Remediating Soil Sterilant-Affected Lands: Summary of Stakeholder Discussions

Bonnie Drozdowski and Simone Levy, InnoTech Alberta

Chris Powter, Enviro Q&A Services

RECLAMATION
250 KARL CLARK ROAD
EDMONTON, ALBERTA T6N 1E4
CANADA

March 29, 2018

DISCLAIMER

This report was prepared as an accounting of work conducted by InnoTech Alberta. Every possible effort was made to ensure that the work conforms to accepted scientific practice. However, neither InnoTech Alberta, nor any of its employees, make any warranty, expressed or implied, or assumes any legal liability or responsibility for accuracy, completeness, or usefulness of any of the information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

InnoTech Alberta assumes no liability in connection with the information products or services made available. References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favouring by InnoTech Alberta. All information, products and services are subject to change by InnoTech Alberta without notice.

ACKNOWLEDGEMENTS

The authors would like to thank staff at the InnoTech Alberta facility in Calgary for hosting the February 8 discussions and the staff in Edmonton for ensuring the remote participation options were available. We would also like to thank all of the individuals who have provided information, documents and insights to kickstart this initiative, particularly Kathryn Bessie, who has been instrumental in previous sterilant research and providing guidance for future directions.

CITATION

This report may be cited as:

Drozdowski, B., S. Levy and C.B. Powter, 2018. Remediating Soil Sterilant-Affected Lands: Summary of Stakeholder Discussions. InnoTech Alberta, Edmonton, Alberta. 42 pp.

EXECUTIVE SUMMARY

InnoTech Alberta's Reclamation Team initiated a project to assess the needs and challenges associated with reclamation and remediation of sites impacted by soil sterilant residues. In Alberta, the problems associated with soil sterilants are becoming more evident as legacy oil and gas sites are abandoned and slated for remediation and reclamation. Many of these sites have been stalled at the remediation phase due to the challenging nature of the contaminants, resulting in a liability and financial burden for industry and an inability to achieve site closure. Sterilants are particularly challenging for a number of reasons:

1. They are difficult to treat, especially to guideline levels;
2. They are often widespread due to the amount of time they have had to migrate, making remedial excavation expensive;
3. Each type of sterilant is unique, with a unique set of challenges; and
4. There are often confounding contaminant issues associated with remediation at legacy sites where sterilants are typically found.

Preliminary conversations with industry indicated there is a need to find a solution to this problem and determine the best approach to manage sites impacted by sterilants. There is a strong indication that companies are interested in participating and would benefit from sharing information and resources. A considerable amount of research and operational activity has occurred over the past 20 years on this topic. Risk-based soil eco-contact remediation guidelines have been developed and adopted by Alberta Environment and Parks (AEP) for Bromacil and Tebuthiuron; researchers have investigated the use of amendments for their effectiveness in remediating herbicide residues in soil as well as other technologies such as enhanced biodegradation, phytoremediation, absorption, thermal desorption and soil flushing. In addition, new technologies and approaches have been developed to remediate other contaminants which may be applicable to sterilant remediation.

InnoTech Alberta organized a series of discussions with stakeholders in Calgary and Edmonton from February 8 to March 6, 2018, *to develop a collective understanding of the number of sites impacted by soil sterilants and the specific challenges associated with their remediation and management*. Thirty-nine people from government, industry and the consulting and services communities participated in the discussions.

Awareness of the extent of sterilant issues is increasing as more sites are being decommissioned. Historical work focused on upstream oil and gas sites but there are many others in the province. Delineation of sterilant impacts is problematic for a variety of reasons, not the least of which is a historical focus on surface expression through plant effects. There is increasing awareness of the prevalence in deeper soils and groundwater, both of which significantly increase the cost and difficulty of treatment. Simple, field-based delineation tools was identified as a priority need.

There are a variety of treatment options available but limited experience in understanding their effectiveness, efficiency and cost in an Alberta setting. Selection of a treatment option should consider the full environmental cost of deployment, especially where soils must be excavated or groundwater pumped. A decision-making tool to help select an appropriate treatment was identified as a priority need.

A common theme in the discussion was a need for better Alberta-specific guidelines that focus on "true" risk to the environment.

There was a strong sense of the need for greater communication amongst practitioners and a desire to form, and participate in, a Community of Practice.

Next steps for this specific project are to circulate this Summary Report, with the associated literature synthesis and Excel inventory to participants and other interested practitioners. The longer term plan includes:

- Establishing a Community of Practice and initiating information sharing.
- Developing a proposal for a sterilants research program to take to potential collaborators for review and sanction.
- Identifying research partners who can work on the approved program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

InnoTech Alberta's Reclamation Team initiated a project to assess the needs and challenges associated with reclamation and remediation of sites impacted by soil sterilant residues. In Alberta, the problems associated with soil sterilants are becoming more evident as legacy oil and gas sites are abandoned and slated for remediation and reclamation. The actual number of sites impacted by sterilants (industrial facilities, oil and gas sites, etc.) is unknown, however Cotton and Sharma (1993) estimated the number of oil and gas sites in Alberta with soil sterilant residues to be over 60,000. Many of these sites have been stalled at the remediation phase due to the challenging nature of the contaminants, resulting in a liability and financial burden for industry and an inability to achieve site closure. Sterilants are particularly challenging for a number of reasons:

1. They are difficult to treat, especially to guideline levels;
2. They are often widespread due to the amount of time they have had to migrate, making remedial excavation expensive;
3. Each type of sterilant is unique, with a unique set of challenges; and
4. There are often confounding contaminant issues associated with remediation at legacy sites where sterilants are typically found.

Preliminary conversations with industry indicated there is a need to find a solution to this problem and determine the best approach to manage sites impacted by sterilants. There is a strong indication that companies are interested in participating and would benefit from sharing information and resources. A considerable amount of research and operational activity has occurred over the past 20 years on this topic. Risk-based soil eco-contact remediation guidelines have been developed and adopted by Alberta Environment and Parks (AEP) for bromacil and tebuthiuron (Alberta Environment and Parks, 2016); researchers have investigated the use of amendments for their effectiveness in remediating herbicide residues in soil as well as other technologies such as enhanced biodegradation, phytoremediation, absorption, thermal desorption and soil flushing. In addition, new technologies and approaches have been developed to remediate other contaminants which may be applicable to sterilant remediation.

1.1 Stakeholder Discussion Format

InnoTech Alberta organized a series of discussions with stakeholders in Calgary and Edmonton from February 8 to March 6, 2018, *to develop a collective understanding of the number of sites impacted by soil sterilants and the specific challenges associated with their remediation and management*. Thirty-nine people from government, industry and the consulting and services communities participated in the discussions (Appendix A).

Participants discussed three key issues related to the reclamation and remediation of sterilant-affected lands:

- Question 1: What is the Problem?
- Question 2: What Remediation Options have been Tested?
- Question 3: What Further Work is Required to Solve the Problem?

1.2 Report Structure

Section 2 summarizes the InnoTech Alberta Sterilants Project and the Sticky Dot Group Exercise – What are the Priorities? The presentation on the InnoTech Alberta sterilants project and workshop overview by Bonnie Drozdowski is in Appendix C).

Section 3 summarizes common themes arising from the discussions on Question 1: What is the Problem? (detailed discussion notes are provided in Appendix D).

Section 4 summarizes common themes arising from the discussions on Question 2: What Remediation Options have been Tested? (detailed discussion notes are provided in Appendix E).

Section 5 summarizes common themes arising from the discussions on Question 3: What Further Work is Required to Solve the Problem? (detailed discussion notes are provided in Appendix F).

Section 6 contains conclusions and next steps.

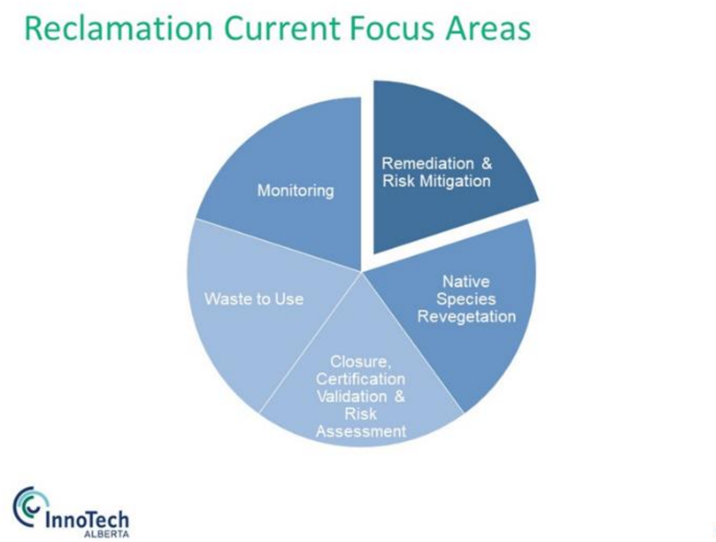
Section 7 contains a glossary of terms and acronyms relevant to the discussions.

