INDEPENDENT CONSULTANT
REVIEW OF THE ECOLOGICAL RISK
ASSESSMENT REPORT ON THE
AGRICULTURAL SYSTEMS OF PORT
COLBORNE

CITY OF PORT COLBORNE
COMMUNITY BASED RISK ASSESSMENT

# WATTERS
# ENVIRONMENTAL
# GROUP INC.

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COMMUNITY BASED RISK ASSESSMENT**

Prepared for:

**PUBLIC LIAISON COMMITTEE &
CITY OF PORT COLBORNE**
c/o City of Port Colborne
66 Charlotte Street
Port Colborne, Ontario
L3K 3C8

Prepared by:

**WATTERS ENVIRONMENTAL GROUP INC.**
8800 Dufferin Street, Suite 303
Concord, Ontario
L4K 0C5

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# EXECUTIVE SUMMARY

Jacques Whitford (JW), as a consultant to Vale Inco (Inco), issued a final Ecological Risk Assessment report concerning the impacts of emissions from a former Inco nickel refinery on agricultural crops within the City of Port Colborne, Ontario (the City). Their report entitled, "*Port Colborne CBRA – Ecological Risk Assessment, Crop Studies*", dated December 2004 (the Crops Report), is one component of a Community Based Risk Assessment (CBRA) that is addressing potential risks from former Inco emissions on agricultural crops, the natural environment, and human health within the City of Port Colborne. The Crops Report relates to Sections 2.1.3 and 3.1 of the Technical Scope of Work document, which was prepared by JW in November, 2000 (i.e., at the outset of the CBRA).

The objective of the Crops Study is, "*to determine the concentrations of historically deposited CoCs in Port Colborne soil that present an unacceptable risk (phytotoxicity) to agricultural crops*". To achieve this objective, studies were carried out to determine soil concentrations that are protective of the crops grown in Port Colborne for the chemicals of concern [CoCs] within each of the main soil types found within the City.

The Ontario Ministry of the Environment (MOE) defines an "unacceptable risk" as having a soil chemical concentration above a specific generic standard provided in its regulation. For nickel, that value is 200 micrograms per gram (μg/g) (or parts per million ["ppm"]). Words such as "protection" and "safety" that are used in this report relate to the MOE's generic standard.

In its report, JW has put forward a new "safe" level (specific to Port Colborne) for soil nickel that is intended to protect crops in Port Colborne to the same extent as the generic standards are assumed to protect crops grown anywhere in the province.

The Chemicals of Concern (CoCs) for the CBRA currently are nickel, copper, cobalt and arsenic. Although not included as a CoC for the CBRA, there is ongoing debate about whether lead should be added to this list.

In order to establish site-specific standards for Port Colborne, it was necessary to address the impact of CoCs on the main soil types found in the area.  Four main soil types were identified:

| | |
|---|---|
| **Welland Clay** | A heavy clay with clay content greater than 40% |
| **Till Clay** | Includes shallow clays and clay loams with clay content between 20% and 40%.  The predominant agricultural soil in Port Colborne |
| **Organic Soil** | Swamp and fen soils with high organic content |
| **Sand** | Eolian and beach sands with less than 20% clay |

The Crops Study involved several greenhouse and field trial studies in 2000 and 2001, using different crops and several soil types.  A biomonitoring study was also completed in 2001, measuring nickel levels in field soils and in goldenrod, a wild plant common across the Port Colborne area.  In the final Crops Report, only the 2001 Greenhouse Study was relied upon to develop the conclusions.  The 2000 data were discarded and the field trials studies were not used.  The conclusions were also developed based on only one CoC (nickel) and one crop (oats).  The results of the biomonitoring study were used to provide validation of the greenhouse trial findings.  Using these selected data, JW attempted to: (i) determine the soil nickel concentration for each soil type that caused an impact (phytotoxicity) on oats, and (ii) establish a soil nickel level that would be low enough to avoid causing deleterious impact on any crop in Port Colborne (i.e., a new soil nickel "standard").  The inherent assumption in that approach is that the conditions selected to derive its findings represent the most sensitive situation(s), and that their proposed soil nickel "standards" have a sufficient "safety factor" to account for the uncertainties and variability associated with each of the various components and factors of the selected study.

Watters Environmental Group Inc. (Watters Environmental) is the current Independent Consultant to the City of Port Colborne and the Public Liaison Committee (PLC) for the CBRA. In this capacity, Watters Environmental was requested to peer review the Crops Report and to evaluate its findings and conclusions.

Independent Consultant reviews of earlier drafts of the Crops Report focused mainly on highlighting technical, presentation and grammatical issues.  For this review of the final Crops Report, Watters Environmental's approach was to assess whether the Port Colborne-specific soil nickel "standards" proposed by JW/Inco are: (i) supported by the data and analyses presented in

the Crops Report (i.e., does the data support their conclusions?), and (ii) as protective of all Port Colborne crops as the MOE's generic standards. The second point involves assessing whether there is a sufficient "safety factor" to address the uncertainties and variability inherent in the selected study conditions and whether JW have justified that the new nickel levels that they propose are as protective to crops as the MOE's generic standard.

As noted, the MOE's generic standard for soil nickel is 200 μg/g (or 200 ppm). The Port Colborne-specific soil nickel intervention levels, as proposed by JW/Inco, are significantly higher than the generic standard, and are as follows:

| Soil Type | JW/Inco-Proposed Port Colborne-Specific Soil Nickel "Standard" |
|---|---|
| Sand | 750 μg Ni/g soil |
| Organics | 2,350 μg Ni/g soil |
| Welland (Heavy) Clay | 1,650 μg Ni/g soil |
| Till (Shallow) Clay | 1,400 μg Ni/g soil |

Based on the technical review undertaken, and on issues raised by members of the Port Colborne community, it is the view of Watters Environmental that JW/Inco's conclusions are not supported by the data. There are too many uncertainties to justify the JW/Inco proposed Port Colborne-specific soil nickel intervention levels.

The sources of uncertainty within the Crops Report and the proposed Port Colborne-specific soil nickel "standards" that lead to this view are derived from the following:

- The use of oat as the primary study species. It is asserted that oat is the most sensitive species, but this is not supported by their data. While the use of oats does not affect the results used to establish a dose-response curve, it does have implications for the certainty that can be placed on the degree of protectiveness that soil CoC concentrations where a 25% reduction is observed in plant response, provide for other crop species;

- Conclusions are based only on the nickel studies, when other CoCs, especially copper, are known to be toxic to plants;

- Findings are based on studies involving manufactured soils blended from soil taken from a limited number of locations. This report will later show that the "low-nickel blended soils" and "high-nickel soils" have significantly different characteristics;

- Lime (calcium carbonate) was added to adjust the pH of all soils used in the greenhouse study. This has been shown to reduce the uptake of nickel and thus there is an unknown influence on the soil concentration of nickel that will cause phytotoxicity under different pH conditions;

- The study relied on assessing impacts to plants based on biomass, rather than crop yield (which is the parameter of importance to a farmer). Also, the study did not address potential aesthetic (discolouration) effects, which occur at an earlier stage of plant development than impacts to plant biomass. Additional safety factors need to be added to address these issues;

- Inconsistent statistical treatment of data was applied in order to get a "best-fit", and there was insufficient data in the important mid-range of nickel concentrations in order to establish a dose-response curve and to extrapolate to no-effect levels; and

- The biomonitoring study was relied on as a reason to obviate the need for further analysis of the impact of confounding variables.

As a result of these issues, and the lack of "safety factors" to address the known (and unknown) uncertainties and variability, Watters Environmental is of the opinion that the JW/Inco proposed Port Colborne-specific soil nickel "standards" cannot be justified based on the data available, and do not offer an equivalent level of protection to the specific site conditions of Port Colborne as the MOE's current generic standard offers to crops throughout the province.

