SPIGEC
Saskatchewan Petroleum
Industry / Government
Environmental Committee

Saskatchewan Upstream Petroleum Sites Remediation Guidelines

Saskatchewan Petroleum Industry / Government Environmental Committee
Guideline No. 4, September 1st, 2000
Revised November 2009

Table of Contents

Introduction

The Saskatchewan Petroleum Industry/Government Environmental Committee developed the Upstream Petroleum Sites Remediation Guidelines to provide a consistent approach for identifying, assessing and remediating upstream oil and gas contaminated sites.

The guidelines provide a common set of remediation criteria for oil and gas companies, surface landowners and regulators. The criteria provided in the guidelines are generally applicable to upstream petroleum sites, such as wellsites, batteries, compressors, upstream waste processing facilities or other facilities impacted by primary exploration, production or transportation of unrefined petroleum resources.

To ensure the guidelines are comprehensive and reflective of today's standards, many sources of information were used to develop the guidelines, including the Canadian Council of Ministers of Environment, Environment Canada, Health Canada, Saskatchewan Energy and Mines, Saskatchewan Environment and Resource Management, Alberta Energy and Utility Board and Alberta Environmental Protection.

In addition, non-health related parameters, such as soil salinity and sodicity, have been developed to ensure sustainable and productive use of the land.

This document is intended for general guidance only, and does not establish or affect legal rights or obligations. It does not establish a binding norm nor prohibit alternatives not included in the document. Furthermore, these guidelines are subject to revision or replacement in the future.

The guidelines do not address the complex and legal issue of environmental liability associated with contaminated sites. The readers are recommended to consult Saskatchewan Environment and Resource Management's (SERM) document titled, *Environmental Liability and Contaminated Site Management, A Strategic Approach for Saskatchewan*. This document outlines SERM's approach to determining liability, such as identifying responsible or innocent parties.

The remediation process has been divided into five distinct steps:

- Identification: identification and environmental site assessment
- Planning: remediation plans
- Remediation: remediation approach and criteria
- Restoration: physical reclamation
- Registration: registering remediation activity information with SEM

1.0 Identification

The identification step is the formal or informal process used by the operator or regulator to identify a contaminated site. Site identification work is often initiated voluntarily during site decommissioning, well abandonment, property transaction or through an internal environmental audit program.

Often a more in-depth and structured site investigation occurs, in the form of an environmental site assessment (ESA), because of:

- a record or evidence of spills and leaks;
- inadequate or dated storage systems (pits or ponds);
- poor or dated operational history;
- complaints;
- detection of contaminant from monitoring system;
- physical evidence (e.g., oil staining, salt crystals on soil and stressed vegetation); and
- warning letters and clean-up orders from regulatory agencies.

The environmental site assessment process is usually divided into two phases. Phase I consists of gathering preliminary information to determine if further site investigation is required. Phase II involves detailed site investigation by undertaking air, soil and water sampling and analysis. Interpretation of the sampling and analytical data is used to determine the extent of the contamination and to build a conceptual model(s) of the contamination at the site.

The level of detail applied to an environmental site assessment will depend on site specific factors, professional judgements of environmental specialists or corporate environmental policies. Detailed environmental site assessments are done to establish a high level of due diligence in order to protect oneself from purchasing or selling a contaminated property, to minimize the financial and civil liability associated with the contaminated sites and to exercise good environmental citizenship.

Many operators have comprehensive in-house environmental site assessment protocols in place. The Canadian Standards Association (CSA) and the Canadian Council of Environmental Ministers (CCME) have published excellent environmental site assessment and investigation guidelines. In addition, *Environmental Site Assessment Procedures for Upstream Petroleum Sites*, Guideline No.5, March 1, 1999, has been developed by SPIGEC to assist the operators in developing their own environmental site assessment programs. We would like to stress that the level of environmental site assessment conducted on a site varies with the degree of due diligence that the operator wishes to establish. In general, operators who exercise a high degree of due diligence are more likely to be protected from the legal and financial liability associated with contaminated sites.

2.0 Planning

The planning step includes exploring remedial options and technologies, consulting with the regulators and stakeholders and establishing an appropriate level of remediation to be achieved.

Establishing the remedial options to be used at the contaminated site and the remediation objectives to be achieved should be based on sound information gathered from the environmental site assessment. It may be useful to consult with an environmental specialist who is familiar with provincial requirements for remediating contaminated sites, infrastructures and technologies available for remediating or disposal of contaminated material, and who has an understanding of local biophysical features which may be impacted or benefited by the remediation work.

2.1 Notification to the Regulator

Saskatchewan Energy and Mines (SEM) requires operators to submit a written notification of intent to remediate an upstream petroleum site at least two working days prior to the commencement of the remediation project. The notification should include the following:

- company (operator) name, contact name, phone number and mailing address;
- project description, e.g., site location, nature of the problem and scope of the work; and
- project plan, e.g., time frame, name of contractors and phone numbers.

The notification shall be submitted to the appropriate SEM field office and a copy to the SEM head office.

2.2 Stakeholder Consultations

Early stakeholder (landowner, occupants or other parties significantly impacted) consultation can provide a number of positive benefits to the remediation process. Consultation assists in establishing a common remediation expectation amongst the operator, the regulator and the landowner(s). It will also promote good community relations.

On an off-lease property, the operator is required to obtain the landowners approval for relevant aspects of the site remediation work impacting their property, such as entry on to land, ground water monitor well installation, adding soil amendments, landfarming, on-site encapsulation, treating contaminants generated from other sites, bringing in fill materials, borrowing topsoil, replacing topsoil or planting vegetation and crops.

On a leased property, the operator should provide an appropriate level of information to the landowner. The operator should work closely with the landowner to obtain consensus on the overall remediation objectives.

3.0 Remediation

The environmental remediation criteria outlined in the guidelines are to protect human and environmental health related to specific uses of soil and water. These criteria are subject to revisions.

The objective of site remediation is to ensure that the contaminants have been removed, contained or treated to protect human health and the environment, and to assist in restoring the land to its equivalent capability. Equivalent land capability is the ability of the land to support various land uses, similar to - but not necessarily identical to - the ability that existed prior to an activity being conducted.