Section 8 contains the references cited.

2.0 OVERVIEW OF THE STERILANTS PROBLEM

An overview of the InnoTech Alberta sterilants project (Appendix C) was provided to participants to provide context for the discussions[1]. The key points in the overview are:

- Sterilant research was conducted in the late 1980s but not a lot of subsequent Alberta-focused research has occurred. Interest in the issue has increased lately due to site decommissioning work.
- InnoTech Alberta is interested in identifying research opportunities in this space to fit in with other work in their Remediation and Risk Mitigation program.



- The InnoTech Alberta Reclamation team's role is to develop applied, innovative, and practical land reclamation and remediation procedures and technologies for landscapes disturbed by industrial activities for the benefit of Albertans, our partners and clients.
- In addition to the stakeholder discussions, InnoTech Alberta is preparing a synthesis of the existing literature to help identify knowledge gaps with an accompanying Excel inventory of the focus areas discussed in each reference to allow users to quickly identify which references are directly relevant to their area of interest.

2.1 "What are the Priorities" Exercise

As an ice breaker, and a means of setting the scope for the discussions, a "sticky dot" exercise was conducted. Each participant was given three sticky dots to indicate their answer to three questions:

1. Which sterilant is the most problematic for you or your clients (Bromacil, Tebuthiuron, Atrazine, Linuron, Diuron, Simazine, other)?
2. Which media is most problematic for you or your clients (surface soil [≤50 cm], deep soil [>50 cm], groundwater, surface water)?
3. Which co-contaminant is most problematic for you or your clients (hydrocarbons, salts, metals, other, none)?

Voting results for the Edmonton and Calgary discussion groups are presented in Figures 1 to 3 (vote counts) and Table 1 (percentages by location). Clearly Bromacil, groundwater and salts as

[1] The presentation given in Edmonton was considerably shortened to allow for more discussion time.

co-contaminants are the biggest concerns at this time. There were differences between the Calgary and Edmonton votes as shown by the green highlights in Table 1.

Although the questions only allowed for a single choice, participants noted that there are often multiple sterilants on a site (Figure 1), deep soil and groundwater impacts are often found together (Figure 2), and that hydrocarbons and salts often go together on sites (Figure 3). Other sterilants identified in the voting exercise and during the discussions include: Imazapyr and Picloram.

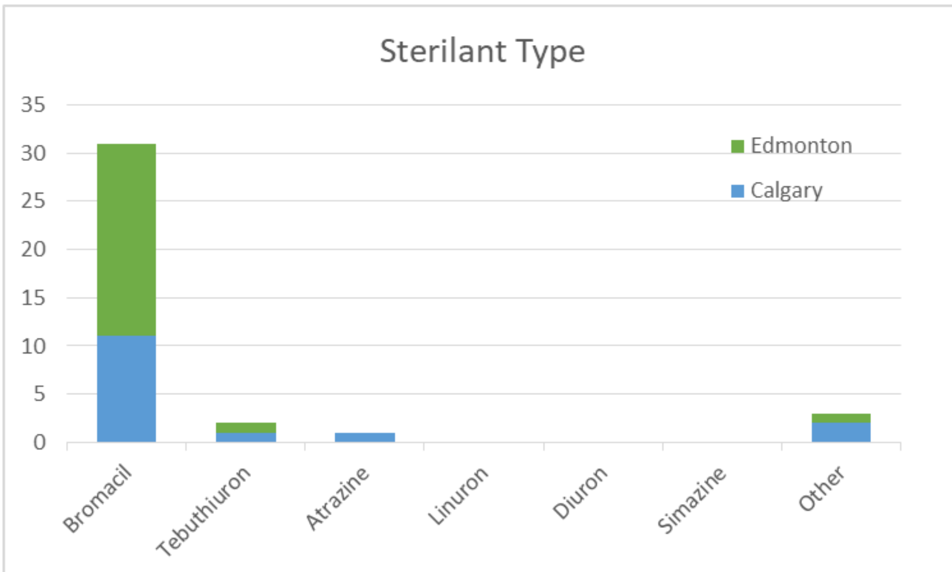


Figure 1. Most problematic sterilant.

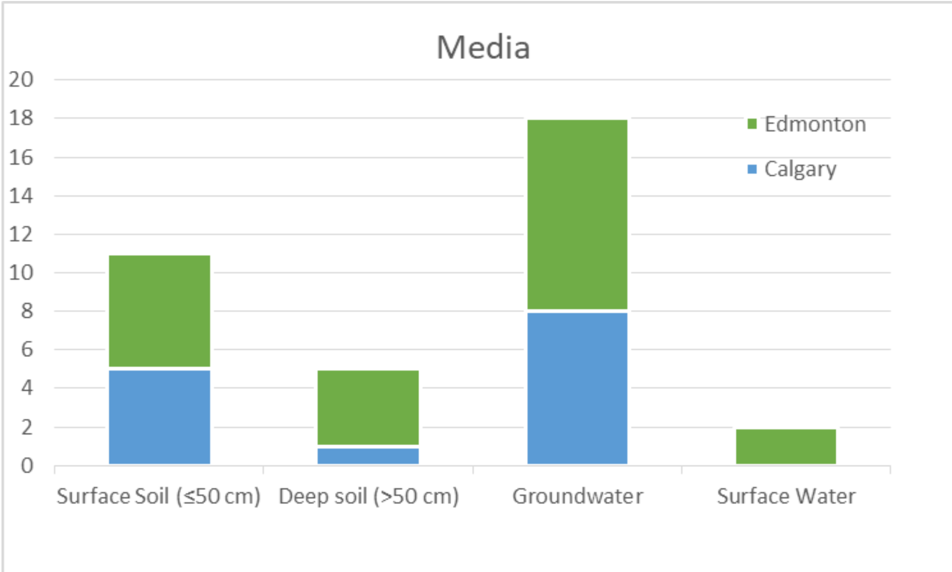


Figure 2. Most problematic media.

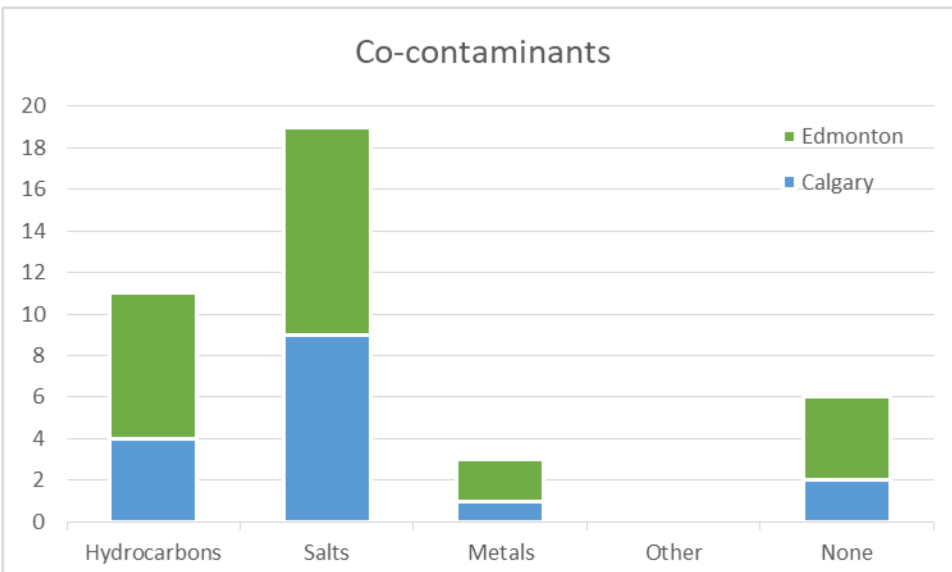


Figure 3. Most problematic co-contaminant.

Table 1. Voting percentages by discussion location.