# TABLE OF CONTENTS

# 1.0     INTRODUCTION

Vale Inco (Inco) operated a nickel refinery in the City of Port Colborne ("the City") from 1918 to 1985. During that time, the refinery emitted several chemicals into the environment, including nickel, copper, cobalt, arsenic and lead. To assess the extent of impact that these emissions have had on the natural environment, crops and human health within the City, and the nature and extent of cleanup (if required), Inco is undertaking a Community Based Risk Assessment (CBRA).

The CBRA comprises a Human Health Risk Assessment (HHRA), and an Ecological Risk Assessment (ERA) that consists of an assessment of the impact of the CoCs on the natural environment and their impact on crops grown in the Port Colborne area (The Crops Study). The Crops Report relates to Sections 2.1.3 and 3.1 of the *Technical Scope of Work* document, which was prepared by JW in November, 2000 (i.e., at the outset of the CBRA).

The CBRA currently address impacts from four chemicals, namely nickel, copper, cobalt and arsenic, referred to collectively as the Chemicals of Concern (CoCs). Although not included as a CoC for the studies making up the CBRA, there is ongoing debate about whether lead should be added to this list.

This review addresses the report of the Crops Study (the Crops Report).

Watters Environmental Group Inc. (Watters Environmental) is the current Independent Consultant to the City and the Public Liaison Committee (PLC) for the CBRA. In this capacity, Watters Environmental was requested to peer review the JW Crops Report and to evaluate its findings and conclusions.

The CBRA Crops Study Report addresses the Field and Greenhouse experiments conducted in 2000 and 2001. The primary objective of the Crop Study is to, "*determine the concentrations of historically deposited CoCs in soil that present a risk (phytotoxicity) to crops grown in the Port Colborne*". To achieve this objective, studies were carried out to determine soil concentrations that are protective of the crops grown in Port Colborne for the CoCs within each of the main soil types found within the City.

The Ontario Ministry of the Environment (MOE) defines an "unacceptable risk" as soil chemical concentrations above a specific generic standard provided in its regulation. For nickel ("Ni"), that value is 200 micrograms per gram (µg/g) (or parts per million ["ppm"]). Words such as "protection" and "safety" that are used in this report relate to the MOE's generic standard.

In the ERA Crops Report, a new "safe" level (specific to Port Colborne) for soil nickel is proposed that is intended to protect crops in Port Colborne to the same extent as the generic standards are assumed to protect crops grown anywhere in the province.

The study uses oat as a reference species, although this crop is not commonly grown in the Port Colborne area (i.e., corn, soy and red clover are the main crops) and is not the most sensitive crop species grown in the area.

The Independent Consultant reviews of earlier drafts of the Crops Report focused mainly on highlighting technical and presentation issues. For this review of the final Crops Report, Watters Environmental's approach was to assess whether the Port Colborne-specific soil nickel "standards" proposed by JW/Inco are supported by the data and analyses presented in the Crops Report (i.e., does the data support the conclusions?), and are they as protective of all Port Colborne crops as the MOE's generic standards.

In this report, we have tested the hypothesis that, "the ERA Crops Study presents scientifically rigorous, Port Colborne-specific, intervention levels that provide, with sufficient certainty, a level of protection to agricultural crops in the Port Colborne area that is equivalent to the Province-wide generic standards for Chemicals of Concern".

## 2.0      BACKGROUND

Inco's consultants issued a 6-volume report, dated December 2004, which describes the possible effects of historical Inco emissions on crops and agricultural lands.  More specifically, the main objective of the work was, "*to determine soil concentrations that are protective of the crops grown in Port Colborne for the CoCs within each of the main soil types found within the City*".

The other objectives of the studies were as follows:

- To compare the concentrations of CoCs in the soil to those within the crops, to see whether there are any relationships;

- To determine if the effects on crop due to the CoCs (referred to as "phytotoxicity") are different for the different soil types within Port Colborne [because soil types can potentially affect the phytotoxic effects of soil concentrations]; and

- To determine the effectiveness of different remediation techniques to reduce the phytotoxic effects of the chemicals of concern on agricultural lands in Port Colborne (i.e., such as liming of the soils).

The following presents an overview of the work completed and the findings of the ERA Crops Study.

The determination of the possible effects of historical air emissions on crops requires a number of complex studies.  The types of factors that need to be considered are: (i) whether the studies should be done in the field and/or a greenhouse, (ii) the types of soils to be tested, (iii) the species of crops to be used in the studies, (iv) the range of concentrations of CoCs to be tested and (v) soil conditions that can influence the relative phytotoxicity of the CoCs and complicate the interpretation of the study results.

First, a detailed map of the different soil types in Port Colborne was prepared, which identified five common soil types on the East side of the City, namely: heavy clay, shallow clay, clay loam, organic, and sand.

Second, a large number of soil samples were taken to understand the distribution of the chemicals of concern across the City (and most particularly for the Crops assessment, the agricultural lands).  Based on this work, it appears that an estimated 1,500 hectares of

agricultural lands is potentially impacted with concentrations greater than the MOE's soil quality criteria for nickel of 200 ppm

Third, there was a survey of the type of crops that are grown in Port Colborne. This found that the predominant crops were corn, soybean and red clover. Oat was added for study because of its previous use by the MOE in establishing soil quality criteria and its known sensitivity to nickel.

Using the findings from the background activities, Inco conducted its evaluation of possible impacts to crops based on three types of studies, namely Greenhouse Trials, Field Trials, and a Biomonitoring Study. The studies were carried over two years (i.e., 2000 and 2001).

Greenhouse Trials

These studies involved growing crops on soils with different concentrations of CoCs in a greenhouse environment, with the purpose of: (i) establishing relationships between soil CoCs and plant response (referred to as "dose-response curves"), and (ii) determining the soil CoC concentrations where a 25% reduction is observed in plant response, for example, growth (referred to as the "$EC_{25}$").

The 2000 Greenhouse Trials used sand, clay and organic soils (with differing soil CoC concentrations) taken from fields within Port Colborne. These soils were used "as is" and were not blended. Corn, oat and soybean were grown in the greenhouse, and crop biomass (i.e. crop yield) was measured as the plant's response to the CoCs.

Plants were grown on a range of nickel concentrations, from "background" (<100 ppm Ni) to "highly contaminated" (>3,500 ppm Ni).

To determine whether liming of the soils could reduce the phytotoxic effects of nickel ("prevent" reductions in crop yields due to the CoCs), various concentrations of limestone were added to the collected soils.

The 2001 trials were conducted with some important changes in the study design:

- The 2001 trials involved only nickel which JW asserted was an adequate surrogate for all the CoCs;

- The 2001 study used "blended soils", generated by mixing soils with a very high nickel concentration with varying amounts of "uncontaminated" background soils to generate soils with a range of nickel concentrations. This was done to attempt to compensate for differences in soil characteristics that significantly alter the plant's response to the CoCs, such as pH, cation exchange capacity, organic matter content;

- The soils were pH adjusted before blending (which was not done in the year 2000 studies);

- Oat was the only species studied broadly (i.e., on all soil types), as it was believed by Inco's consultants to be the crop most sensitive to the CoCs, although some studies were also conducted on radish;

- The plants' response to CoCs was asserted by measuring changes in plant biomass; and

- As with the Year 2000 studies, the soils were amended to determine possible benefits of using certain amendments to reduce the effects of the CoCs. For all soils except sand, limestone was used. For sandy soils, mushroom compost was used.

