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Low Probability Receptor (LPR)
Current Precedent & Probability Derivation

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1.0 INTRODUCTION

In most cases, assessment, remediation and subsequent reclamation (herein referred to as remediation) of contaminated sites in Alberta are driven by the regulatory requirement that these sites meet guidelines that are protective of all receptors and exposure pathways which are linked, by definition, to a given land use. Unless exposure pathways can be excluded, thereby removing applicability of receptors 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 present. There is no explicit ability to adjust the remediation process to account for sites where the receptor does not exist and is unlikely to occur in the future (*i.e.,* Low Probability Receptors [LPRs]) nor is there a defined process to modify receptor characteristics to be more reflective of site conditions. Thus, for a certain number of sites in Alberta, remediation criteria are driven to end-points that are disconnected from site receptors, either by non-existent receptors or pathways which may have a very low probability of future occurrence or by receptor profiles that are not appropriate for site circumstances. In relation to future receptors, examples of LPRs could include dugouts, residences, drinking water wells or absent ecological taxa. In relation to existing receptors, receptor profiles modification examples could include eco-site controlled vegetation, ecological communities *vs* individual species, characteristics of residential buildings.

It has long been recognized that negative consequences associated with remediation programs are not considered under current guidance. When remediation is conducted for the protection of receptors that are not present there is no benefit to protection of human health or environment; however, the remediation activity creates impacts and the potential for adverse effects to environmental receptors and human health. Sites that are subject to remediation based on the protection of an absent receptor are associated with non-beneficial consequences (avoidable risks), including: (1) increased production of green-house gases during the mobilization of remediation resources, (2) direct physical impacts from remediation including ecosystem damage/destruction, (3) indirect impacts from remediation, such as accelerated wear on Alberta's infrastructure, increased risk of traffic accidents, occupational accidents and unnecessary use of resources such as landfill capacity, and (4) inflated remediation costs that do not result in any reduction in current risk levels. Similar comments can be applied to remediation based on non-applicable receptor profiles.

1.1 Background – Low Probability Receptor Assessment

Potential risk of an adverse impact can be defined as the simultaneous occurrence of a hazard (usually a contaminant source), an operative exposure pathway, and a present receptor (Figure 1). If one of these three components do not occur, then there is no present risk. Currently, Alberta guidance allows for characterization and refinement of a contaminant source and the modification or elimination of pathways based on land use.

Characterization and refinement of a contaminant source is conducted through completion of Phase 1 assessments where chemical constituents are screened to identify contaminants of potential concern (COPC) and through Phase 2 assessments where the degree and extent of contamination is determined. Tier 2 contaminated sites guidance allows for the modification or elimination of pathways based on site-specific land use and other considerations. Outside of receptors associated with specific land uses, there is no consideration allowed for the assessment of potential future receptors that may never exist or for the modification of receptors or receptor characteristics in general. Furthermore, hazards associated with conventional remediation conducted in the absence of a governing receptor results in non-beneficial consequences of remediation. These risks are not addressed in current guidance. It is postulated that those consequences, when aggregated over the large number of contaminated sites existing in Alberta, will result in substantial negative impacts (or avoidable risks) that should not be considered acceptable.

Multiple non-beneficial impacts are associated with sites remediated in the absence of a governing receptor, three of which are discussed herein. Firstly, the mobilization of remediation resources has a quantifiable environmental impact in the form of consumption of diesel fuel and production of greenhouse gases (GHGs) as well as other more qualitative impacts (*e.g.*, destruction of habitat and wildlife corridors). For those sites where the probability that a receptor will occur is very low, remediation of the site does not improve the predicted level of risk to current populations but will, with certainty, result negative consequences (the consumption of fuel and production of GHGs and other potentially harmful chemicals/substances, and damage to existing ecosystems and present ecological receptors). Secondly, there is a considerable direct financial cost to industry, and in some cases the public, associated with the remediation of such sites, especially when considered on an aggregate basis across the province. Avoiding financial expenditures that do not result in any reduction in current risk levels would allow the redirection of funds towards the remediation of higher priority sites. Thirdly, there are indirect financial cost to the Province of Alberta such as accelerated wear on Alberta's infrastructure and use of resources such as landfill airspace. There may also be an indirect economic cost to future investment in Alberta associated with a substantive overstatement of liability within the Province.

Application of LPR assessment will reduce the occurrence of unnecessary negative consequences as well as reduce potential liability associated with the site. By avoiding expenditure of remediation funds where no benefit is derived (to protect a non-existent receptor with a low probability of occurrence), and by focusing on protecting existing receptors, the overall reach of industry's remediation spend will be expanded.

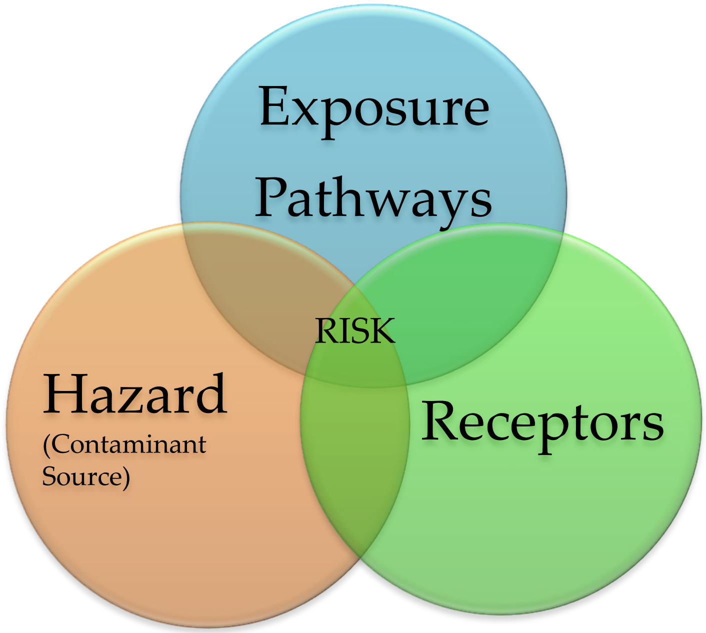


Figure 1 Requirements of potential risk of negative impacts.

Based on the premise that site specific consideration of receptors would be beneficial to overall net environmental protection, then a basis for receptor modification methodology would also be required.

2.0 REGULATORY PRECEDENT FOR SITE SPECIFIC RECEPTOR ASSESSMENT

2.1 Federal

In Canada, the development of assessment and remediation protocols progressed rapidly in the late 1980's and early 1990's. In 1989 the Canadian Council of Ministers of the Environment (CCME) initiated a five-year program entitled the National Contaminated Sites Remediation Program (NCSRP). This program was developed in response to growing public concern over potential adverse effect to both humans and ecological receptors following exposure to contaminated sites. As a part of this effort, an interim set of numerical standards was released in 1991. These interim standards were designed to promote consistency in assessing and remediating contaminated sites through the release of a numerical set of quality guidelines. The Interim Canadian Environmental Quality Criteria for Contaminated Sites established defined land uses (agricultural, residential/parkland, commercial and industrial [CCME 1991]) but often lacked scientifically defensible limits; many of the criteria values were adopted from pre-existing provincial criteria that were based on professional judgement.

In 1996, the first protocol for human and ecological health guideline derivation was released and became the standard by which several of the CCME soil quality guidelines (SQGs) were developed and updated (CCME 1999 with updates). The protocol was updated in 2006 and remains the standard by which the provinces have defined human and ecological receptor relevance for a specified land use, it is herein referred to as 'the CCME Protocol'.

The CCME Protocol explicitly states that land use definitions are based on sustaining "normal" activities under the four land use categories. Under this framework "generic" scenarios were envisioned and used to define typical exposure conditions which place boundaries on the receptors and exposure pathways considered in the guideline derivation for a specified land use. Therefore, the very definition of land use incorporates judgement as to the probability of a receptor being present and the degree of that receptor's exposure.

The pre-existing framework is easily identifiable when looking at the difference imparted within the CCME Protocol when we move from one land-use scenario to another. The livestock receptor is not considered under a residential/parkland land use because it has a low probability of being present. Similarly, the degree of human exposure is inherently modified when assessing commercial or industrial land use because it is of low probability that a worker would spend 24 hours a day for 365 days on-Site.

The concepts provided within the CCME Protocol are also entrenched in other jurisdiction within the Federal Government. Such guidance documents include:

- Health Canada. 2012a. Federal Contaminated Site Risk Assessment in Canada, Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA), Version 2.0;
- Health Canada. 2010a. Federal Contaminated Site Risk Assessment in Canada, Part II: Health Canada Toxicological Reference Values (TRVs) and Chemical-Specific Factors, Version 2.0; and
- Health Canada. 2010b. Part V: Guidance on Human Health Detailed Quantitative Risk Assessment for Chemicals (DQRAChem).

2.2 Alberta

2.2.1 Contaminated Sites Policy

Alberta's framework for the management of contaminated sites is designed to achieve three policy outcomes (ESRD 2014):

- Pollution prevention: Avoid impairment of, or damage to, the environment, human health or safety, or property.
- Health protection: Take action on contaminated sites that is commensurate with risk to human health and the environment.
- Productive use: Encourage remediation and return of contaminated sites to productive use.

While regulatory precedent for considering the presence or absence of receptors under the Alberta guidelines is discussed further in the following subsections, it is noted that the overall objectives of the LPR approach are entirely consistent with the above policy outcomes of Alberta's contaminated sites management framework.

2.2.2 Generic Assessment

In Alberta, the Tier 1 and Tier 2 guidelines (AEP 2016a,b) are aligned almost entirely with the CCME (2006) protocol with respect to receptor selection under specified land use designations. The one exception is the addition of the natural area land use designation, which does not exist within the CCME. This land use designation is unique in comparison to the CCME as it protects areas where an absence of most potential human health receptors and associated exposure pathways is assumed, but the potential presence of a domestic use aquifer (DUA) pathway is retained. The land use is defined as being "away from" human habitation activities with the "primary" concern being ecological. These descriptors are qualitative, judgement-based concepts which consider the probability of exposure.

Of note, under the Alberta guidelines the elimination of the protection of freshwater aquatic life pathway is based only on existing surface water bodies and does not require consideration of the potential for future surface water bodies, either of natural or man-made origin.

