Determining the Aquatic Toxicity of Deicing Materials

Barr Engineering Company

CLEAR ROADS
research for winter highway maintenance

Project 99083/CR11-02
December 2013

Pooled Fund #TPF-5(218)
www.clearroads.org

Determining the Aquatic Toxicity of Deicing Materials

December 2013

research for winter highway maintenance

www.clearroads.org

4700 West 77th Street
Minneapolis, MN 55435-4803
Phone: (952) 832-2600
Fax: (952) 832-2601

Technical Report Documentation Page

<table>
<tr><td>1. Report No.</td><td colspan="2">2. Government Accession No</td><td colspan="2">3. Recipient's Catalog No</td></tr>
<tr><td colspan="3" rowspan="2">4. Title and Subtitle
Determining the Aquatic Toxicity of Deicing Materials</td><td colspan="2">4. Report Date
December, 2013</td></tr>
<tr><td colspan="2">5. Performing Organization Code</td></tr>
<tr><td colspan="3">7. Authors
Keith M. Pilgrim</td><td colspan="2">8. Performing Organization Report #</td></tr>
<tr><td colspan="3" rowspan="2">9. Performing Organization Name & Address
Barr Engineering Company
4700 West 77th Street, Minneapolis, MN 55435</td><td colspan="2">10. Purchase Order No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
99083</td></tr>
<tr><td colspan="3" rowspan="2">12. Sponsoring Agency Name & Address
Clear Roads Pooled Fund
Minnesota Department of Transportation
395 John Ireland Blvd
St. Paul, MN 55155-1899</td><td colspan="2">13. Type of Report & Period Covered</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code</td></tr>
<tr><td colspan="5">15. Supplementary Notes</td></tr>
<tr><td colspan="5">16. Abstract
Recognizing that there is limited published aquatic toxicity information for liquid deicer chemicals, Clear Roads commissioned this current study to test the acute and chronic toxicity of several deicer chemicals using standard toxicity testing species. The goal of this study was to develop a ranking of the relative toxicity of the deicing materials. The project scope included toxicity testing of deicer chemicals in the following base chemical categories: sodium chloride, magnesium chloride, calcium chloride, potassium acetate and glycerol. Two inhibitor products were identified and tested for sodium chloride, magnesium chloride, and calcium chloride while only one product was available for potassium acetate and one for glycerol. Acute and chronic toxicity endpoints are provided as part of the study report.</td></tr>
<tr><td colspan="2">17. Key Words
Liquid deicing products, aquatic toxicity, toxicity ranking, salt aquatic toxicity</td><td colspan="3">Distribution Statement
No restriction. This document is available to the public through the Clear Roads Organization and the Minnesota Department of Transportation.</td></tr>
<tr><td>19. Security Classification (this report)
Unclassified</td><td colspan="2">20. Security Classification (this page)
Unclassified</td><td>20. No. of pages</td><td>21. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) Report of completed page is authorized

Determining the Aquatic Toxicity of Deicing Materials

December 2013

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

Clear Roads is an ongoing pooled fund research project aimed at rigorous testing of winter maintenance materials, equipment and methods for use by highway maintenance crews. Launched in 2004 by experienced winter maintenance professionals, Clear Roads responds to a need for research based on practical experience. Recognizing that there is limited published aquatic toxicity information for deicer chemicals, Clear Roads commissioned this current study to test the acute and chronic toxicity of several deicer chemicals using standard toxicity testing species. The goal of this study was to develop a ranking of the relative toxicity of the deicing materials. Results of this study are provided in this report.

The project scope included toxicity testing of deicer chemicals in the following base chemical categories: sodium chloride, magnesium chloride, calcium chloride, potassium acetate and glycerol. The Clear Roads Technical Advisory Committee intended to test two commercially available corrosion-inhibitor products in each category. Two inhibitor products were identified and tested for sodium chloride, magnesium chloride, and calcium chloride while only one product was available for potassium acetate and one for glycerol.