Field Trials

These trials involved growing crops in actual field soils with different concentrations of CoCs, and measuring the effects of these varying CoC concentrations on crop biomass. By conducting these studies in parallel with the greenhouse trials, comparisons could be made between the crop responses to CoCs in a natural field setting and a controlled [but not "natural"] greenhouse setting, to provide some validation of the greenhouse results.

In 2000, field trials were carried out on oat, soybean, corn and radish grown on three fields located on nickel-impacted soils containing organic and clay soils downwind from the Inco refinery. Sand soils were not included as the local sand soils are not routinely cultivated.

As with the greenhouse trials, limestone was added to determine whether liming could reduce the phytotoxic effects of nickel.

The 2001 study employed two field test sites, located in areas of heavy clay soils. An "Engineered Field Plot" study was included to further validate the greenhouse results. This involved growing crops initially in pots with blended heavy clay soil in a greenhouse and subsequently exposing them to field conditions by moving the pots to a sub-plot of a field test site.

Biomonitoring

In 2001, a biomonitoring study of a commonly growing wild plant (Goldenrod) was undertaken to characterize the extent of CoC contamination in the plant tissue of existing natural vegetation within Port Colborne, and to determine whether there is a relationship between concentrations of CoCs in soils and within the tissue of natural vegetation.

# 3.0      SOURCES OF UNCERTAINTY IN THE ESTABLISHMENT OF SITE SPECIFIC INTERVENTION LEVELS

In this report, we have tested the hypothesis that, *"the ERA Crops Study presents scientifically rigorous, Port Colborne-specific, intervention levels that provide, with sufficient certainty, a level of protection to agricultural crops in the Port Colborne area that is equivalent to the Province-wide generic standards for Chemicals of Concern".*

Because of a number of study design issues and experimental errors the investigators, JW, dismiss the 2000 study as not being of value in producing useful results and conclusions and report the 2000 work as only being useful in guiding the study design for the 2001 studies (pages 3-30). While we do not fully agree with JW's opinion that the 2000 study does not yield useful results, particularly as these studies employed natural, rather than blended soils, we have respected JW's own assessment of the worth of their work. Therefore, we have focused on the 2001 studies in assessing the effectiveness of the Crops Studies in being able to generate soil concentration values for CoCs that will allow the farmers of the Port Colborne Region to effectively utilize their land for cultivation of crops. However, the very fact that significantly different results were developed by the 2000 and 2001 studies is a source of uncertainty that has not been adequately addressed and which, necessarily, casts significant doubt on the conclusions of the Crops Report.

Our review of the Crops Report, and its supporting appendices and addenda, leads us to conclude that the report fails in its objective to provide defensible CoC intervention levels that realistically serve as community-specific, risk-based values for the Port Colborne Region.

There are several problems with the study design for the 2001 studies, the subsequent treatment of the data and the inferences drawn. Together, these add such a high degree of uncertainty in the results obtained in the study that reliance cannot be placed in the conclusions presented in the report.

The concerns with the studies that lead us to this opinion are:

- The use of oat as the primary study species. While it is asserted that oat is the most sensitive species, but this is not supported by the data. While the use of oats does not affect the results used to establish a dose-response curve, it does have implications for

the certainty that can be placed on the degree of protectiveness that $EC_{25}$'s provide for other crop species;

- Conclusions were based only on the nickel studies, when other CoCs, especially copper, are known to be toxic to plants;

- Findings were based on studies involving manufactured soils blended from soil taken from a limited number of locations. This report will later show that the "low-nickel blended soils" and "high-nickel soils" have significantly different characteristics;

- Lime (calcium carbonate) was added to adjust the pH of all soils used in their greenhouse study. This has been shown to reduce the uptake of nickel and thus there is an unknown influence on the soil concentration of Ni that will cause phytotoxicity under different pH conditions;

- The study relied on assessing impacts to plants based on biomass, rather than crop yield (which is the parameter of importance to a farmer). Also, the JW study did not address potential aesthetic (discolouration) effects, which occur at an earlier stage than impacts to plant biomass. Additional safety factors need to be added to address these issues;

- Inconsistent statistical treatment of data was applied in order to get a "best-fit", and there was insufficient data in the important mid-range of nickel concentrations in order to establish a dose-response curve and to extrapolate to no-effect levels; and

- The biomonitoring study was relied on as a reason to obviate the need for further analysis of the impact of confounding variables.

## 3.1      UNCERTAINTIES RELATING TO THE USE OF BLENDED SOIL

In order to obtain soils with a range of nickel concentrations to establish a dose-response curve, blended soils were manufactured by mixing soil with a high nickel concentration with soil having a low nickel concentration (background) from one site each for each of the four soil types studied. JW contend that they were unable to find high nickel and background soils that were similar with respect to many soil parameters that are known to have an important influence on plant nutrition and growth and for nickel uptake. The impact that these factors might have on the validity of the results of the study is not established in the report as it was accepted that it would

be impossible to separate out their influence on plant growth relative to the effect of CoCs. They were accepted by the investigators as confounding variables with the exception of pH which was assessed to be an important concern. To address the issue of pH, the study soils were amended to adjust the pH to a consistent level before blending the soils to create the range of soil Ni concentrations necessary to create a dose-response curve.

This choice to blend heterogeneous soils and to subsequently amend them raises important concerns that greatly impact the credibility of the results of the study:

- The influence of other soil factors, such as cation exchange capacity (CEC), which is extremely important for plant growth, is not sufficiently considered;

- The influence on soil fertility that may result from physically reworking the soil during blending is unknown; and

- Contaminated soils will have received overall enhancement of their nutrition by the addition of fresh, uncontaminated soil.

These concerns are exacerbated by the large differences with respect to a number of important soil parameters between contaminated soil and the control soils. For example, the Welland Clay and the Organic soils are highly contaminated with 8,655 milligram/kilogram (mg/kg) and 10,045 mg/kg of nickel, respectively. More confidence could be placed in the study if soils were used that more nearly represented the range of soils needed for the study and which, therefore, would have needed less dilution with fresh uncontaminated soil. The dilution with fresh, uncontaminated soil has the effect of masking the effect of any soil nutritional factors, such as microbial action, that may have been suppressed through metal, or other refinery emission-contamination, particularly in soils in the mid-range concentrations of CoC contamination.

The important confounding variables that can significantly influence the study outcome, and which in many cases are unquantifiable, are not adequately addressed in the report. These confounding influences are of particular importance in view of the way that the soils were blended to derive soils with varying nickel concentrations. The variability of soil parameters caused by the act of blending and the lack of diligence in pursuing the influence of these variables is problematic. The choice was made not to fully assess these variables, in large measure, because of the conclusions drawn from the Bioavailability study. It was believed that

this study showed a strong relationship between nickel concentrations in goldenrod plant tissue and log nickel concentrations in the soil in which they were growing. They also noted a similar relationship between oat tissue nickel and log soil nickel in pooled greenhouse data. This was interpreted to mean that, "*variation in soil parameters that were confounded with soil Ni, do not have a large influence on plant accumulation of Ni, thus are not likely to have a large influence on the determination of $EC_{25}$*" (see Figure 1).