A breakdown of the receptors within each of the designated land use scenarios in Alberta, under a Tier 1 approach, is provided as follows:

<u>Natural Area Land Use</u>

- Protection of DUA (human)
- Direct Soil Contact (ecological)
- Livestock/Wildlife Soil and Food Ingestion (ecological)
- Nutrient Energy Cycling (ecological)
- Protection of Freshwater Aquatic Life (FAL) (ecological)
- Protection of Wildlife Water (ecological)

Agricultural Land Use

- Protection of DUA (human)
- Vapour Inhalation (human)
- Direct Soil Contact (human & ecological)
- Livestock/Wildlife Soil and Food Ingestion (ecological)
- Nutrient Energy Cycling (ecological)
- Protection of Freshwater Aquatic Life (FAL) (ecological)
- Irrigation Water (ecological)
- Protection of Livestock and Wildlife Water (ecological

Residential/Parkland, Commercial and Industrial

- Protection of DUA (human)
- Direct Soil Contact (human and ecological)
- Vapour Inhalation (human)
- Nutrient Energy Cycling (ecological)
- Protection of Freshwater Aquatic Life (FAL) (ecological)

The Tier 1 guidelines are intended to be a conservative screening tool, whereby the lowest guideline calculated for each of the exposure pathways under the appropriate land use and soil texture is the overall remediation guideline (AEP 2016a). However, while the Tier 1 remediation guidelines act as the standard by which sites with minimal information are screened, additional site information is needed to ensure that site conditions are adequately represented by the assumptions used to develop the Tier 1 guidelines. Within current legislation, the collection of additional site information may result in a site being determined to be more or less sensitive than assumed in the Tier 1 derivation (AEP 2016b). Notably, where Sites are not appropriately represented by Tier 1 assumptions (Sections 5.1.2, 5.1.5, 5.2.1 and 5.2.2 [AEP 2016b]) conditions exist where receptors or pathways should be added; however, no provision is made for conditions in which non-present receptors could be removed.

It is noted that the Tier 1 guidelines are intended to be protective of more sensitive receptors expected to be present within each generic land use classification. The protection of sensitive sites or receptors ensures that less sensitive sites are also protected; however, the level of protection implicitly afforded to less sensitive sites exceeds the stated protection endpoints of the policy.

Under specific scenarios, both pathways and pathway-receptor combinations may be excluded at Tier 2 if they are not operative at a given site and their exclusion does not lead to a requirement for land and/or water use restrictions (AEP 2016b). Such examples already include the elimination of a surface water body beyond 300 m, or a DUA where a barrier unit exists. The LPR approach is a continuation of this model.

Both Tier 1 and Tier 2 guidelines are intended to allow regulatory closure without conditions or restrictions (*i.e.,* exposure control or risk management) being imposed on land or water use at a site. Implicit in the definition of the generic land use categories is the assumption that the absence of receptors not ordinarily expected to be present, such as humans at a natural area site, does not require the imposition of conditions or restrictions to allow regulatory closure. Again, this assumption reflects a consideration of the low or negligible probability of such receptors being present, but still does not lead to any requirement for exposure control or risk-management. It is considered possible, and entirely consistent with current policy, that land use classifications could be further refined in future to account for receptors not expected to be present on a regional basis, for demographic or physiographic reasons, without departing from the generic nature and unconditional goal of Tier 1 or Tier 2 management.

2.2.3 Site-Specific Risk Assessment

There is also precedent under site-specific risk assessment in Alberta for excluding low probability receptors. Several approved risk assessments for sites within natural areas have been based on the demonstrated health of ecological communities that are actually present rather than comparison to a generic guideline intended to protect ecological function of soil based on theoretical high-sensitivity species, on the premise that if the ecosystem is healthy and functioning, any remediation would have a net negative environmental effect. This approach intrinsically assumes that the ecological communities (plant species) being protected are the communities that are presently at the location, rather than any conceivable ecological community.

2.3 British Columbia

The approach taken in Alberta is not without precedent; British Columbia (BC) Wildlands land use designation allows for the elimination of all human health pathways except for a modified direct soil contact pathway and the protection of groundwater used for drinking (BC CSR 2018). Furthermore, BC does not require consideration of potential future irrigation and livestock watering (BC Ministry of Environment Protocol 21, 2017), and under risk-based closure, arguments of low probability of receptor exposure can be made in the risk-assessment itself (*e.g.,* future likelihood of the area becoming a viable wildlife habitat). BC also explicitly separates out a "high density residential land use" with different assumed characteristics than the traditional residential exposure scenario.

2.4 Ontario

In Ontario the guiding principles for the development of effects-based criteria were described first in the "*Rationale for the Development and Application of Generic Soil, Groundwater and Sediment Criteria for Use at Contaminates Sites in Ontario*" (MOEE 1996). The principles were updated and refined in the 2011 update (OMOE 2011). Primarily, remediation of contaminated sites protects "potential" adverse effects and the "likelihood" of adverse effect through the removal of waste. However, should materials remain on-site, the use of Generic Site Condition Standards may not be appropriate and risk management measures or risk assessment may be required. Under the risk-based approach it is this "potential" and "likelihood" of receptor impact that becomes the question that must be answered.

2.5 Regulatory Precedent Summary

The LPR concept is already implicitly incorporated into various aspects of the Alberta framework, as well as that of other jurisdictions. Tier 1 guidelines are derived to be protective of receptors considered most likely to be present under each defined generic land use while excluding, by definition, those not likely to be associated with that land use. Tier 2 allows the further exclusion of specified receptors or exposure pathways if they are demonstrated to be absent or non-operative, and Tier 2 site-specific risk assessment additionally allows further refinement of exposure scenarios based on site-specific conditions.

A key premise of the current regulatory framework is that all levels of site management ensure an equivalent level of protection of human health and the environment. The LPR approach is entirely consistent with this goal in that all receptors that are present or likely to be present are protected to the same degree as they would be under Tier 1, and receptors with a low probability of occurrence can be excluded without the need for risk management or exposure control. The LPR approach is therefore simply an extension of the existing Tier 1/Tier 2/SSRA continuum of contaminated site management, while also supporting Alberta's stated policy outcomes related to pollution prevention, health protection and the promotion of productive use. Consequently, regulatory adoption of the LPR approach would not be expected to necessitate a significant change or departure from current legislation or regulatory provisions. Options for incorporating LPR into the regulatory framework are the subject of a future phase of this work.

In summary, the LPR approach is consistent with the protection goals of Tier 1 and Tier 2, and simply represents an extension of the current Tier 1/Tier 2 framework for the management of contaminated sites. As such, it does not represent a significant departure from current contaminated sites policy in Alberta.

3.0 FUTURE RECEPTOR EVALUATION

The objectives of the LPR approach are to provide for pollution prevention, health protection, maximize productive use and to reduce impacts to the environment and human health associated with remediation activities that are not providing receptor protection. The objective of this document is to provide the scientific rationale supporting a LPR approach and to provide technical considerations into the application of LPR.

This section of the scientific rationale provides technical considerations to:

- Methodologies used to predict probability of future receptors;
- Application of probability of future receptor outcomes; and
- Site-specific modification of future probability mapping.

As outlined in Section 2.2.2, the LPR approach is consistent with current Tier 2 guidance and will be another tool used to achieve site closure on a site-specific basis. Comparable to the Tier 2 approach for excluding the DUA based on the presence of a barrier unit, the application of the LPR could be used to exclude a water well receptor based on the probability of its future existence being extremely low.

The following sections provide the methodology by which the future probability of a receptor's occurrence at any given location within Alberta can be determined.

3.1 LPR Calculation Methodology

3.1.1 Receptor Selection

A number of receptors included in Alberta's land use framework are frequently absent and/or not present under the receptor profile assumed in regulatory guidance and should therefore be considered for inclusion within a site-specific receptor analysis approach. The receptors include, but are not limited to, dugouts, water wells used for consumption, residential buildings, agronomic crops, vegetation species, burrowing wildlife and freshwater aquatic life species.

MEMS completed a review of receptors and initially selected dugouts, water wells, residences and plants (ecological direct contact) for calculating future probability. The detailed results for dugout methodology and water well methodology are presented herein. The status of assessment of residential buildings is summarized at high level.

3.1.1.1 Dugouts

In Alberta, surface water or shallow groundwater may be intercepted by dugouts used for livestock watering or irrigation water under an agricultural land use scenario or grazing lease (AEP 2016a). Without consideration of the actual future potential for a dugout to be created, removal of this pathway is generally considered Exposure Control. The only existing modification is that impacts must be proven to exist beyond the depth of surficial excavations for these purposes or that the aquifer was pre-determined to not be suitable for livestock watering and/or irrigation.

3.1.1.2 Water Wells

The definition of a Domestic Use Aquifer (DUA) is dependent on the amount of water an aquifer can produce, rather than the quality of the water in the aquifer. A DUA is an important current and future groundwater resource and, under current Alberta policy and regulation, must be protected to the maximum extent possible and therefore the compliance point for the human health water ingestion pathway is everywhere within a defined DUA. No consideration is provided on the actual future potential for a water well to be drilled for domestic (drinking water) purposes. In Alberta, the only existing modifications which are allowable for a DUA exclusion include:

- presence of a geological barrier or isolating unit between the base of impact and the surface of the DUA (applicable only to non-conservative chemicals) (AEP 2016b);
- exclusion of the DUA in a community with a by-law prohibiting the installation of water wells under an Exposure Control program (AEP 2016b); and
- naturally saline conditions precluding the aquifer for use as a drinking water source (AEP 2016b).

3.1.2 Calculating Future Probability

When a receptor is absent from a site, there is no current risk to that receptor. In order to predict the probability of future risk to receptors (*e.g.,* dugouts or water wells), a prediction of the rate of change in the number of these receptors over time is required. Figure 2 shows four scenarios for the rate of change in the number of receptors: i) where no presence has occurred historically, a < detection limit value is set, ii) where there is a linear increase in the number of receptors over time, iii) where there is a non-linear increase over time, and iv) where there is a non-linear decrease over time.

