Contaminated Sites Soil Task Group Workshop on the Development and Implementation of Soil Quality Standards for Contaminated Sites

-- Summary Report --

Prepared For:

Industrial Waste and Hazardous Contaminants Branch
Environmental Protection Department
B.C. Ministry of Environment, Lands, and Parks
510 - 1175 Douglas Street
Victoria, British Columbia
V8V 1X4

Prepared By:

Donald D. MacDonald
MacDonald Environmental Sciences Ltd.
2376 Yellow Point Road, RR #3
Ladysmith, British Columbia
V0R 2E0

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1.0 Introduction

In 1993, the Waste Management Amendment Act was proclaimed to address public concerns related to contaminated sites in British Columbia. Under the provisions of the Act, numerical soil quality standards (SQSs) must be developed to support the assessment and remediation of contaminated sites. Specifically, these SQSs are required to:

- determine if a site is contaminated;
- determine if remediation has been adequately performed at a site; and,
- address issues related to the relocation of contaminated soils.

In addition, a framework for applying the SQSs is also required to support the implementation of the contaminated sites legislation. To expedite this process, the Contaminated Sites Soil Task Group (CSST) was established and charged with the responsibility of deriving numerical standards for priority contaminants in soils and developing a framework for their effective implementation in the province.

The CSST adopted a pragmatic approach to the development of SQSs. As a formal protocol for deriving soil quality guidelines had already been established under the auspices of the Canadian Council of Ministers of the Environment (CCME 1995), CSST decided to use this protocol as a basis for developing numerical SQSs in British Columbia. However, CSST believed that direct application of the CCME protocol resulted in soil quality criteria that were too stringent for the contaminated site remediation and management program envisioned for British Columbia. For this reason, CSST developed unique derivation procedures that would create SQSs that more specifically addressed the needs of the British Columbia Ministry of Environment Lands and Parks (BCMOE) needs.

The philosophy underlying CSST's procedures differed significantly from that expounded by the CCME. While the CCME soil quality criteria are intended to provide a high level of protection for environmental receptors at contaminated sites, the CSST SQSs are intended to provide a *reasonably healthy, functioning ecosystem* capable of sustaining the site under prescribed land usage. However, total protection of all species will neither be targeted nor achieved at remediated sites. CSST believes that it is unreasonable and unnecessary to provide equivalent protection to all species under all circumstances.

In formulating its strategy, CSST recognized the need for both scientific-defensibility and flexibility in the contaminated sites assessment and remediation process. For this reason, CSST endeavoured to develop a protocol that could be used to derive SQSs for a broad range of management applications. Consequently, the protocol provides a basis for deriving SQSs that apply to five major types of land uses, including agricultural, residential, urban parkland, commercial, and industrial. In addition, the protocol addresses the major exposure pathways at contaminated sites, including direct soil contact for invertebrates and plants, ingestion of soil and fodder by livestock, consumption of groundwater by livestock, irrigation of agricultural crops with groundwater, and groundwater recharge of surface water sources (thereby potentially affecting aquatic life). This matric approach to the development of SQSs is unique and is considered to provide greater flexibility in managing contaminated sites.

It is anticipated that the SQSs derived using the CSST protocol will be incorporated into the pending Contaminated Sites Regulation for British Columbia. It is important to note that the SQSs represent 'clean down to' numbers and are not meant to be used as 'pollute up to' numbers. Moreover, these SQSs are intended to be used only at contaminated sites and should not be used for the management of pristine sites or for the management of certain land uses, such as wetlands, wildlands, rangelands, forest, or tundra.

The BCMOE is confident that the CSST framework and protocol for deriving SQSs will contribute significantly to the contaminated site assessment and remediation process in the province. However, BCMOE recognizes that this approach is new and requires detailed peer-review prior to implementation. For this reason, experts from a wide range of disciplines were invited to attend a two day workshop in Vancouver, B.C. The primary objectives of this workshop were to present, review, and discuss the policies and procedures established by CSST under the Waste Management Amendment Act. More specifically, the workshop was conducted to provide BCMOE with practical advice on the development and implementation of numerical SQSs for contaminated in British Columbia. This report summarizes the recommendations provided by workshop participants.