RELATIONSHIP BETWEEN Ni TISSUE CONCENTRATIONS OF GOLDENROD AND SOIL Ni CONCENTRATIONS

greenhouse $r^2$=0.69 (closed circles, dash line)

goldenrod $r^2$=0.68 (open triangles, solid line)

*It is contended that there is a strong correlation between soil Ni and plant tissue Ni in goldenrod growing in natural soil and that the same is demonstrated in crops grown in blended soil.*

*This is cited as support for the view that the $EC_{25}$ thresholds generated from soils grown in blended soils are legitimate.*

**Figure 1 (Figure 3.24. in the Crops Report).**

The strength of the correlation between greenhouse data and goldenrod data for the soil Ni:tissue Ni relationship is contentious, but what is clear is that the different soil types do demonstrate quite different soil Ni:tissue Ni relationships (see Figure 2). This graph, which presents the relationship between Ni tissue concentrations and soil Ni concentrations in goldenrod for different soil types, shows that the data sets that were combined to establish the relationship identified by JW as "*quite strong*" in Figure 3.24 in the Crops Report are actually quite dissimilar, with clay soils having low soil Ni concentrations compared with other soil types.
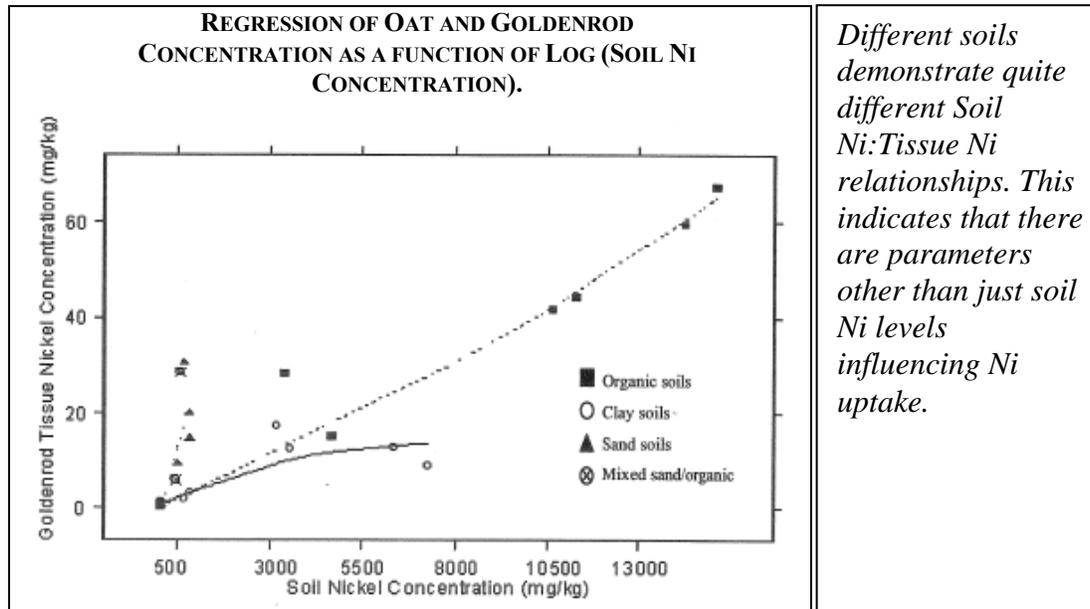
**Figure 2. (Figure 5.3 in the Crops Report).**

The Bioavailability study demonstrated that plant:soil Ni ratio was influenced by Soil Type and CEC. As CEC increased, ratios of plant:soil Ni decreased, particularly for clay and sandy soils. CEC, pH and other soil characteristics are all important confounders that may have a significant effect on plant growth and nickel uptake and which, in the Crops Study, are unquantified. As will be discussed below, these parameters become highly variable through the various sets of soils used in the greenhouse study as a result of blending to establish different Ni concentrations, consequently throwing doubt on the conclusions.

There is no merit to the contention that the strength of relationships between regressions for goldenrod and oats grown in a greenhouse with soil nickel "*...provides solid legitimacy of the EC$_{25}$ thresholds generated from plants grown in soil blends*". Similarly, the view expressed in the Greenhouse 2001 Conclusions that the goldenrod study "*.....suggests that variation in soil parameters that were confounded with soil Ni, do not have a large influence on plant accumulation of Ni, thus are not likely to have a large influence on the determination of EC$_{25}$*" is simply not supported by the data.

Watters Environmental believe that confounding variables exert a very significant influence on the metal toxicity in plants. These confounders have not been sufficiently considered in the Crops Report resulting in considerable uncertainty in the results.

### 3.1.1      Uncertainty Due To Variability in Available Nutrient

The consequence of blending two soils with highly disparate Ni concentrations but also with other varying soil parameters has resulted in soils with high Ni concentrations also having significantly higher nutrient levels than the "control" soil that is used to establish the 100% point for relative yield.  For example, in the case of Welland Clay, the high Ni blends have a 30% higher CEC than the control soil.  There is a similar disparity for Total Organic Carbon ("TOC"), with the control soil having 5.49% TOC and the soil with 1,900 mg/kg Ni having 7.2% total organic carbon. (i.e., 31% additional TOC).

The situation is even more extreme for Till Clay.  The control soil has a CEC level almost half that of the high (2,540 mg/kg Ni) Ni blend soil (CEC 5 meq100 vs. 9.5 meq100).  The TOC increases from 3.36% in the control soil to 14.5% in the high Ni blend, a 400% increase (see Figure 3).  The substantial variation in key soil properties among blends is acknowledged in the discussion of soil characteristics [Appendix GH-7].  It is postulated that the increase in CEC may contribute to binding of CoCs and contribute slightly to protecting plants from CoC impacts.  As a consequence of blending two disparate soils there is considerably more nutrient available for plant growth in higher Ni soil blends than in lower concentration soils.  The amount of available nutrient is a primary influencer of crop yield.

Thus for the Till Clay, there is a strong likelihood that the yield achieved in higher nickel soil concentrations is enhanced relative to the yield in low concentration soils through reduced nickel uptake and more vigorous growth attributable to more available nutrient.  Consequently, for the predominant agricultural soil across the Port Colborne region the actual $EC_{25}$ is almost certainly lower than the $EC_{25}$ calculated from the study employing dissimilar, blended soils. There is a less marked increase for organic soil and there is no similar trend for sand soils [Reference Tables GH16, GH21, GH26 and GH35].
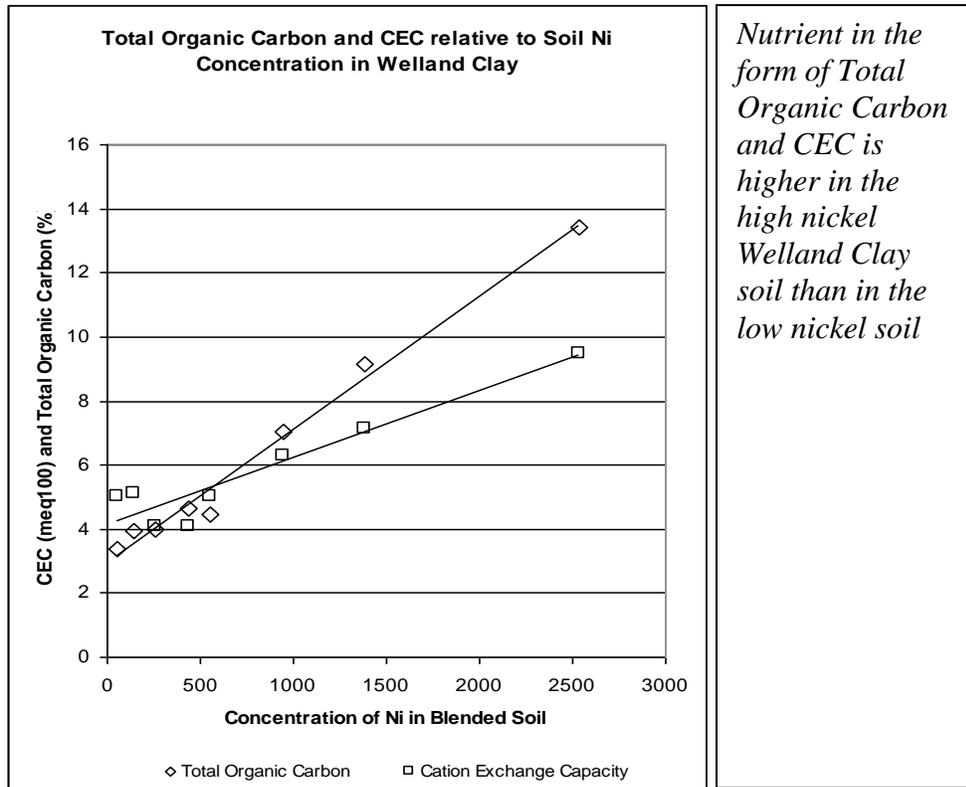
Figure.3 (Data from Table GH35 in the Crops Report).