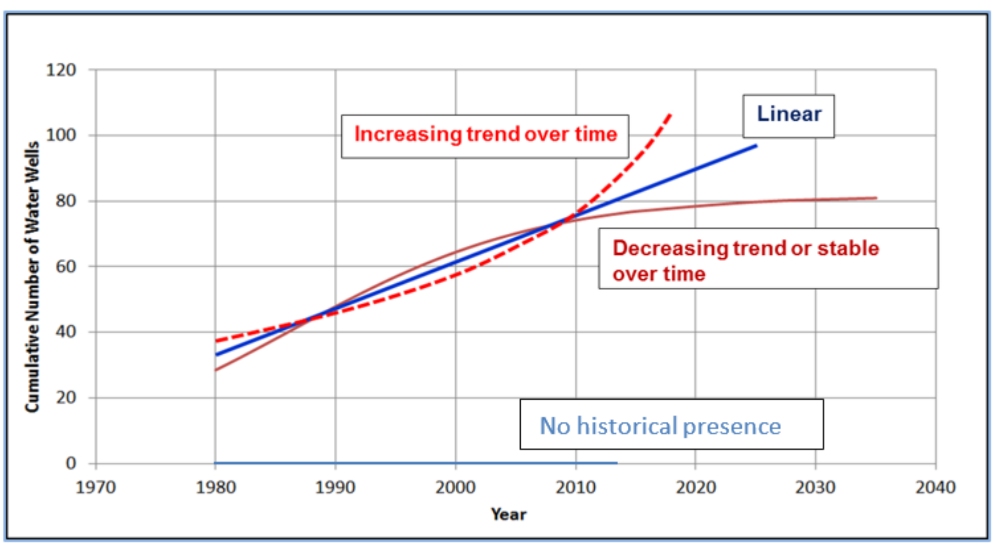


Figure 2. Rate of Change in the Number of Receptors Over Time

3.1.3 Dugouts

In order to quantify the historical and current density of dugout within a specific region of Alberta, MEMS accessed historical aerial photography from 1988 to 2012 and the Alberta Biodiversity Monitoring Institute (ABMI) database.

A comprehensive statistical analysis was conducted with the goal of determining the likelihood of a dugout being present in the vicinity of a site, based on actual spatial dugout density data; and, the likelihood of a dugout occurring in the vicinity of a site in the future. In this manner, providing the ability to estimate the probability of a dugout occurring within a given region, municipality, land management area or other appropriate map unit allows for an estimate of the future potential probability of a dugout occurrence.

3.1.4 Dugout Data Source

The data used for dugout assessment was based on the recently released land use footprint datasets by ABMI (ABMI 2016). The datasets provide digitalized identification of dugouts and other surface features occurring in tiles approximately 3 by 7 km distributed evenly across the province (Figure 3). The datasets are available for the years from 1999 to 2014.

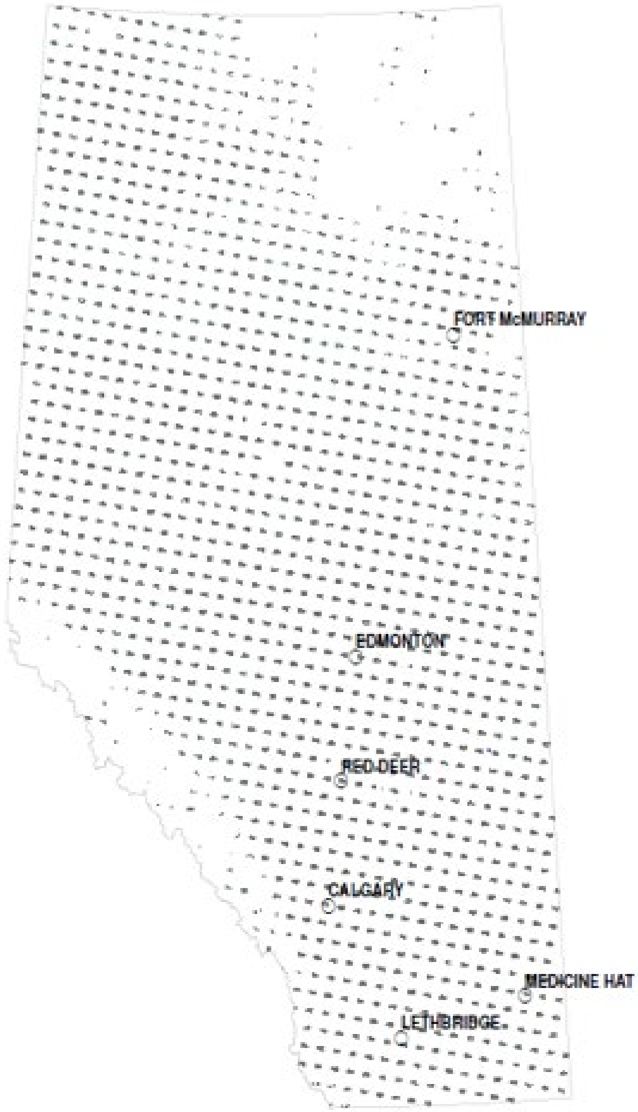


Figure 3. ABMI dataset. The grey dashed areas represent individual tile data, each tile measures approximately 3 km by 7 km.

3.1.4.1 Prediction of Future Dugouts

Prediction of future dugout numbers is made by establishing trends based on historical data. The trend analysis is the cumulative number of dugouts in the tile based on a year over year review. The total number of dugouts per tile is plotted overtime and the data is assessed under a linear and a decreasing or stable non-linear (hereto described as non-linear) extrapolation.

A linear extrapolation is computed using the default Excel linear trend line fitting tool. The predictions based on a linear trend line extrapolation are considered to be a conservative overestimation of future dugout numbers, since the growth of dugouts is more likely to be non-linear and bounded by a maximum number of dugouts required or physically feasible in the area. The non-linear trend line is established based on the concepts as described below.

To establish the non-linear trend line, the following formula is used to fit the historic cumulative number of dugouts:

$$\boldsymbol{N_T = \frac{N_{max}}{1+e^{-\alpha(t-t_0)}}} \qquad \text{Equation 1.}$$

Where:

N_T	=	cumulative number of dugouts at time t
N_{max}	=	maximum number of dugouts in the area
t	=	years
t_0	=	time when half of the max number of dugouts is constructed
α	=	a parameter describing how fast N approaches N_{max}

For the dugout trend line, parameters $\boldsymbol{t_0}$ and $\boldsymbol{\alpha}$ are determined by matching the data using the least square fit method. The maximum number of dugouts ($\boldsymbol{N_{max}}$) is derived from the area required to collect surface runoff to support a typical dugout (assembly 1 million imperial gallons in volume). Using Alberta Agriculture and Forestry (AAF) mapping data, the area required to support a typical dugout is computed. That area (supporting the assembly of 1 million imperial gallons) is then scaled to the area of a tile (21 km^2), and the maximum number of dugouts ($\boldsymbol{N_{max}}$) within that tile is estimated. The number is further adjusted (upward) based on an assumption that two third of the dugouts are supported by surface runoff and one third are connected to surface water bodies directly (the total number of dugouts is increased by one third).

3.1.4.2 Calculation of Probability -Theory and Formulae

The probability of occurrence of a future dugout within the boundaries of the contaminant plume is estimated using the binomial cumulative distribution function:

$$\boldsymbol{\Pr(x \le Nt) = \sum_{i=1}^{Nmax} \binom{N_t}{i} p^i \,(1-p)^{N_t - i}} \qquad \text{Equation 2.}$$

$$p = \frac{APEC_{MAX}}{A_D} \qquad \text{Equation 3.}$$

Where:

Pr(x)	=	cumulative probability of obtaining x successes in Nt independent trials.
N_{max}	=	maximum number of dugouts supported in the area.
Nt	=	predicted total number of future dugouts in the area from now to time t ($N_t \le N_{max}$).

x	=	x is the number of dugouts occurring on the Site ($1 \leq x \leq N_t$).
p	=	constant probability of a future dugout occurring in the area of impact for each independent trial.
$APEC_{MAX}$	=	Maximum Predicted Area of Potential Environmental Impact (km^2)
A_D	=	Area used to define dugout growth potential (either the area of a Tile [data ABMI] or the area of a township [MEMS dataset]).

Each time a dugout is constructed in the area (defined as A_D) there is a probability that the dugout will occur within the boundaries of the impact; defined as the Maximum Predicted Area of Potential Environmental Contamination ($APEC_{MAX}$). That probability is defined by the binomial distribution function (Equation 2). As time passes and more dugouts are added into the area defined as A_D it was assumed that each new dugout has the potential to occur on the Site at an equal probability and a cumulative probability that one or more of those newly constructed dugouts will occur within the boundaries of the $APEC_{MAX}$ was calculated.

The probability of having one or more dugouts occurring at the Site is calculated as a cumulative probability function. It is the cumulative probability that $x \geq 1$ dugouts will occur at the Site for Nt dugouts constructed in the area. Another way to consider this is that we are calculating the cumulative probability that one or more dugouts could be constructed within the contaminant plume up to and including the maximum number of dugouts that would be supported in the area (N_{max}). Since we are interested in the probability that no dugouts occur at any given location we can simplify the expression provided in Equation 2 as follows:

$$\Pr(x < 1) = \binom{N_t}{x} p^x (1-p)^{N_t - x} \qquad \text{Equation 4.}$$

Where x = 0 (there is no dugout at the Site) Equation 3 can be further simplified:

$$\Pr(0) = \binom{N_t}{0} p^0 \, (1-p)^{N_T - 0} \qquad \text{Equation 5.}$$

$$\Pr(0) = (1-p)^{N_T - 0} \qquad \text{Equation 6.}$$

Equation 6 is therefore the probability that no dugouts will occur on Site. Since the probability is any number between 0 and 1, we can calculate the probability that any number of future dugouts will occur at the Site ($1 \leq x \leq N_{max}$) by subtracting 1 by Pr(0):

$$\Pr(\mathrm{x}) = 1 - [(1-p)^{N_t}] \, ; 1 \leq x \leq N_{max} \qquad \text{Equation 7.}$$

As previously defined, p is the ratio of the impacted area ($APEC_{MAX}$) to the area in which the prediction of future dugout numbers was made (A_D). Since the area of the $APEC_{MAX}$ is small relative to the size of A_D (either a township [93.2 km^2] or a tile [21 km^2]) p is also very small. In fact, when both N_t and p are relatively small (Nt < 45 and p < 0.05) the expression $(1-p)^{N_t}$ approaches 1; the entire equation can be simplified as follows:

$$\Pr(x) = x\,\frac{APEC_{MAX}}{A_D}\,;\ 1 \le x \le N_{max} \qquad \text{Equation 8.}$$

Interestingly, as the number of dugouts is bound by a theoretical limit (N_{max}), and $A_D \gg APEC_{MAX}$, the probability of a future dugout regardless of location in the province is confined and there is negligible difference in evaluation of the future probability by either binomial or linear extrapolation (Figure 4).

