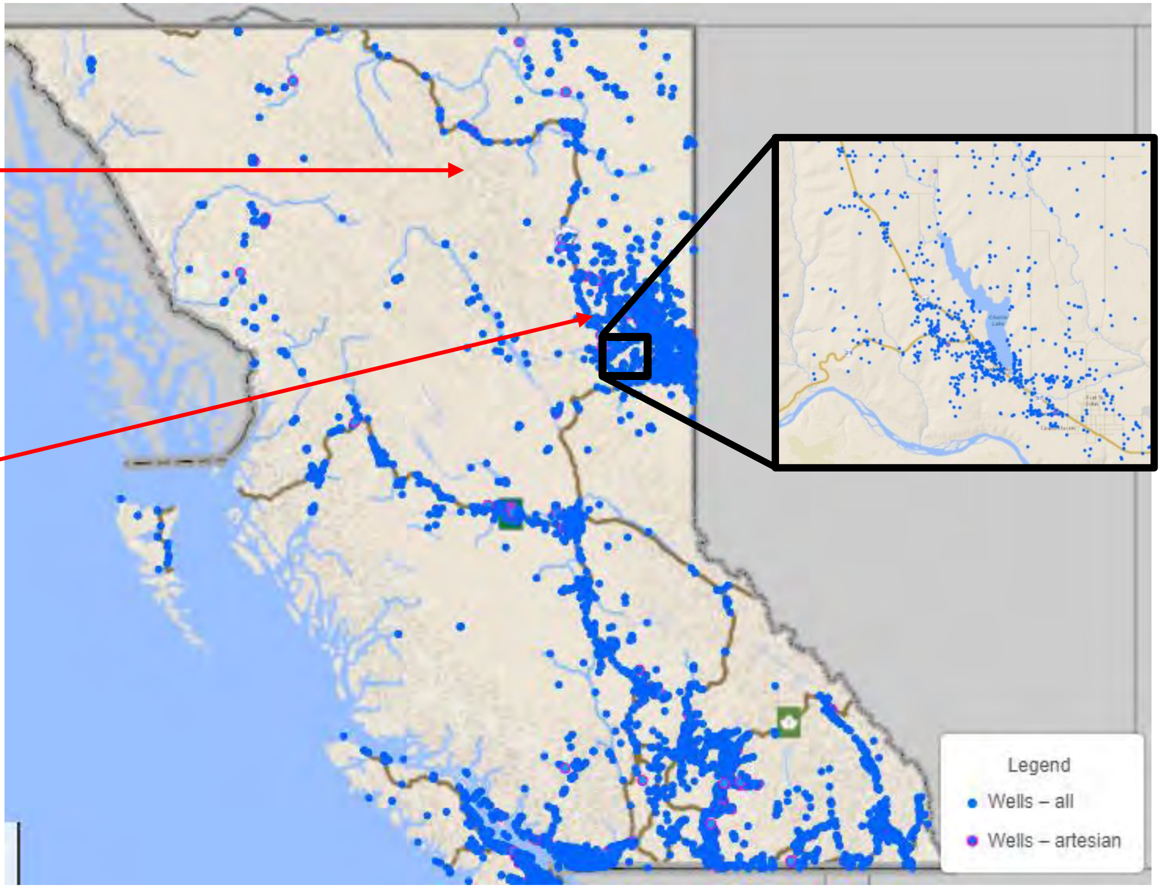
This process is repeated 7,128 times for all TWP across the Province.



Probability Mapping - BC

Regions of the province with
"no historic presence"
of the water wells

Regions of the province with
"historic presence" of the
water wells. Used to create
probability
Map for BC



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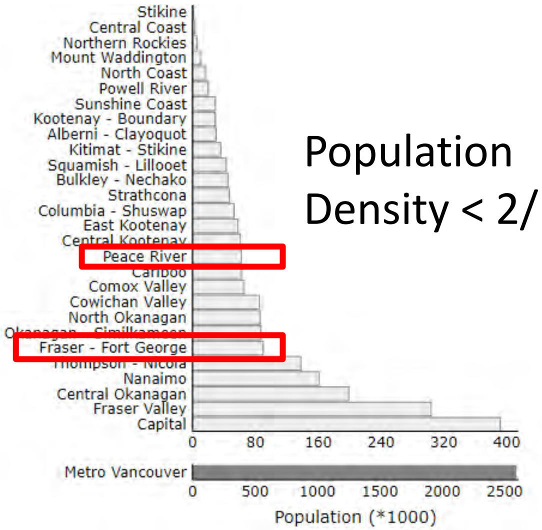
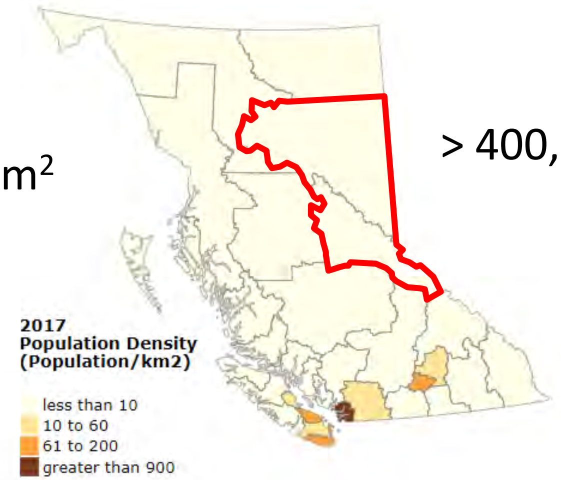
LPR Assessment Probability vs. Density Maps

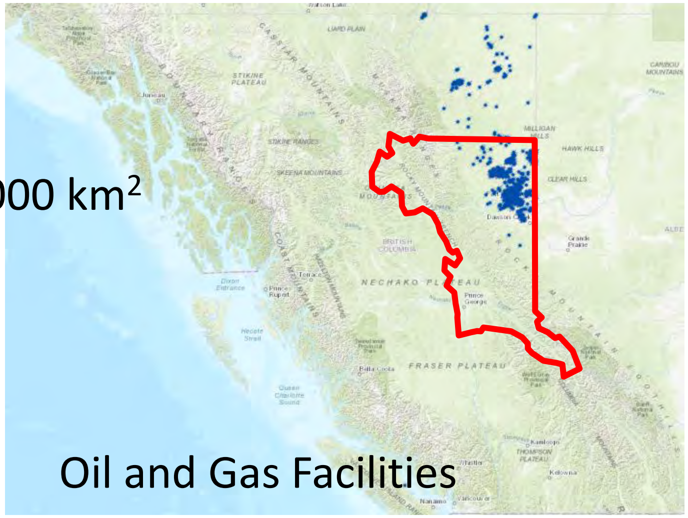
- *Majority of oil & gas site in NE BC are **Remote**, where human inhabitation is unlikely after abandonment.*