As part of this study, a literature review was conducted (Section 2.0). This review included published studies with aquatic toxicity data derived from laboratory tests performed with deicing chemicals (preferably the chemicals tested in this current study). Because of limited toxicological data for deicing chemicals, this literature review was expanded to include a limited number of studies with published acute and chronic endpoints for pure solutions of sodium chloride, calcium chloride, magnesium chloride, potassium salts and potassium acetate. These data provide some additional context with which to evaluate the relative effect of the whole deicing product relative to the component salt.

The scope of toxicity testing included chronic toxicity tests using US EPA methods (US EPA, 2002 and US EPA, 2002b). Tests were conducted in a controlled laboratory setting using an invertebrate (*Ceriodaphnia dubia*), a fish (fathead minnow-*Pimephales promelas*), and a phytoplankton (*Selenastrum capricornutum*). Acute toxicity data were also derived from the chronic tests by using measurements taken on day 2 for *Ceriodaphnia dubia* and day 4 for fathead minnows. Chemical analyses were conducted on the undiluted product solutions used in testing. Section 3.0 (Methods) provides additional descriptions of testing methods, performance requirements, and statistical calculation of toxicological endpoints.

Section 4.0 (Results) includes a general description of the test results, some interpretation of the results, toxicological endpoints, and a brief discussion of deicing chemicals in the broader environment. This section also includes a ranking of the relative toxicity of the deicer chemicals. Section 5.0 (Discussion) provides a discussion of results and how these results should be interpreted and applied.

2.0 Literature Review

The effect of salts on aquatic life has been extensively studied and it is now understood that the concentration of salt that induces aquatic toxicity varies among the several anion and cation combinations that may potentially make up a salt. In addition, several studies (Elphic et al., 2011, Goodfellow et al., 2000) have shown that the toxicity of a given salt may change when combined with other salt mixtures (NCASI, 2009). Given this complexity, logistic regression models have been applied to tease out the relative toxicity of salt components in complex mixtures. Regardless, literature (Mount et al., 1997, NCASI, 2009) largely supports the conclusion that the toxicity potential of the “cation” component of salt can be ranked as follows (high toxicity potential to low): $K^{+}>Mg^{2+}>Na^{+}=Ca^{2+}$. This relationship also holds true when each of the cations is held in salt form by chloride (NCASI, 2009). Acute and chronic toxicity data from a few studies have been compiled in Table 1 for the test species *Ceriodaphnia dubia*, *Pimephales promelas, and Selenastrum capricornutum*. Although there is variability between studies, potassium chloride is the most toxic, followed by magnesium chloride, and then sodium and/or calcium chloride. It is interesting to note that acetate as the corresponding anion to potassium is more toxic than when sulfate or chloride is the corresponding anion. It is often presumed, although not proven, that acetate contributes to toxicity by consuming dissolved oxygen during the toxicity test and thereby inducing stress on the test species.

The potential aquatic toxicity of a deicer is a function of the base salt, the corrosion inhibitor, the salt concentration in the corrosion inhibitor, and impurities. As part of a literature review, three studies were identified that provided useful endpoint (e.g., LC50, IC25, IC50) data for the test organisms used as part of this current study. Data from two relevant studies are summarized in Table 2. The study by the Insurance Corporation of British Columbia, 2000, included toxicity tests with several inhibitors and salts. Some inhibitors were tested without salt as well as with different salts and salts at different concentrations. This enabled the user of this study to roughly identify the toxicological effect of the inhibitor separately from the salt. For example, the *Ceriodaphnia dubia* acute 2-day LC50 (concentration at which there is 50 percent survival of the test species for an acute or chronic test) for the product IceBan was 395 mg/L as product. This demonstrates that by themselves, corrosion inhibitors have toxic properties at concentrations (as product mass) that can be notably less (i.e., more toxic) than salts commonly used in combination with inhibitors. When a sodium chloride brine was mixed with IceBan (20 percent by volume), the acute LC50 for *Ceriodaphnia dubia* was 2,127 mg/L. The acute LC50s listed in Table 1 for *Ceriodaphnia dubia* and sodium chloride only (no inhibitor) ranged from 790 to 2,308 mg/L. Similarly, for a 50 percent mixture of calcium chloride salt brine and IceBan, the acute LC50 for *Ceriodaphnia dubia* was 676 mg/L. Given a range of acute LC50 values for *Ceriodaphnia dubia* of 1,794 to 1,830 mg/L for calcium chloride only (no inhibitor), it can be seen that an increased percentage of inhibitor increased the differential between the salt only toxicity and the salt plus corrosion inhibitor toxicity (e.g., more inhibitor equated with more toxicity). Although this is a useful observation, from these data the degree of toxicity contribution by the inhibitor cannot be quantified.