2.0 Methods

A workshop was conducted on September 21 and 22, 1995 in Vancouver, B.C. to obtain advice and guidance on the development and implementation of soil quality standards for contaminated sites in British Columbia. The objectives of this workshop were to:

(i) establish a common understanding among participants on the procedures that have been developed for deriving SQSs in B.C.;

(ii) obtain guidance on the recommended procedures for deriving soil-contact based SQSs;

(iii) obtain guidance on the recommended procedures for deriving groundwater-contact based SQSs; and,

(iv) obtain guidance on the recommended framework for applying the SQSs at contaminated sites in B.C.

A total of 40 recognized experts in the soil quality assessment, management, and remediation field were invited to the CSST Workshop (see Appendix 1). Each of these invited experts was provided with several key documents to facilitate their effective participation in the workshop. These documents included, *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1995), *Guidance Manual for Developing Site-Specific Soil Quality Remediation Objectives for Contaminated Sites in Canada* (CCME 1994), *Summary of the CSST Protocol for the Derivation of Soil Quality Matrix Numbers for Contaminated Sites* (BCMOE 1995a), and *Policy/Decision Issues Related to CCME Protocol and Site-Specific Objectives Documents* (CSST 1995). Each of the invited experts was asked to review these documents prior to the workshop.

At the workshop, BCMOE staff made several presentations to provide the experts with additional information on the SQSs development and implementation process. First, Lanny Hubbard (Director, Industrial Waste and Hazardous Contaminants Branch) provided an overview of the CSST policy decisions and framework for implementing the SQSs. Next, Glyn Fox and Mike Macfarlane (Contaminated Sites Risk Assessment Unit) summarized the procedures that have been developed for deriving soil-contact based SQSs. Finally, Robert McLenehan (Contaminated Sites Remediation Unit) presented an overview of the groundwater model that has been used to support the derivation of SQSs for contaminated sites (see BCMOE 1995b for a detailed description of the model).

Following the presentations, a total of four work groups were formed to discuss several high priority issues related to the CSST initiative. To focus these discussions, each of the work groups was asked to consider six questions that related to the CSST SQS derivation protocol and the framework for implementing these standards (see Appendix 2 for a list of questions). The first three questions addressed the protocol for deriving soil-contact based SQSs for the protection of soil, invertebrate, plants, and livestock. The next two questions dealt with the groundwater model and its application in the SQSs derivation process. The final question was designed to allow workshop participants to express their views on the CSST framework for implementing the SQSs in British Columbia. At the end of the first day of the workshop, each work group presented its responses to the first three questions. The reports presented on the second day encompassed the work group responses to the last three questions.

The format for the workshop (i.e., four work groups) was selected for several reasons. First, with a total of forty experts invited to the workshop, there was a need to split the participants into manageable groups to facilitate discussions. That is, it was thought that people could express their opinions more effectively in smaller groups. In addition, multiple work groups provided an opportunity to examine similarities and differences in the responses to the questions between groups. In this way, it was possible to identify the issues of greatest importance to the participants. Therefore, each of the four work groups was charged with the task of responding to each of the six questions.

3.0 Results and Recommendations

The CSST Workshop was conducted to provide BCMOE with practical guidance on the development and implementation of soil quality standards for contaminated sites in British Columbia. The participants at this workshop provided detailed guidance on five important technical issues related to the development of numerical soil quality standards. In addition, the invited experts provided their advice on the current applications of the standards within the Ministry's policy framework and the options for future improvement of the process overall. The detailed recommendations provided by each of the work groups are presented in Appendix 2. The major results and recommendations resulting from the workshop are summarized below.

(i) Workshop participants emphasized that the methods developed for formulating ecological SQSs will significantly improve the assessment and management of contaminated sites in British Columbia. In particular, the development of SQSs for multiple land uses and exposure pathways represents an important advancement over single generic criteria.

(ii) The matrix of SQSs was considered to increase flexibility in the contaminated site assessment and management process; however, many participants were concerned that the process was complex. For this reason, it was recommended that a guidance document be prepared to support the implementation of the SQSs. It was also recommended that BCMOE provide guidance on the sampling of environmental matrices at contaminated sites and on the methods for analysing these samples (particularly to address the bioavailability of soil-associated contaminants).