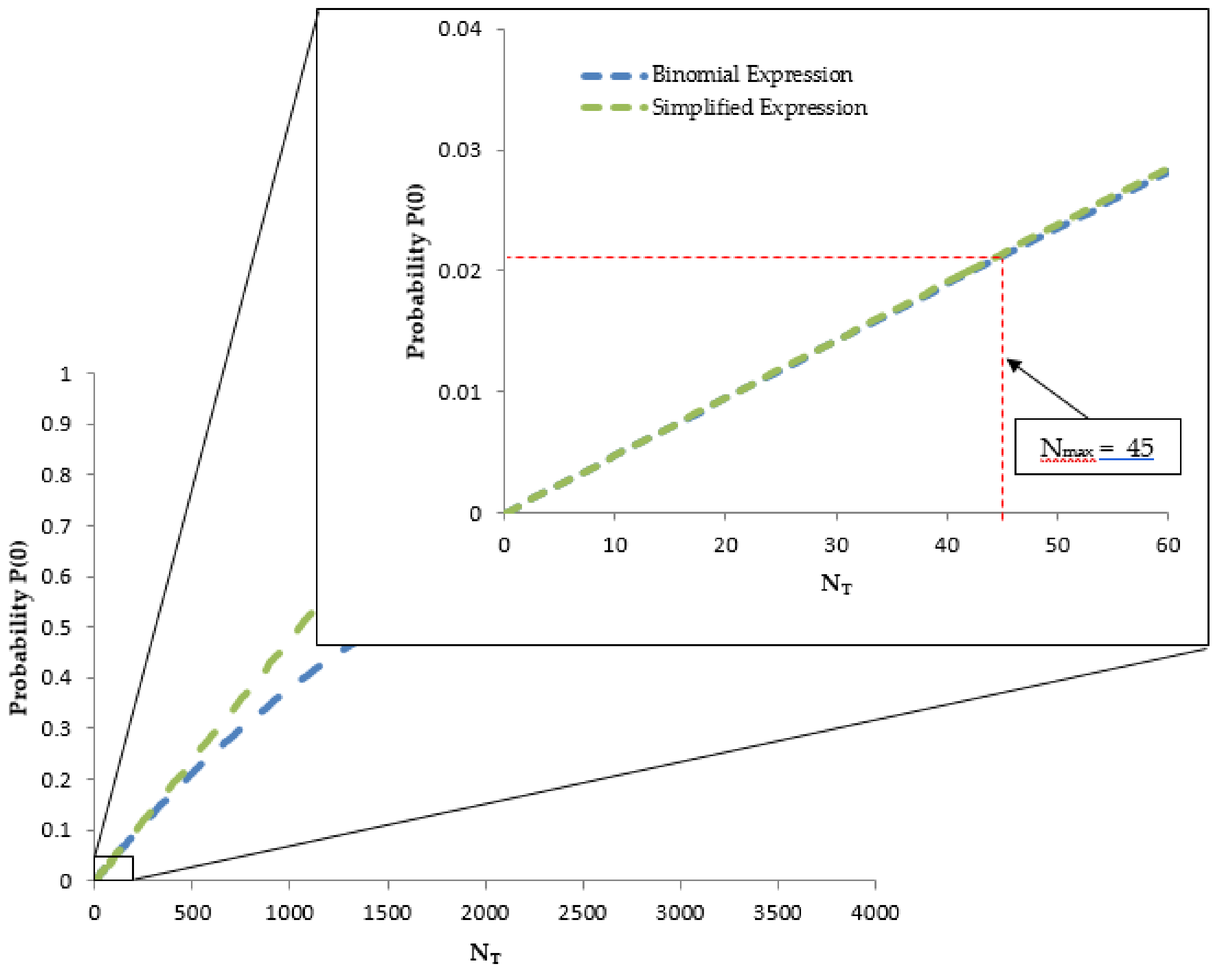


Figure 4. The probability of a future dugout occurring on the Site scaled from 0 (0%) to 1 (100%) as a function of the predicted number of future dugouts. Note that the Figure is zoomed in to show the probability of a future dugout at an N_{max} of 45 (the maximum number of future dugouts that is typically supported in a 21 km² agricultural area in Alberta).

A shown in Figure 4, the future receptor probability is adequately expressed through non-linear extrapolation, and therefore it is unnecessary to define an upper bound (N_{max}). Instead, the number of dugouts is simply calculated, as previously indicated, using the default Excel linear trend line fitting tool:

$$x = mt + b \qquad \text{Equation 9.}$$

Where:

x	=	number of future dugouts
m	=	slope (as defined by Excel linear trending)
t	=	number of years defined in model prediction
b	=	intercept at time zero

3.1.4.3 Determining Area of Impact

The $APEC_{MAX}$ for the dugout assessment can be determined based on the results obtained during an intrusive investigation (*e.g.,* Phase 2 ESA) or through more advanced modelling practices (*e.g.,* Mod-flow, HYDRUS 3D, *etc.*).

3.1.5 Probability Derivation

With respect to the derivation of dugout probability, a limited coverage of the province is available (a scattering of 3 x 7 km tiles). Hence, those areas between the tiles are not independently evaluated but were instead calculated using a geostatistical gridding method (*i.e.,* kriging) in order to express trends between the tiles. This technique could result in either an under or overly conservative LPR calculation.

The regression model used in approximating the number of dugouts is, at times, negative. This indicates that fewer dugouts occurred in the region over time. A cause of this could be the conversion of land from a grazing lease to a crop. When trends were negative, the slope (linear approximation) was forced to zero (non-increasing). This is a conservative step as it assumes neutrality or growth only; resulting in a conservative LPR calculation.

3.1.5.1 Dugout Assessment Assumptions

The ABMI data-set is missing data from three years (2000, 2002 and 2003) and relies on human interpolation of what is and is not a confirmed dugout. As probability is based (in part) on a linear extrapolation of the AMBI data set the absence of these three years (given the dataset spans from 1999 to 2014) is not expected to impart a material effect on the interpolation of the data. In addition, the data while not being publicly available at this time, is in process of being updated and therefore future refinement is possible.

The ABMI data-set has, at times, misidentified water bodies (*e.g.,* sewage lagoon) as a dugout. While the misidentification of a water body as a dugout may lead to an increase in the assumed number of dugouts in an area, the reverse, not identifying a water body that is, in fact, a dugout appears to be a low likelihood occurrence. The potential error of misidentified water bodies is therefore considered to impart conservatism in the model. To verify the ABMI dugout data, MEMS conducted an additional detailed aerial photo review and cross-referenced the data in ABMI to air photos taken in 1988, 2000 and 2012. The MEMS data was used to create an alternative assessment of the dugout probability in comparison with the assessment based on the ABMI datasets (prediction methods are detailed in the following sections). Findings of the dugout review provided independent verification/validation for the use of ABMI dugout data.

3.2 Calculating Future Water Wells Probability

3.2.1 Water Well Data Sources

Alberta Environment and Parks (AEP) Alberta Water Well Information Database (AEP Water Well Database) is used in the water well probability assessment. The dataset provides information for water wells drilled in the province and provides both the geographical locations of water wells drilled and the depth at which the wells were completed.

3.2.1.1 Prediction of Future Water Wells

Prediction of future water well numbers is made using trends based on the historic water well records from the AEP Water Well Database. Due to the variability in completion depths, probability estimates are generated at a range of completion intervals which are generally associated with the underlying aquifer. Linear trend lines are established using the default Excel linear trend line fitting. Non-linear trend lines are established using the same method as the predictions for dugout number (Equation 1, Section 3.1.2) except that the maximum numbers of water wells are estimated based on curve fitting.

3.2.1.2 Calculation of Probability

Calculation of future water well probability is conducted using the same method as the calculation for the dugouts (Equation 8; Section 3.1.3), with some changes which may be applied on a Site-specific basis:

- The N_{MAX} is based on the land density allowance for title per quarter section (0.65 km^2) and scaled to the area of a township (approx. 93.2 km^2).
- Depth to a DUA. If a DUA has not been identified in any of the historical boreholes advanced on Site (as part of the Phase 2 ESA) then the DUA is assumed to exist beneath the maximum

depth of investigation. For example, if the maximum depth of investigation was 20 m the DUA would be assumed to exist at a depth of >20 m bgs.

- The $APEC_{MAX}$ changes with depth as the plume migrates. Therefore, the probability is independently evaluated for the various depths at which a well could theoretically be screened.

3.2.1.3 Water Well Assessment Assumptions

Not all water well records in the database have complete information datasets as required to complete an LPR assessment (*e.g.*, depth of installation, or purpose of well). As a result, not all water well records can be used in the LPR calculations and these wells were removed from the dataset. The result is that this may reduce the number of wells assumed in an area and therefore result in a less conservative approximation. However, inclusion of these water wells could be used to generally identify the presence and/or absence of water wells in a given area. The result of this inclusion, if applied, would increase the total number of water wells and therefore add a level of conservatism to the model.

It is assumed that all water wells drilled and documented in the AEP Waterwell Database still exist and are in use. This does not account for wells that have been abandoned, and as a result imparts a more conservative approximation of the number of wells in an area as the database is constantly additive (replacement wells are assumed as new installs).

While it is mandatory that water wells be updated into the AEP Waterwell Database, this assumption may not always hold true. Missing water wells from the database is more prevalent for wells installed pre-1980. The absence of a water well record would make the resultant LPR calculations less conservative.

3.2.2 Residential Buildings

Work conducted on residential buildings, and therefore residential receptors in agricultural land use areas, has identified a future probability mapping approach similar to the dugout work undertaken will be suitable for this receptor.

3.2.3 Application of Probability Mapping Outcomes

Four scenarios for the probability of future receptors were identified, these being:

- where no presence has occurred historically and a < detection limit value is set for future receptors;
- where there is a linear increase in the number of receptors over time;

- where there is a non-linear decrease or stable over time; and
- where there is a non-linear increase over time.

The potential applications of these scenarios are discussed below.