Population Density < $2/km^2$

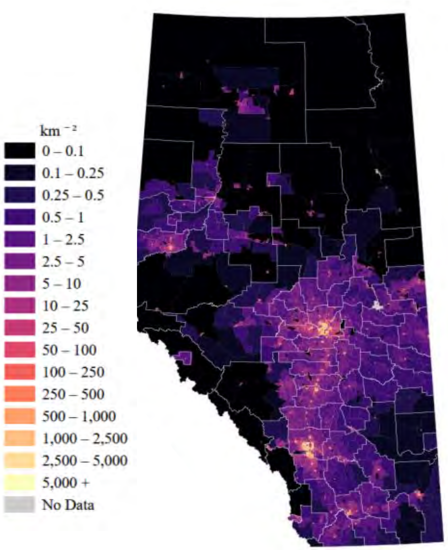


> $400,000\ km^2$



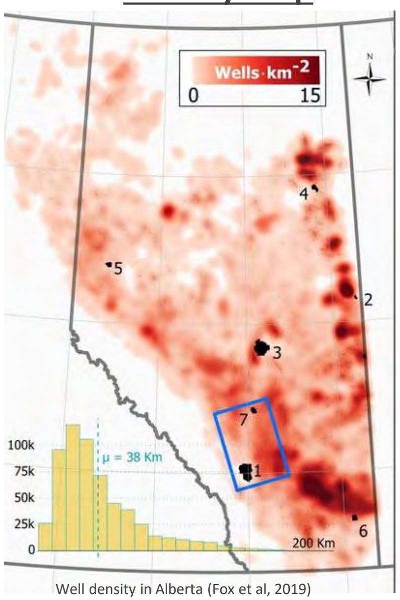
LPR Assessment
Probability vs. Density Maps

Population Density Map



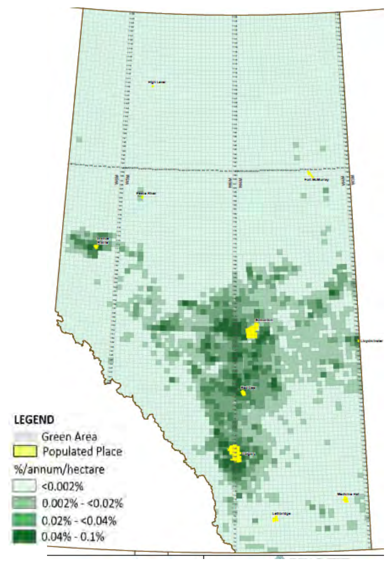
Composite of 2016 Census data (Wikipedia 2019)

Oil and Gas Well Density Map



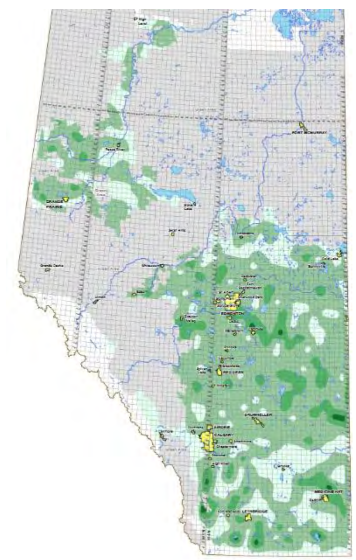
Well density in Alberta (Fox et al, 2019)

Probability of Water Well Map



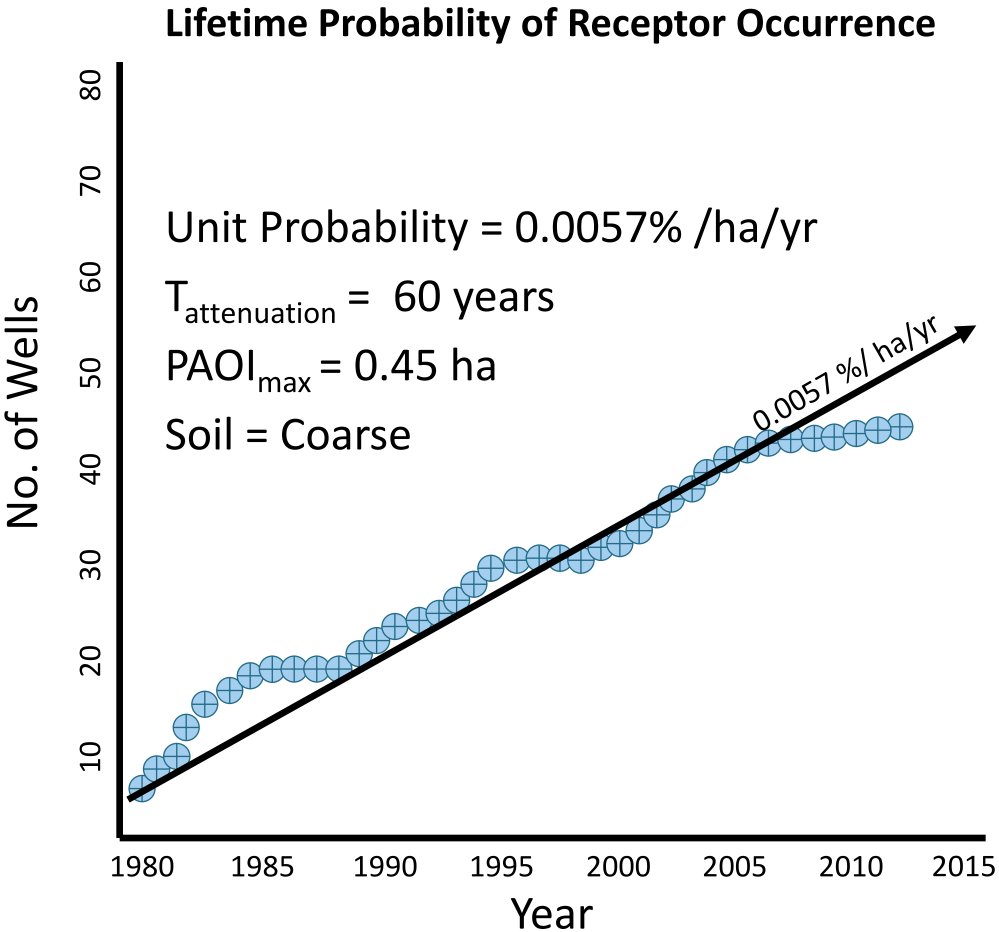
Probability Map of water well occurrence (MEMS 2018)