It is important to distinguish the conceptual difference between restoration and remediation. Restoration refers to the physical reclamation process involving recontouring, replacing topsoil, and re-vegetating to restore the surface of the land to its equivalent land capability. Remediation refers to the decontamination of the soil or water to provide protection to human and environmental health. Therefore, the goal of remediation is not to remove every grain of contaminated soil but to achieve a safe level of remediation which protects human and environmental health.

3.1 Criteria Based Approach

The remediation criteria for certain parameters associated with potentially impacting human health have been adopted directly from the *CCME Interim Canadian Environmental Quality Criteria for Contaminated Sites*, (CCME EPC-CS34), September 1991, the *CCME Recommended Canadian Soil Quality Guidelines*, March 1997 and Saskatchewan Environment and Resource Management's *Risk Based Corrective Action at Petroleum Contaminated Sites*. These criteria are considered to be the most cautious environmental clean-up criteria available in Saskatchewan and protective of human and environmental health.

Two non-health related parameters have been modified, including soil salinity (determined by electrical conductivity) and sodicity (determined by sodium adsorption ratio). These parameters impact soil physical structures and crop yields but they do not have an impact on human health.

Finally, hydrocarbon remediation criteria have been developed specifically to deal with the Saskatchewan upstream petroleum industry.

3.1.1 Land Use Definition

The remediation criteria for soil are presented within the context of the intended land use following remediation. The specific contaminant must be within or less than the specified range of the criteria. If the remediation criteria are lower than the background levels (levels in similar soil series that has not been impacted by upstream petroleum activities), then the background levels shall be considered as the primary remediation criteria. Landuse definitions are as follows:

- **Agricultural** soil means the soil horizon(s) that are used, or potentially used, for growing crops or tending livestock and includes agricultural lands providing habitat for resident and transitory wildlife as well as native flora. The agricultural soil includes the total depth of soil where the intended agricultural crop's rooting zone exists or where activities to support agriculture products takes place. The agriculture soil remediation criteria are considered the most cautious clean-up criteria and they are designed to be protective in essentially all situations.
- **Forest** soil means the topsoil located on forest.
- **Residential** soil means the soil horizon(s) that is used for residential use. The residential soil includes the total depth of soil where residential development can take place (e.g., basement construction).
- **Subsoil** is a soil layer that are contained at a sufficient depth from the surface, separated by or within a confining soil matrix (e.g. clay) where all relevant transport mechanisms and exposure pathways have been mitigated to prevent impact or potential to impact the agricultural, residential or forest soil. The transport mechanisms include, but are not limited to, vapour migrations, groundwater flow, surface water runoff, phase separation and physical disturbances (e.g. human disturbances such as dugouts, water wells and basements). Exposure pathways include, but are not limited to, agricultural crop root penetration, human and animal exposure by inhalation of vapour, and ingestion of soil or water. For the purpose of these guidelines, subsoil is defined as:
  - soil layer that is located 1.5 metres below the base of topsoil, 1.5 metres above the water table with 600 millimetres of impermeable soil (or equivalent, e.g. synthetic liner) located immediately above and below the subsoil layer (refer to the subsoil diagram in the glossary).

This is only a general description. As part of a due diligence process, it is the responsibility of the operator to provide and document justifications for using subsoil remediation criteria.

3.1.2 Soil Remediation Criteria

How to use Table 1, Soil Remediation Criteria

Salinity and Sodicity

Salinity is a measure of the total concentration of soluble salts in water and soil. The accumulation of soluble salts in the soil curtails crop growth by increasing the osmotic potential of the soil solution and inducing specific ion toxicities or nutrient imbalances. The predominant solutes responsible for salinity include the cations sodium, calcium and magnesium, and the anions sulfate and chloride. The total solute concentration in the various extracts is normally determined by analysis of the electrical conductivity. Although relationships between conductivity and salt concentration vary somewhat depending on the ionic composition of the solution, electrical conductivity provides a rapid and reasonably accurate estimate of solute concentration.

Aside from the direct effects on crop growth, salts can also limit productivity by adverse effects on soil structure. In particular, high concentrations of sodium on cation-exchange sites on clay particles will disperse the soil and impede water and air movement (hard pan). This is a common problem with sodic soil. Soil with Sodium Adsorption Ratio (SAR) values greater than 13 are considered to be sodic. SAR is the calculated ratio used to represent the relative activity of sodium, calcium and magnesium with respect to ion exchange reactions in soil. It is calculated as:

$$\mathbf{SAR = [Na^{+}] \div ([Ca^{2+}] + [Mg^{2+}])^{0.5}}\ \text{(mmol/L) or } \mathbf{SAR = [Na^{+}] \div (([Ca^{2+}] + [Mg^{2+}])/2)^{0.5}}\text{(meq/L)}$$

Over the years, the relationship between crop growth and electrical conductivity of saturation extracts for a variety of crops has been extensively reviewed. General salinity effects are as follows:

EC (dS/m at 25°C)	Crop Response
0-2	**almost negligible effects**
2-4	**yields of very sensitive crops restricted**
4-8	**yields of most crops restricted**
8-16	**only tolerant crops yield satisfactorily**
>16	**only very tolerant crops yield satisfactorily**

Adapted from Bernstien, L., Annu. Rev. Phytopathol., 13, 295, 1975.

The crop response to salinity at a given site may vary somewhat from reported values because of the differences in salt composition, crop varieties, climatic factors and soil properties. To this end, we have designed our salinity (measured by EC) remediation criteria to reflect the specific land use factors (e.g., crop varieties) and the site specific factors (e.g. climatic factors and soil textures).