Sterilant	Calgary %	Edmonton %
Bromacil	73.3	90.9
Tebuthiuron	6.7	4.5
Atrazine	6.7	0.0
Linuron	0.0	0.0
Diuron	0.0	0.0
Simazine	0.0	0.0
Other	13.3	4.5
Media	**Calgary %**	**Edmonton %**
Surface Soil (≤50 cm)	35.7	27.3
Deep soil (>50 cm)	7.1	18.2
Groundwater	57.1	45.5
Surface Water	0.0	9.1
Co-contaminant	**Calgary %**	**Edmonton %**
Hydrocarbons	25.0	30.4
Salts	56.3	43.5
Metals	6.3	8.7
Other	0.0	0.0
None	12.5	17.4

Values in green highlight key differences between the Calgary and Edmonton discussion groups.

3.0 SESSION 1: WHAT IS THE PROBLEM?

The common themes arising from the group discussions on *what is the problem* are presented below (the detailed discussion notes are provided in Appendix D):

- **How many sites are there and where are they located?** Previous estimates of how many sites are impacted by soil sterilants are low because they only took into account oil and gas sites; laboratory detection limits were previously too high to detect low level concentrations; and, sites were only screened for sterilants when vegetation impacts were visible. There would be value in more accurately determining the extent of the problem by identifying the number of sites likely impacted by sterilants and the geographical regions in which they exist. This would provide industry with stronger justification for screening for sterilants in certain areas of the province.
- **What products are currently being used for full vegetation control and are they really "better"?** A discussion around products currently being used for full vegetation control concluded that there would be value in investigating the potential long-term impacts from "new products" to ensure the list of problematic sites doesn't increase.
- **Delineation is a big issue; often require multiple trips to a site to get a clear picture.** Given the nature of the products and the length of time they have been in the environment, it is difficult to predict how far the impacts have moved beyond the original application site. Differences in chemical formulation (granular vs liquid) and multiple applications over a number of years at relatively unknown rates also confound the predictability of sterilant concentration and impacts; therefore delineation based on standard phased environmental assessments is challenging. Models are relatively inaccurate in estimating the extent of a sterilant plume given the inconsistency of information available for input. Large differences are observed in the field regarding sterilant movement in the subsurface and groundwater zones than what is predicted in models. Half-lives of sterilants reported in the lab are considerably different under field conditions and are influenced by environmental parameters (temperature and moisture).
- **Need a standard "workflow" for sampling and analysis – what is the decision tree for determining if we should be screening for sterilants?** Given the low guideline levels (sometimes below detection limits) and low detection limits (ppb range) sampling error can cause major concerns with data accuracy. A standardized sampling methodology would help ensure sterilant impacts are being accurately delineated. Lab analysis currently provides a value for "total sterilant" concentrations rather than "bio-available".
- **The real issue is waterbody contamination.** The irrigation pathway is the most restrictive pathway for sterilants and is driving the majority of remediation at sites. There were concerns that this pathway was not being adequately eliminated through Tier 2 approaches given the conservative nature of the models being used.
- **The guidelines are overly conservative given Alberta conditions**.

4.0 SESSION 2: WHAT REMEDIATION OPTIONS HAVE BEEN TESTED?

The common themes arising from the group discussions on *what remediation options have been tested* are presented below (the detailed discussion notes are provided in Appendix E):

- **A variety of options were mentioned, including several examples of one-off trials that have been conducted to test methods.** Challenge with remediation of sites impacted by sterilants is that generally the sites are small and of low value requiring expensive remediation treatments, therefore limited funding available for clean-up. Previous research has primarily focused on activated charcoal (AC) application at the surface or was conducted outside of Alberta. There are several case studies of effective site remediation, however extrapolation of that information to generalize learnings is challenging due to the nature of the contaminants and site variability. In Alberta, the majority of the issues are associated with Bromacil and Tebuthiuron which have largely moved from the surface to depths inaccessible to conventional in-situ soil remediation technologies (below 50 cm) and are impacting groundwater which is more challenging to remediate. Surface contamination has largely been dealt with by applying AC and mixing, however no long term data are available to verify the length of time sterilants remain adsorbed to the AC, whether the sterilants are available for biodegradation and/or "bioavailable" sterilant concentrations post-AC application.
- **For many of the treatments the key is increasing contact between amendment and the sterilant.** This applies to most technologies, both in-situ and ex-situ – chemical oxidation/reduction, activated carbon, bioremediation (enhanced and natural), thermal desorption, soil washing and flushing.
- **Treatment options and success are sterilant- and site-dependent.** The site characteristics, length of time the sterilant has been in the environment, sterilant characteristics and concentrations are important considerations for treatment selection. Generally this requires extensive site information and good delineation of the contamination which can be challenging.
- **Treatment selection is based on a variety of factors, but cost is primary driver.**
- **There is uncertainty around length of time the in-situ treatments are effective.** The uncertainty associated with "sequestration or sorption" of sterilants by AC and/or other amendments may impact the ability to achieve site closure (certification) therefore research is needed to verify bioavailability and activity of sterilants over time.
- **Need to test combinations of treatments (e.g., charcoal to bind plus oxidant or enzymes to degrade; treatment of sources (hot spots) and risk management for remainder; etc.).** Research on other sterilants elsewhere in the world has proven that combinations of treatment technologies are likely more successful at remediating residual pesticides than individual technologies.
- **Risk-based remedial approaches are challenging due to the conservative guidelines and uncertainty in model input parameters** (lab vs. field half-lives; mobility in groundwater, etc.).

- **Need more documented successful (or unsuccessful) trials so people can understand if and how they work and what the costs and timeframes are.**

5.0 SESSION 3: WHAT FURTHER WORK IS REQUIRED TO SOLVE THE PROBLEM?

The common themes arising from the group discussions on *what further work is required to solve the problem* are presented below and in Table 2 (the detailed discussion notes are provided in Appendix F):

- **Get a sense for current and upcoming workload**. A province-wide inventory (estimation) that provides information about regional distribution, site sizes, media impacted, historical sterilant use, concentration ranges, etc. would be useful.
- **Increase information sharing – some kind of formal group (Community of Practice) would be helpful** both to share information and identify and guide future research and/or projects.
- **Work is required to develop Alberta-specific soil eco-contact guidelines for products other than Bromacil and Tebuthiuron**.
- **A lab analysis method that can evaluate "bio-available" concentrations rather than "total" concentrations** would be helpful in evaluating sites treated by in-situ remediation technologies.
- **A best management practice guide for sampling and analysis** to enable industry to delineate the problem faster and more accurately.
- **A field screening tool** – vegetation impact is not useful, especially for deep soil impact or groundwater.
- **A treatment technology decision-making tree,** including risk management as an option.
- **Investigate better mechanisms to get treatments into heterogeneous matrices** instead of excavating soil and/or pumping groundwater.
- **Develop a better understanding of fate and behaviour of Bromacil and Tebuthiuron in various media**.
- **Undertake real-world, field-scale pilots of treatments**, not more lab work and share the results with the "community of practice".

Table 2. R&D and research opportunities by remediation stage.

R&D Opportunities	Remediation Stage	Knowledge Sharing Opportunities
Determine scope of problem Review existing Phase 1's and reclamation certificate applications to see if there are records of sterilant usage and treatment and use those sites for research Review Big Data opportunities to better utilize existing and future data	General	Develop Sterilants Community of Practice Export technical and regulatory learnings to other jurisdictions
Develop field screening kit Improve laboratory detection limits and methods Develop better understanding of sterilant migration – mechanisms and rates – to provide empirical evidence for risk assessment Determine if there are surrogate chemicals we can use for models (e.g., Cl for Bromacil as they are both highly mobile)	Delineation	Sampling and analysis Best Management Practices guide
Review technologies applied to other contaminants for potential use on sterilants Evaluate biochar effectiveness Assess treatment combinations Compare different treatment products/methods from different suppliers/vendors Develop a better understanding of the impacts and treatment options when sterilants have co-contaminants, especially salts Assess potential of shared treatment facilities	Technology Selection	Technology selection decision tree

R&D Opportunities	Remediation Stage	Knowledge Sharing Opportunities
Develop Soil Eco-Contact values for other sterilants of concern Revisit the protection for irrigation water guideline Develop a better understanding of fate and behaviour in various media Determine field-based half-lives for key sterilants (may be soil/ecoregion dependent) Develop more extensive data on Alberta-based receptor sensitivity to assist in guideline modification Develop a better understanding of the "true" risk to receptors in Alberta-specific conditions	Guideline Selection	Synthesis of sterilant properties and behaviour in Alberta settings Synthesis of sterilant environmental risks
Develop improved mechanisms to get treatment into the ground Develop better understanding of application methods/rates and incorporation methods	Deployment	Document remediation trials
Obtain better data on actual removal rates of sterilants by various treatment technologies Develop method to determine bioavailable levels to be able to assess treatment effectiveness Determine longevity of treatments	Confirmation	Discuss stabilization as an appropriate technology with regulators

6.0 SUMMARY AND NEXT STEPS

6.1 Summary

Awareness of the extent of sterilant issues is increasing as more sites are being decommissioned. Historical work focused on upstream oil and gas sites but there are many others in the province. Delineation of sterilant impacts is problematic for a variety of reasons, not the least of which is a historical focus on surface expression through plant effects. There is increasing awareness of the prevalence in deeper soils and groundwater, both of which significantly increase the cost and difficulty of treatment. Simple, field-based delineation tools was identified as a priority need.