Interpretation of the data in Table 2 also suggests that 50 percent solutions of salt and 50 percent solutions of IceBan have largely similar toxicity regardless of whether calcium or magnesium chloride is used as the salt brine. It appears that the sodium chloride (23 percent) and IceBan (20 percent) mixture is less toxic than the magnesium chloride (80 percent) and IceBan (20 percent). However, the chloride concentration of the magnesium chloride mixture was 18.6 percent by weight compared to 14.4 percent for the sodium chloride mixture, suggesting that the magnesium chloride solution was more concentrated. Reviewing all of the data it Table 2, a general rule could not be developed with respect to the relative toxicological effect of the salt component of a brine-corrosion inhibitor mixture. It is clear, however, that the toxicity of different inhibitors varies greatly and that potassium acetate is consistently the most toxic deicer. It is recommended that the original literature also be reviewed to gain a full understanding of the contents of these studies.

3.0 Methods

To minimize variability and site specific effects inherent with studies conducted in the natural environment, this study employed established toxicity testing methods (US EPA, 2002 and US EPA, 2002b) and a controlled laboratory environment to examine the potential aquatic toxicity of deicer materials. A fish (fathead minnow, *Pimephales promelas*), a crustacean (*Ceriodaphnia dubia*), and an algae (*Selenastrum capricornutum*) were used to represent the range of aquatic biota that might be resident in a water body receiving road runoff. These species were also chosen because of readily available and established toxicity testing methods, a well-established body of toxicity literature exists for these species, and some of these species, in particular *Ceriodaphnia dubia*, are among the most sensitive of aquatic biota. *Ceriodaphnia dubia* and fathead minnows were cultured by the toxicity testing laboratory (Environmental Toxicity Control, Woodbury, Minnesota) and *Selenastrum capricornutum* was from C-K Associates in Baton Rouge, Louisiana. Synopses of toxicity testing methods are provided in Tables 3, 4, and 5.

Deicer materials used in testing were chosen by the Clear Roads Technical Advisory Committee. A total of eight deicers were selected and included the base salts sodium chloride, calcium chloride, magnesium chloride, potassium acetate and the organic-based deicer glycerol. The deicers used, base salt, manufacturer, and Pacific Northwest Snowfighter (PNS) product category included:

- Sodium chloride brine with corrosion inhibitor Watershed Cl from Rivertop Renewables (PNS product category A1). 850 milliliters of salt brine with sodium chloride (biological grade salt from Fisher Scientific) at a concentration of 23.5 percent (by weight) was mixed with 42.5 milliliters of inhibitor giving a final targeted salt content of 20.6 percent by weight.
- Sodium chloride brine with corrosion inhibitor Beet 55 from Smith Fertilizer and Grain (PNS product category A3). 850 milliliters of salt brine with sodium chloride (biological grade salt from Fisher Scientific) at a concentration of 23.5 percent (by weight) was mixed with 255 milliliters of inhibitor giving a final targeted salt content of 16.7 percent by weight.
- FreezGard CI Plus by North American Salt. PNS Category 1 products contain no less than 25 percent magnesium chloride. FreezGard CI Plus contains 30 percent magnesium chloride.