(iii) The workshop participants concluded that the procedures developed by BCMOE to derive ecological soil quality standards that apply to direct soil contact are reasonable and generally scientifically-defensible. However, it was recommended that minimum data requirements be established to assure that concerns regarding data quality, quantity, and ecological-relevance are addressed. In addition, the experts recommended that the criteria for accepting the hypothesis that dose-response data are linear be reevaluated and more fully justified. Several methods for improving the distribution of the toxicity data were also proposed by the participants, including consideration of specific endpoints and normalization to account for environmental variables (see Appendix 2).

(iv) Although workshop participants generally agreed that the numerical SQSs would provide a reasonable level of protection for most ecological receptors, concerns were expressed about the level of protection afforded at agricultural sites. In addition, concerns were expressed about the potential for adverse effects at higher trophic levels in the food web and about the marketability of agricultural products due to the bioaccumulation of soil-associated contaminants.

(v) The experts attending the workshop generally agreed that the SQSs would have significant ecological consequences on site and, potentially, in nearby areas. Depending on the number and size of contaminated sites in an area, and extent of contamination at these sites, it is possible that the ecological consequences of the SQSs could be more widespread. It is unlikely, however, that the SQSs would have adverse significant impacts at the regional or provincial levels. On the contrary, the SQSs may result in net ecological benefits because they could facilitate the cleanup of sites that otherwise would not be actively remediated.

(vi) Workshop participants agreed that the CSST procedures for deriving SQSs for the protection of livestock are reasonable and that the resultant SQSs would provide an adequate basis for assessing metal-contaminated soils. It was emphasized, however, that there is also a need to consider the effects of organic contaminants on livestock and on the marketability of agricultural products. While it was recognized that toxicological data are limited, it was also noted that information on the effects of certain organic contaminants is available and that cross-species extrapolations from these data was preferable to not considering these substances at all.

(vii) There was virtually unanimous agreement among participants that it was important to develop soil quality standards that would protect designated groundwater uses, including livestock watering, crop irrigation, and aquatic life (i.e., due to the potential for groundwater recharge of surface water sources). Moreover, workshop participants agreed that the chemical transport model that has been proposed for deriving SQSs is scientifically-defensible. While the experts agreed that the model assumptions for the generic site matrix were reasonable, they thought that these assumptions were too conservative for certain areas of the province (e.g., interior areas with little precipitation). Therefore, it was suggested that groundwater-contact based SQSs be derived which account for differences in easily definable parameters, such as regional precipitation patterns. It was also recommended that the model be calibrated with field-collected data to assure that the default assumptions are valid.

(viii) One of the important limitations of the chemical transport model is that it applies only to nonpolar organic substances. For this reason, the potential for groundwater contamination by metals and polar organics must be addressed by other means. The approaches that were recommended for evaluating the hazards posed to groundwater uses by these classes of contaminants included compiling information from existing contaminated sites (e.g., mines, etc.), using predictive tools (such as leachate tests), and using more conservative SQSs (e.g., applying a safety factor to a soil-contact based SQS). In addition, ecological risk assessments should be conducted at sites where potential groundwater concerns are identified. Additional monitoring is also needed to determine the extent of chemical transport through soils at metal- and polar organic-contaminated sites. In the longer-term, appropriate models should be developed and calibrated for these chemical classes.

4.0 References

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Appendix 1

List of Invited Workshop Participants

Work Group 1

Paul West - Facilitator
Environmental Studies Program
University of Victoria
Victoria, B.C.
V8W 2Y2

Beth Power for Peter Chapman - Rappateur
E.V.S. Consultants
195 Pemberton Avenue
North Vancouver, B.C.
V7P 2R4
Phone: (604) 986-4331
Fax: (604) 662-8548

Lloyd Manchester
Earthcare
1476 Water Street
Kelowna, B.C.
V1Y 8P2

Jozef van Brussel
Senes Consultants Ltd.
Suite 910 Catherdral Place
925 West Georgia Street
Vancouver, B.C.
V6C 3L2