No Historical Presence

In instances of no historical presence, the probability of a future receptor is defaulted to a detection value based on the data set of the receptor and the particular area of Alberta. This default value is typically less than 0.001%/annum/hectare. In other words, <0.1% over a hundred years in a given hectare. It is proposed that an occurrence of <0.1% in the next hundred years coupled with no occurrence to date would mean that this receptor is not a "normal" activity under the four land use categories. Should this viewpoint be accepted, then the application of this outcome could be the removal of the receptor from the land use for the specific area of the province under consideration.

Linear Increase in Future Probability

A linear increase in future probability is used as a conservative approximation of a non-linear decreasing trend. The linear future projection extrapolates from exiting historical data, per the discussion under methods. The application of linearly increasing trend is to represent future probability within a local study area without site specific modifications, *i.e.*, a generic future probability of receptor at local study area level. This circumstance differs from the "no historical presence" scenario as the presence of the receptor at a certain level would represent a normal activity for the land use category. It is proposed that remedial objective criteria can be modified to remove low probability future receptors provided that appropriate backstop measures are in place to address changing circumstances at the site. This position is analogous to current AEP/AER guidance relating to concentrations of chemicals or concern which frequently states "… this does not absolve any party from future liability should the land use change or additional concerns arise from contaminants remaining onsite or offsite".

Non-Linear Decrease

A non-linear decrease is similar to a linear increase with the exception that site-specific attributes are included in the local study area future probability assessment to produce a site-specific prediction of future occurrence.

Non-Linear Increase

It is proposed that an occurrence of a non-linear increase in predicted future probability would mean that the particular receptor with increasing future probability cannot be removed or modified using LPR approaches.

3.3 Mapping Future Dugout and Water Well Probability

To assess the future potential probability of occurrence across the whole of the province two key input assumptions are required. Specifically, the size of the impact ($APEC_{MAX}$) and the number of years (t) to be run in the prediction model. This was simplified by assuming $APEC_{MAX}$ is equal to 1 hectare (*i.e.*, a typical oil and gas lease size, 100 x 100 m) and the number of years run in the prediction model is 1; effectively generating a provincial map providing the %probability/annum/hectare.

3.3.1 Provincial Probability Mapping

Using the equations presented in Section 3.2, MEMS mapped the entire province of Alberta for the future probability of both a dugout (Figure 5) and water wells installed from 0 to 10 m (Figure 6), 10 to 20 m (Figure 7), 20 to 30 m (Figure 8) and depths >30 m (Figure 9).

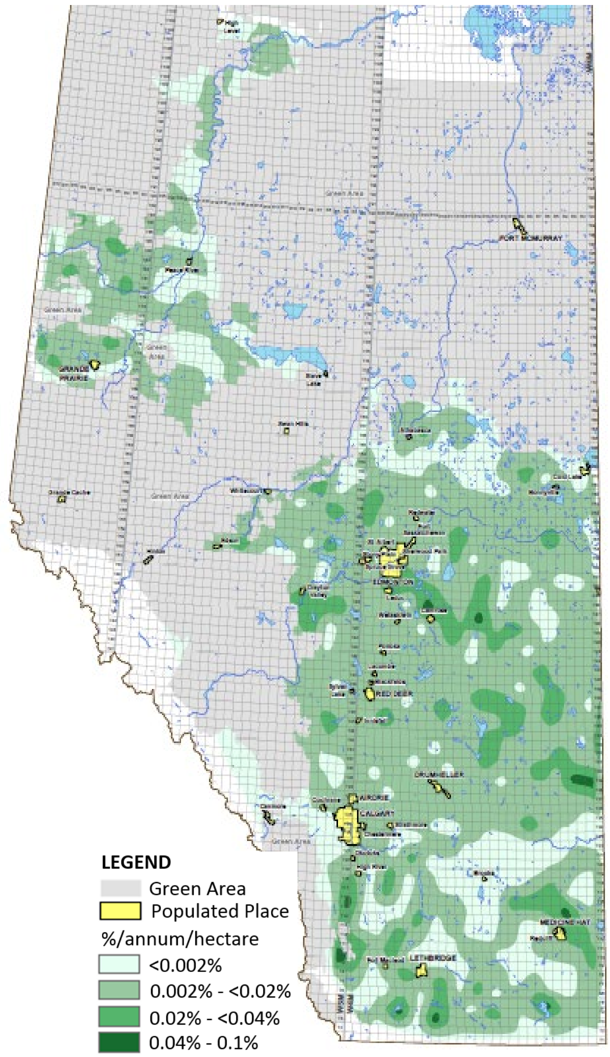


Figure 5. Province-wide dugout probability mapping (% probability/annum/hectare).

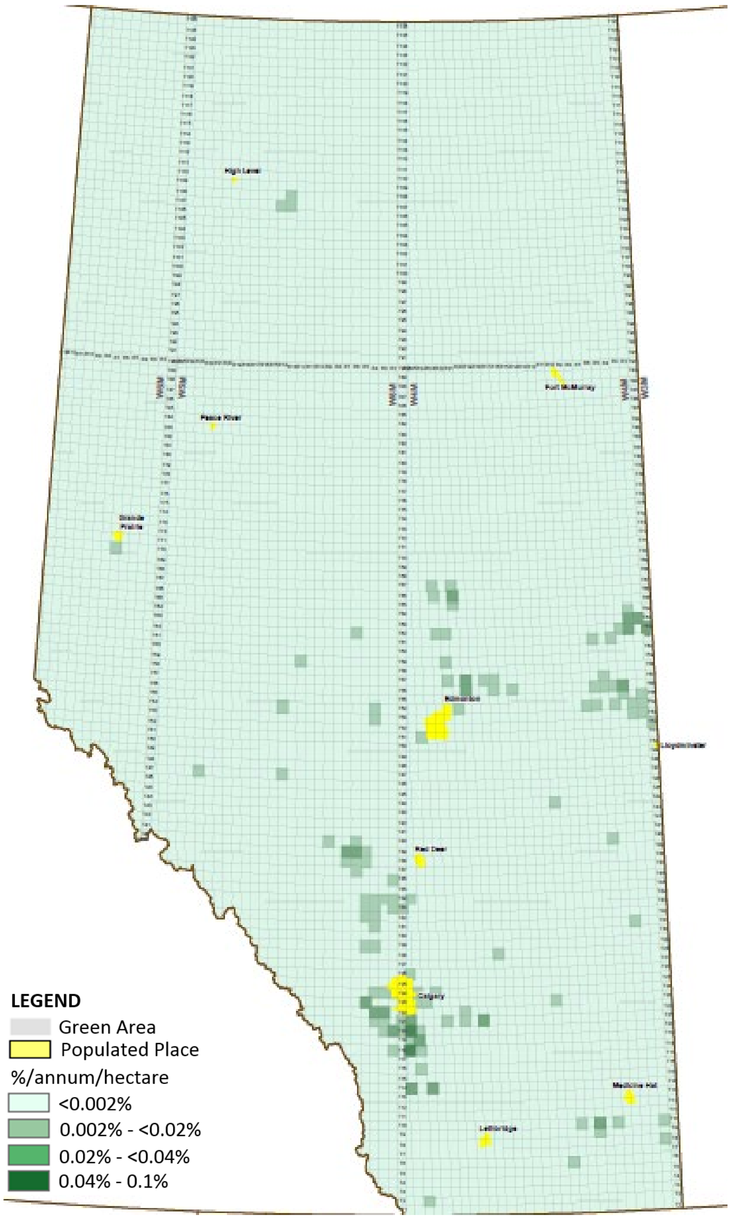


Figure 6. Province-wide water well probability mapping for wells installed from 0 to 10 m bgs (% probability/annum/hectare).

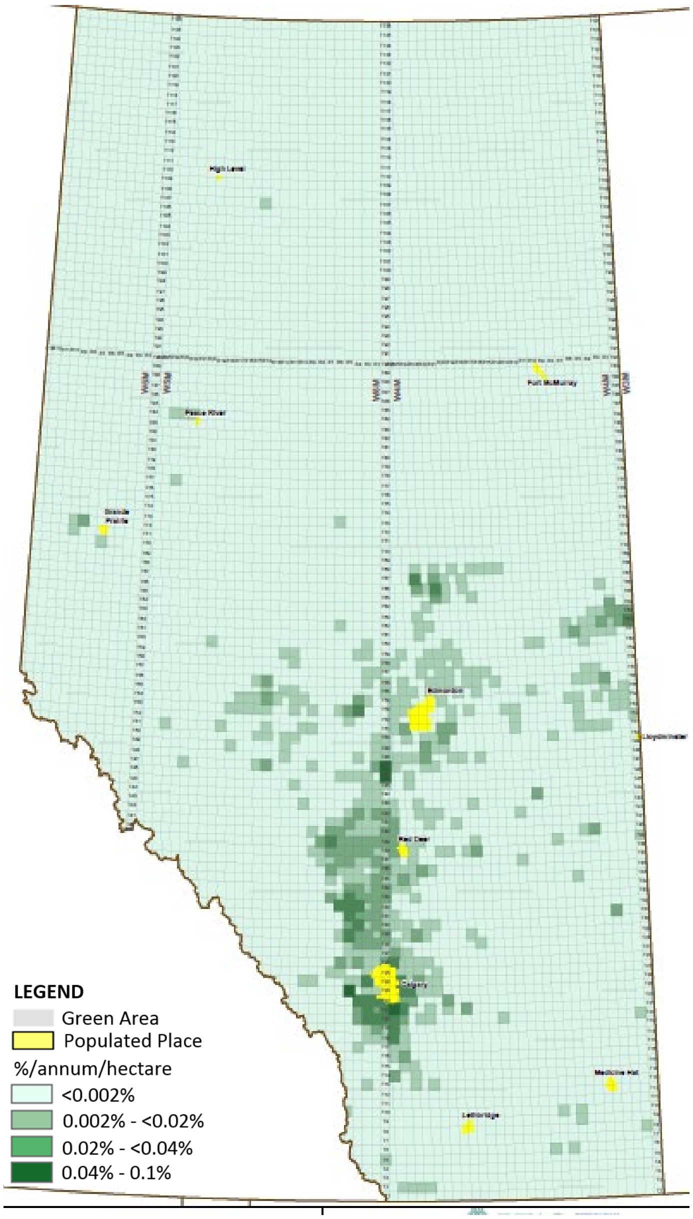


Figure 7. Province-wide water well probability mapping for wells installed from 10 to 20 m bgs (% probability/annum/hectare).