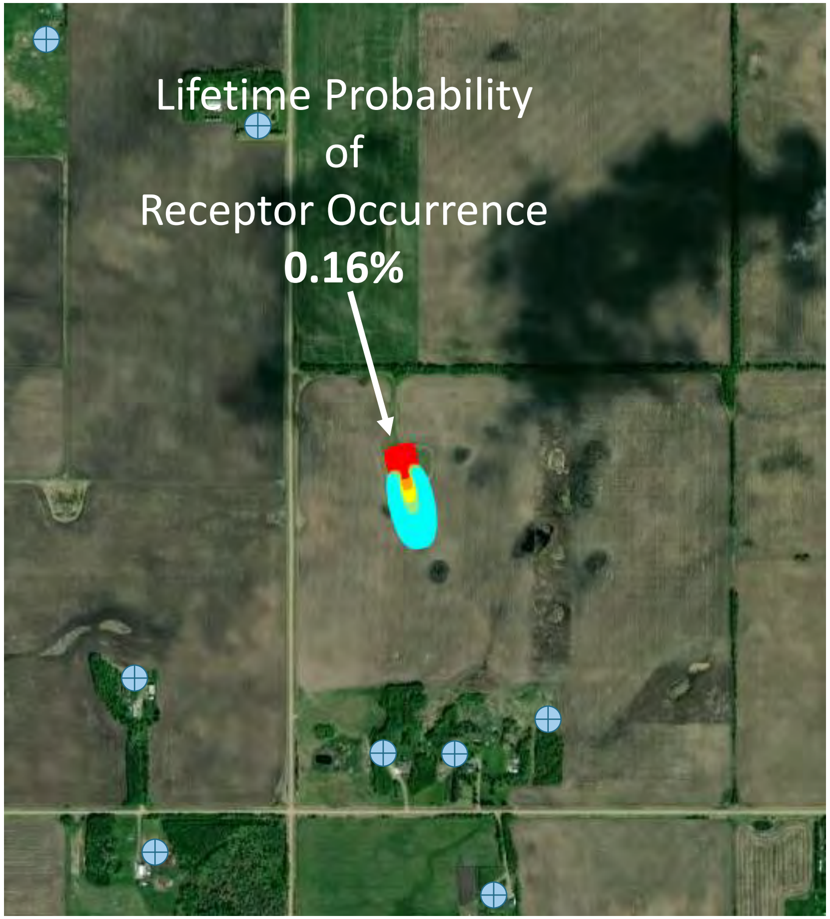
Probability of Dugouts Map



Probability Map of Dugout occurrence (MEMS 2018)