Janice Pasloski
O'Connor Associates
1000, 639 - 5th Avenue S.W.
Calgary, Alberta
T2P 0M9
Phone: (403) 294-4200
Fax: (403) 294-4240

Richard Glue
Environment Canada
224 West Esplanade
North Vancouver, B.C.
V7M 3H7

Don Fast
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 387-9993
Fax: (604) 365-9836

Ted Nason
Alberta Environment
BAG 3014, 3rd Floor, Cousins Bldg.
Lethbridge, Alberta
T1J 4C7

Rob McLenehan
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 387-9948
Fax: (604) 387-9935

John Ward
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 387-9951
Fax: (604) 387-9935

Work Group 2

Ilze Rupners - Facilitator
Agriculture and Agri-Food Canada
202 - 620 Royal Avenue
P.O. Box 2523
New Westminster, B.C.
V3L 5A8
Phone: (604) 666-0741
Fax: (604) 666-6130

Dennis Konasewich - Rappateur
Envirochem Special Projects Inc.
310 East Esplanade
North Vancouver, B.C.
V7L 1A4
Phone: (604) 986-0233
Fax: (604) 986-8583

Tim Shum
City of Burnaby
6161 Deer Lake Avenue
Burnaby, B.C.
V5G 4A3
Phone: (604) 294-7390
Fax: (604) 660-7050

Jim Malick
Norecol, Dames & Moore, Inc.
Crestwood Corporate Centre, Suite 250
13571 Commerce Parkway
Richmond, B.C.
V6V 2R2
Phone: (604) 273-7763
Fax: (604) 273-7791

Jerome Cura
Menzie • Cura and Associates Inc.
1 Courthouse Lane, Suite 2
Chelmsford, MA 01824
Phone: (508) 453-4300
Fax: (508) 453-7260

Doug Walton
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 387-2218
Fax: (604) 365-0605

Brian Baehr
Ministry of Agriculture and Fisheries
Room 200, 1690 Powick Road
Kelowna, B.C.
V1X 7G5

Jack Bryden
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 356-8386
Fax: (604) 387-9935

Frank Gobas
Resource Management
Simon Fraser University
Burnaby, B.C.
V5A 1S6

Don Chorley
Golder Associates Ltd.
500-4260 Still Creek Drive
Burnaby, B.C.
V5C 6C6

Work Group 3

Craig Peddie - Facilitator
Greater Vancouver Regional District
4330 Kingsway
Burnaby, B.C.
V5H 4G8

Francis Law - Rappateur
Department of Biological Sciences
Simon Fraser University
Burnaby, B.C.
V5A 1S6

John Wiens
AGRA Earth and Environmental
694 Sumas Street
Victoria, B.C.
V8T 4S6
Phone: (604) 382-5141
Fax: (604) 382-3103

Mark Bonnell
Bonnell Environmental Consulting
872 Melfa Crescent
Ottawa, Ontario
K2C 0P3
Phone: (613) 224-9707
Fax: (613) 224-9707

Ross Wilson
CanTox Inc.
666 Burrard Street, Suite 1300
Vancouver, B.C.
V6C 3J8
Phone: (604) 688-8255
Fax: (604) 688-2419

Eric McGreer for Steve Samis
Fisheries and Oceans Canada
555 West Hastings Street
Vancouver, B.C.
V6B 5G3
Phone: (604) 666-0280
Fax: (604) 666-7907

Anne Hillyer
Westcoast Environmental Law Association
1001 - 107 West Hastings
Vancouver, B.C.
V6B 1H7

Lanny Hubbard
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 387-9992
Fax: (604) 365-9836

Narender Nagpal
B.C. Ministry of Environment Lands and Parks
Third Floor, 780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 387-9507
Fax: (604) 356-8298

Mike Macfarlane
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 356-0557
Fax: (604) 356-0605

Work Group 4

Connie Gaudet - Facilitator
Environment Canada
Place Vincent Massey, 8th Floor
351 St. Joseph Boulevard
Hull, Quebec
K1A 0H3
Phone: (819) 953-3199
Fax: (819) 953-0461