Figure 1. Determining Topsoil Salinity and Sodicty Remediation Criteria

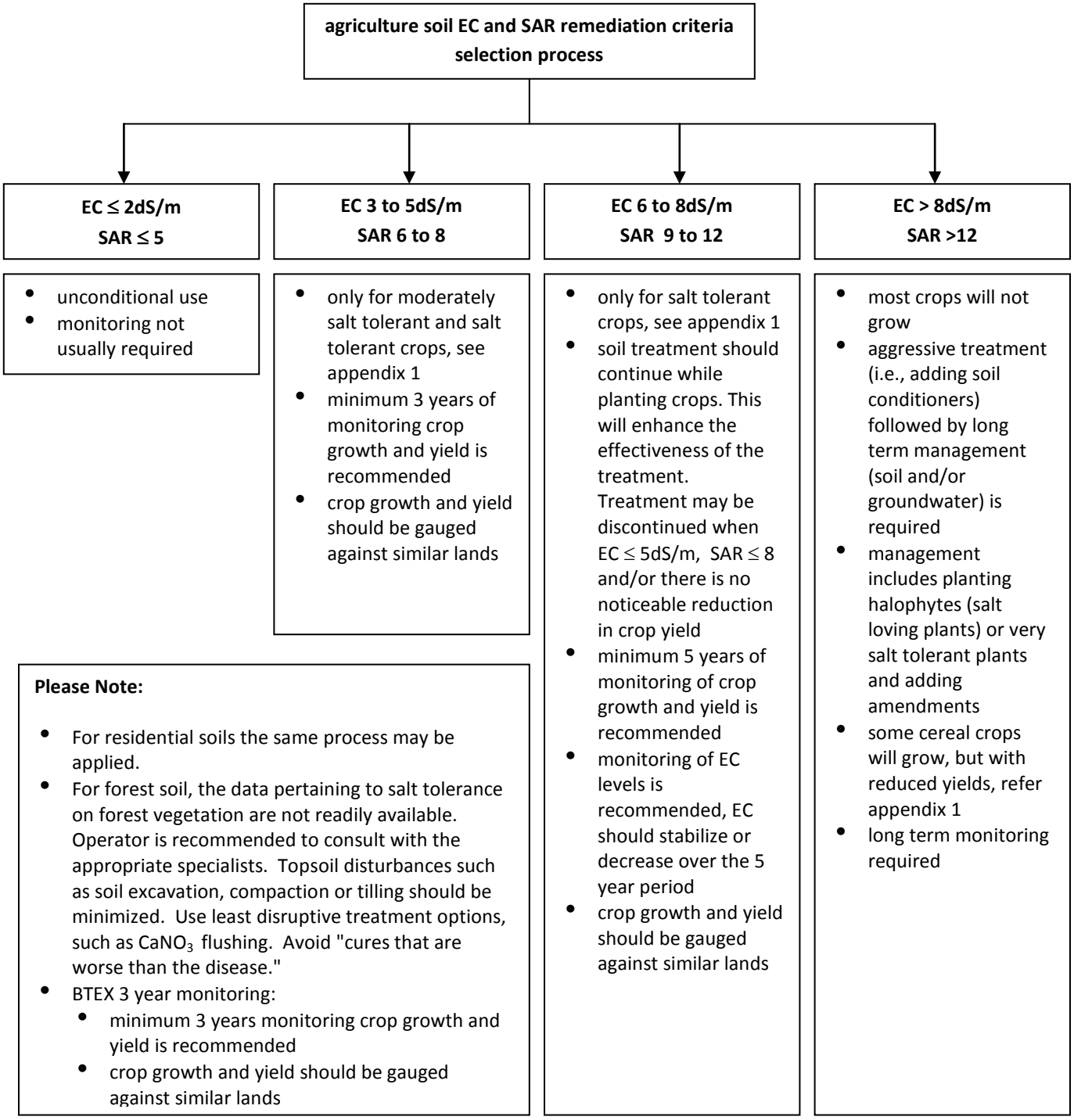
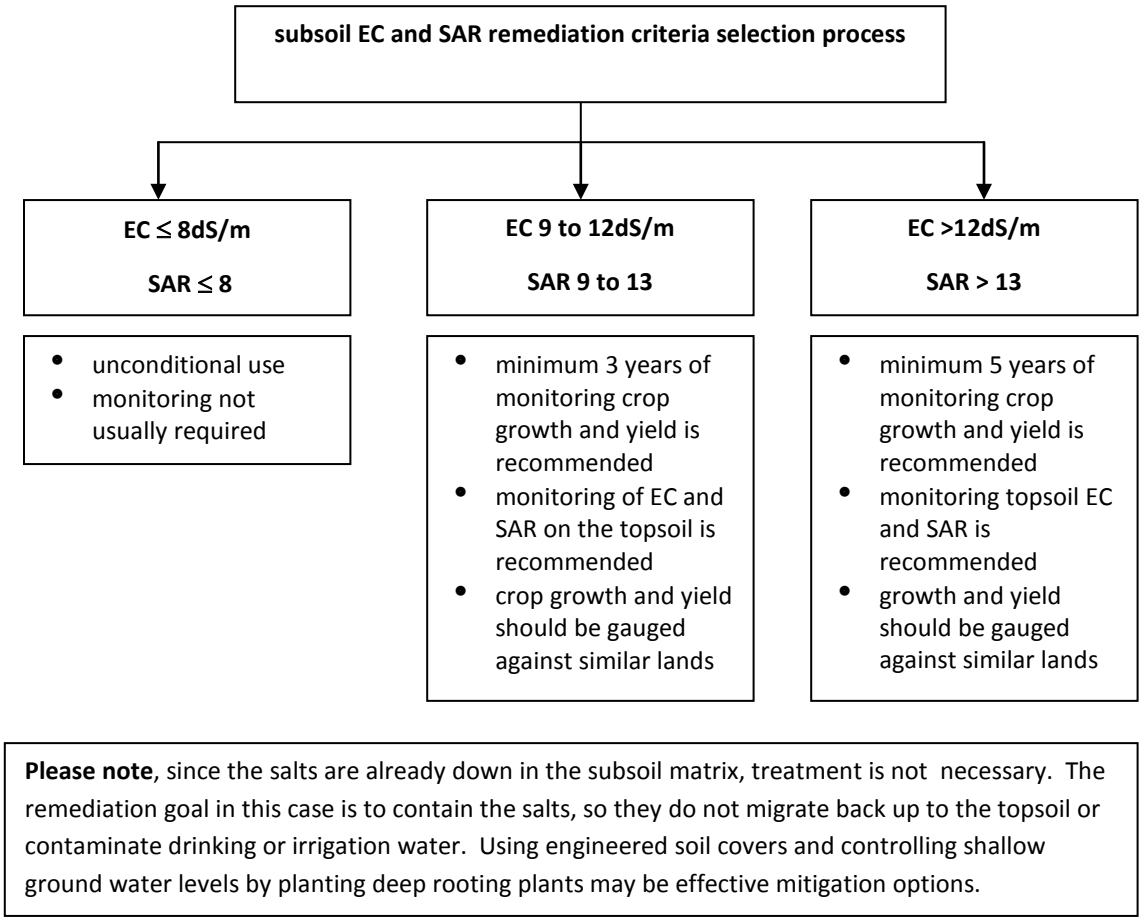