LPR Assessment Example





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Discussion and Questions

Extra Slides

Saturated Zone Decay Algorithms

$\Gamma = 0.5$ Linear Decay Mass Discharge

Model 1

Source dissolution, no bio λs = 0

$$M = M_o - \frac{QC_o}{2}t$$

$$C = C_o - \frac{QC_o^2}{2M_o}t$$

$$t = \frac{2M_o}{QC_o}$$

Model 2

Source dissolution and 1st-order bio, λs > 0

$$M = M_o - \frac{(Q + \lambda\phi V)C_o}{2}t$$

$$C = C_o - \frac{(Q + \lambda\phi V)C_o^2}{2M_o}t$$

$$t = \frac{2M_o}{(Q + \lambda\phi V)C_o}$$

t = depletion time

Model 3

Source dissolution and BC bio model

$$M = M_o - \frac{Q(C_o + BCxBF)}{2}t$$

$$C = C_o - \frac{Q\,(C_o + BCxBF)^{\,2}}{2M_o}t$$

$$t = \frac{2M_o}{(C_o + BCxBF)}$$

Saturated Source Decay Algorithms

$\Gamma = 0$ Step-function Mass Discharge

Model 1

Source dissolution, no bio λs = 0

$$M = M_o - QC_o t$$

$$Cs(t) = Co$$

$$t = \frac{M_o}{QC_o}$$

Model 2

Source dissolution and 1st-order bio, λs > 0

$$M = M_o - (Q + \lambda\phi V)C_o t$$

$$Cs(t) = Co$$

$$t = \frac{M_o}{(Q + \lambda\phi V)C_o}$$

Model 3

Source dissolution and BC bio model

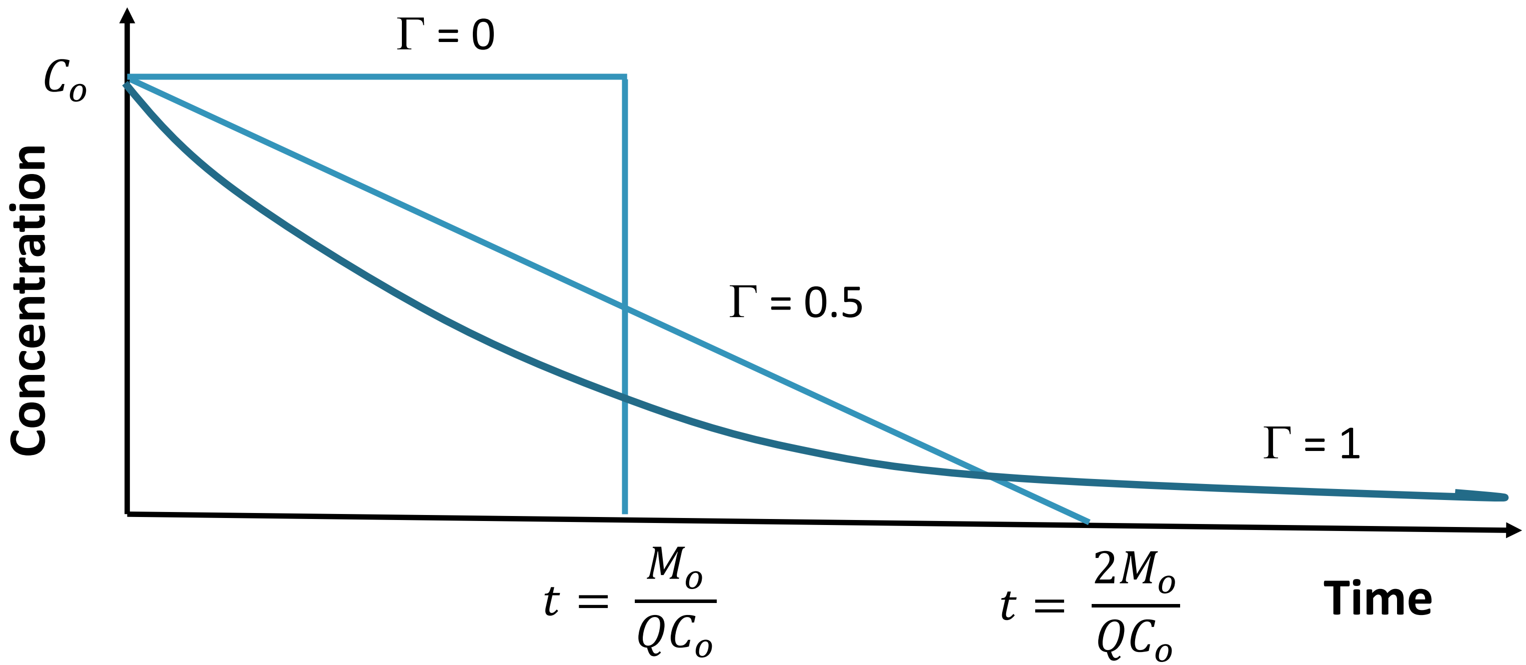
$$M = M_o - Q(C_o + BCxBF)t$$

$$Cs(t) = Co$$

$$t = \frac{M_o}{Q(C_o + BCxBF)}$$

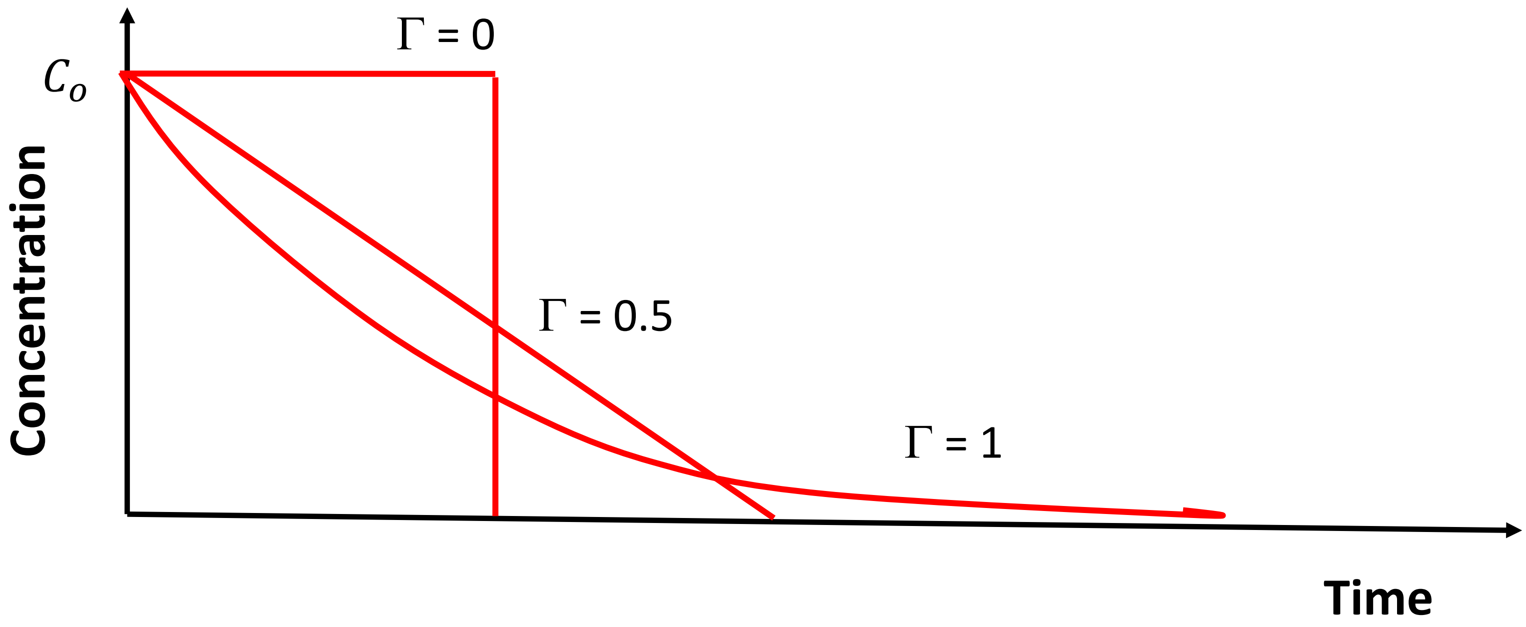
Source Zone Concentration Attenuation

Model 1: Dissolution only ($\lambda = 0$)



Source Zone Concentration Attenuation

Model 2: Dissolution + 1st-order bio ($\lambda > 0$)



BC GPM

Soil leachate partitioning

From EPA SSG [1]:

$$C_s = \frac{C_L\left[K_d + \left(\frac{n_w + H'n_a}{\rho_b}\right)\right]}{1000}$$

$$n_a = n - n_w$$

Unsaturated fate and transport of leachate

Unsaturated zone transport as modified from Kool *et al.*, 1994 [2]:

$$C_L = \frac{C_z}{\exp\left[\frac{b}{2\,\partial_u}\left(1 - \left(1 + \frac{4\lambda_u\,\partial_u R_u}{v_u}\right)^{1/2}\right)\right]}$$

$$b = d - Z$$

$$\partial_u = 0.1b$$

$$\lambda_u = \frac{\ln 2}{t_{1/2u}}\left(1 - \frac{D_{fr}}{365}\right) \text{ where } \ln 2 = 0.6931$$

$$R_u = 1 + \frac{\rho_b}{n_w}K_d$$

$$v_u = \frac{I}{n_w}$$

BC GPM

Leachate/groundwater mixing

Water balance from EPA SSG [1]:

$$C_z = C_{gw} * DF$$

$$DF = 1 + \left(\frac{d_m V}{X\,I}\right)$$

$$d_m = r + s = 0.1X + d_a\left[1 - \exp\left(-\frac{XI}{Vd_a}\right)\right]$$

$$r = 0.1X$$

$$s = d_a\left[1 - \exp\left(-\frac{XI}{Vd_a}\right)\right]$$

$$I = P - (RO + EV)$$

Solute transport in the saturated zone

$$C_x = C_{gw}\ \exp\left\{\frac{x}{2\,\partial_x}\left[1 - \left(1 + \frac{4\lambda_s\,\partial_x R_f}{v}\right)^{1/2}\right]\right\}\ \mathrm{erf}\left[\frac{Y}{4(\partial_y x)^{1/2}}\right]$$

$$C_{gw} = \max\ (C_{gw'},\ C_{gwmax})$$

$$\partial_x = 0.1x \text{ and } \partial_y = 0.1\,\partial_x$$

$$\lambda_s = \frac{\ln 2}{t_{1/2s}} \text{ where } \ln 2 = 0.6931$$

$$R_f = 1 + \frac{\rho_b}{n}K_d \text{ where } K_d = K_{oc}f_{oc}$$

$$v = \frac{V}{n_e} = \frac{K\,i}{n_e}$$

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Low Probability Receptor (LPR) Tool – Update

Integration into BC CSR Module

Millennium EMS Solutions

JANUARY 14, 2022

Presentation Outline

- Harmonization with BC regulatory framework
- Precedent for application of LPR assessments
- How does LPR fit into the BC CSR?
- Regulatory framework for SLRA
- LPR implementation

LPR Assessment Integration into BC CSR

- Is there precedent in using an LPR Assessment approach to evaluate risk?
- Does the application of an LPR Assessment align with the Risk Assessment methodologies endorsed by BC ENV?
- Where does an LPR Assessment fit into the BC Contaminated Sites Regulations?

LPR Assessment - Precedent?

Protocol for Land Use Designations

- Based on sustaining "normal" activities under the four primary land use categories (CCME)
  - BC CSR, Part 1 → Eight land uses differentiated based on primary purpose and exposure assumptions.
- Defines "generic" scenarios with boundaries on the receptors and exposure pathways for a specified land use.
- Incorporates judgement as to the probability of a receptor being present and the degree of that receptor's exposure.