The decision by the investigators to unconditionally accept confounding soil factors (other than pH) is problematic in view of the information derived from the 2000 greenhouse study that demonstrated the influence that localized soil factors can have on growth. For example, it was found that an organic soil employed in the study would not support germination. This was subsequently attributed to the soil having been contaminated with an herbicide from a neighbouring field. Conversely, unusually vigorous growth was encountered in another organic soil that, on examination, was found to have high phosphorus levels from previously applied fertilizer. The strong influence that soil site selection can have on the study was demonstrated in a clay series, where clays taken from the edge of a field supported higher growth than soils away from the edge. It was believed that stray fertilizer at field edges was responsible for more vigorous growth.

These examples of unexpected results from unanticipated confounding factors serve to demonstrate the considerable caution that has to be exercised in interpreting the soil studies. With reliance on only one (blended) soil sample for each soil type to exemplify the soil growing conditions across the whole of the Port Colborne Region, an unanticipated and unrecognized confounder has the potential to exert a very large and unquantifiable influence on the results of the study. Therefore, unusual data sets must be regarded with the utmost suspicion.

The reliance placed on only two soil selection sites per soil type in the 2001 greenhouse study adds significantly to the uncertainty that exists in the results obtained in the study.

Anomalous results from the study of Oat on Welland Clay also raise concern that factors other than Ni concentration have an important, and insufficiently understood, influence on calculated $EC_{25}$. In the Welland Clay experiment, the amended soil $EC_{25}$ was lower than that for unamended soil (amended $EC_{25}$ = 1,300 mg/kg, unamended = 1,880 mg/kg). It was postulated that this was due to Mn deficiency in plants grown in amended soil.

Conversely, the Till Clay amended soil demonstrates a higher $EC_{25}$ than is derived for unamended soil (Amended $EC_{25}$ = 2,430 mg/kg, Unamended = 1,950 mg/kg), and this is ascribed to the amendment having reduced the bioavailability of nickel. The varying influence that amendment has on yield (either enhancing or retarding it), suggests that the level of amendment conducted to adjust pH is problematic. The variability of response in these studies does not lead to confidence that the crops studies establish credible $EC_{25}$ levels as the uncertainty deriving from poorly understood confounders is just too great.

The data sets for the 2001 greenhouse studies show considerable spread, obviously reducing the certainty that can be placed in the results. More concerning, are unusual results that derive from the studies, such as the reported relative yield for Till Clay remaining consistently high through all ranges of Ni concentration, other than the highest, while for Welland Clay, there is a great deal of variability throughout the data set.

The field trials also have uncertainty in the results, leading to their conclusion that, "...*one cannot predict the crop tissue concentrations of CoCs using total soil concentrations alone. The plant uptake of CoCs, was influenced by a variety of soil parameters, including pH, cation exchange capacity and other (unspecified) soil characteristics*". If there is an acknowledgement that factors other than soil Ni concentration influence uptake of CoCs, and if these factors are not understood or quantifiable, this begs the question; what credence can be placed in $EC_{25}$ numbers

based only on soil Ni concentration in manufactured soil samples that can in no way be considered representative of the diversity of soils across the Port Colborne region?

### 3.1.2    Confounding due to Variability in Soil Texture Characteristics within each Set of Soils

In their discussion of soil characterization, JW asserted that, "*Soil blends were made from the control and the highly-impacted soils for each of the four major soil types **while ensuring consistency in soil physical and chemical characteristics***" [our emphasis].  This clearly is not the case (see Figure 4).



*The Two Soils used to create the series of blended soils to represent the Till Clay Soil had very different Soil Textures.*

*The very high Ni soil has more than twice the clay content of the control and half the sand fraction.*
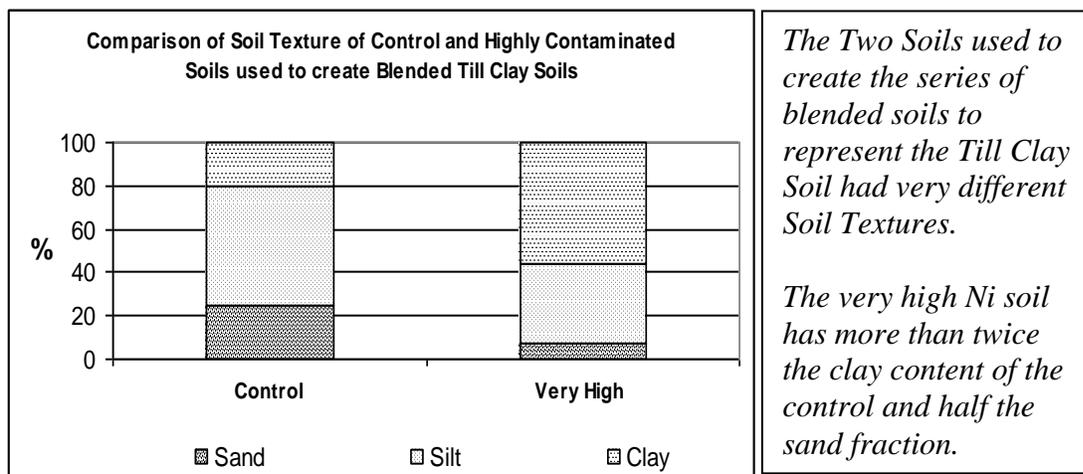
**Figure 4 (Data from Table 2-16 in the Crops Report).**

There are important differences in soil texture between low and high Ni blends in the Till Clay study (see Figure 5), although the soils are more homogeneous in the Welland Clay series.  The high Ni soils are considerably less sandy than the low concentration soils and this has implications for the binding of nickel (and thence bioavailability), root development, nutrient transfer and water retention.