Bill Donald - Rappateur
Keystone Environmental
#250-10691 Shellbridge Way
Richmond, B.C.
V6X 2W8
Phone: (604) 273-0898
Fax: (604) 273-0895

Philip Ross
B.C. Ministry of Environment, Lands and Parks
3726 Alfred Avenue
P.O. Box 5000
Smithers, B.C.
V0J 2N0
Phone: (604) 847-7251
Fax: (604) 847-7591

Tony Farrell
Department of Biological Sciences
Simon Fraser University
Burnaby, B.C.
V5A 1S6

Mike Rankin
Golder Associates Ltd.
500-4260 Still Creek Drive
Burnaby, B.C.
V5C 6C6

Steve Sibbick
B.C. Ministry of Energy, Mines and Petroleum Resources
5th Floor, 1810 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 952-0399
Fax: (604) 952-0381

Jim van Barneveld
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 387-9945
Fax: (604) 356-5104

Geoff Hughes-Games
B.C. Ministry of Agriculture, Fisheries and Food
1767 Angus Campbell Road
Abbotsford, B.C.
Phone: (604) 556-3102
Fax: (604) 556-3099

Tom Watson
Triton Environmental Consultants Ltd.
#120 - 13511 Commerce Parkway
Richmond, B.C.
V6V 2L1
Phone: (604) 279-2093
Fax: (604) 279-2047

Glyn Fox
B.C. Ministry of Environment Lands and Parks
780 Blanshard Street
Victoria, B.C.
V8V 1X4
Phone: (604) 356-0475
Fax: (604) 365-0605

Appendix 2

Detailed Recommendations Provided by Workshop Participants

Q1. The soil contact protocol used by CSST assigns discrete lethal and non-lethal endpoint distributions to the ecological data included in the CCME criteria assessment documents. The resultant discrete data sets for both lethal and non-lethal effects are plotted as percent response versus contaminant concentration by forcing linearity to the respective effect distributions. Regression lines of best fit are then calculated and the critical intercept points estimated.

Work Group 1	Work Group 2	Work Group 3	Work Group 4
Is splitting the data set into lethal and non-lethal data sets reasonable ?			
Yes Providing there are enough data. It is important to consider data quality, data quantity, and ecological relevance of endpoints (i.e., assure that reproduction, growth, and mortality are considered).	***Yes*** Lethal and non-lethal data are commonly split in toxicological assessments. However, care must be taken to assess whether enough data are available, the data are technically-valid, and the data represent a range of species.	***Yes*** There are some fundamental differences between lethal and non-lethal data that justify splitting the data sets. A combined data set would tend to show a bimodal distribution. Splitting the data supports the establishment of protection goals for different land uses.	***Yes*** However, the use of lethality data without sufficient consideration of non-lethal endpoints and/or sensitive species could lead to under-protection.
Is forcing linearity to the data-set reasonable? Would any other alternative be more reasonable?			
Not necessarily Biological data are rarely linear; therefore, other techniques (e.g., curve fitting, sensitivity analysis, etc.) should also be used to analyze the data sets. Also, it is important to evaluate the significance of the relationship before adopting the linear model.	***Yes*** Providing that the data set is sufficient and the results of the regression analysis generates valid results (i.e., is the relationship significant? Is the correlation coefficient acceptable?). Alternate methods (e.g., curve fitting, professional judgement) should be used to analyze the data if regression analysis does not provide valid results.	***Yes*** The linear model is simple, practical, and reasonable. However, the potential for violating the basic assumption of parametric statistical methods in applying the linear model should be considered. Also, there must be room for professional judgement in analyzing the data.	***Possibly*** But there is a need to inspect the data before applying the linear model (i.e., homogeneity vs. heterogeneity). Also, there is a need to justify the selection of 0.25 as the critical correlation coefficient for accepting the linear model. Perhaps 0.5 would be more justifiable.