There are a variety of treatment options available but limited experience in understanding their effectiveness, efficiency and cost in an Alberta setting. Selection of a treatment option should consider the full environmental cost of deployment, especially where soils must be excavated or groundwater pumped. A decision-making tool to help select an appropriate treatment was identified as a priority need.

A common theme in the discussion was a need for better Alberta-specific guidelines that focus on “true” risk to the environment.

There was a strong sense of the need for greater communication amongst practitioners and a desire to form, and participate in, a Community of Practice.

6.2 Next Steps

Next steps for this specific project are to circulate this Summary Report, with the associated literature synthesis and Excel inventory to participants and other interested practitioners. The longer term plan includes:

- Establishing a Community of Practice and initiating information sharing.
- Developing a proposal for a sterilants joint industry program to take to potential collaborators for review and sanction.
- Identifying research partners who can work on the approved program.

7.0 REFERENCES

Alberta Environment and Parks, 2016. Alberta Tier 1 Soil and Groundwater Remediation Guidelines. Alberta Environment and Parks, Land Policy Branch, Policy and Planning Division, Edmonton, Alberta. 197 pp. http://aep.alberta.ca/land/land-industrial/inspections-and-compliance/documents/AlbertaTier1Guidelines-Feb02-2016A.pdf

Cotton, M.M. and M.P. Sharma, 1993. Reclamation Techniques for Soils Treated with Non-Selective Residual Herbicides (Soil Sterilants). Land Conservation and Reclamation Council, Reclamation Research Technical Advisory Committee, Edmonton, Alberta. Report No. RRTAC 93-12. 84 pp.

7.1 Additional Reading – Sterilants in Regulatory and Contractual Documents

Canadian Association of Petroleum Landmen, 2015. Alberta Surface Lease Agreement. Canadian Association of Petroleum Landmen, Calgary, Alberta. 7 pp. http://caplacanada.org/wp-content/uploads/2015/02/Alberta-Surface-Lease-Agreement.pdf.

> 7. Weeds. The Lessee shall control all weeds on the leased premises but in so doing, will not use a soil sterilant without the written consent of the Lessor.

Municipal District of Taber, 2015. Use of Municipal Lands for Oil & Gas Related Activities. Handbook – Procedures and Policies. 5 pp. http://www.mdtaber.ab.ca/DocumentCenter/Home/View/967.

> 5. Soil sterilant use is not permitted for weed control – section 4(iii)(a)

Environment and Sustainable Resource Development, 2013. 2010 Reclamation Criteria for Wellsites and Associated Facilities for Native Grasslands (July 2013 Update). Environment and Sustainable Resource Development, Edmonton, Alberta. 92 pp. https://open.alberta.ca/dataset/3192a712-f484-44b3-ac10-24665690fc2f/resource/27278624-9d4b-4230-bf01-47b055a7d457/download/2013-2010-Reclamation-Criteria-Wellsites-Native-Grassland-2013-07.pdf

> All contaminants must be treated prior to application for certification. Specific criteria for the assessment and remediation of contaminants (e.g., salts, metals, sterilants, organic chemicals) are addressed by [Tier 1 and 2 criteria]. – p. 11.

Government of Alberta, 2010. Environmental Code of Practice for Pesticides. Government of Alberta, Edmonton, Alberta. 26 pp. http://www.qp.alberta.ca/1266.cfm?page=PESTICIDE.cfm&leg_type=Codes&isbncln=9780779766772

> (11) Unless the pesticide label requirements specify that the pesticide shall only be applied by an authorized applicator, certified applicator, pest control operator, or other

approved applicator, or any similar restriction, an applicator or an authorized assistant must be physically present throughout the following pesticide applications:

(e) application of any nonselective residual herbicide containing any of the following active ingredients:

(i) atrazine;

(ii) bromacil;

(iii) diuron;

(iv) hexazinone;

(v) imazapyr;

(vi) simazine;

(vii) sodium chlorate;

Government of Alberta, 2017. Master Schedule of Standards and Conditions. Alberta Environment and Parks, Edmonton, Alberta. 88 pp. https://open.alberta.ca/dataset/133e9297-430a-4f29-b5d9-4fea3e0a30c2/resource/04c0806b-dcb2-41f7-b703-1b662ea318ff/download/MasterSchedStandardsConditions-Jun28-2017.pdf

Condition 1142. Soil sterilants are prohibited. – p. 27.

8.0 GLOSSARY OF TERMS AND ACRONYMS

8.1 Terms

Adsorption

Physical or chemical binding of an herbicide to soil or an amendment.

Degradation

Chemical, photochemical or biological breakdown of an herbicide.

Dissipation

Removal of an herbicide through leaching, runoff, volatilization, plant uptake, photodecomposition, microbial decomposition or adsorption. Also called transfer.

Mobility

Ability of an herbicide to move or be moved. Mainly influenced by adsorption coefficient and water solubility.

Non-Selective Herbicide (Broad Spectrum Herbicide)

An herbicide that kills all actively growing vegetation by contact or by a systemic mode of action (chemical transported throughout plant).

Persistence

Continued or prolonged existence of a herbicide; related to half-life which depends on application rate, soil moisture, pH, temperature, OM content, structure, chemistry, physical properties, composition and microbial content.

Residual Herbicide

An herbicide that persists in the soil and kills regrowth and/or germinating seedlings. It can be selective or non-selective.

Selective Herbicide

Herbicide formulated to control specific weeds or weed categories. A material that is toxic to some plant species but less toxic to others.

Sorption

The retention process with no distinction between the specific processes of adsorption, absorption and precipitation.

Sterilant

A chemical that temporarily or permanently prevents the growth of all plants and animals. Soil sterilants are a type of non-selective herbicides generally restricted to industrial site use.

8.2 Sterilants

Atrazine

$C_8H_{14}ClN_5$

6-chloro-N^2-ethyl-N^4-(propan-2-yl)-1,3,5-triazine-2,4-diamine

Bromacil

$C_9H_{13}BrN_2O_2$

5-bromo-3-(butan-2-yl)-6-methylpyrimidine-2,4(1H,3H)-dione

Diuron (DCMU)

$C_9H_{10}Cl_2N_2O$

3-(3,4-dichlorophenyl)-1,1-dimethylurea

Linuron

$C_9H_{10}Cl_2N_2O_2$

3-(3,4-Dichlorophenyl)-1-methoxy-1-methylurea

Simazine

$C_7H_{12}ClN_5$

6-Chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine

Tebuthiuron

$C_9H_{16}N_4OS$

1-(5-tert-Butyl-1,3,4-thiadiazol-2-yl)-1,3-dimethylurea

8.3 Acronyms

AC	Activated Carbon
AEP	Alberta Environment and Parks
OM	Organic Matter

APPENDIX A. List of Participants

Thirty-nine people participated in the discussions from February 8 to March 6, 2018.