- Meltdown Apex by Envirotech Services. This is a PNS Category 1 product that contains 25 percent magnesium chloride.
- Road Guard Plus by Tiger Chemical. This is a PNS Category 2 product that contains 25 percent calcium chloride.
- Boost by America West. This is a PNS Category 2 product that contains 32 percent calcium chloride.
- CF-7 by Cryotec. This is a potassium acetate based deicer that is not currently on the PNS Qualified Product List and is in the Experimental Category. CF-7 contains 50 percent potassium acetate.
- Apogee by Envirotech Services. This is a glycerol based deicer. The glycerol concentration of this product is not provided by the product material safety data sheet.

In 1 to 2 liter plastic bottles, salt brine-corrosion inhibitor mixtures were added to moderately hard synthetic water (for *Ceriodaphnia dubia* and fathead minnows) and Woods Hole nutrient medium (for *Selenastrum Capricoruntum*) to create a range of deicer doses that could be both chronically and acutely toxic. Moderately hard synthetic water is an US EPA prescribed (US EPA, 2002) acute and chronic testing formula that produces balanced salt concentrations and micronutrients that mimic natural water and also provides a medium in which many organisms can survive, grow, and reproduce normally (Table 6). The use of moderately hard synthetic water was also necessary to provide good control results, to mimic that which would normally occur with salt application and the dilution of salt with snow and ice-melt, and to avoid the effects of the diluent on toxicity at the different deicer doses (e.g., deionized water by itself would be toxic). Woods Hole medium (Table 7) provides the necessary nutrients for algal growth. Doses were identified based upon range finding tests conducted with five of the test products. Chemical analyses were conducted on the stock solutions (e.g., undiluted deicers) at a commercial laboratory (see Table 7 for a list of the parameters and a summary of the analytical results; also see Appendix A for the laboratory reports). Chemical and physical measurements taken during the toxicity tests are provided as part of the toxicity testing laboratory reports (Appendix B).

Although the tests were conducted according to chronic toxicity testing procedures for *Ceriodaphnia dubia* and fathead minnows (US EPA, 2002) and the tests were conducted for 7 days, doses were chosen such that acute and chronic toxicological endpoints could be calculated. Acute testing deviated from standardized procedures in that only 10 *Ceriodaphnia dubia* test organisms were used for testing (chronic tests) rather than the 20 that are called for. Similarly for fathead minnows, acute testing deviated from standardized procedures in that 40 fathead minnow test organisms were used for testing (chronic tests) rather than the 20 that are called for. Because the *Selenastrum capriconutum* bioassay is conducted for 4 days, only chronic data were generated.

The following toxicological endpoints were calculated for the acute and chronic test results:

- **NOEC**: No observed effect concentration. This is the highest concentration in a test series in which the result (survival, growth, or reproduction) is not significantly different from the controls.
- **LC50**: Lethal concentration with 50 percent mortality. This is the test concentration in which there is 50 percent mortality.
- **IC25**: Inhibition concentration with 25 percent reduction (growth, reproduction) compared to the controls.
- **IC50**: Inhibition concentration with 50 percent reduction (growth, reproduction) compared to the controls.

All toxicological endpoints were calculated using US EPA programs that are described in the US EPA "Chronic" manual (US EPA, 2002) and the "Acute" manual (US EPA, 2002b). To maintain consistency between the chemicals tested, Dunnett's test was used to calculate NOECs for all deicers and for acute and chronic survival. The Spearman-Karber or the Trimmed Spearman Karber (if there was some mortality in the controls) was used to calculate acute and chronic LC50s for survival. Linear interpolation using the ICPIN program was used to calculate IC25 and IC50 values for growth and reproduction.