As noted by JW, "*a higher concentration of metal can be retained in fine textured soils such as clay and clay loam, compared to coarse textured soils such as sand (Saxena et al. 1999).  This is part due to reduced leaching, as metals are bound to the soil matrix in fine textured soils (Webber and Singh 1995) [page 5-23].  Clay soils should have less CoCs available to plant uptake for this reason, and a lower plant: soil ratio should result*".
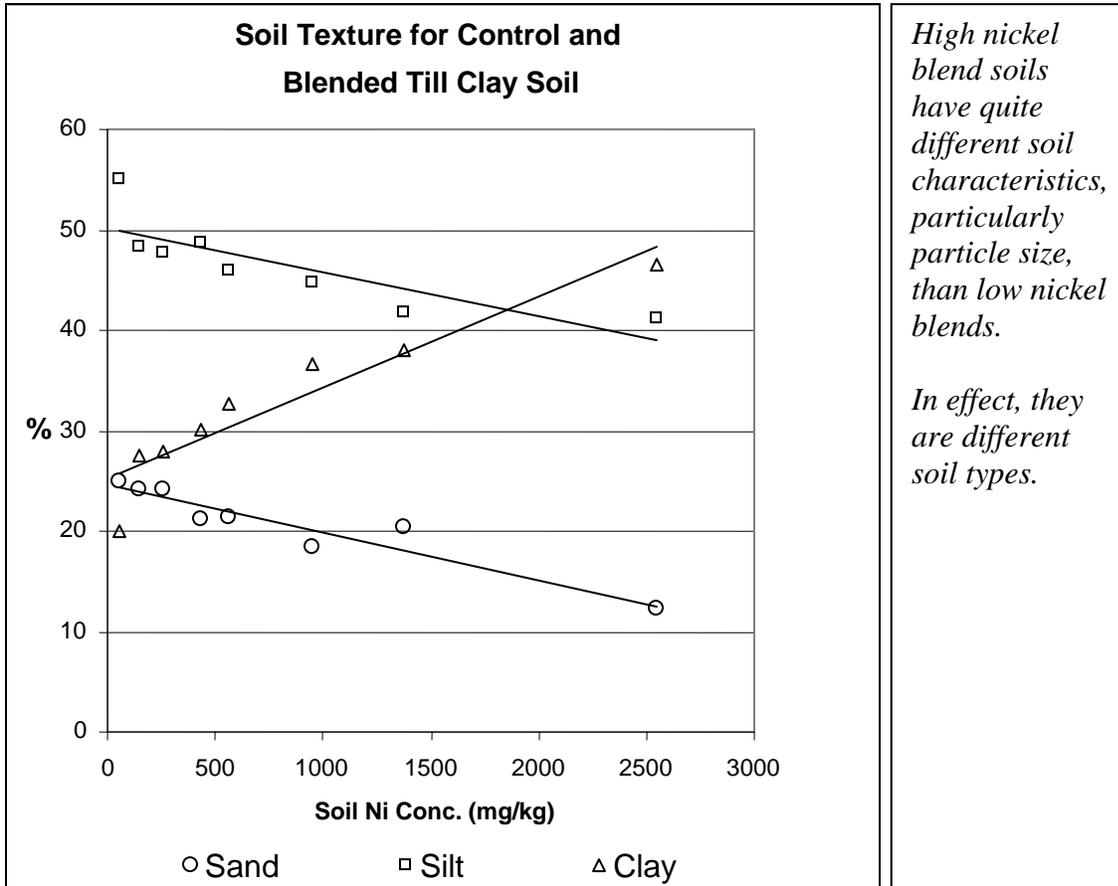
**Figure 5. (Data from Table 2-16 in the Crops Report)**

The high Ni concentration, Till Clay blend texturally is a clay (>40% clay fraction) while the low Ni concentration blend more closely resembles a silty loam with clay content as low as 20% and sand fraction around 45% (See Table 2-1 in the Crops Report). As the nickel binding capacity of the high Ni soil blend is likely significantly higher than that of the low Ni blend, there will be a relatively reduced toxicity in high concentration soils. Consequently little credence can be placed in the calculated dose-response curve and derived EC$_{25}$ and PNEC for the most important agricultural soil in the Port Colborne area.

## 3.2.      UNCERTAINTIES RELATING TO PH ADJUSTMENT THROUGH THE ADDITION OF CALCIUM CARBONATE

The benefit, in terms of increased yield, of adding lime to adjust pH is well demonstrated in the pH experiment on Welland Clay [Study GH5 in the Crops Report].

In soils with very low (background) levels of CoC, addition of calcium carbonate did not greatly change yield.  In fact, yield declined with the addition of lime.  However, in high nickel soils (1,900 mg/kg Ni) increasing pH resulted in a significant increase in yield, actually a 300% increase in biomass from plants grown at pH 5 to those at pH 7 (see Figure 6).

The strong influence on growth exerted by changing pH raises concerns about the uncertainty of the results of the studies caused by adjusting pH by liming.



*The addition of lime exerts a significant beneficial yield on highly contaminated soils while not demonstrating the same influence on "clean" soils.*

*Liming soil to adjust the pH of soils employed in the experiment therefore introduces an important and unquantified confounding effect on the results of the studies.*
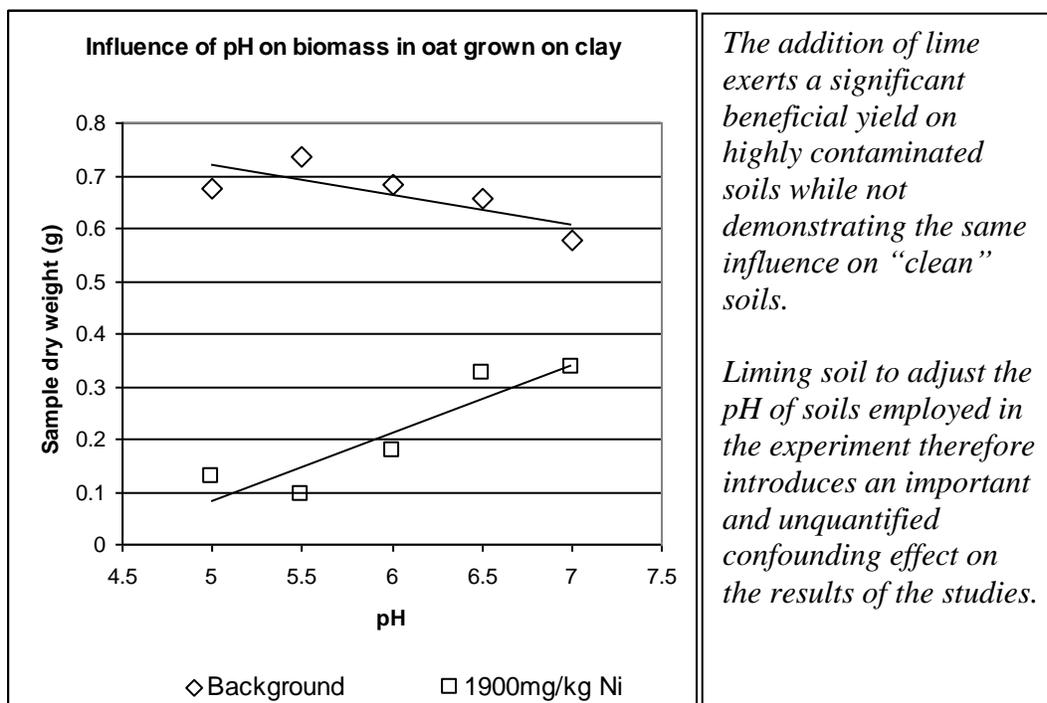
**Figure 6 (Data from Section GH5 in the Crops Report).**

The addition of lime to study soils raises important concerns respecting the validity of the results of the study by the introduction of yet more uncertainty. The Crops Report acknowledges that pH will have a significant impact on plant growth, and thence, $EC_{25}$. For example, the field trials conclude that amending soils with limestone reduces the uptake of CoC by plants even though it does not immediately increase soil pH.

The act of liming can also be expected to affect microbial activity in the soil and influence the accessibility of nutrients thereby introducing yet another source of uncertainty into the study. In the field trials calcareous treatment resulted in lower biomass for corn and soy bean which was attributed to mineral nutrient deficiency. Oat did not demonstrate the same reduction in yield in the calcareous treatment.

Manganese deficiency is known to occur naturally in soils with high levels of free carbonate. It was postulated that that Mn deficiency may be the cause of anomalous results, such as relatively lower than expected tissue Ni values in plants grown in some soils, especially Till Clay in the greenhouse trials.

The influence of pH on phytotoxicity and Ni uptake is uncertain and probably is affected by other soil parameters, e.g., amendment of clay soils (and consequent raising of pH) in Welland Clay resulted in relatively lower yield than "unamended" soil. Conversely, with Till Clay, amendment increased yield.