February 8, Calgary

Name	Organization
Kathryn Bessie	TetraTech
Monica Brightwell	ATCO Pipelines
Jim Burke	Ecoventure Inc.
Michelle Cotton	Solstice Canada Corp.
James Kiryakos	AER
Kirk Osadetz	Containment and Monitoring Institute
Jean Pare	Chemco Inc.
Tyler Riewe	Maxxam
Allan Seech	PeroxyChem
Wanda Sakura	Orphan Well Association
Chris Swyngedouw	Exova
Aaron Tangedal	Advisian
Ron Thiessen	Advisian/UofC
Eric Van Gaalen	Trace Associates Inc.
Troy Wawrinchuk	Keneco Environmental Services

Edmonton – March 6

Name	Organization
Hans Bakker	Nichols Environmental
Kathryn Bessie	TetraTech
Lori Burndred	ATCO Electric
Gary Byrtus	AEP
Gordon Dinwoodie	AEP
Mark Fawcett	TetraTech
Paul Fuellbrandt	ATCO
Andrea Hachkowski	Ch2M Hill
Greg Haryett	Advisian
Tyrel Hemsley	TetraTech

Name	Organization
Cory Kartz	MEMS
Doug Keyes	Matrix Solutions
Jill Kaufmann	Husky Energy
Lisa Kinasewich	ESAA
Matthew Kowalchuk	EcoVenture
Tim Kulka	ATCO
Michael Lakustiak	Trace Associates Inc.
Brian Lambert	AEP
Shelia Luther	Matrix Solutions
Patrick Mah	Advisian
Zsolt Margitai	City of Edmonton
Darryl Nelson	Nelson Environmental Remediation Ltd.
Peggy Popel	TetraTech
Eric Van Gaalen	Trace Associates Inc.

APPENDIX B. Workshop Agenda

Remediating Soil Sterilant-Affected Lands Workshop

AGENDA

The **objective of the workshop** is to develop a collective understanding of the number of sites impacted by soil sterilants and the specific challenges associated with their remediation and management.

1:30	Welcome, Introductions and Safety Moment
1:45	InnoTech Alberta Sterilants Project and Workshop Overview
2:00	Sticky Dot Group Exercise – What are the Priorities?
Table Discussions	
2:15	Session 1: What is the Problem?
2:55	Session 2: What Remediation Options have been Tested?
3:20	Session 3: What Further Work is Required to Solve the Problem?
3:50	Group Discussion – What we Learned
4:15	Wrap-up and Next Steps

APPENDIX C. InnoTech Alberta Sterilants Project and Workshop Overview

Bonnie Drozdowski outlined the InnoTech Alberta sterilants project to provide context for the Workshop. The presentation provided below was given in Calgary – the Edmonton version was shortened to allow for more discussion time.

Remediating Soil Sterilant-Affected Lands

Workshop

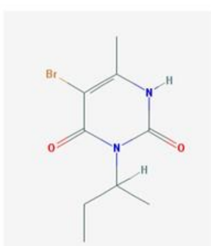
February 8, 2018

InnoTech ALBERTA

1

Workshop Objective

To develop a collective understanding of the scope of sites impacted by soil sterilants and the specific challenges associated with their remediation and management.



InnoTech ALBERTA

2

Intended Outcomes of Initiative

1) an **advisory committee** is established to guide future direction and/or research needs
2) a **plan** is developed to identify and evaluate **strategies** and **best management practices** for companies operating in Alberta to manage sites impacted by soil sterilants
3) a workshop summary report

InnoTech ALBERTA

3

Agenda

Share past **learnings**, discuss applicable **approaches** and **technologies** for managing sterilant- affected sites and identify key **knowledge gaps**

1:30	Welcome, Introductions and Safety Moment
1:45	InnoTech Alberta Sterilants Project and Workshop Overview
2:00	Sticky Dot Group Exercise – What are the Priorities?
Table Discussions	
2:15	Session 1: What is the Problem?
2:55	Session 2: What Remediation Options have been Tested?
3:20	Session 3: What Further Work is Required to Solve the Problem?
3:50	Group Discussion – What we Learned
4:15	Wrap-up and Next Steps

InnoTech ALBERTA

4

As of November 1, 2016

- Consolidation of the four Alberta Innovates corporations
- Applied research now a separate subsidiary, called **InnoTech Alberta**
  - *Same people, expertise, quality of work!*
- Intent is to:
  - Create a more streamlined, efficient and transparent innovation system
  - Fund and drive innovation
  - Make it easier for researchers, companies and partners to access and navigate the opportunities and support available to them

InnoTech ALBERTA

5

InnoTech Alberta Role

- To provide innovation, research and commercialization services to enhance and deliver environmental, economic and social benefits to Alberta

InnoTech ALBERTA

6

How does InnoTech Fit in with Sterilants?

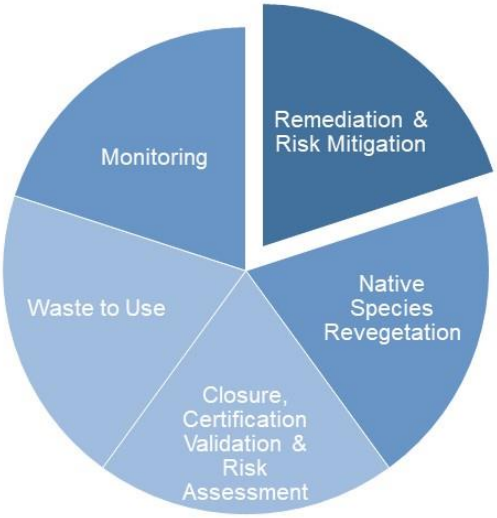
Reclamation Team Role

- To develop applied, innovative, and practical land reclamation and remediation procedures and technologies for landscapes disturbed by industrial activities for the benefit of Albertans, our partners and clients.
- Connectors with industry, regulators, academia and SMEs

InnoTech ALBERTA

7

Reclamation Current Focus Areas



InnoTech ALBERTA

8

Sterilants – What is the problem?

- Best estimate - >60,000 sites (Cotton and Sharma 1992) **BUT what do we know now?**
- Remediation stalled due to challenging nature of contaminants
  - Difficult to treat to guideline level
  - Widespread given length of time had to migrate
  - Each sterilant is unique, with unique challenges
  - Confounding contaminant issues

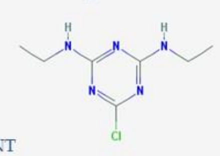
InnoTech ALBERTA

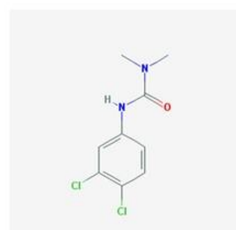
9

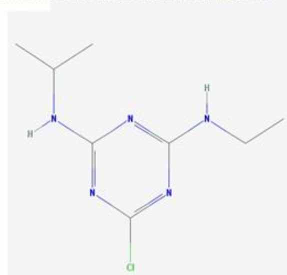
Sterilants - What do we know?

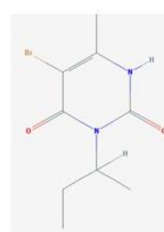
Soil Sterilant Remediation: Literature Synthesis

1.0 INTRODUCTION
2.0 STERILANT OVERVIEW
3.0 REGULATORY GUIDELINES
4.0 PERSISTENCE AND FATE IN THE ENVIRONMENT
5.0 ECOTOXICOLOGICAL INFORMATION AND ENVIRONMENTAL IMPACTS
6.0 REMEDIATION TECHNOLOGIES
7.0 IMPLEMENTATION CHALLENGES
8.0 KNOWLEDGE GAPS









InnoTech ALBERTA

10

Sterilants in Alberta

- 5 compounds generally screened for by commercial labs: bromacil, tebuthiuron, atrazine, simazine, diuron

Sterilant	Lab 1			Lab 2		
	Detection Limit (mg/kg)±	# Samples Analyzed in 2017	# of Exceedances in 2017	Detection Limit (mg/kg)	# Samples Analyzed in 2017	# of Exceedances in 2017
Bromacil	0.008	552	102	0.009	508	119
Tebuthiuron	0.005	400	38	0.001	508	9
Atrazine	0.005	400	2	0.009*	506*	17*
Simazine	0.02	400	0	0.01	508	1
Diuron	0.02	400	2	0.01	508	0

* Atrazine + Desethyl-atrazine
±Note Bessie (2009) reports lower soil detection limits and indicates a detection limit of 0.1 μg/L detection limit for water.