Figure 2. Determining Subsoil Salinity and Sodicity Remediation Criteria



Please note, since the salts are already down in the subsoil matrix, treatment is not necessary. The remediation goal in this case is to contain the salts, so they do not migrate back up to the topsoil or contaminate drinking or irrigation water. Using engineered soil covers and controlling shallow ground water levels by planting deep rooting plants may be effective mitigation options.

Figure 3. Total Extractable Hydrocarbons Remediation Criteria

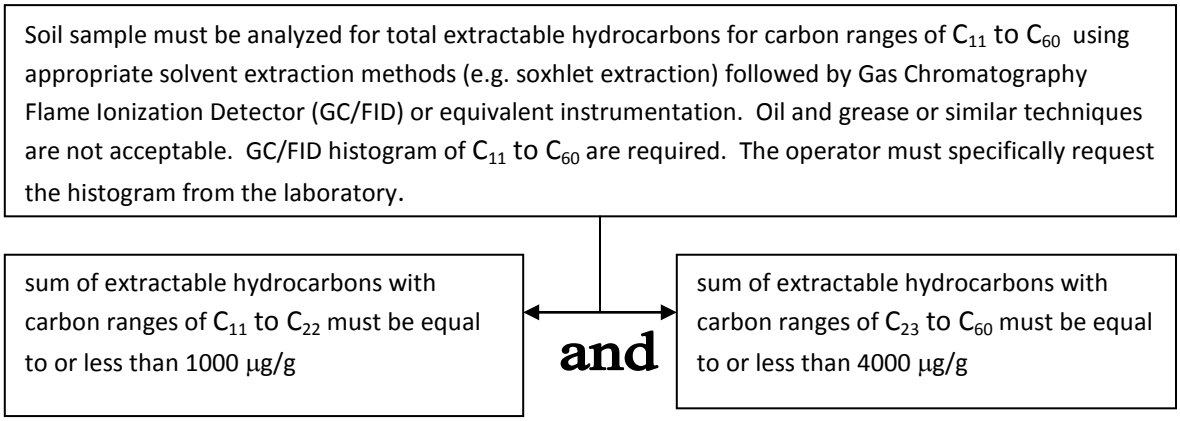


Table 1. Saskatchewan Upstream Petroleum Site Soil Remediation Criteria

SOIL REMEDIATION CRITERIA						
PARAMETERS		Agricultural µg/g		Residential µg/g	Forest µg/g	Subsoil µg/g
Soil Chemical Parameters						
pH		**6 to 8**		**6 to 8**	**4 to 7**	**6 to 8**
electrical conductivity (EC) @ 25°C dS/m	unconditional use	**2**		**2**	**2**	**8**
	moderately tolerant crops	**3[A] to 5[A]**		**3[A] to 5[A]**	**3[A] to 5[A]**	**9[A] to 12[A]** / **>12[B]**
	tolerant crops	**6[B] to 8[B]**		**6[B] to 8[B]**	**6[B] to 8[B]**	
sodium adsorption ratio SAR	unconditional use	**5**		**5**	**5**	**8**
	conditional use	**6[A] to 8[A]**		**6[A] to 8[A]**	**6[A] to 8[A]**	**9[A] to 13[A]** / **>13[B]**
Organic Parameters						
Total Extractable Hydrocarbons (TEH)						
total extractable hydrocarbons (C_{11}-C_{22}) µg/g		**1000**		**1000**	**1000**	**1000**
total extractable hydrocarbons (C_{23}-C_{60}) µg/g		**4000**			**4000**	**4000**
BTEX (Mono Aromatic Hydrocarbon)						
benzene µg/g		**0.5**	**5[A]**	**0.5**	**5**	**5**
toluene µg/g		**3**	**30[A]**	**3**	**30**	**30**
ethyl benzene µg/g		**5**	**50[A]**	**5**	**50**	**50**
xylene µg/g		**5**	**50[A]**	**5**	**50**	**50**
Glycol						
ethylene glycol (EG) µg/g	pasture (grazing animals)	**97**		**97**	**97**	**410[C]**
	crop land (no grazing)	**410**				**960[D]**
Chlorinated Phenols						
polychlorinated biphenyl (PCB) µg/g		**0.5**		**5**	**5**	**5**
Trace Metals						
barium (Ba) µg/g		**750**		**500**	**500**	**2000**
cadmium (Cd) µg/g		**1.4**		**10**	**10**	**27**
chromium (Cr) µg/g		**64**		**64**	**64**	**87**
copper (Cu) µg/g		**63**		**63**	**63**	**100**
lead (Pb) µg/g		**375**		**500**	**500**	**1000**
mercury (Hg) µg/g		**6.6**		**6.6**	**6.6**	**30**
nickel (Ni) µg/g		**150**		**100**	**100**	**500**
vanadium (V) µg/g		**130**		**130**	**130**	**130**
zinc (Zn) µg/g		**200**		**200**	**200**	**380**

Legend:

[A] must monitor crop growth and crop yield for a minimum of three years see figure 1 or 2

[B] must monitor crop growth and crop yield for a minimum of five years see figure 1 or 2

[C] general clean-up value, unconditional use

[D] groundwater check value, operator must provide site-specific impact information and justification

- **pH, EC and SAR should be prepared as saturation extract**
- **TEH measured by using appropriate solvent extraction/GC-FID or equivalent.**
- **trace metals measured by appropriate digesting/ICP or AA**
- **mercury measured by cold vapour method/electrothermal AAS or ICP/MS**

3.1.3 Water Quality Objectives

The SPIGEC committee strongly encourages the operator to use site specific background water quality as the clean-up criteria for water. The water quality objectives listed in the table below are provided as general assessment information in order to determine if further monitoring or assessment is required. They are not to be interpreted as remediation criteria. Please refer to *CCME Canadian Water Quality Guidelines* for a comprehensive listing of water quality recommendations in Canada.