4.0 Results

Tables 8 through 15 provide survival, growth, and reproduction results recorded on the second, fourth, and seventh day of testing for all three test species, all eight test products, and for all of the doses tested. For fathead minnows, acute test results provided in Tables 8 through 15 were measured on test day four, while acute test results for *Ceriodaphnia* dubia were measured on test day two. All *Ceriodaphnia dubia* and fathead minnow tests were run to completion (day seven). Chronic test results in Table 8 through 15 for fathead minnows and *Ceriodaphnia dubia* were both measured on day seven of the test while measurements for *Selenastrum capricornutum* were taken only on the fourth and final day of this test.

For *Ceriodaphnia dubia* and fathead minnows, control survival was greater than 80 percent in the controls and there were no abnormalities observed during tests. For *Ceriodaphnia dubia*, young production in the controls exceeded the minimum requirement of 15 neonates per adult female. For both *Ceriodaphnia dubia* and fathead minnow, results of reference toxicity tests were within the range of results typically generated by the testing laboratory (also see US EPA, 1991). All test results can be considered acceptable and useable. Toxicity testing reports provided by the testing laboratory are provided in Appendix B.

For all of the products tested except for Apogee, there was a normal "dose-response" relationship in which higher deicer product concentrations generally led to reduced survival, growth, or reproduction. Acute as well as chronic effects were produced for all products tested except for Apogee where doses were not high enough to elicit a pronounced acute toxic effect. A general description of the results obtained for each product is provided below. A discussion of acute and chronic endpoints is provided after this general discussion.

General Description of Test Results

Watershed CI

For fathead minnows, acute and chronic effects on survival can be seen at doses greater than 12 grams product per liter of diluent (Table 8, Figure 1). The chronic effect on survival was nearly identical to the acute effect (see Figure 1). It can be also seen that very low concentrations of product (e.g. 0.5 grams product per liter of diluent) had a stimulatory effect on minnow growth measured as weight at the end of the seven day test. This was observed for nearly all of the products tested. Chronic effects (weight) can also be seen at doses greater than 12 grams product per limit of diluent.

For *Ceriodaphnia dubia*, a noticeable acute effect on survival can be seen at doses greater than 12 grams product per liter of diluent. Chronic survival effects were observed at doses greater than 3 grams product per liter of diluent. The effect of product on reproduction, the chronic endpoint, was variable between doses of 0.005 and 0.5 grams product per liter of diluent. Reproductive effects began to occur at approximately 0.5 to 1.0 grams product per liter of diluent.

It is difficult to isolate what constituent in the deicer product is responsible for toxicity; however *Ceriodaphnia dubia* reproduction, for example, began to decline between 0.5 and 1.0 grams product per liter (IC25 of 0.990 grams product per liter of diluent, toxicity endpoints are discussed below). These doses correspond to specific conductance levels of 458 to 483 us/cm and sodium chloride concentrations of 141 and 254 mg/L (Table 8). According to a study by Lasier and Winger, 2004, the IC25 for *Ceriodaphnia dubia* expressed as total dissolved solids averaged 787 mg/L (dissolved solids components included chloride, sulfate, and bicarbonate). A concentration of 787 mg/L is approximately equal to 1,100 us/cm specific conductance. Because the sodium and chloride concentrations are far below expected chronic toxicity thresholds (see Table 1) and yet there is toxicity at 0.5 to 1.0 grams product per liter of diluent, it appears that the inhibitor is contributing to observed chronic toxicity to *Ceriodaphnia dubia*. Specific conductance was greater than 1,387 us/cm and greater than 704 mg/L sodium chloride at doses of 3.0 grams product per liter of diluent or greater, and it can be assumed that dissolved salts in the salt brine-inhibitor mixture were contributing to the observed reduction in reproduction at these concentrations. The purpose of this discussion is simply to point out that the inhibitor and the salt appear to both contribute to toxicity. It was not the intent of this study to identify the degree to which they each contribute to toxicity. Further study and a different study design would be required to isolate the relative contribution of salt and inhibitor.

All product doses up to 15 grams product per liter of diluent stimulated the growth of *Selenastrum capricornutum* when compared to the controls. A dose of 30 grams product per liter was required to cause a notable reduction in growth.