There are uncertainties around the influence of pH on metal uptake, both from a beneficial viewpoint in suppressing nickel uptake and negatively through reduction in availability of mineral nutrients. This raises the questions as to whether different PNECs should be derived for crops grown in soils of different pH and whether the PNECs established for oat really can be applied with any confidence to other crops.

## 3.3     FOCUS ON NICKEL

In the Year 2000 Greenhouse study (used to guide the study design for the 2001study), it is concluded that, "*Based on the concentrations of individual CoCs present in the plant tissues, phytotoxicity effects in Port Colborne soils may reasonably be attributed to nickel as opposed to copper or cobalt, although it is quite possible that they contribute. Their effect may be to make the plants more or less sensitive to Ni; although this sounds like a problem, it is of little concern*". It certainly does sound like a problem, and the influence of a metal, such as copper, known to exert phytotoxic effect is a concern. The conclusion that, "…*the studies using Port*

*Colborne soils can reasonably be expected to represent the integrated interaction among these CoC's in the field*" needs substantiation. The lack of support presented for this conclusion in the report adds another confounding variable which casts further doubt on the "safe" levels proposed in the Crops Report. Only $EC_{25}$ "calculations" were provided for other CoCs using "experimental shoot biomass data".

## 3.4      STATISTICAL TREATMENT AND ESTABLISHMENT OF A DOSE-RESPONSE CURVE

The Crops Report indicates that the investigators found there was a great variation in the relationship between relative shoot growth and soil Ni concentration between the four soil types studied. The same was found for $EC_{25}$ values. JW inform us that different statistical treatments had to be employed to get a fit for these data. The Weibull function was applied for the clay and sand soils, but only a weak fit could be achieved for Welland Clay. A linear function had to be applied to organic soil, as the Weibull function did not fit the data.

It is more usual in a scientific experiment to propose a hypothesis and select the statistical test that is most appropriate to the hypothesis and the type of data developed through the experiment. The idea of "shopping around" for a statistical test that will provide a best fit for the data is curious. The use of different models to attempt to explain the data is very concerning and, even then, a poor fit obtained is obtained. Consequently, we have considerable reservations that meaningful $EC_{25}$ concentrations can be derived from these data sets.

Particularly at lower concentrations there is a broad range in the data and there is a general inconsistency in average yield at different soil Ni concentrations suggesting that some factor other than Ni concentration is exerting an influence on yield.

The studies carried out on Organic Soil are particularly problematic and the statistical treatment and interpretation of the data is very concerning. Organic Soil yields were significantly lower in plants grown in amended soil than they were in soil that had only been subject to pH adjustment (unamended). These anomalous results further call into question the value of the study. The Organic soil is nutrient rich compared with the other soil types in Port Colborne with relatively high CEC and Total Organic Carbon levels. There were consistently high relative yields on organic soil at all concentration levels, including the most contaminated.

In order to be able to construct a dose response curve for the anomalous organic soil, JW took the most unusual step of choosing to employ data from the discredited 2000 greenhouse study using meta-analysis to combine the data sets. The 2000 data also demonstrated highly anomalous results with the High Ni soil (3,200 mg/kg) experiencing "significantly higher growth than the Medium and Very High CoC soils".

The difficulties with organic soils encountered in the 2000 study, and the anomalous data generated in the 2001 study leads to a conclusion that no the calculated $EC_{25}$ for organic soils are without credibility.

The concerns with the statistical treatment of the data are compounded when the relatively large gap between high and very high Ni soil concentrations is taken into account. It is in this critical part of the graph that the change in slope in the fit line occurs resulting in a large zone of uncertainty, especially for the clay soils. For example, in Till Clay there are six data points up to 1,357 mg/kg Ni, and then no other data than the highest concentration at 2,545 mg/kg. Similarly, for Welland Clay, there is no data between 1,081 mg/kg and the highest concentration of 1,806 mg/kg. In both cases, it is in this zone of sparse data that critical change in the slope of the dose-response curve lies and where the $EC_{25}$ is calculated to be positioned.

## 3.5    USE OF OATS AS AN INDICATOR SPECIES

It was asserted that oat is the most sensitive species, but this is not supported by their data. While the use of oats does not necessarily invalidate the results used to establish a dose-response curve for this crop species, it does have implications for the certainty that can be placed on the degree of protectiveness that the calculated $EC_{25}$ provides for *other* crop species.

The initial study, in 2000, included corn and soybean, which are grown as agricultural crops in the Port Colborne Area. A third species, oat was selected based on its inclusion in an earlier MOE study used to establish provincial soil quality clean-up criteria. It was decided that the focus would be exclusively on oat in the 2001 study as "*Oat was found to be the most sensitive species to the soil CoCs according to the preliminary trials conducted in the year 2000*". This was based on oat being found to accumulate relatively more nickel than corn or soy bean. This, of course, says nothing about the different influence that tissue nickel concentration has on toxic response in different species with varying tolerance to nickel or other contaminants.

While accepting that the validity of the 2000 data was dismissed because of uncontrolled confounding variables, experimental error and inadequate design, the 2000 study does provide some information that demonstrates that the contention that oat is the most sensitive species is not correct.

In clay soil, soy demonstrated visible reduction in plant growth at 500 mg/kg, while this was not the case for Corn or Oat, suggesting that Soy, actually a crop of economic importance in the Port Colborne Area, is more sensitive than oat.  This is acknowledged in the 2004 revised report (pg. 4-35 in the Report), where they state that "*in general, the monocots (oats and corn) were more resistant to phytotoxicity than the dicots (radish and soybean).*"

The use of oat, rather than a more sensitive species, does not detract from the validity of the study approach employed in the Crops Report.  However, it does require the application of an additional "protection factor" to ensure that the calculated soil clean-up criteria ensure "safe" conditions for any more sensitive crops likely to be grown in the area.  Because of the variable response of different plants under varying growing conditions (e.g., pH) and the different toxicity end point that would be of concern (e.g., biomass for leafy crops such as lettuce, crop yield for grains or aesthetic appearance for radish or lettuce etc.), it is not clear how an additional, science-based protection factor could be derived (assuming that the calculated PNECs actually had validity).

## 3.6     USE OF SHOOT BIOMASS RATHER THAN CROP YIELD AS AN END-POINT OF CONCERN

In the 2001 study, shoot biomass was chosen by the investigators as the endpoint to assess the plant toxicity of CoCs. In reality, shoot biomass is of less importance to a farmer than crop yield. In the Crops Report, there is no discussion of the relationship between the two endpoints for agricultural crops growing on contaminated soil.

The calculated PNEC derived from the dose-response curves is a no-effect level for reduction in biomass and is not able to give any quantifiable indication of the usefulness of contaminated agricultural land in Port Colborne for commercial crop production (crop yield).  Prudence would dictate that some downward adjustment in PNEC should be applied to consider the influence of CoCs on crop yield, compared with their effect on biomass.  However, with the information available, it is probably not possible to derive such an adjustment factor.

For many crops, crop yield is only one characteristic important to the farmer in determining whether he has a crop that is financially valuable and suitable for market. For many vegetables, appearance is an important factor. While there is some discussion of this concern in the report, primarily relating to chlorosis in spinach and radish, no guidance is provided on how the oat PNEC, based on reduction in biomass, relates to safe soil concentrations to prevent esthetic blemishes in crops.