Table 2. Water Quality Objectives

WATER QUALITY OBJECTIVES - Please note the background water quality data for the site will be considered to be the primary clean-up criteria.				
PARAMETERS	FRESHWATER AQUATIC LIFE	IRRIGATION	LIVESTOCK WATERING	DRINKING WATER
General				
pH	6.5 - 9.0	---	---	6.5 - 8.5
total dissolved solids	---	500 - 3500 mg/L	3000 mg/L	□500 mg/L
Inorganic				
barium	---	---	---	1000 □g/L
boron (total)	---	500-6000 □g/L	5000 □g/L	5000 □g/L
cadmium (Cd)	0.2-1.8 □g/L	10 □g/L	20 □g/L	5 □g/L
chloride (total)	---	100-700 mg/L	---	□250mg/L
chromium (total)	2-20 □g/L	100 □g/L	1000 □g/L	50 □g/L
copper (Cu)	2 - 4 □g/L	200-1000 □g/L	500 - 5000 □g/L	□1000 □g/L
lead (Pb)	1-7 □g/L	200 □g/L	100 □g/L	10 □g/L
mercury (Hg)	0.1 □g/L	---	3 □g/L	1 □g/L
sodium (Na)	---	---	---	200mg/L
ammonia (NH_3)	1.37-2.2mg/L	---	---	---
nitrate (NO_3)	---	---	---	45mg/L
nitrate/nitrite (NO_3/NO_2)	---	---	100mg/L	---
nitrite (NO_2)	0.06mg/L	---	10mg/L	4.5mg/L
sulphate (SO_4)	---	---	1000mg/L	□500mg/L
zinc (total) (Zn)	30 □g/L	1000-5000 □g/L	50000 □g/L	□5000 □g/L
Organic (□g/L)				
BTEX (Mono Aromatics Hydrocarbons)				
benzene	300 □g/L	---	---	5 □g/L
ethyl benzene	700 □g/L	---	---	□2.4 □g/L
toluene	300 □g/L	---	---	□24 □g/L
xylene	---	---	---	□300 □g/L
Phenolic Compounds (□g/L)				
polychlorinated biphenyls (PCB)	1ng/L	---	---	---

3.2 Contaminants Potentially Present at Upstream Petroleum Sites

The table below has been designed to assist you in determining the appropriate chemical parameters that should be tested for at an upstream petroleum site.

Parameters		pH, EC, SAR	TEH	BTEX	PCB	EG	Trace Metals
well sites	well head	O	O	▲			
	storage tank and area	O	O	O			
	flare pit	O	O	O	▲		
	emergency earthen pit (brine)	O	▲	▲			
	pits of unknown origin	O	O	O	O		O
batteries, compressors, treatment and processing facilities	flowline/pipeline	O	O	O			
	gas pipeline		O	O	O		
	blow down tank & area	O	▲	▲	▲		
	metering equipment		▲	▲			Hg
	pig trap (flowline)	O	O	O			
	pig trap (pipeline)	O	O	O	▲		
	treater and separator	O	O	O			
	dehydrator	▲	O	O		O	
	salt water storage tank	O	▲	▲			
	crude oil storage tank	O	O	O			
	other storage tank	O	O	O	▲		
	tankfarm area	O	O	O			
	refined product storage		O	O	▲	▲	O
	ecology pit (OBSST)	O	O				
	desand tank	O	O	▲			
	flare knock out tank	O	O	O		▲	O
	flare line	O	O	O			
	flare pit	O	O	O	▲		O
	emergency earthen pit (brine)	O	▲	▲			
	pits of unknown origin	O	O	O	O	▲	O
spills	saltwater	O					
	crude oil	▲	O	O			
	emulsion	O	O	O			
	condensate	▲	O	O			
	refined product(s)	▲	O	O	▲	▲	▲

Legend:

O **there is a very strong potential that the parameter is present and it should be tested**

▲ **parameter should be tested only if evidence exits or it is strongly suspected, for example during pit excavation if electrical capacitors are found in the pit then PCB analysis must be carried out**

Hg **means test for mercury if evidence exists or it is strongly suspected**

3.3 Risk Based Approach

This approach requires the use of a site specific risk assessment study to characterize potential risk, hazards and exposure of receptors to contaminants at a particular site. Based on this study, site-specific risk based criteria are established. The implementation of a site specific risk assessment study is reserved for large-scale contaminated sites or acute and environmentally significant remediation projects. It is a compulsory requirement to have the site specific risk assessment study conducted by environmental specialists with appropriate knowledge and experience in this field.

The operator is required to submit written notification to Saskatchewan Energy and Mines prior to conducting an official risk assessment study. The notification must include the following:

- operator's name;
- description of the project, e.g., site location, environmental specialist doing the work, nature of the problem, findings of environmental site assessment, scope of the study and justification for using a risk based approach;
- project plan, e.g., stakeholder consultation, time-frame of work; and
- description of risk assessment model.

The operator is responsible for carrying out the necessary stakeholder consultations, and specifically advising and obtaining agreement from the landowner. In certain circumstances, the operator may be required to carry out public consultations. In most cases where risk based remediation criteria are applied, the operator may be required to carry out long-term monitoring.