InnoTech ALBERTA

11

Sterilants in Alberta

- Other sterilants of potential concern
  - Linuron, amitrole, borax, hexazinone, imazapyr, sodium chlorate, sodium metaborate octahydrate, sodium metaborate tetrahydrate, picloram, dicamba
- Sterilants have different modes of action, half-life, physical and chemical characteristics, and environmental fate and behavior

→ Different challenges and thus remediation and management options

InnoTech ALBERTA

12

Bromacil

- Chemical Name: 5-bromo-3-(butan-2-yl)-6-methylpyrimidine-2,4(1H,3H)-dione
- Molecular Formula: $C_9H_{13}BrN_2O_2$
- Product Name(s): Bromacil, 317-40-9; Bromazil, Uragan, Hyvar X

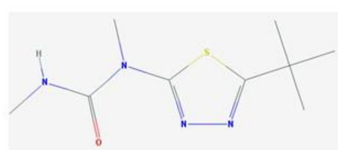
- Major Challenges:
  - Variable effects to vegetation in coarse vs. fine soils
  - Variable effects depending on moisture content
  - Not historically analyzed for unless vegetation issues obvious
  - Variable plant tolerance levels
  - Low concentration guidelines with limiting pathways for protection of aquatic life and irrigation water
  - Degradation half life 60 to >1400 days

InnoTech ALBERTA

13

Tebuthiuron

- Chemical Name: 1-(5-tert-Butyl-1,3,4-thiadiazol-2-yl)-1,3-dimethylurea
- Molecular Formula: $C_9H_{16}N_4OS$
- Product Name(s): Spike, 34014-18-1, Graslan, Perflan, Brulan



- Major Challenges:
  - Resistant to abiotic/biotic degradation in soil and water
  - High mobility (low absorbance to soils (↑ with ↑ SOM and clay content)
  - Resistant to hydrolysis and photolysis in aquatic environments
  - Most sensitive indicator of toxicity is seed emergence, therefore not easily detected if plants are established
  - Chronic exposure to low concentrations = toxic
  - Variable plant tolerances (sensitivity) (species and growth stages)
  - Degradation half life 60 to >1400 days

InnoTech ALBERTA

14

Sterilants - Guidelines

	Alberta Tier 1 Guidelines (Agricultural Land Use)											
	Soil (Coarse-grained; mg/kg)						Soil (Fine-grained; mg/kg)					
	Ecological				Human		Ecological				Human	
Soil Sterilant	Protection of Irrigation Water	Protection of Freshwater Aquatic Life	Direct soil contact	Protection of Livestock Water	Protection of Domestic Use Aquifer	Direct Soil Contact	Protection of Irrigation Water	Protection of Freshwater Aquatic Life	Direct soil contact	Protection of Livestock Water	Protection of Domestic Use Aquifer	Direct Soil Contact
Bromacil	BDL	0.009	0.12	2.0	10.0	2,000	BDL	0.009	0.20	2.0	7.0	2,000
Tebuthiuron	BDL	BDL	0.046	0.11	3.7	1600	BDL	BDL	0.046	0.12	2.5	1600
Atrazine	0.057	0.01	--	0.028	0.19	11	0.049	0.0088	--	0.025	0.10	11
Simazine	--	0.022	--	0.038	0.25	29	--	0.033	--	0.15	0.14	29
Diuron	--	--	--	--	**3.5**	350	--	--	--	--	**1.9**	350

Red is lowest applicable guideline

InnoTech ALBERTA

15

Sterilants- Remediation

Method		Technology	Applicable Sterilants	Limitations	Advantages
Physical	Ex-situ	**Remedial Excavation and Disposal**	All	Maximum depth limitations; transportation costs; clean fill required to replaced removed soil	Rapid contaminant removal, complete removal of contaminant from soil
		Thermal Desorption	Atrazine, Tebuthiuron, Bromacil, [All]	Dewatering may be necessary to excavated soils for treatment; relatively costly given the size of impacted sites; invasive soil excavation	Effective for 99% removal of organic contaminants.
		Enhanced Thermal Conduction	[All]	Invasive soil excavation; soil must be done in batches (up to 700 tonnes) per pile.	Scalable; can be done on-site
	In-situ	**In situ thermal Remediation**	[All] – uncertain effectiveness	Contamination must be correctly delineated to ensure it captured in heating zone; high groundwater tables hamper efficacy making sites un-suitable	Less invasive than ex-situ thermal treatment; high efficiency (>90%); can be done under existing structures
		Electrokinetic Remediation	[All] – uncertain effectiveness	Restricted to polar organic compounds; redox reactions can produce unwated by-products; possible soil acidification; on-site pilot tests required.	Effective in low permeability soils; short remediation time; low cost

InnoTech ALBERTA

16

Method		Technology	Applicable Sterilants	Limitations	Advantages
Chemical	Ex-situ	Soil Washing	Requires testing	Cost; requires construction and installation of scrubbing units, treatment plant, water and detergent tanks; production of large amount of solid and liquid waste requiring further treatment; invasive	
	In-situ	Chemical Oxidation and Reduction	[ALL] Organic compounds including sterilants	Only remediates to incorporation depth, not suitable for deep contaminants. Possible unwanted or hazardous by products.	Low cost; non-invasive – surface soil remains intact; proven success in breaking down organic compounds
		Liquid Activated Carbon	[All] – testing required	Complex hydrogeology can make it difficult to ensure contaminant plume is captured; difficult injection sites, unidentified contaminant transport zone; cannot sorb when there is high concentration/high mass of contaminants; long term effectiveness unknown	Rapid deployment and remediation; can be combined with other treatment options (oxidation and reduction chemicals inject along with liquid activated carbon, microbial inoculants); immobilizes contaminant migration
		Activated Carbon	All - Bromacil, Diuron, Linuron, Simazine, Tebuthiuron	Only appropriate for contaminants that will sorb. Fine textured, clay-type soils may prevent contaminant being sorbed onto activated carbon. In practice, carbon prevents microbe access to contaminants. Once activated carbon breaks down, contaminants get released back into the soil; Long term effectiveness unknown	Remediates any contaminant that will sorb; improves soil quality and can promote plant growth

InnoTech ALBERTA

17

Method		Technology	Applicable Sterilants	Limitations	Advantages
Biological	In-situ	Bioremediation	Bromacil, Diuron, Linuron, Simazine	Limited to warm climate conditions; high levels of contaminants or toxic contaminants can retard or stop the growth of desired microbial activity; inconsistent results	Low cost; non-invasive, surface soil remains intact; uses naturally occurring microbes found in the area; bacteria beneficial to soil biome
		Enzymatic Remediation	unknown	Enzymes for specific contaminants or by products may not be identified; incomplete conversion can create undesirable or hazardous by-products; sourcing enzymes may be difficult and/or costly; relatively new and unproven at field scale	Can be used to target specific contaminants or broad range of contaminants; can be used where microbial activity would be limited either by environment or high toxicity; can completely convert contaminates to harmless inorganic by-products
		Enhanced Rhizosphere Biodegradation (phyto-remediation)	Atrazine, Linuron [others]	Limited to the area of root/soil contact, generally surficial. Bacterial strains must be determined before remediation, soil conditions effect bacterial activity/survival, inoculated seeds have short shelf life, requires special approval, new technology that has inconsistent results	Low cost; improves soil hydraulic properties, root proliferation, plant nutrients, carbon sequestration and nitrogen fixation; uses naturally occurring microbes found in the area; bacteria beneficial to all aspects of plant growth and enhances remediation; small amounts of inoculum required; surface soil remains intact; can potentially treat multiple contaminants

InnoTech ALBERTA

18

APPENDIX D. Discussion Notes for Session 1: What is the Problem?

Workshop participants were provided some Guiding Questions to help stimulate the discussions:

What sterilants are a concern?

What other contaminants are present?

What media is most problematic to address?

What kinds of facilities are affected?

Where geographically or ecologically is the problem?

Is the concern heavily contaminated media or residual levels?

What is the desired remediation outcome?

What is a realistic remediation outcome?

Are the current guidelines achievable?

Will the problem disappear over time?

Are there issues with delineation?

Are there issues with analysis?

Is there adequate information available to develop a reliable remediation strategy?

How many sites are there? Previous estimates are low because only took into account oil and gas and detection limits were high.

Note just an upstream oil and gas issue – railways, electrical utilities, tank farms, midstream plants.

We could work on getting these numbers through individual conversations with ATCO (current estimate is 3,000 sites for ATCO Gas), CNRL, TransCanada and others.

Poor records as to what was applied, when, how many times, and at what rate.

Prescribed mixing rates may have been followed but application rates were highly variable – worse for powdered/pellet forms than liquid forms.

Sites in the Green Area should have more documentation about historical practices.

Examples of Green Area sterilant usage were provided: flare pits in Whitecourt / Fox Creek area, central Alberta gas plants and batteries, Lloydminster area.

Ace Vegetation kept good records of sterilant usage.

On the flip side, there is anecdotal evidence that with the increased moisture common in many Green Area sites the sterilants may have been leached out of the surface and therefore do not show surface impacts and have therefore not been tested.

Other areas of the province where sterilants were used?

City of Lethbridge industrial sites.

Accidental use of Hyvar (Bromacil) on five sites in City of Edmonton.