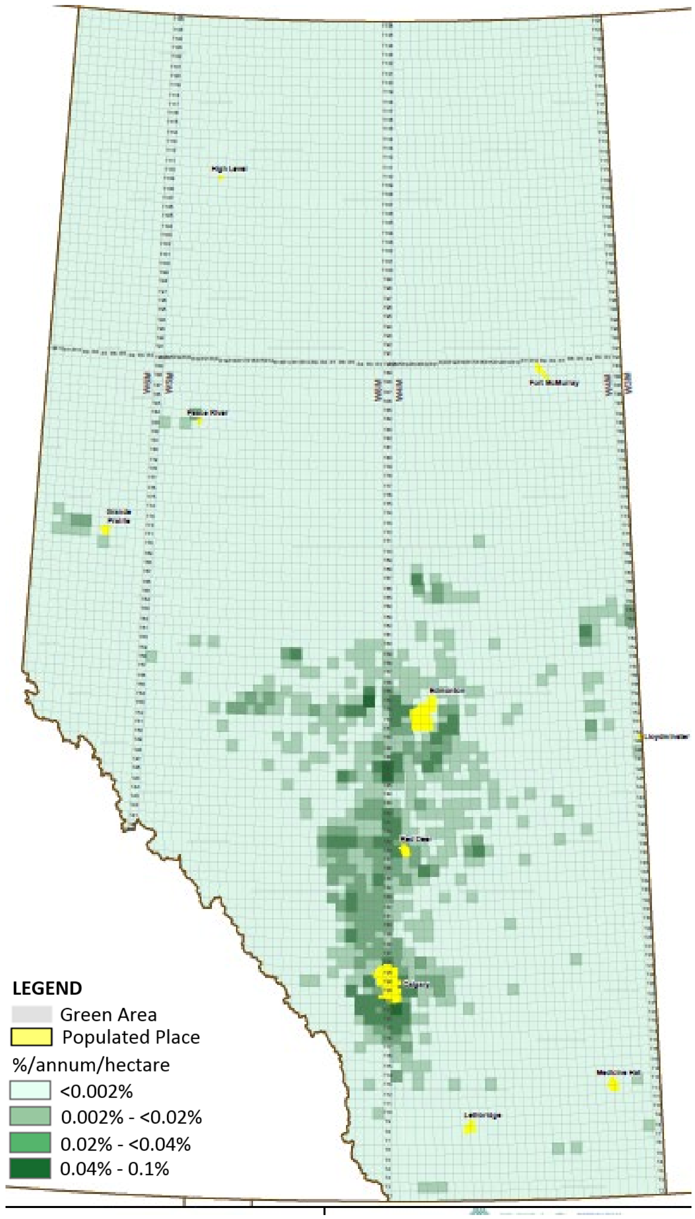


Figure 8. Province-wide water well probability mapping for wells installed from 20 to 30 m bgs (% probability/annum/hectare).

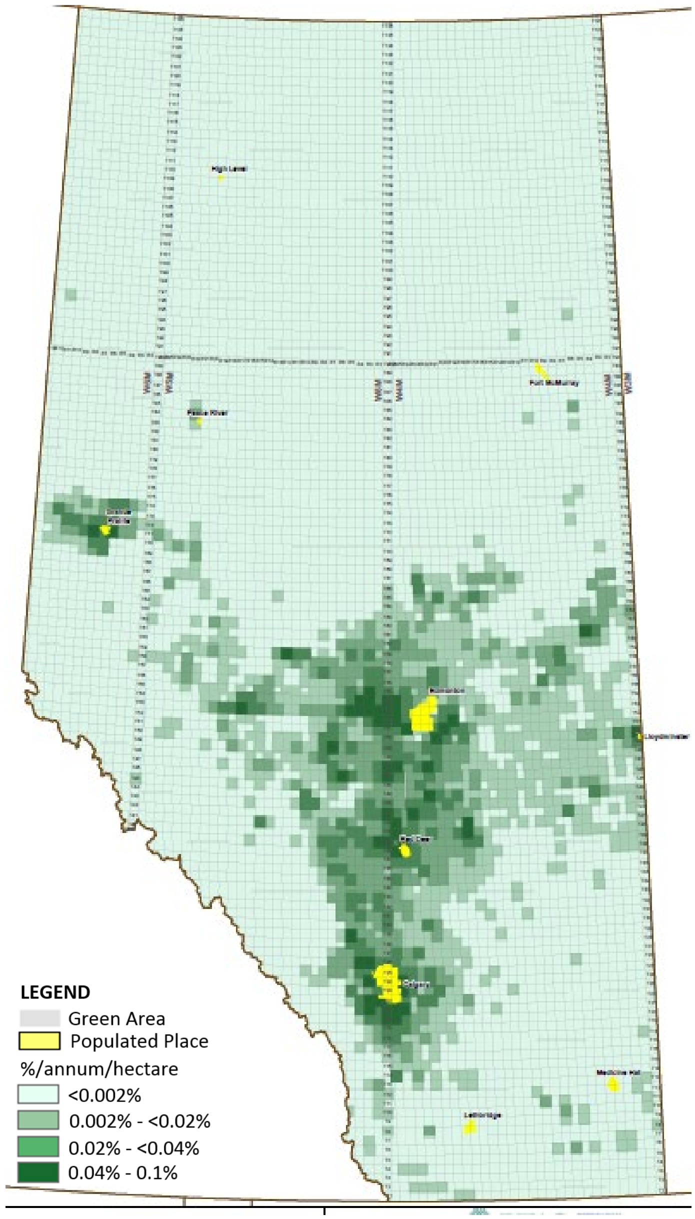
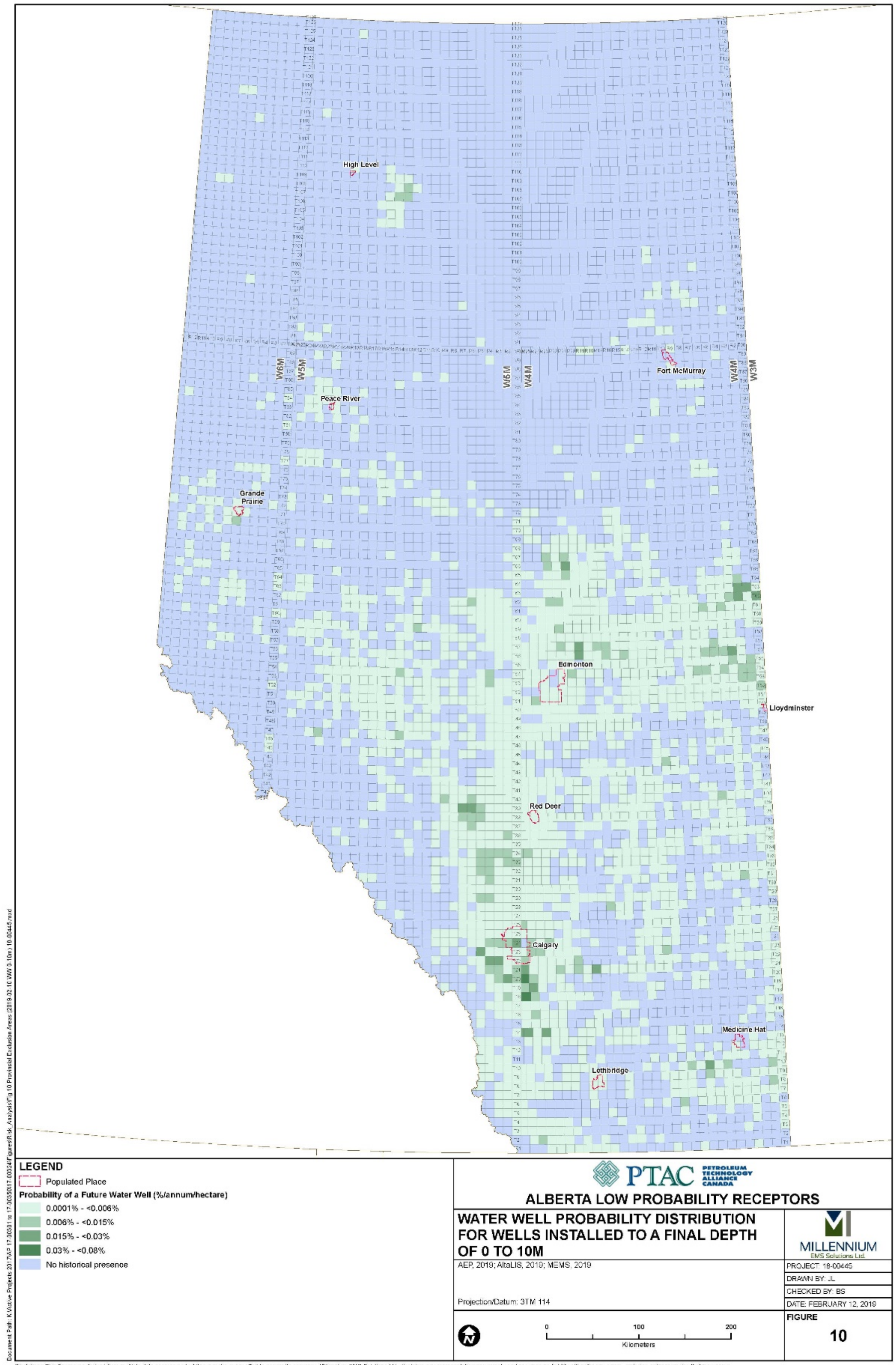
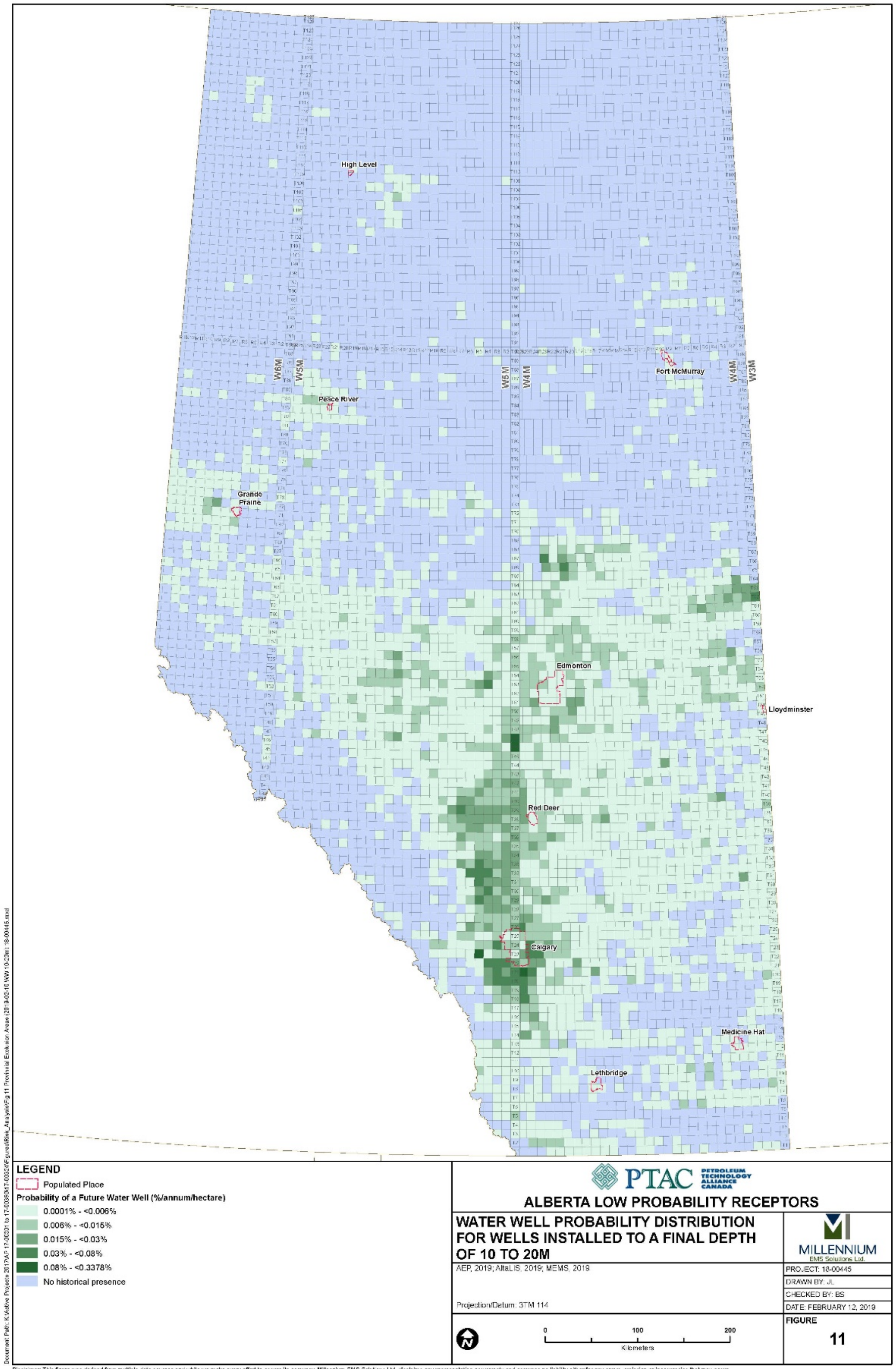