## 3.7.      UNCERTAINTIES THAT ARISE FROM THE DIFFERENCE IN RESULTS OBTAINED FROM THE 2000 AND 2001 GREENHOUSE STUDIES

We concur with the conclusions in the report prepared by Inco's own external peer reviewer (Dr. Murray McBride) that, "*The year 2000 and year 2001 greenhouse experiments produce conflicting conclusions about acceptable levels of Ni in the soils. The 2000 trials indicate reduced crop growth at the lowest Ni levels tested (200- 300 mg/kg Ni) in some soils and crops. Much higher soil Ni thresholds (1,000 mg/kg – 2,000 mg/kg) were established by the 2001 method of blending contaminated with uncontaminated soils…It is essential that the discrepancy between the year 2000 and 2001 (blended soil) greenhouse experiments be resolved*."

The response provided indicates that they disagree with the reviewer is simply not sufficient. They rationalize discarding the 2000 results on the basis that, "*The limitations of the year 2000 experiments were severe enough that defendable phytotoxicity thresholds could not be calculated*". In the opinion of Watters Environmental, the same comment applies equally to the year 2001 study [Reference: p.A-23].

In the Crops Report, the 2000 study results are dismissed as valueless because the data, "*were compromised by uncontrolled confounding variables, experimental error and inadequate design in some components. When combined, these factors introduce unmeasurable uncertainties into the data analysis*". While we admire the objectivity respecting the value of the work carried out in 2000, we would have liked to see this objectivity applied equally to the 2001 studies [Reference: p. 3-18].

The reasons given for rejecting the 2000 studies included uncontrolled confounding variables and "huge" gaps between medium and high blends. These failings apply equally to the 2001 study. In fact, the uncertainties in the 2001 study are so great that no more credibility can be given to these results than to those of the previous year's study.

# 4.0      SENSITIVITY ANALYSIS

A discussion is presented in the Greenhouse section of the report that addresses uncertainty. In our view this is inadequate. The uncertainty analysis associated with blending soils only addresses bioavailability of CoCs in soils and not other important soil parameters that are acknowledged in the report to be confounders and that exert potentially significant influence. The contention that bioavailability is not affected by blending is based on a diethylene triamine pentaacetic acid extraction of Ni from soils. This contention is not borne out by observations in the field or greenhouse trials.

Our review of the Crops Report leads us to conclude that there are many sources of uncertainty in the study. These incompletely understood and unquantified variables result in considerable doubt that the suggested safe levels for CoCs in Port Colborne soils are, in fact, protective.

Table 1 below presents some of the important confounders and other sources of uncertainty that Watters Environmental have identified in this review of the Final Crop Studies Report.

**Table 1:    Sources of Uncertainty and their Influence on the Conclusions of the Crops Study**

| Aspect | Influence |
|---|---|
| Oat not the most sensitive species – Does not influence validity of results obtained for oat but introduces uncertainty for other crops. | High uncertainty<br>Calculated PNEC too high for many crop species grown in the Port Colborne Area |
| Blending of Soil - Replacement of nutrients in depleted soils resulting in relative nutrient enrichment of mid to high Ni range soils | High uncertainty<br>Calculated PNEC too high |
| Blending of Soil - Difference in soil structure in Till Clay – High Ni concentration soils less sandy than low and control soils. | High uncertainty<br>Calculated PNEC too high for Till Clay |
| Confounding soil factors - Welland and Till Clay high Ni soils relatively higher in CEC and Total Organic Carbon | Very high uncertainty.<br>Calculated PNEC too high for Clay soils |

**Table 1:    Sources of Uncertainty and their Influence on the Conclusions of the Crops Study (Continued)**

| Aspect | Influence |
|---|---|
| Confounding soil factors - Limited number of soil samples to represent the whole of the Port Colborne Area | Very high uncertainty.<br><br>Unknown whether calculated PNEC is too high or too low |
| Confounding soil factors - Anomalous results for Organic soil and use of discredited 2000 data to construct dose-response curve | Very high uncertainty<br><br>Calculated PNEC too high for organic soil |
| Addition of lime to adjust soil pH -<br><br>Reduces uptake of Ni | High Uncertainty<br><br>Calculated PNEC too high |
| Addition of lime to adjust soil pH -<br><br>Need to provide factor for soils at different pH than study pH | Moderate uncertainty<br><br>Calculated PNEC too high for low pH soils |
| Manganese deficiency – Mn deficiency noted as an important confounder reducing Ni uptake but influence not fully addressed | High Uncertainty<br><br>Calculated PNEC too high |
| Focus on Nickel - Other CoCs known to be phytotoxic have not been studied | High uncertainty<br><br>Calculated PNEC too low where high concentrations of other CoCs are present |
| Statistics – Large degree of scatter in data | Extremely high uncertainty<br><br>Calculated PNEC likely too high |

**Table 1:    Sources of Uncertainty and their Influence on the Conclusions of the Crops Study (Continued)**

| Aspect | Influence |
|---|---|
| Statistics – Use of different models to fit data | Extremely high uncertainty<br><br>Calculated PNEC likely too high |
| Statistics – Gap in data at moderate to high CoC concentrations at critical point in dose-response curve | Extremely high uncertainty<br><br>Calculated PNEC likely too high |
| Use of shoot biomass as a surrogate for crop grain yield | High Uncertainty<br><br>Calculated PNEC too high |

**[Note: The adjectives in the "Influence" column that describe the level of uncertainty that we believe exists are for relative ranking purposes only].**

# 5.0     CONCLUSIONS

The Technical Scope of Work for the CBRA commits to a scientifically sound, risk based approach to solving the issue of contamination as a result of Inco's operations, using the Site Specific Risk Assessment (SSRA) approach established by the MOE.

The MOE requires that, if site-specific numeric values above the appropriate generic standards are to be proposed for a SSRA, then the uncertainty in each element of the Environmental Risk Assessment must be properly assessed and the overall uncertainty analysis must be sufficient for the valued ecosystem components.  Also it is required that the conclusions be fully justified in relation to risk characterization and the degree of uncertainty.

The Port Colborne CBRA Crops Studies Report presents PNECs based on studies to establish $EC_{25}$ values.  The calculated PNECs have, in our opinion, little credibility because of the large and in many cases immeasurable uncertainties in the studies from which they are derived.

Uncertainty resulting from the blending of soils that are heterogeneous and addition of lime to adjust the pH of soil gives rise to doubts regarding the usefulness of yield results to develop the appropriate $EC_{25}$.  These concerns are compounded through the way in which the data was treated statistically.  There are also concerns that the relationship between crop grain yield and shoot biomass yield is not understood and that other crops, especially dicots, may be more sensitive than the study species, oat.  Also, there are a large number of confounding variables, mostly related to soil parameters that are insufficiently understood, let alone accounted for.

These concerns lead us to conclude that confidence cannot be placed in the $EC_{25}$ values presented in the CBRA Crops Studies Report, which are almost certainly too high.  This concern is especially held for Till Clay, the predominant agricultural soil in the Region.

Therefore, the calculated PNEC values generated from the $EC_{25}$'s, and presented as the conclusions of the CBRA Crops Report, cannot be regarded as being sufficiently and assuredly protective of agriculture in the Port Colborne Area.

The Crops Report fails to meet the test for the acceptance of site specific criteria to replace the Ontario MOE's generic standards for the City of Port Colborne.

## 6.0      REFERENCES

1       *The Technical Scope of Work for the Community Based Risk Assessment Plan for Port Colborne, Ontario*, Jacques Whitford Environment Limited, November 30, 2000.

2.      Port Colborne CBRA – Ecological Risk Assessment, Crop Studies, Jacques Whitford Limited, December 2004.

3.      Guidance on Site Specific Risk Assessment for Use at Contaminated Sites in Ontario, Ontario Ministry of the Environment, Energy, Standards Development Branch, May 1996

4.      Procedures for the Use of Risk Assessment under Part XV.1 of the Environmental Protection Act, Ontario Ministry of the Environment, October 2005.