Q2. Under the proposed Contaminated Site Regulation, SQSs for the remediation of sites are identified for five defined land uses: Agricultural, Residential, Urban Park, Commercial and Industrial. The proposed CSST Protocol specifies using the available toxicological data for deriving SQSs for the protection of soil invertebrates and plants. The toxicity to soil invertebrates and plants standards for Agricultural, Residential and Urban Park land uses will be derived using the concentration corresponding to the lower of the estimates of the LC_{20} and EC_{50}-NL (non-lethal). The Commercial and Industrial toxicity to soil invertebrates and plants standards will be derived using the higher of the estimates of the LC_{20} and EC_{50}-NL (non-lethal).

Work Group 1	Work Group 2	Work Group 3	Work Group 4
For purposes of identification and remediation of contaminated sites, do the levels of effects specified above provide reasonable protection for receptors which may be affected by direct soil contact at such sites?			
Uncertain For agricultural, residential and urban parks, it is not clear that the approach would provide an adequate level of protection. For commercial and industrial, the approach is probably acceptable. It is important to note that bioaccumulation is not taken into account.	***Yes*** Statistically, it is difficult to detect differences from control responses of less that 20%. Therefore, an LC_{20} probably represents a threshold toxic concentration. However, this approach does not provide receptors with any protection against bioaccumulation of toxic substances in the food web. Therefore, bioaccumulation should be explicitly considered in the SQGs.	***Yes*** The approach provides a means of defining concentrations of contaminants that will result in tolerable impacts rather than reasonable protection. However, this approach is probably acceptable because many populations can tolerate 20% mortality and additional protection will be afforded for soils that are relocated. Also, the potential for bioaccumulation of toxic substances is not considered. The marketability of farm products should also be considered in the matrix numbers.	***Not always*** The agricultural SQSs should never be based on a lethal effect. Rather, an effective concentration should be selected (i.e., that is lower than the LC_{20}) after reviewing the available data. For commercial and industrial uses, this approach is acceptable. For residential and urban parkland, this approach is acceptable with the possible exception that it might not adequately protect urban wildlife.
Would significant ecological consequences from the application of these effect levels at contaminated sites be expected?			
Yes This approach will definitely have ecological consequences. However, the nature, severity, and extent of the ecological effects would be dependent on the size of the site and the nature of the proximate land uses.	***Yes*** There will be ecological consequences that will be a net benefit to the environment (i.e., the SQSs will permit sites to be cleaned-up that otherwise might not have been). There is also a need to evaluate the socio-economic impacts of this approach.	***Uncertain*** Currently there is very little data to document the ecological consequences of the approach. Certainly the consequences at commercial and industrial sites would be greater than at agricultural, residential, and urban parkland sites. However, other activities at commercial and industrial sites are likely to have even greater impacts (e.g., habitat loss, etc.). It is important to conduct environmental monitoring programs and site audits to document the impacts of these decisions as they are implemented at contaminated sites.	***Uncertain*** The approach is probably acceptable for commercial sites; however, the impacts of these decisions on other land uses could be significant.

Q3. The CSST protocol for developing the soil quality standards for livestock protection uses Toxicity Reference Values (TRVs) for heavy metals. Specifically, the lower bound concentration of the estimated high dietary intake reported in Puls (1994) is used. The CSST approach is proposed to provide a relevant real world estimate of receptor exposure to contaminants rather than attempting to extrapolate data across test species.

Work Group 1	Work Group 2	Work Group 3	Work Group 4
Does this procedure seem reasonable and suitably protective of livestock at contaminated sites?			
Probably The approach selected seems reasonable, but it is difficult to determine if it adequately protects livestock without further evaluation. Specific recommendations for improving the approach include: (i) expand data sources; (ii) work with Agriculture Canada to obtain more data; (iii) work with Health Canada to ensure that human health is being protected (also, marketability of agricultural products); and, (iv) consider protecting the agricultural land use rather than individual species.	***Yes*** Methodology is fine, but BCMOE may require support from other agencies to fully address issues related to livestock protection (e.g., marketability of agricultural products). Also, there is a need to address organic contaminants when acceptable data are available. The necessary data on certain contaminants already exists (e.g., PCBs, organochlorine pesticides, etc.); data on industrial chemicals will be harder to obtain.	***Probably*** The methodology is probably adequate for protecting livestock; however, it applies to metals only. Other methods, such as using cross-species extrapolations of toxicity data, will be required for other substances (e.g., organics). It may also be important to consider the dermal and inhalation exposure route (i.e., don't allocate all of the acceptable daily dose to the oral route of exposure). Since the TRVs are within a non-toxic range of dietary metal exposures, it is possible that this approach will also protect product quality and human consumers of agricultural products. The use of the CCME interim soil quality criteria is recommended when no dietary data are available.	***Probably*** The methodology is probably adequate for protecting livestock; however, it should be noted that the calculations specifically apply to animals with the same body weights and daily food intake rates as those represented in Puls (1994). Other life stages may not be protected. Also, consideration must be given to the potential for effects on human health due to the accumulation of contaminants in livestock tissues.