4.0 Restoration

The restoration of abandoned well sites (wellbores which have been plugged) and associated facilities in Saskatchewan is the responsibility of the operator. Two documents have been prepared to provide the operators with restoration guidelines that ensure a consistent quality of restoration resulting in reclaimed sites that are clean, stable and have little risk of impaired capability. The two documents are:

- *Restoration of Saskatchewan's Agricultural Crown Rangelands - Guidelines and Procedures for Developers*, prepared by Saskatchewan Agriculture Food (SAF), available at SAF Publication Section; and
- *Restoration of Well Sites and Associated Facilities on Cultivated Lands in Saskatchewan*, prepared by SPIGEC, Guideline No. 2, January 1, 1999.

Please note, **decommissioning** refers to the removal of all facilities from a well site; **remediation** refers to the decontamination of the soil or water; and **restoration** refers to the physical reclamation process involving recontouring, replacing topsoil, and re-vegetating to restore the surface of the land to its equivalent land capability.

It is important for industry to recognize that restoration is impacted by construction practices, by operational management during the life cycle of the site and by the practices used during the decommissioning, remediation and restoration processes. Soil conservation, prevention of contamination and timely remediation of problems during the life of the site will result in easier, more successful restoration at the end of its productive life.

The operator is responsible for negotiating and undertaking well site restoration to the satisfaction of the landowner or occupant. Occupant means a person or tenant, other than the owner, who is in actual and lawful possession of land.

If a satisfactory agreement cannot be reached, either party has access to an arbitration process administered by the Saskatchewan Surface Rights Arbitration Board. The Surface Rights Arbitration Board is governed *by The Surface Rights Acquisition and Compensation Act*, which was implemented in 1968. It is the Arbitration Board that is used as a last resort when a landowner and an oil/gas or potash operator are unable to reach an agreement on their own. The Board holds Hearings similar to court of law. Its orders are binding and can only be appealed for two reasons -- jurisdiction or a point of law. Operators should be familiar with *The Surface Rights Acquisition and Compensation Act.*

GLOSSARY

Decommissioning refers to the removal of all facilities from a well site.

Equivalent land capability is the ability of the land to support various land uses, similar to - but not necessarily identical to - the ability that existed prior to an activity being conducted.

Electrical Conductivity (EC): the ability of solution to carry an electric current.

Exchangeable Sodium Percentage (ESP): measure of soil sodicity, the molar portion of cation-exchanges sites in a soil (CEC- cation exchange capacity) occupied by sodium (Na_{exch}). Sodic soil have been defined as having an ESP>15. ESP = Na_{exch}/CEC x 100.

GC/FID: gas chromatography flame ionization detector. Instrumentation used to quantify hydrocarbons.

Groundwater: subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated.

ICP or AA: inductively coupled plasma or atomic absorption spectroscopy. Instrumentation used to quantify trace metals and other inorganic parameters.

Impermeable subsoil material: refers to continuous subsoil layer soil with water coefficient of permeability (k_w) less than 10^{-8} m/s. For the purpose of these guidelines it refers to a continuous layer of clay.

Landowner means the owner of the surface land whose name is in the certificate of title issued under *The Land Titles Act*.

Operator means a person, company, syndicate or partnership and their agents who hold the right to a mineral or the right to drill for or produce or recover a mineral.

Remediation refers to the decontamination of the soil or water to provide protection to human and environmental health;

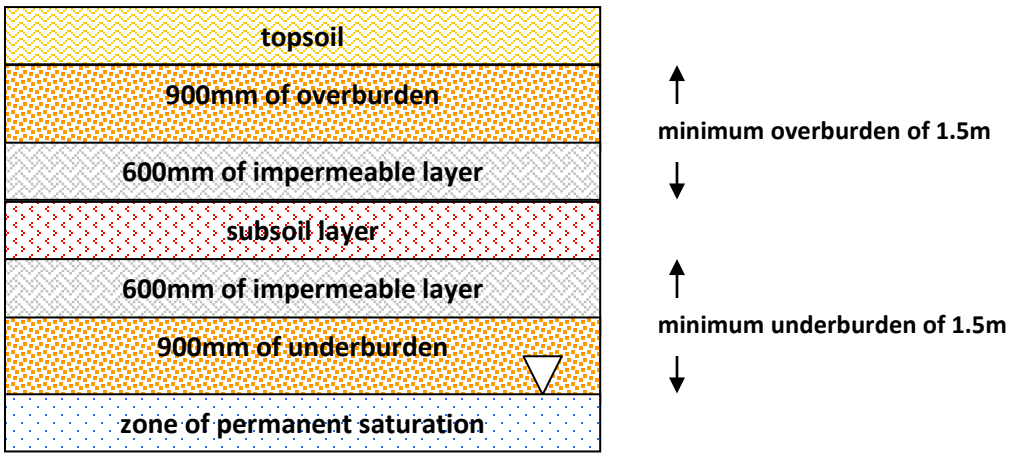
Restoration refers to the physical reclamation process involving recontouring, replacing topsoil, and re-vegetating to restore the surface of the land to its equivalent land capability.

Saturation Extract - saturated paste extract such as **Method 18.2.2 in Cater (1993).**

Sodic Soil: soil having an exchangeable sodium percentage (ESP) of 15 or more, which is not saline. By convention, soils with SAR values greater than 13 are considered to be sodic.

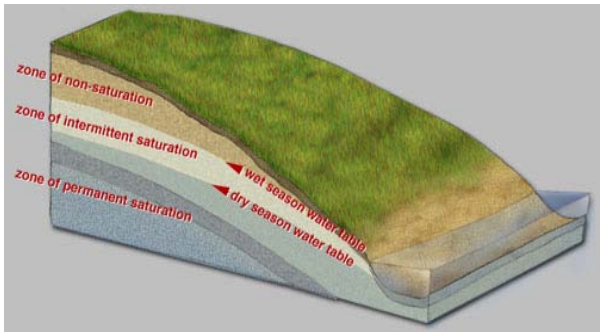
Sodium Adsorption Ratio (SAR): calculated ratio used to represent the relative activity of sodium, calcium and magnesium with respect to ion exchange reactions in soil. A surrogate for exchangeable sodium percentage. **SAR = $[Na^+] \div ([Ca^{2+}] + [Mg^{2+}])^{0.5}$** where ions concentrations are in millimol per litre (mmol/L) or **SAR = $[Na^+] \div (([Ca^{2+}] + [Mg^{2+}])/2)^{0.5}$** where concentrations of ions are in milliequivalent per litre (meq/L).