Beet 55

For fathead minnows and at product doses of 2 grams per liter of diluent, both acute and chronic survival effects were not notable, however, there was 100 percent mortality at the next highest dose of 6 grams product per liter of diluent (Table 9, Figure 2). The chronic effect on survival was identical to the acute effect (see Figure 2). It can be also seen that very low concentrations of product (e.g. 0.5 grams product per liter of diluent or less) had a stimulatory effect on minnow growth measured as weight at the end of the seven day test.

For *Ceriodaphnia dubia*, acute effects on survival can be seen at doses greater than 10 grams product per liter of diluent. Chronic survival was reduced compared to controls at product doses as low as 0.002 grams product per liter of diluent. The effect of product on reproduction, the chronic endpoint, was variable between doses of 0.0005 and 0.004 grams product per liter of diluent. Reproductive effects were more apparent at approximately 0.01 to 0.1 grams product per liter of diluent.

All product doses up to 4 grams product per liter of diluent stimulated the growth of *Selenastrum capricornutum* when compared to the controls. A dose of 6 grams product per liter was required for growth reduction to be apparent.

FreezGard CI Plus

For fathead minnows and at product doses of 0.03 to 0.5 grams per liter of diluent, both acute and chronic survival effects were variable with toxic effects becoming apparent at 1.0 grams product per liter of dilution and complete acute and chronic mortality at a dose of 8 grams product per liter of diluent (Table 10, Figure 3). Compared to Watershed Cl and Beet 55 (discussed above), there was a larger difference between acute and chronic survival effects (see Figure 3). It can be also seen that at concentrations up to 1.0 grams product per liter of diluent there was a stimulatory effect on minnow growth measured as weight at the end of the seven day test (because there was complete mortality at 8 grams product per liter diluent, there was no growth at this dose).

For *Ceriodaphnia dubia*, noticeable acute effects on survival can be seen at doses greater than 8 grams product per liter of diluent. Chronic survival was reduced compared to controls at product doses as low as 0.5 grams product per liter of diluent. The effect of product on reproduction, the chronic endpoint, was variable between doses of 0.05 and 0.15 grams product per liter of diluent.

In contrast to Watershed Cl and Beet 55, there was no stimulatory effect on *Selenastrum capricornutum* growth with the addition of product to diluent. Phosphorus concentrations were higher but some nitrogen species (nitrate plus nitrite) were lower in FreezGard CI Plus (Table 7) compared to the other products. It is possible but not certain that a lack of available nitrogen also explains the lack of stimulatory response with this product. Growth was reduced at the lowest dose tested (1 gram product per liter of diluent) as well as all other test doses.

Meltdown Apex

For fathead minnows and at product doses of 0.06 to 1.0 grams per liter of diluent, both acute and chronic survival effects were variable with toxic effects more apparent at 2.0 grams product per liter of dilution and complete acute and chronic mortality at a dose of 16 grams product per liter of diluent (Table 11, Figure 4). There was very little difference between acute and chronic survival effects (see Figure 4). It also can be seen that at concentrations up to 2.0 grams product per liter of diluent there was a stimulatory effect on minnow growth measured as weight at the end of the seven day test (because there was complete mortality at the next highest dose of 16 grams product per liter diluent, there was no growth at this dose).

For *Ceriodaphnia dubia*, noticeable acute effects on survival can be seen at doses greater than 8 grams product per liter of diluent. Chronic survival was reduced compared to controls at product doses as low as 0.5 grams product per liter of diluent. The effect of product on reproduction, the chronic endpoint, was variable between doses of 0.05 and 0.15 grams product per liter of diluent.

Similar to FreezGard CI Plus, there was no stimulatory effect on *Selenastrum capricornutum* growth with the addition of product to diluent. Since phosphorus and nitrogen concentrations were lower in FreezGard CI Plus (Table 7) compared to the other products with a stimulatory growth response, lack of nutrients may be the cause of this observed difference. Growth was reduced at the lowest dose tested (1 gram product per liter of diluent) as well as all other test doses.