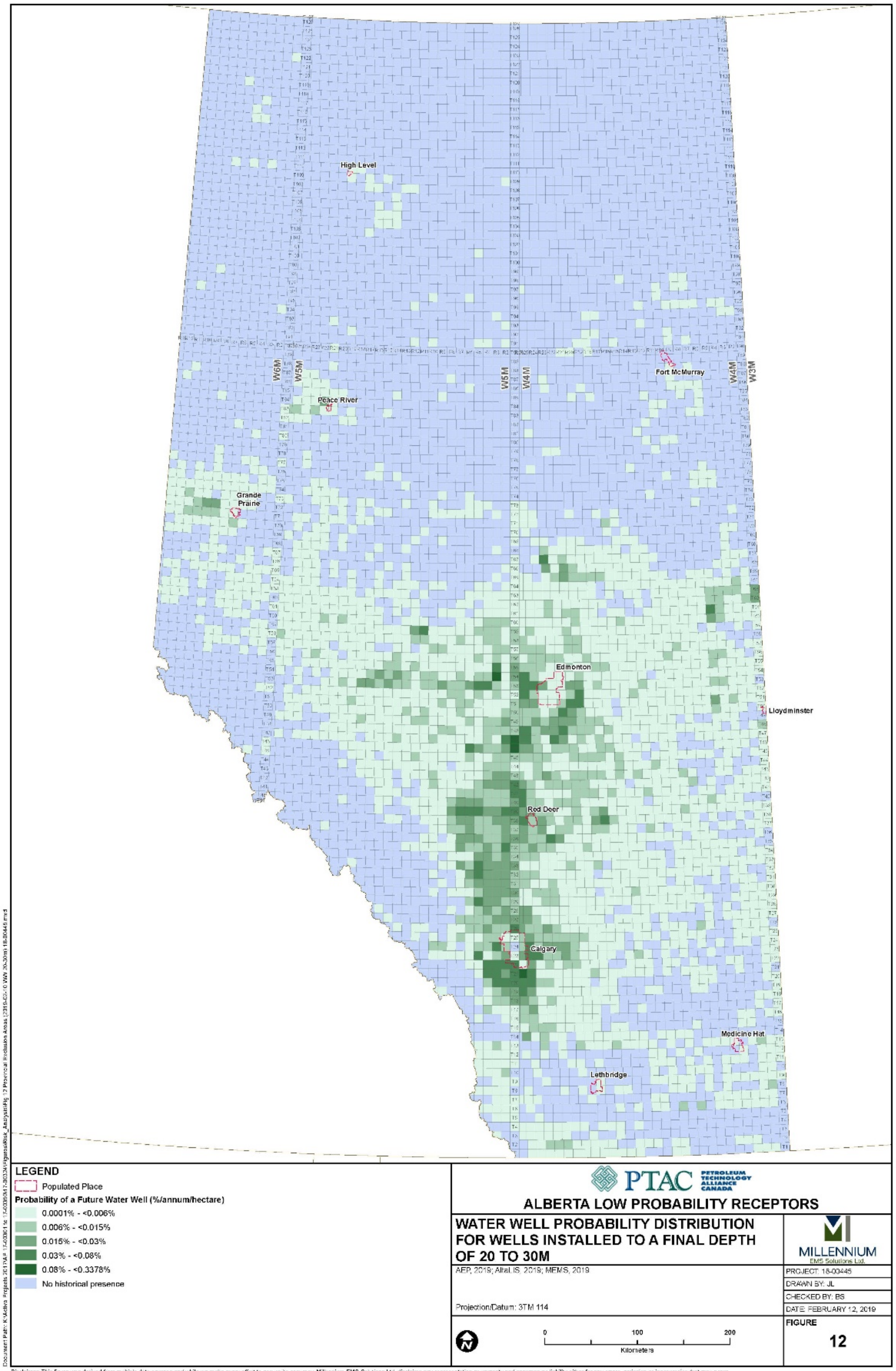
Figure 9. Province-wide water well probability mapping for wells installed > 30 m bgs (% probability/annum/hectare).

MEMS has also mapped regions of the province with "no historic presence" of the water well receptors. This mapping is presented in Figures 10, 11, 12 and 13.