Subsoil: contaminated soil diagram as mentioned in section 3.1.1.



Total extractable hydrocarbons: hydrocarbons with carbon number between C_{11} - C_{60}, quantified by GC/FID.

Water Table: area between the zone of saturation and the zone of aeration; that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.



The three water zones below ground surface can be identified:

- zone of permanent saturation - where pore spaces are always filled with water
- zone of intermittent saturation - where pore spaces are filled with water only after heavy rain
- zone of non-saturation - where pore spaces are never saturated, though water may pass through

By definition water table is the upper surface of the zone of permanent saturation. Its level migrates from season to season. Operators may determine the water table by excavating a pilot hole or installing groundwater monitoring wells. They may also consult with hydrogeologists, local water well users or check well records.

REGULATORY CONTACTS

Saskatchewan Energy and Mines

Head Office
2101 Scarth Street, Regina, S4P 3V7

Petroleum Development Branch

General Inquiry	(306) 787-2221
Director, Todd Han	(306) 787-2221
Manager, Environment, Brad Wagner	(306) 787-2348
Fax	(306) 787-2478

Communications Branch

Publications Orders	(306) 787-2528
Fax	(306) 787-7338

Petroleum Development Branch Field Offices

Estevan
1219 - 5th Street, Estevan, S4A OZ1

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APPENDIX 1: Relative Salt Tolerance of Herbaceous Crops (USSL)

Table 1. Fiber, Grain, and Special Crops

Common Name	Botanical Name (b)	Threshold dS/m (c)	Slope % per dS/m	Rating (d)
Artichoke, Jerusalem (Tabers)	Helianthus tuberosus	0.4	9.6	MS
Barley (e)	Hordeum vulgare	8.0	5.0	T
Bean	Phaseolus vulgaris	1.0	19.0	S
Broadbean	Vicia Faba	1.6	9.6	MS
Corn (f)	Zea mays	1.7	12.0	MS
Cotton	Gossypium hirsutum	7.7	5.2	T
Cowpea	Vigna unguiculata	4.9	12.0	MT
Flax	Linum usitatissimum	1.7	12.0	MS
Guar	Cyamopsis tetragonoloba	8.8	17.0	T
Kenaf	Hibiscus cannabinus	8.1	--	MT
Millet, foxtail	Setaria italica	--	--	MS
Oats	Avena sativa	--	--	MT*
Peanut	Arachis hypogaea	3.2	29.0	MS
Rice, paddy	Oryza sativa	3.0 (g)	12.0 (g)	S
Rye	Secale cereale	11.4	10.8	T
Safflower	Carthamus tinctorius	--	--	MT
Sesame (m)	Sesamum indicum	--	--	S
Sorghum	Sorghum bicolor	6.8	16.0	MT
Soybean	Glycine max	5.0	20.0	MT
Sugarbeet (h)	Beta vulgaris	7.0	5.9	T
Sugarcane	Saccharum officinarum	1.7	5.9	MS
Sunflower	Helianthus annuus	--	--	MS*
Triticale	X Triticosecale	6.1	2.5	T
Wheat	Triticum aestivum	6.0	7.1	MT
Wheat (semidwarf) (i)	T. aestivum	8.6	3.0	T
Wheat, Durum	T. turgidum	5.9	3.8	T

Table 2. Vegetables and Fruit Crops

Common Name	Botanical Name (b)	Threshold dS/m (c)	Slope % per dS/m	Rating (d)
Artichoke	Cynara scolymus	--	--	MT*
Asparagus	Asparagus officinalis	4.1	2.0	T
Bean	Phaseolus vulgaris	1.0	19.0	S
Bean, mung	Vigna radiata	1.8	20.7	S
Beet, red (h)	Beta Vulgaris	4.0	9.0	MT
Broccoli	Brassica oleracea botrytis	2.8	9.2	MS
Brussel Sprouts	B. oleracea gemmifera	--	--	MS*
Cabbage	B. oleracea capitata	1.8	9.7	MS
Carrot	Daucus carota	1.0	14.0	S
Cauliflower	Brassica oleracea botrytis	--	--	MS*
Celery	Apium graveolens	1.8	6.2	MS
Corn, sweet	Zea mays	1.7	12.0	MS
Cucumber	Cucumis sativus	2.5	13.0	MS
Eggplant	Solanum Melongena esculentum	1.1	6.9	MS
Kale	Brassica oleracea acephala	--	--	MS*
Kohlrabi	B. oleracea gongylode	--	--	MS*
Lettuce	Lactuca sativa	1.3	13.0	MS
Muskmelon	Cucumis Melo	--	--	MS
Okra	Abelmoschus esculentus	--	--	S
Onion	Allium Cepa	1.2	16.0	S
Parsnip	Pastinaca sativa	--	--	S*
Pea	Pisum sativum	--	--	S*
Pepper	Capsicum annuum	1.5	14.0	MS
Potato	Solanum tuberosum	1.7	12.0	MS
Pumpkin	Cucurbita Pepo Pepo	--	--	MS*
Radish	Raphanus sativus	1.2	13.0	MS
Spinach	Spinacia oleracea	2.0	7.6	MS
Squash, scallop	Cucurbita Pepo Melopepo	3.2	16.0	MS
Squash, zucchini	C. Pepo Melopepo	4.7	9.4	MT
Strawberry	Fragaria sp.	1	33	S
Sweet potato	Ipomoea Batatas	1.5	11	MS
Tomato	Lycopersicon Lycopersicum	2.5	9.9	MS
Tomato, cherry	L. esculentum var cerasiforme	1.7	9.1	MS
Turnip	Brassica Rapa	0.9	9	MS
Watermelon	Citrullus lanatus	--	--	MS*