Road Guard Plus

For fathead minnows, there was a clear and stepwise decrease in acute and chronic survival as well as a reduction in growth with an increase in product dose (Table 12, Figure 5). There was very little difference between acute and chronic survival effects (see Figure 5).

For *Ceriodaphnia dubia*, noticeable acute and chronic effects on survival were observed for doses greater than 6 grams product per liter of diluent. Young production (the chronic endpoint) increased compared to controls at product doses between 0.10 to 1.5 grams per liter diluent while there were pronounced effects on young production at doses above 1.5 grams.

All product doses up to 4 grams product per liter of diluent stimulated the growth of *Selenastrum capricornutum* when compared to the controls. Road Guard Plus had higher nitrogen concentrations compared to products that did not stimulate *Selenastrum capricornutum* growth (Table 7). It is possible that nitrogen is responsible for growth stimulus at lower doses. A dose of 6 grams product per liter was required for growth reduction, compared to controls, to become apparent.

Boost

For fathead minnows, there was largely a clear and stepwise decrease in acute and chronic survival as well as reduced growth with an increase in product dose (Table 13, Figure 6). There was a small difference between acute and chronic survival effects (see Figure 6). With the exception of Metldown Apex, FreezGard Plus, and CF-7 (discussed below) and for the products discussed to this point it has been noted that there was little difference in acute and chronic mortality (similar to Boost); indicating that most of the toxic effect occurred in the first few days of testing. This suggests that an assessment of aquatic effects with deicer application should consider acute as well as chronic effects and in some situations acute affects may more readily align with the time scale of a storm event (see Section 5.0 Discussion).

For *Ceriodaphnia dubia*, noticeable acute effects on survival occurred at doses greater than 1.5 grams product per liter of diluent while chronic effect were observed at doses greater than 0.5 grams product per liter of diluent. Young production (the chronic endpoint) increased compared to controls at product doses between 0.10 to 0.5 grams per liter diluent while there were pronounced effects on young production at doses above 0.5 grams.

All doses up to 2 grams product per liter of diluent stimulated the growth of *Selenastrum capricornutum* when compared to the controls. Boost had higher nitrogen (e.g., total Kjeldahl nitrogen and nitrate plus nitrite) concentrations compared to products that did not stimulate *Selenastrum capricornutum* growth. It is possible that nitrogen is responsible for growth stimulus at lower doses. A dose of 4 grams product per liter was required for growth reduction (compared to controls) to be apparent.

CF-7

For fathead minnows there was largely a stepwise decrease in acute and chronic survival as well as reduced growth with an increase in product dose (Table 14, Figure 7). Compared to the other products tested, there was a larger difference between acute and chronic survival effects (see Figure 6). With respect to growth (chronic effects) there was only a slight stimulatory effect at low doses and growth steadily declined with product dose.

For *Ceriodaphnia dubia*, acute and chronic survival effects were highly variable between doses of 0.0025 to 1.0 grams product per liter of diluent. Conversely, young production (the chronic endpoint) compared to controls declined at very low doses (e.g., 0.0025 grams product per liter of diluent) and young production remained low and somewhat variable between 0.0075 to 1.0 grams product per liter of diluent. There was no young production at the highest dose tested (2.0 grams product per liter of diluent).

It appears that CF-7 had no stimulatory effect on *Selenastrum capricornutum* growth. Compared to the other products that stimulated *Selenastrum capricornutum* growth, CF-7 had higher total phosphorus (as P) but lower total Kjeldahl nitrogen concentrations and lower nitrate plus nitrite (Table 7). There was largely a stepwise decrease in growth with an increase in product dose (Table 14, Figure 7).

Apogee

From an aquatic toxicity and chemical composition perspective, Apogee was notably different from the other products tested. At the doses tested, there was little acute toxicity (maximum dose of 20 grams product per liter of diluent) while at day seven of the test (chronic testing period) there was very little survival even at low doses (e.g., 10 percent survival at 0.5 grams product per liter of diluent). Only a slight stimulatory growth effect was observed at the lowest dose (0.05 grams product per liter of diluent) and there was reduced growth for all higher doses.