Q4. The quality of groundwater aquifers has the potential to be affected by contaminated soils. For this reason, the CSST Protocol provides procedures for deriving soil quality standards that protect groundwater which may impact on surface waters or which may be used directly. Protection for aquatic organisms, agricultural plants, and livestock is considered. These procedures rely on the application of a standardized hydrogeological model to predict the movement of non-polar organic substances.

Work Group 1	Work Group 2	Work Group 3	Work Group 4
Do you think it is important to develop soil quality standards for the protection of groundwater against contamination?			
Yes It may be important to consider the quality of aquatic sediments as well.	*Yes* The BCMOE should provide some generic guidance for application of the groundwater-contact based SQSs (e.g., distance from receiving water body).	*Yes* It is important to protect groundwater resource values.	*Yes!* It is essential to consider the potential for groundwater contamination.
Does this model provide an adequate basis for predicting groundwater contaminant concentrations arising from contaminated soils?			
Yes But this pathway may result in other exposure routes that have not yet been addressed (e.g., potential effects of contaminated sediments on benthic communities).	*Yes* But it may be too conservative because it does not consider the potential for dilution at the discharge point. In this way, it is not consistent with existing federal or provincial discharge limits.	*Probably* The model appears to be based on well established model functions, but it is important to generate data to calibrate the model. Also, the model should be distributed (free) by BCMOE for the use and evaluation of consultants.	*Probably* However, it is important to make sure that the model assumptions are not violated (e.g., homogeneity of soils, aquifer type, etc.).
Are the risks of not being able to model impacts and set soil quality standards for inorganic substances or polar organic substances significant?			
Yes Ignoring the potential effects of inorganic substances is not an option. It is important to measure the concentrations of these substances at the site to evaluate the potential for groundwater contamination. In addition, more conservative soil quality standards (i.e., apply a safety factor) should be used if the potential for groundwater contamination is indicated.	*Yes* But it will be difficult to address this issue. For this reason, the results of monitoring conducted at existing sites should be compiled to provide a database for evaluating the potential for groundwater contamination by these classes of chemicals. Also, other predictive tools (such as leachate tests) could be used in the absence of modeling capabilities.	*Possibly not* It is possible that the human health and ecological soil quality standards for direct contact may adequately protect against problematic levels of groundwater contamination by metals and polar organics. These classes of contaminants tend to be less mobile in soils than nonpolar organics. Nonetheless, empirical data should be collected on site to check the level of protection provided by the mandatory SQSs.	*Yes* A groundwater model to predict the movement of metals and polar organics in soils should be developed. The site-specific soil quality objectives or risk assessment methods should be used at sites where significant groundwater concerns are identified until such a model is available. Also, site monitoring is needed to confirm the predictions provided by the other methods.

Q5. Application of the CSST groundwater model is dependent on a number of conservative assumptions about the characteristics of the site (e.g., depth to groundwater, sources depth, etc.). These assumptions primarily apply to the conditions typical of the lower mainland area of British Columbia.

Does the use of these assumptions present an acceptable basis for assessing the potential for groundwater contamination at contaminated sites in British Columbia?