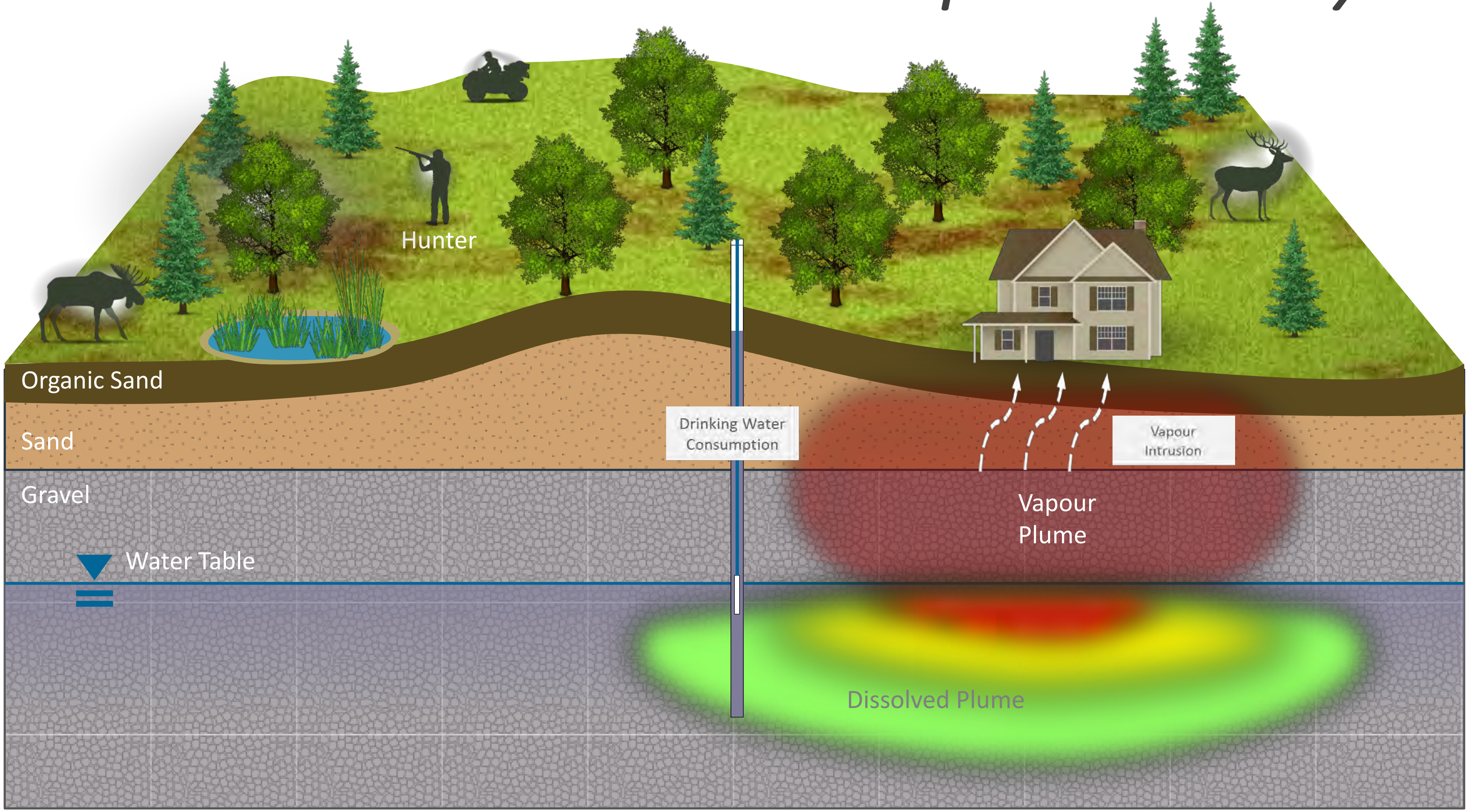
LPR Assessment - Precedent?

Example: Wildlands

- Normal Actives: *Primary purpose of supporting natural ecosystems, including the use of lands for ecological reserves, national and provincial parks, protected wetlands or woodlands, native forests, tundra and alpine meadows.*
- Generic Scenarios: *Modified exposure duration terms of 0.5 → Subsistence users should be evaluated in detailed human health risk assessment using site-specific values.*
- Professional Judgment: *Is it appropriate to include receptor(s) that are not present? If we are to include those receptor(s) for consideration, what is the probability of said receptor(s) occurring at a specific point in time in the future?*

LPR Assessment - Precedent?

Remote Wildlands – Vapour Pathway



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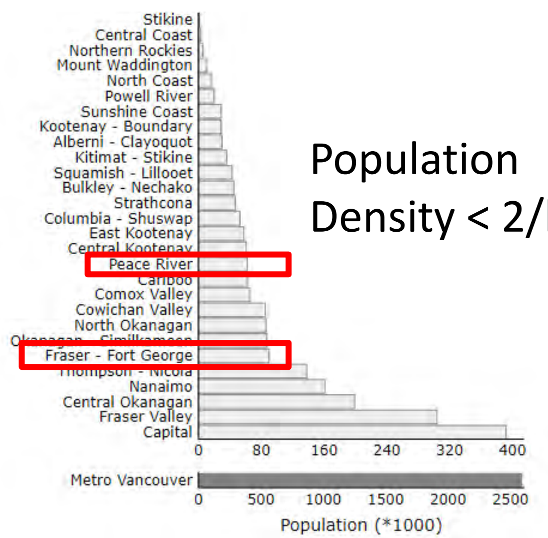
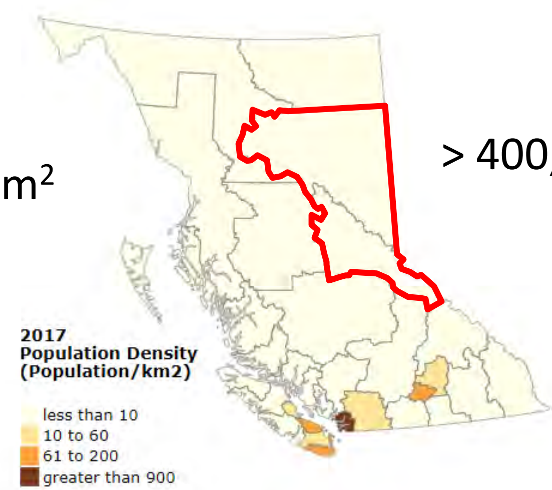
LPR Assessment - Precedent?
Rationale for Vapour Pathway Exclusion

- *Majority of oil & gas site in NE BC are **Remote**, where human inhabitation is unlikely after abandonment, thus a vapour assessment is only required if (OGC, 2020):*
  - *Land is currently zoned, or designated for future parkland, residential, or commercial use within an official community plan, or*
  - *Site is located within 30 m of an existing building not associated with onsite infrastructure.*



Population Density < 2/km^2



> 400,000 km^2

How does LPR fit into the BC Regulatory Framework?

- LPR concepts are consistent with the approaches used in detailed risk assessment.
- LPR aligns with a "*simple assessment of exposure pathways and receptors*", as defined in BC ENV Protocol 13 for Screening Level Risk Assessment (SLRA).
- Acceptance under a SLRA would increase the usability of the approach.
- Consistent with exclusion of vapour pathway for Wildlands Land use

Assess risk to human health and the environment based on the assessment of contaminant concentrations, potential exposure pathways and the <u>presence of receptors</u> (OGC 2020). If there are no unacceptable risks identified the Site is considered to satisfy the risk-based standards of the CSR and eligible for Certificate of Restoration (CoR).

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How does LPR fit into the Regulatory Framework?

Five Types of Standards

1) Matrix numerical standards
2) Generic numerical standards
3) Site-specific standards
4) Director's interim numerical standards
5) Risk-based standards

"The application of **risk-based standards** requires the completion of a human and environmental health risk assessment that assesses risked posed to human and environmental receptors from exposure to contaminated substances at a site."