Table 3. Grasses and Forage Crops

Common Name	Botanical Name (b)	Threshold dS/m (c)	Slope % per dS/m	Rating (d)
Vetch, common	Vicia angustifolia	3.0	11.0	MS
Rescuegrass	Bromus unioloides	--	--	MT*
Rhodesgrass	Chloris Gayana	--	--	MT
Rye (forage)	Secale cereale	--	--	MS*
Ryegrass, Italian	Lolium italicum multiflorum	--	--	MT*
Ryegrass, perennial	L. perenne	5.6	7.6	MT
Saltgrass, desert	Distichlis stricta	--	--	T*
Sesbania	Sesbania exaltata	2.3	7.0	MS
Sirato	Macroptilium atropurpureum	--	--	MS
Sphaerophysa	Sphaerophysa salsula	2.2	7.0	MS
Sudangrass	Sorghum sudanense	2.8	4.3	MT
Timothy	Phleum pratense	--	--	MS*
Trefoil, big	Lotus uliginosus	2.3	19.0	MS
Wheat (forage) (i)	Triticum aestivum	4.5	2.6	MT
Wheat, Durum (forage)	T. turgidum	2.1	2.5	MT
Wheatgrass, standard crested	Agropyron sibiricum	3.5	4.0	MT
Wheatgrass, fairway crested	A. cristatum	7.5	6.9	T
Wheatgrass, intermediate	A. intermedium	--	--	MT*
Wheatgrass, slender	A. trachycaulum	--	--	MT
Wheatgrass, tall	A. elongatum	7.5	4.2	T
Wheatgrass, western	A. Smithii	--	--	MT*
Wildrye, Altai	Elymus angustus	--	--	T
Wildrye, beardless	E. triticoides	2.7	6.0	MT
Wildrye, Canadian	E. canadensis	--	--	MT*
Wildrye, Russian	E. Junceus	--	--	T
Trefoil, narrowleaf birdsfoot	L. corniculatus tenuifolium	5.0	10.0	MT
Trefoil, broadleaf birdsfoot	L. corniculatus arvenis	--	--	MT
Panicgrass, blue	Panicum antidotale	--	--	MT*
Rape	Brassica napus	--	--	MT*
Alfalfa	Medicago sativa	2.0	7.3	MS
Alkaligrass, Nuttall	Puccinellia airoides	--	--	T*
Alkali sacaton	Sporobolus airoides	--	--	T*
Barley (forage) (e)	Hordeum vulgare	6.0	7.1	MT
Bentgrass	Agrostis stolonifera palustris	--	--	MS
Bermudagrass (j)	Cynodon Dactylon	6.9	6.4	T
Bluestem, Angleton	Dichanthium aristatum	--	--	MS*

Brome, mountain	Bromus marginatus	--	--	MT*
Brome, smooth	B.inermis	--	--	MS
Buffelgrass	Cenchrus ciliaris	--	--	MS*
Burnet	Poterium Sanguisorba	--	--	MS*
Canarygrass, reed	Phalaris arundinacea	--	--	MT
Clover, alsike	Trifolium hybridum	1.5	12.0	MS
Clover, Berseem	T. alexandrinum	1.5	5.7	MS
Clover, Hubam	Melilotus alba	--	--	MT*
Clover, ladino	Trifolium repens	1.5	12.0	MS
Clover, red	T. pratense	1.5	12.0	MS
Clover, strawberry	T. fragiferum	1.5	12.0	MS
Clover, sweet	Melilotus	--	--	MT*
Clover, white Dutch	Trifolium repens	--	--	MS*
Corn (forage) (f)	Zea mays	1.8	7.4	MS
Cowpea (forage)	Vigna unguiculata	2.5	11.0	MS
Dallisgrass	Paspalum dilatatum	--	--	MS*
Fescue, tall	Festuca elatior	3.9	5.3	MT
Fescue, meadow	F. pratensis	--	--	MT*
Foxtail, meadow	Alopecurus pratensis	1.5	9.6	MS
Grama, blue	Bouteloua gracilis	--	--	MS*
Hardinggrass	Phalaris tuberosa	4.6	7.6	MT
Kallargrass	Diplachne fusca	--	--	T*
Lovegrass (k)	Eragrostis sp.	2.0	8.4	MS
Milkvetch,Cicer	Astragalus cicer	--	--	MS*
Oatgrass, tall	Arrhenatherum, Danthonia	--	--	MS*
Oats (forage)	Avena sativa	--		MS*
Orchardgrass	Dactylis glomerata	1.5	6.2	MS

Legend:

Rating System

S- the crop is sensitive to salt

MS - the crop is moderately sensitive to salt

MT - the crop is moderately tolerant to salt

T - the crop is tolerant to salt

Threshold dS/m - the threshold limit of a plant to salinity before an observable reduction in growth or yield is apparent

Slope % per dS/m - the percentage of crop yield reduction per every one dS/m that exceeds the threshold limit

(a) These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending upon climate, soil conditions, and cultural practices.
(b) Botanical and common names follow the convention of Hortus Third (Liberty Hyde Bailey Hortorium Staff, 1976) where possible.
(c) In gypsiferous soils, plants will tolerate EC about 2 dS/m higher than indicated.
(d) Ratings with a * are estimates.
(e) Less tolerant during seedling stage, EC at this stage should not exceed 4 or 5 dS/m.
(f) Grain and forage yields of DeKalb XL-75 grown on an organic muck soil decreased about 26% per dS/m above a threshold of 1.9 dS/m.
(g) Paddy rice is grown under flooded conditions, thus electrical conductivity of the soil water refers to the plants while submerged. Less tolerant during seedling stage.
(h) Sensitive during germination and emergence, EC should not exceed 3 dS/m.
(i) Data from one cultivar, "Probred".
(j) Average of several varieties. Suwannee and Coastal are about 20% more tolerant, and common and Greenfield are about 20% less tolerant than the average.
(k) Average for Boer, Wilman, Sand, and Weeping cultivars. Lehmann seems about 50% more tolerant.
(l) Broadleaf birdsfoot trefoil seems less tolerant than narrowleaf.
(m) Sesame cultivars, Sesaco 7 and 8, may be more tolerant than indicated by the S rating.