Work Group 1	Work Group 2	Work Group 3	Work Group 4
Yes In general the assumptions incorporated into the model appear to be reasonable.	***Possibly*** However, the model may be too conservative for areas of the province outside the lower mainland. It is important to note that the model is most sensitive to differences in the depth to groundwater, the organic carbon content, and the half-life of the chemical between sites.	***Yes*** All of the assumptions appear reasonable, however, monitoring should be conducted at selected sites to evaluate the applicability of the assumptions.	***No*** Regional differences in values for key variables in the model could influence its application. Therefore, the matrix of SQSs should be expanded to account for regional differences in these values. For example, regional precipitation patterns are well documented and could be incorporated into the model fairly easily to develop regionally applicable SQSs. At minimum, the BCMOE offices should be provided with a matrix of numbers that apply to their region, thereby providing a mechanism for exempting proponents from further investigations if their soil concentrations are below the regional groundwater-contact based SQSs (i.e., preempting the need for engaging in the site-specific soil quality objectives or risk assessment processes).

Q6. An objective of CSST was to develop methods to improve flexibility and bring some site-specific considerations to bear in setting soil quality standards. The CSST Protocol proposes the development of a matrix of soil quality standards which encompasses five land uses and multiple exposure pathways.

Work Group 1	Work Group 2	Work Group 3	Work Group 4
What are the options for future enhancement of these methods?			
These methods could be enhanced by: (i) conducting groundtruthing to verify the models and assumptions used; (ii) conducting sensitivity analysis to identify the key variables in the models; (iii) establishing a good greenfields policy; (iv) normalizing toxicity data to standard levels of clay and organic carbon (this may remove some of the variability in the data); (v) evaluating off-site impacts at contaminated sites to assure that the SQSs are adequate (particularly important at commercial and industrial sites); (vi) publishing the toxicity data that support the SQSs (to increase their availability); (vii) considering the application of toxic units models to account for the toxicity of complex mixtures of contaminants; (viii) indicating that the SQS are intended to provide 'environmental' rather than 'ecological' protection; and, (ix) explicitly addressing the potential for bioaccumulation in soil invertebrates, plants, and livestock.	Several important enhancements to these methods should be considered, including: (i) establish a review process for refining the SQSs periodically; (ii) develop site sampling protocols to accompany the SQSs; (iii) identify relevant analytical techniques (i.e., which consider bioavailability); (iv) monitor existing sites to verify the model and to provide real world data; and, (v) reconsider the use of the ecologically-based soil contact SQSs at industrial sites that have no compelling need to protect soil invertebrate or plants.	The recommendations for improving the methods in the future include: (i) develop a guidance manual for applying the SQSs; (ii) distribute the groundwater model to interested parties; (iii) conduct auditing and monitoring programs to evaluate the validity of assumptions, policies, and models; (iv) review empirical data for metals and polar organics to evaluate their leaching potential; (v) reconsider the direct use of ambient water quality criteria for aquatic life for developing groundwater-contact based SQSs (i.e., these criteria may be too conservative); and, (vi) establish analytical methods for metals that reflect their bioavailability.	Several options for enhancing the methods that have been developed include: (i) assure that the potential impacts of site remediation are considered before remedial activities are initiated (i.e., habitat loss associated with remediation may be more detrimental than the effects of *in situ* contaminants). Also, follow-up studies should be conducted to evaluate the validity of these assessments; (ii) provide the regional offices with guidance on the application of the SQSs (i.e., guidance manual); (iii) harmonize the SQSs with other federal and provincial regulations; (iv) establish a mechanism to facilitate adaptive management in the site assessment and remediation process (i.e., refinement of framework and SQSs); (v) use the results of risk assessments and other investigations to refine the matrix SQSs (e.g., literature searches, site registry, toxicity tests, etc.); (vi) re-evaluate the toxicity data used to generate the SQSs to account for differences between measured endpoints in each study (e.g., EC_{50} for 9% reduction in growth vs. EC_{50} for 80% reduction in growth); (vii) explicitly identify the rationale for the human health-based SQSs; (viii) consider the bioavailability of soil-associated contaminants (i.e., weak acid digestion may be a more appropriate analytical technique than total metals analysis); (ix) more fully reflect multiple land use objectives in the land use classifications; (x) consider additional ecological processes in future refinements of the SQSs (i.e., ecosystem functions); and, (xi) establish *a priori* effect targets (e.g., 20% reduction in corn yield) that would trigger further investigations and/or remedial actions for sites that have contaminants for which SQSs have not been developed.