- *Technical Guidance 7 (BC ENV, 2017*)

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Regulatory Framework
Risk-Based Standards

2 Methods for Assessing Risk:

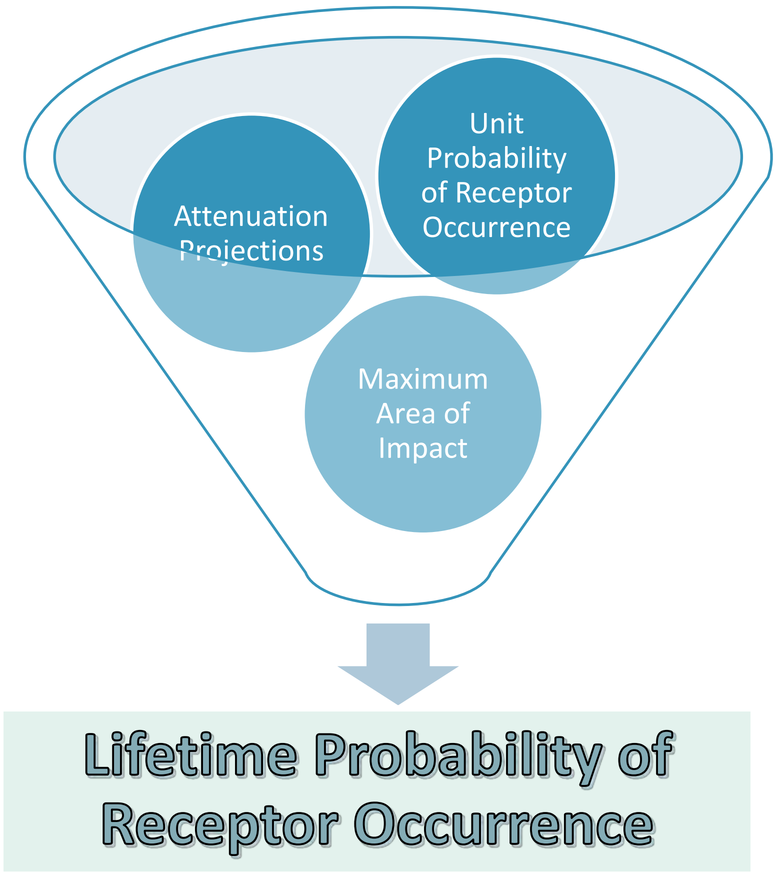
1. Screening Level Risk Assessment (SLRA)

- Used to evaluate whether contamination at a specific site meets or exceeds benchmark screening criteria based on default assessment of key exposure pathways and receptors.

2. Detailed Risk Assessment (Human and Ecological)

- Deterministic or probabilistic approach for assessing risk based on site-specific exposure scenarios for current and future land use.

LPR Assessment Methods *Detailed Risk Assessment*



LPR Assessment is a deterministic approach for evaluating receptor occurrence that is in alignment with the methodologies used in detailed risk assessments, thus providing an evaluation of "*applicable human and ecological receptors known, or reasonably inferred, to be present at a site under current and future use*" *(BC ENV, 2017).*

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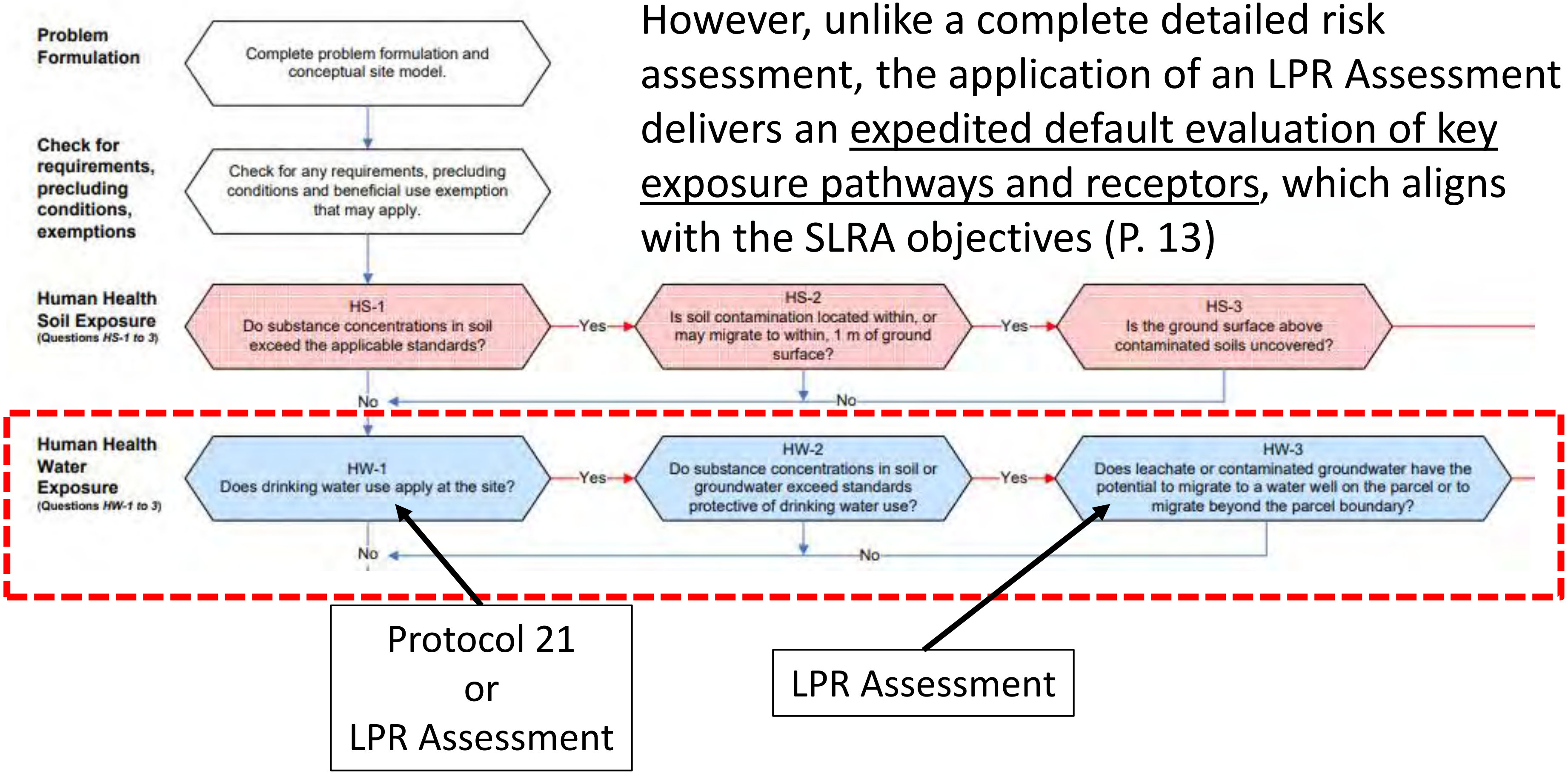
LPR Assessment Methods
Screening Level Risk Assessment