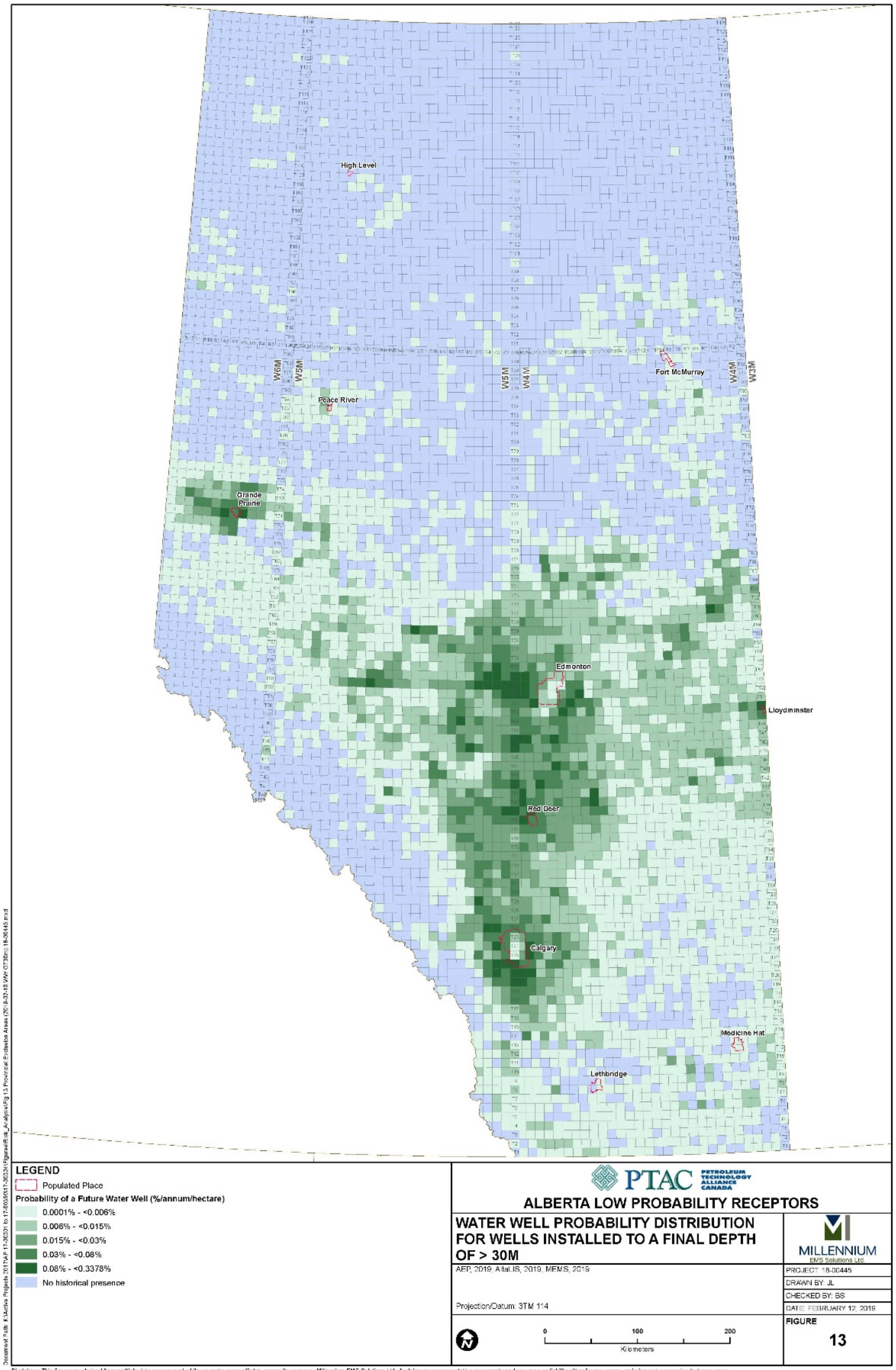

High Level
Peace River
Fort McMurray
Grande Prairie
Edmonton
Lloydminster
Red Deer
Calgary
Medicine Hat
Lethbridge
W6M
W5M
W4M
W3M
LEGEND
Populated Place
Probability of a Future Water Well (%/annum/hectare)
0.0001% - <0.006%
0.006% - <0.015%
0.015% - <0.03%
0.03% - <0.08%
No historical presence
PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA
ALBERTA LOW PROBABILITY RECEPTORS
WATER WELL PROBABILITY DISTRIBUTION FOR WELLS INSTALLED TO A FINAL DEPTH OF 0 TO 10M
MILLENNIUM EMS Solutions Ltd.
AEP, 2019; AltaLIS, 2019; MEMS, 2019
PROJECT: 18-00445
DRAWN BY: JL
CHECKED BY: BS
Projection/Datum: 3TM 114
DATE: FEBRUARY 12, 2019
FIGURE
10
0
100
200
Kilometers
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.



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.



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.


High Level
Fort McMurray
Peace River
W6M
W5M
W4M
W3M
Grande Prairie
Edmonton
Lloydminster
Red Deer
Calgary
Medicine Hat
Lethbridge
LEGEND
Populated Place
Probability of a Future Water Well (%/annum/hectare)
0.0001% - <0.006%
0.006% - <0.015%
0.015% - <0.03%
0.03% - <0.08%
0.08% - <0.3378%
No historical presence
PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA
ALBERTA LOW PROBABILITY RECEPTORS
WATER WELL PROBABILITY DISTRIBUTION FOR WELLS INSTALLED TO A FINAL DEPTH OF > 30M
MILLENNIUM EMS Solutions Ltd.
AEP, 2019; AltaLIS, 2019; MEMS, 2019
Projection/Datum: 3TM 114
PROJECT: 18-00445
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CHECKED BY: BS
DATE: FEBRUARY 12, 2019
FIGURE
13
0
100
200
Kilometers
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.

3.4 Future Probability Assessment

In effort to simplify this process the Future Probability Assessment has been designed to progress through the three LPR assessment approaches (as outlined in Section 3.3): No Historical Presence approach; Linear LPR approach; and Non-Linear Decreasing (Site-Specific) approach.

Under the **No Historical Presence approach**, the receptor is removed from assessment.

Using the province wide mapping data, which provides the probability of future occurrence of either a dugout or a water well, the actual probability of a future receptor occurring at a Site becomes a function of multiplying the %probability/annum/hectare by the size of the impact footprint ($APEC_{MAX}$) and the duration of time (t) that the model is to be run.

Under the **Linear LPR approach**, inclusion of receptors (*i.e.,* water well and dugouts) is assessed based on the probability of their future existence given factors related to the site's geographic location within a specific region of Alberta. The only required information for a Linear LPR assessment is the impact footprint ($APEC_{MAX}$) and the duration of time (t) that the model is to be run.

The Linear LPR approach generally includes conservative assumptions regarding the probability of a future receptor's existence; however, there are situations whereby a Linear assessment is not applicable, either where conditions exist that violate one or more assumptions inherent in the model or where the maximum predicted impact area exceeds the threshold limit.

Under the **Non-Linear Decreasing (Site-Specific) LPR approach**, the inclusion of receptors (*i.e.,* water well and dugouts) is assessed the same way as outlined in the Linear LPR approach; however, additional site-specific modifiers, including topography, proximity to road access, type of contaminant, land use and the sites proximity to existing receptors, are included in deriving the probability of future receptor occurrence.

3.4.1 Linear LPR Approach

The application of the Linear LPR approach is considered a generic conservative assessment and is based on the methodology outlined in the previous sections. In order to determine the Linear LPR the assessor need only to provide the geographic location of the site, the maximum area of impact and the duration over which the receptor may occur. For sites that are determined to fall within an LPR zone of <0.002%/annum/hectare they are considered low risk as the probability of a given receptors future existence is negligible. For example, at the lowest end of the predictions limit (<0.002%/annum/hectare) it would take 500 years (assuming a plume dimension of 1 ha) for a cumulative 1% probability of the receptor occurring on-Site.

3.4.2 Non-Linear Decreasing LPR (Site-Specific) Approach

The application of the Non-Linear Decreasing LPR approach includes site-specific modifiers which are applied in the derivation of the probability of future reception occurrence.

To simplify this process of a Non-Linear Decreasing LPR approach, MEMS created the prototype LPR Tool which includes a site-specific analysis package. The LPR Tool allows the user to build out the foundation of an LPR assessment using an interactive platform offered through Microsoft excel. The LPR Tool uses Google Earth Mapping to provide a real-time APEC$_{MAX}$ mapping interface augmented with satellite imagery and the pre-determined provincial probability mapping distribution to calculate a site-specific potential future occurrence of the receptor based on the Linear LPR approach. The LPR Tool is designed to work with inputs that would typically be gathered as part of a Phase 2 ESA meeting the conditions as described in CAN/CSA-Z769-00 (R2008).

3.4.2.1 Site-Specific Modifiers

Topography

Site stability and receptor suitability are influenced by the topography of the site. Sites which exhibit a maximum topographic slope of greater than 30% are considered unstable (ESRD 2014) and would inherently have a lower probability for the future occurrence of a receptor such as a dugout or water well being constructed.

The topography of the site, as well as the surrounding area, provides information that can inform the assessor on the suitability of the site with respect to the location of a future receptor. Understanding this information at a site-specific level allows for the appropriate modification of the future probability of receptor occurrence.

Proximity to Road Access

Ease of access may impart positive influence on the future potential development of a receptor such as the water well or a dugout. Specifically, if the access is only present as a result of the creation of the site, then reclamation, which would remove the access, is likely to also reduce the potential for construction of the dugout or water well.

Type of Contaminant

The type of contaminant provides a number of useful criteria that influence the likelihood of adverse effect on a future receptor. For example, a chemical's half-life can be included in the Non-Linear Decreasing (site-specific) LPR approach to demonstrate the likelihood of chemical degradation within the model LPR timeframe. In this context the Linear LPR approach might indicate a low to moderate probability of future receptor occurrence; however, the type of chemical may have an extremely short half-life which would result is an overall low probability of risk to the receptor.

Land Use

Primary land use criteria provide an indication of the applicability of the receptor(s) inclusion. For example, if the primary land use is restricted heavy industrial, the potential for the presence of a dugout is considered negligible. Conversely, if the land use is agricultural the potential future presence of dugout is assumed to exist regardless of whether or not the dugout is currently present. In addition, secondary land use criteria may also influence future receptor presence. For example, if the Site is within a known grazing lease the potential for a future dugout would be expected to increase at a greater rate than a area used for other agricultural practices.

Proximity to Nearest Existing Receptor

Selection of an appropriate guideline depends on several factors including the type of receptor, the type of contaminant and the distance between the source and the nearest existing receptor. An important consideration as part of an LPR assessment is to understand which pathways are influenced by receptor off-sets (*e.g.*, protection of Freshwater Aquatic Life [FAL]) and whether or not those guidelines would still drive remedial objectives if offset distances were included in a guideline modification under a Tier 2 assessment.

This is an important site-specific modifier as the application of a Tier 2 guideline adjustment can, under specific circumstances, adjust which receptor is driving remedial objectives. Therefore, the LPR Tool provides a mechanism, based on the aforementioned inputs, for which to inform the user if a site is an appropriate candidate for an LPR assessment.

3.4.3 LPR Model Application

There are two specific areas of uncertainty built into the derivation of the future potential probability of a receptor's occurrence. These include:

- Number of years run in the model; and
- Maximum Predicted Area of Potential Environmental Impact ($APEC_{MAX}$).

3.4.3.1 Model Duration

Currently, the number of years run in the model is a user input. Considerations should include, but not limited to, the following:

- Degradation rate (chemical half life); and
- Plume reduction through dispersion, mixing and dilution.

The degradation rate is an important consideration as the longevity of the impact will vary from chemical to chemical. As an example, inorganic contaminates (such as metals) are essentially non-degrading whereas organic chemicals (such as light-end hydrocarbons) will have half-lives that can be on the order of months.

The plume concentration may also decrease over time due to a combination of dispersion, mixing and dilution resulting from contaminant plume migration and freshwater infiltration, all of which are dependent upon atmospheric and/or geological conditions (fine *vs*. coarse grained material). The rate of decrease adds a level of uncertainty when looking to establish a reasonable time-frame by which to run the model prediction.

3.4.3.2 $APEC_{MAX}$

The Maximum Predicted Area of Potential Environmental Impact ($APEC_{MAX}$) is the largest footprint that the impact could conceivably become under the timeframe by which the model is run. In the current framework, the $APEC_{MAX}$ dimensions are defined as the boundary at which soil concentrations meet the lowest applicable guideline (either for the protection of livestock watering [dugout] or protection of the DUA). It should be noted, that this boundary may change as a function of time as well as depth. Hence, $APEC_{MAX}$ may increase, but it can also decrease as the contaminant migrates in both the lateral and vertical directions simultaneously.

To reduce these uncertainties the LPR model does not attempt to predict iterative interpolation year over year of plume dimension. Instead, the $APEC_{MAX}$ plume dimension is assumed as the maximum footprint at a specific depth interval irrespective of time. In this way, the probability function, which is reliant on an estimate of the impact area, retains a level of conservatism.

4.0 EXISTING RECEPTOR EVALUATION

Deliverable due 2019.

4.1 Site Eligibility

4.1.1 Geophysical and Geographical Qualifiers

4.1.2 Chemical Composition

4.2 Receptor Modification

5.0 NET BENEFIT ANALYSIS

6.0 REGULATORY SETTING

Deliverable due 2019.

7.0 REFERENCES

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