Example of an area where sprayer used Ag Canada/Alberta Agriculture approved herbicide for grazing lease control of shrubs; contained Picloram.

Nose Hill in Calgary is sprayed.

Sterilants used for aesthetic reasons as well as industrial purposes so may be some surprise locations.

Some uncertainty around ongoing use of sterilants.

Sterilants were applied well into the 1980s – what has happened since then?

There are still regulatory requirements for full vegetation control so if not sterilants what is being used (and are they really "better").

Primary focus now seems to be on remediation but it is important to reduce future impacts of current practices as well.

Would be helpful to get a regulatory requirements and practices timeline in place so we can separate sites for treatment and research purposes.

There are few sterilants that are pure active ingredient.

Need to be aware of the additives in a formulation as they may also be toxic.

Also have to be aware of their metabolites if degradation is a proposed treatment process.

General agreement that there is no such thing as a "typical site" thus general rules of thumb are not going to be helpful.

Delineation is a big issue; often requires multiple trips to the site to get a clear picture.

Sterilants migrate horizontally and vertically; but there is a disconnect between model results and what is being seen in the field – need better site-specific models.

Not just "were they applied?", but "where on the site were they applied?" Sterilants were applied in heavier doses along fencelines as it was difficult to use other control methods – leads to increased likelihood of off-site impacts.

Vegetation impact as a tool is problematic as different species react differently.

Just because there is no surface (vegetation) impact doesn't mean there are no sterilants.

Visible impacts don't always correlate with measured values.

Often find sterilants in the groundwater and/or surface water but no surface impacts.

Often sites have other contaminants present thus not sure what source of impact is.

Some other contaminants mimic sterilant effects so not always sure it is a sterilant problem.

Assuming sterilants will be at one specific depth based on application is a big mistake – there may have been multiple applications over time which have moved to different depths (individual slugs moving through soil) and in large industrial sites there may have been extensive cut and fill so the current surface may not have been where the sterilants were applied.

Reported half-lives for sterilants are often very different than what is seen in the field (i.e., there are still problems on 50+ year old sites).

Sterilant issues do not improve with time – in fact are likely to spread.

Finding high sterilant values at low-value (e.g., small) sites – very hard to get funding for remediation in these cases.

> There is fear about setting a precedent in industry for expensive clean-ups.

Because small amounts (e.g., ppt in water) trigger guidelines, cross-contamination of samples, especially for deeper sampling, is a concern.

Some analytical problems.

> Getting different results from different labs due to detection limits of equipment.
>
> Getting false positive and false negative results from labs.

A field screening technique would be very helpful

> Now have a maximum 14 day hold in a lab for samples but the problem has been in place for 50+ years. As a result we extract the sample but don't analyze right away.
>
> There are immunoassay field kits for other chemicals (e.g., TNT) – are there any for sterilants (check with University of California at Davis for Bromacil)? Could they be developed? These are much cheaper and quicker than lab analysis or bioassays.

Plant bioassays are a good "integrative" tool for determining cumulative (synergistic) effects.

> Many sites have multiple contaminants, therefore individual chemical tests do not tell the whole story.

Is there a standard "workflow" for sampling and analysis – what is the decision tree for determining if we should be screening for sterilants? That would help spot areas for improvement.

> No.
>
> Often we select sites to sample based on anecdotal information; there is limited or poor historical operational practice information on file. Therefore Phase 1's are hard to do based paper reviews.
>
> Thinking about automatic testing vs. anecdotal information approach – we are finding that Bromacil is at many of our sites, but are concerned about the standardization of the process to screen for sites.
>
> Often reactive testing – see a problem and then try to figure out source; flip side is no visible problem means no testing for deeper contamination – therefore very possible that there are sites with sterilant contamination that have been deemed to be uncontaminated.
>
> Sampling scheme, if any, really depends on the nature and extent of surface impacts.
>
> We analyze groundwater even if no surface impacts seen as it is often a limiting pathway; simpler if there is a groundwater monitoring network already in place.
>
> If we see Bromacil in soil and it exceeds detection limits we automatically sample groundwater as Bromacil is mobile.

Other contaminants are the often drivers for remediation and sterilants generally are dealt with in combination (or accidentally).

The real issue is waterbody contamination.

> Level of concern depends on whether or not the waterbody is collecting and storing water (potential for concentration) or transmitting water.
>
> Mobility in groundwater appears to be much lower than expected – see surface plume same a groundwater plume when you'd expect groundwater to have moved further. Example of site with surface application of granular sterilant showing impacts to 5 m depth but no sterilant in groundwater wells 5 m away.
>
> Contribution of subsurface inflow vs. surface flow/seepage will affect groundwater concentrations and mobility.
>
> For groundwater the issue is the pathways from groundwater to receptor and nature (transmissivity) of soil materials
>
> Big problem in coarse materials but even in till materials there can be sand lenses.

Common direction to install monitoring wells is not as simple as it sounds.

> Cost is a factor, especially for a small site.
>
> Not just installation but ongoing monitoring and reporting plus eventual decommissioning.
>
> Don't need full human health risk assessment done; risk can be evaluated at lesser cost ($20K to $50K).

The guidelines are overly conservative given Alberta conditions.

> CCME sets (and Alberta adopts) groundwater and irrigation guidelines; Alberta sets soil Eco Soil Contact guidelines.
>
> Existing literature is not useful for guideline development as the methods don't meet CCME's strict requirements.
>
> Originally guidelines were set based on herbicide carryover information from herbicide industry and crops; more recently looking at environmentally-focused values.
>
> Health Canada has guidelines for water and that is why CCME put the guidelines in for these compounds.
>
> Irrigation guidelines set for most sensitive agriculture species (likely cucumber in Eastern Canada) – is there potential to reset the guidelines for Alberta crops? Not likely – hard to find a relevant receptor for a full suite of crops and/or a full crop rotation.
>
> Irrigation pathway is the most restrictive. Driving the majority of remediation. Many irrigation canals being replaced with pipelines there potential for getting into irrigation water is reduced.
>
> Direct soil eco contact values were not originally present in Guidelines but were added in 2016 for Bromacil and Tebuthiuron. There may be cases where there are still impacts below these guidelines. Not a lot of information available on native plant sensitivities.

Lab results are for total sterilant not available – that may explain positive lab data when there is no plant affects. NOVA developed a plant-available method for Bromacil but it wasn't effective.

Tier 1 values are very low so often have to go to Tier 2.

Surface water and groundwater guidelines are often below laboratory detection limit.

Need effects-based numbers not guideline values.

There was some question around why the Domestic Use Aquifer values were so much higher than the ecological values – likely reflects receptor sensitivity.

Recent revisions to the model used for groundwater guidelines will have limited impact on highly mobile sterilants like Bromacil but may have an impact on those with high Koc values. There will be a greater impact on values developed through Tier 2 modeling.

APPENDIX E. Discussion Notes for Session 2: What Remediation Options have been Tested?

Workshop participants were provided some Guiding Questions to help stimulate the discussions:

What methods have been tried?

What media have been remediated?

What are the costs?

What was the target endpoint of remediation?

Have remediated sites been certified or otherwise signed off?

What factors were considered in selecting a method?

What data were required to select a method?

What data were required to evaluate the method?

Are laboratory and/or greenhouse trials needed before field deployment?

A variety of options were mentioned:

Dig and dump – often thought of as a cheaper alternative but have to figure in cost of backfill for excavation and life cycle analysis (carbon, etc.). There is a volume cut-off where onsite treatment may be more cost-effective.

Excavate + charcoal + manure.

Manure – adding organic matter for sorption (but concerns about longevity).

Liquid activated carbon used for ex-situ groundwater clean-up; name is a misnomer as it is still solid suspended in water.

Activated carbon used for pump-and-treat groundwater solution.

Thermal desorption done at one site (interestingly, getting much more attention and work outside Alberta than within – likely affected by relative difference between landfill costs and treatment costs). A concern about physical and chemical properties of residual soil and its use for reclamation.

Chemical oxidation – only persulphate has enough "kick" to effectively oxidize sterilants plus treatment action lasts longer (weeks) than peroxide (days); however, some experience that results were not positive.

Soil washing equipment brought up from the States to test at 3 sites – limited by fine textured soil, worked well in coarse textured soil and gravels.

Incorporation into soil (dilution) – but creates more contaminated volume.

One example of burial of sterilant-contaminated soil – had to dig it back up later for proper disposal.

One example of a microbially-charged activated carbon project.

One company (Lehigh) is incorporating contaminated soil into cement.