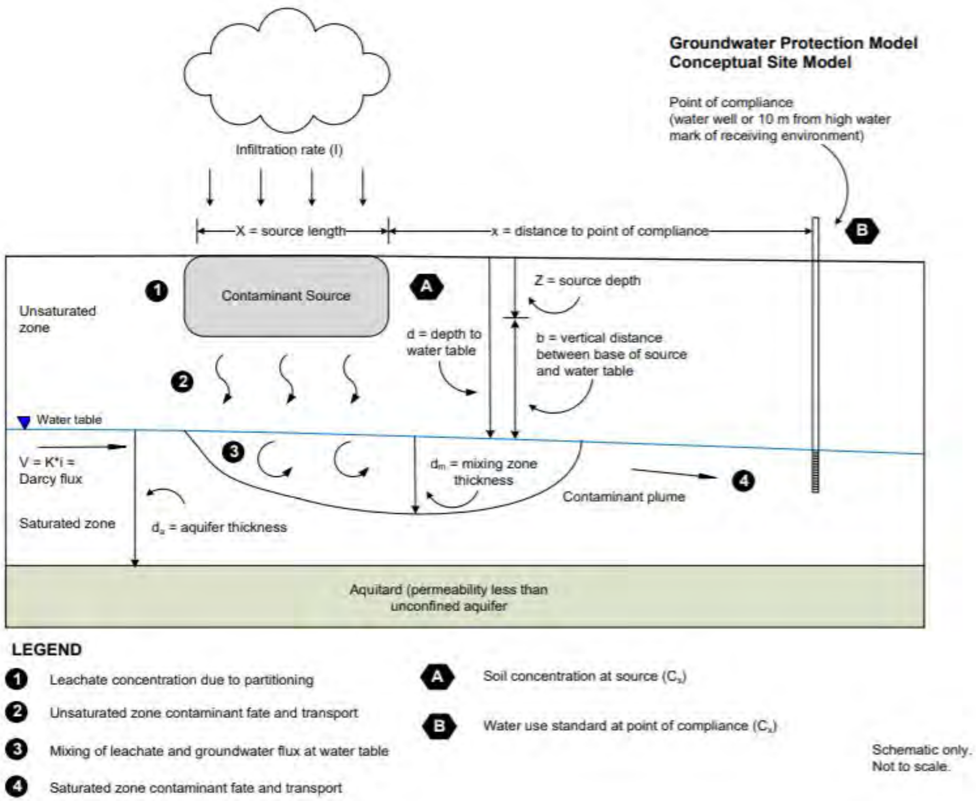
However, unlike a complete detailed risk assessment, the application of an LPR Assessment delivers an expedited default evaluation of key exposure pathways and receptors, which aligns with the SLRA objectives (P. 13)



BC ENV SLRA

BC Groundwater Protection Model

- SLRA point of compliance is property boundary (or receptors if on site)
- Proposed adaptation: if there is LPR, offsite point of compliance, with institutional control

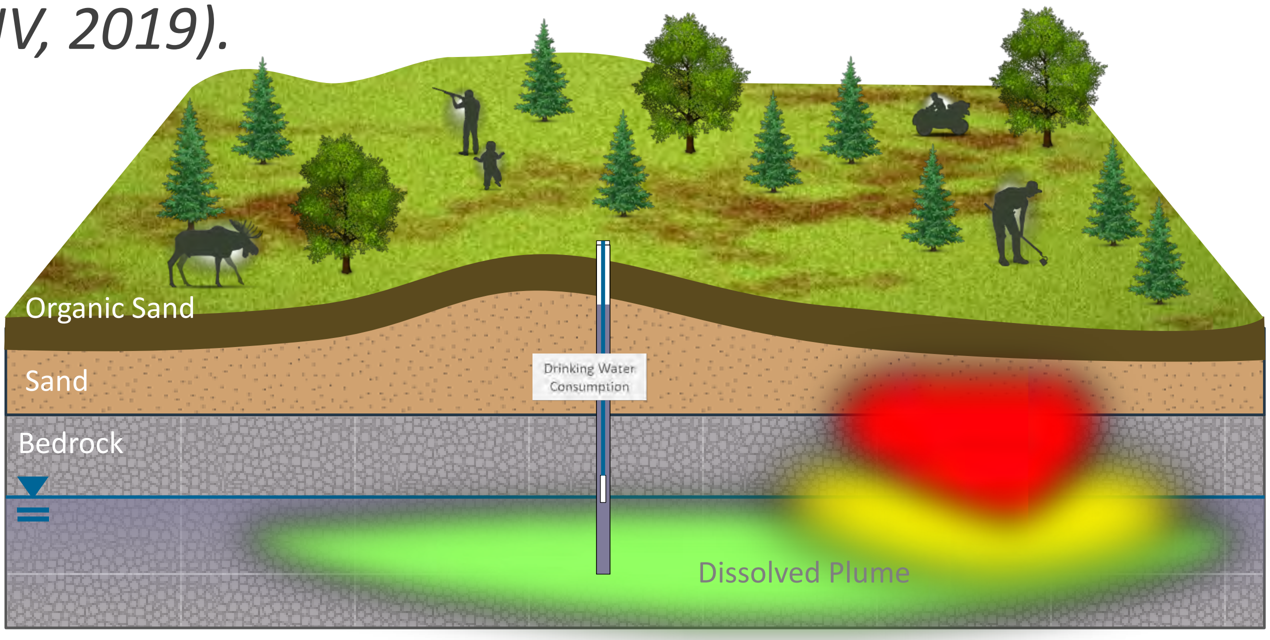


LPR Assessment Methods
Screening Level Risk Assessment

*The intension of a Screening Level Risk Assessment (SLRA) is to evaluate whether contamination at a specific site poses acceptable or unacceptable risks to human health and the environment. Such an evaluation includes a **simple assessment of exposure pathways and receptors** (BC ENV, 2019).*

LPR Assessment

What is the probability of a receptor occurring over the time period to which the COPC are anticipated to attenuate to within the applicable numeric standards?



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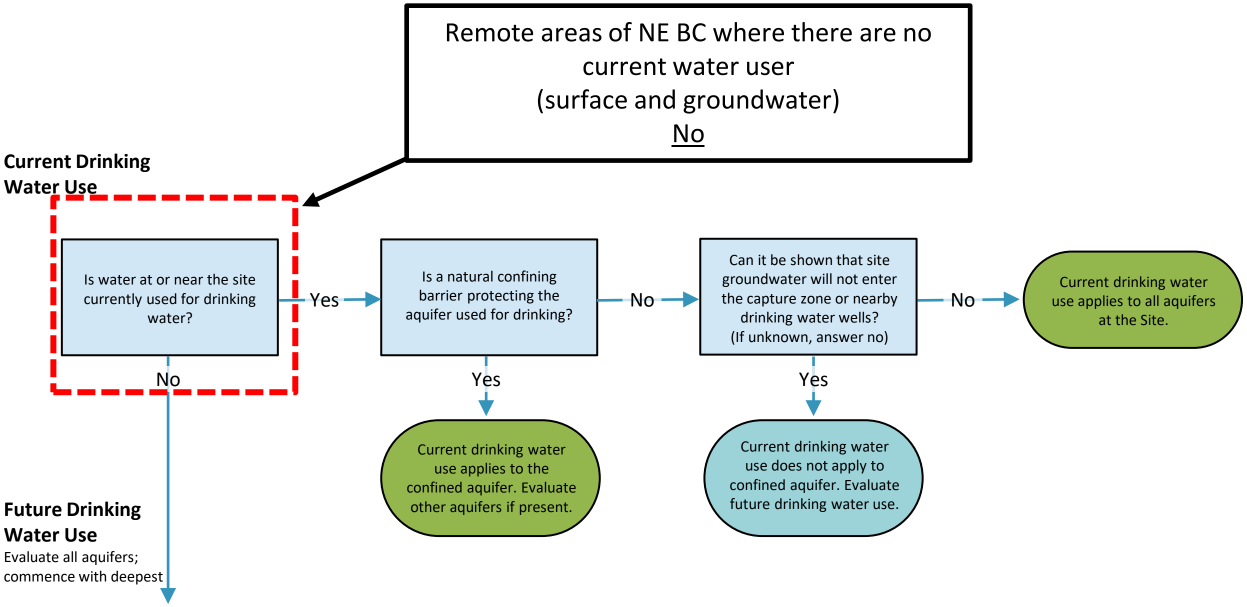
What does a Risk-Based Standard derived using an LPR Assessment look like?

- *An LPR Assessment is a "simple assessment of the exposure pathways and receptors", thus the LPR is an extension of the SLRA.*
- Under a SLRA if the probability of receptor(s) occurrence over time is sufficiently low the user is effectively excluding them from consideration when developing the applicable Risk-Based Standards.
- The exclusion of receptor(s) would therefore be included in the Certificate of Compliance (CoC) or Certificate of Restoration (CoR), consistent with current Schedule B conditions.
- If the conditions applied under Schedule B are violated (*i.e.,* change in Site conditions that violate the assumptions of the SLRA), then the CoC / CoR would be revoked.

Protocol 21



Determined through an LPR Assessment

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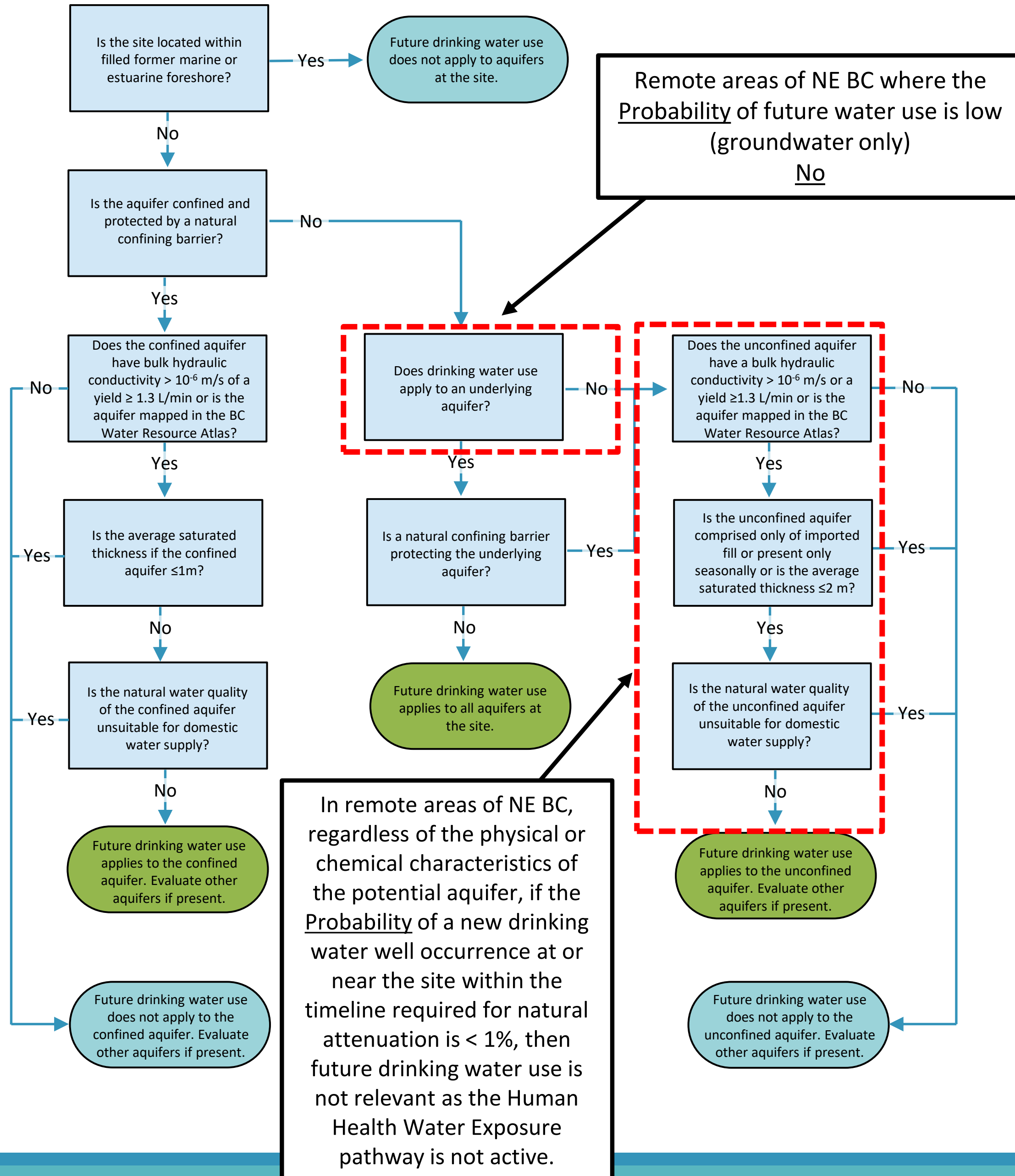

Determined through an LPR Assessment

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Low Probability Receptor Assessment Regulatory Implementation Recap

- *An LPR Assessment uses the complex methods in alignment with a Detailed Risk Assessment but delivers, in an automated manner, a "<u>simple assessment of the exposure pathways and receptors</u>".*

- Acceptance of the LPR Assessment under SLRA would increase the usability of the approach.

- Application of an LPR Assessment under SLRA will increase and accelerate the number of sites progressing towards closure using risk-based standards, thus reducing overall environmental liability while providing the same level of protection as other applicable tools.

BC Implementation Process

- Determine receptors to be considered in LPR approach
- Conduct regional probability mapping
- Complete development of site-specific attenuation model – BC GPM saturated transport model + source depletion
- Define what represents a LPR, i.e., acceptable probability, and maximum allowable plume transport distance

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BC Implementation Process (cont.)

- Adapt current SLRA approach to include LPR (refine point of compliance, add source depletion, identify required source characterization)
- Include institutional control as required depending on land use
- Consider adding post-closure development & economic opportunities in framework
- Consider any other limits for adaptation of LPR as an accepted closure approach

Discussion and Questions