Incineration is very effective but expensive.

Fracking a site by massive electrical discharge.

Possibility of nanoparticle treatments should be investigated.

A hybrid approach with a combination of treatments may be needed.

Triage the site – remove hotspots and look at alternative treatments for remaining product.

Monitored natural attenuation is not really considered a treatment but is practiced; natural attenuation is practiced by default when the sterilant is present but we haven't sampled for it and therefore don't know it is present (therefore no monitoring).

Concern that some of the technologies may be considered sequestration rather than treatment therefore will require regulator acceptance for closure.

Surface treatment approach means the surface (depth of incorporation) may be fine but there are sub-surface problems that may or may not be found depending on root penetration depth (for plants) and/or migration into groundwater.

Treatment selection based on:

Cost – note there can be reduced unit costs when the volumes are high enough.

Timeframe for treatment.

Likelihood of success.

Duration of success (long-term effectiveness).

Should focus on net environmental benefit of treatment.

For many of the treatments the key is increasing contact between amendment and the sterilant.

Physical mixing (in-situ and ex-situ) and injection are two common methods for amendment incorporation.

Have to understand chemistry of sterilant, amendment and site soil/groundwater to increase chance of getting amendment and sterilant together – especially important for processes that require the sterilant to move to the amendment (like chemical oxidation processes).

Solubility of the compound is critical for the oxidation of the contaminant. So if it is sorbed to a small particle it is extremely challenging. Adding a surfactant in cases where sterilant has low solubility helps.

New surfactants can help in the vadose zone to increase solubility. Tried on similar compounds (not Bromacil or Tebuthiuron) that are difficult to solubilize and would be more than willing to try these technologies.

Treatment options and success are sterilant-dependent:

Atrazine is easy to degrade.

The bromine atom in Bromacil has to be removed first (it is easily removed/degraded) before the remaining molecule can be addressed. The process is very similar to dehalogenation. In fact, bromide and chloride act in a very similar way in the soil (and water) as conservative tracers and at minimal concentrations (after cleaved) bromide would be less of a concern.

Tebuthiuron is not halogenated so it is very difficult to degrade anaerobically (i.e., in-situ).

Remediation success is more than just meeting Tier 1 or 2 guidelines.

Have to meet reclamation goals (e.g., vegetation).

Need to remove liability.

Risk-based closure is desired goal as Tier 1 levels are low.

Some uncertainty around length of time the treatments are effective.

Some technology providers are guaranteeing 30 year treatment effectiveness.

How tightly are sterilants bound to activated carbon and for how long? Ontario MOE very interested in the degradation within the activated carbon matrix – there needs to be assurance in terms of longevity and a better understanding of the breakdown mechanism for the product sorbed onto/into the activated carbon.

Are sterilants bound to activated carbon biodegraded?

Paul Sharma did go back after 10 years to some of his early sites and found the treatments were still working but need longer period of evaluation (also some of the sites had very high application rates so may not be applicable to operational practice).

There are probably a lot of industry sites we could go back to but data on treatments are sparse.

A University of Colorado study was mentioned that looked at treatment effectiveness.

Is biochar an option and would it act differently than activated carbon?

Biochar would be a lot cheaper and has demonstrated abilities to bind organics like Bromacil.

Texture and pore size may be a concern as you want to maximize contact with sterilants.

It wouldn't bind things as tightly as activated carbon therefore might actually be a better option to then use redox technology.

Need to test combinations of treatments (e.g., charcoal to bind plus oxidant or enzymes to degrade).

Activated carbon is an organic compound and so is the contaminant. So the oxidizer would destroy the activated carbon in addition to the contaminant.

No one has looked at destroying contaminants through chemical oxidant that are sorbed on activated carbon. But the surface tightness of activated carbon really prevents it from being re-released.

Need more documented successful (or unsuccessful) trials so people can understand if and how they work and what the costs and timeframes are.

Two Ontario examples were discussed and documentation provided to InnoTech Alberta.

Novartis site (herbicide – metalachlor – similar to Bromacil in many aspects chemically; 245-T; Agent Orange) treated with daramend process. Upper 60 cm of soil treated with powdered iron, nutrients and finely ground plant materials – promoting dehalogenation, and then degradation .

APPENDIX F: Discussion Notes for Session 3: What Further Work is Required to Solve the Problem?

Workshop participants were provided some Guiding Questions to help stimulate the discussions:

What data or information is required?

What methods need to be evaluated?

What guidelines need to be developed or modified?

What information needs to be shared?

What scale of research or demonstration is required – bench, plot, full site?

Do we know enough to compile a Best Practices manual?

Are there others who need to be involved?

General

Get a sense for current and upcoming workload.

Methane reduction targets are going to drive significant increase in site closures which will give us a better sense for the scale of the upstream oil and gas problem.

A province-wide inventory, rather than company-specific would be very useful.

Regional distribution.

Site size distribution.

Concentration ranges.

Which media are impacted.

Review existing Phase 1's and reclamation certificate applications to see if there are records of sterilant usage and treatment; those sites could be used for future research.

Increase information sharing – some kind of formal group (Community of Practice) would be helpful.

Could share info.

Could identify and direct research.

Need feedback loop from R&D to operators.

Review Big Data opportunities to better utilize existing and future data.

Export our technical and regulatory learnings to other jurisdictions (these chemicals are still being used in other countries).

A number of people/organizations were identified who should be contacted for further information:

Mandy Parker (City of Lethbridge)

Miles Tindal (re guidelines development)

George Ruddock

George Ivy

Dr. Greenberg

Ian MacDonald (ACE Vegetation)

Mike Smith (ex reclamation inspector)

UC Davis

University of Colorado

Guidelines

Develop Eco Soil Contact values for other sterilants of concern; Diuron suggested as most immediate need.

Revisit the protection for irrigation water guideline so you don't have to redo the site specific guideline all the time.

Determine field-based half-lives for key sterilants (may be soil/ecoregion dependent).

Develop more extensive data on Alberta-based receptor sensitivity to assist in guideline modification.

Develop a better understanding of the "true" risk to receptors in Alberta-specific conditions.

Analytical

Develop a field screening tool – vegetation impact not useful, especially for deep soil impact or groundwater.

AER's drilling waste Microtox test used as a screening tool – it is lab-based and expensive but might be helpful.

Determine if mobile labs could analyze for sterilants. Would be more cost-effective for multiple sites in an area.

Improve laboratory detection limits and methods (including sample storage and transport).

Develop method to determine bioavailable levels to be able to assess treatment effectiveness (i.e., how tightly bound is the sterilant?).

Analytical methods often use solvent extraction (therefore total sterilants) rather than bioavailable.

Develop a best management practice guide for sampling and analysis to delineate the problem.

Delineation

Develop simple, field-based method to delineate sterilant plumes; fluorescence probe mentioned.

Develop better understanding of sterilant migration – mechanisms and rates – to provide empirical evidence for risk assessment.

Determine if there are surrogate chemicals we can use for models (e.g., Cl for Bromacil as they are both highly mobile).

Treatment

Develop a treatment technology decision-making tree, including risk management as an option.

Review technologies applied to other contaminants for potential use on sterilants, especially for contamination at depth.

Assess potential of shared treatment facilities

> Potential for common treatment sites for thermal desorption being evaluated.
>
> Has occurred in Quebec where landfilling of contaminated soils is not allowed.

Develop better mechanisms to get treatment into the ground instead of excavating soil and/or pumping groundwater.

> Some work in northeastern BC using 400 to 2,000 psi to inject treatment.
>
> Large diameter augers are available and may work for localized contamination. Cost less than excavation.

Develop better understanding of application methods/rates and incorporation methods.

Compare different treatment products/methods from different suppliers/vendors.

Develop a better understanding of fate and behaviour in various media and over time.

> What are the effects of soil physical, chemical and microbiological characteristics?
>
> What are the field-based attenuation rates and mechanisms?
>
> What are the actual removal rates of various sterilants in various media.
>
> What are the weathering and microbial degradation rates of sterilants in various soil types (especially organics in Green Area vs. arid agriculture zones).

Develop a better understanding of the impacts and treatment options when sterilants have co-contaminants, especially salts.

Undertake real-world, field-scale pilots of treatments, not more lab work.

> Real world results are very different than lab results!
>
> They costs about the same and get more applicable data than lab / greenhouse studies.
>
> We are past the "proof of concept" stage for most treatments.
>
> There are a lot of sites available with variable sterilants and levels and environmental settings.