For *Ceriodaphnia dubia*, there was no consistent dose-response relationship with either little or no acute or chronic (survival) toxicity observed for all doses tested. The highest dose was 10 grams product per liter of diluent, and hence, higher doses should have been tested to elicit reduced survival and to more accurately quantify the toxicity of this product. Young production (the chronic endpoint) was highly variable across all the doses tested except for the two highest doses tested (3.0 and 10.0 grams product per liter of diluent) where there was 1.5 and 0.0 young produced per adult female.

It appears that Apogee had no stimulatory effect on *Selenastrum capricornutum* growth. Compared to the other products that stimulated *Selenastrum capricornutum* growth, Apogee had higher phosphorus but lower total Kjeldahl nitrogen concentrations and lower nitrate plus nitrite (Table 7). There was largely a stepwise decrease in growth with an increase in product dose (Table 15, Figure 8), however, doses were not large enough to reduce growth such that NOECs, IC25, and LC50 endpoints could be calculated.

Toxicity Endpoints

For each test species and each deicer product tested, a series of acute and chronic endpoints were calculated. The endpoints calculated included: NOEC-acute (survival), LC50-acute (survival), NOEC-chronic (survival), LC50-chronic (survival), NOEC-chronic (young production or growth), IC25-chronic (young production or growth), and IC50-chronic (young-production or growth). These endpoints were defined in Section 2.0 of this report. Endpoints were calculated using three different approaches: (1) product mass basis, (2) mass of major salt component, and (3) volumetric basis. Endpoints on a product mass basis are provided in Tables 16, 17, and 18. Endpoints calculated on a major salt component basis are provided in Tables 19, 20, and 21 and endpoints calculated on a volume of product basis are provided in Tables 22, 23, and 24. Although these products were tested in liquid form, the product mass used for each test can be readily calculated by multiplying the product density by the volumetric dose or endpoint. Each salt brine-product mixture or product was analyzed for a range of analytes, including the primary salt component (e.g., sodium and chloride). Endpoints provided on a volumetric basis were simply converted to a "mass of major salt basis" by multiplying the volume dose or endpoint by salt concentration of the undiluted deicer. This was conducted to normalize the results and to facilitate comparison of the different products because they had a range of salt concentrations which are prescribed by PNS specifications.

The endpoints in Tables 16 through 24 could be applied in various ways including a comparison of the relative toxicity of the products tested (discussed in more detail below) and an estimation of potential toxicological effect with product application. It is important to note that the effect should be considered "potential" because there are several site specific (e.g., water content of snow) and receiving water variables (e.g., chemistry, temperature, resident biological species) that are not included in this laboratory-based study.

The acute NOECs and LC50s could be used to estimate the potential toxicological effect of a given mass or volume of product when diluted in snowmelt and/or the receiving water body. These endpoints provide an indication of short term toxicity and may be best suited to receiving waters such as streams and rivers where the exposure period for resident biota is equal to the storm event length. Chronic NOECs and LC50s for survival may be more applicable for water bodies with longer residence times such as lakes or for climates in which storm events are generally longer. Chronic growth and young production NOECs, IC25s, and IC50s may be best suited to estimate effects in lakes or wetlands or for rivers and streams with particularly sensitive biota (e.g., trout). In general, NOECs and IC25 values are similar in that they demarcate the concentration at which there is largely no toxicity (e.g., at the NOEC or IC25) and the concentration at which toxicity becomes noticeable (e.g., at concentrations greater than the NOEC and IC25). The IC50, which is the point at which there is a 50 percent reduction in growth or reproduction compared to the controls, could also be used to evaluate potential aquatic toxicity; however, this endpoint is probably best suited to compare the relative chronic toxicity of the products tested.

Toxicity Ranking

Given the multiple toxicological endpoints provided in Tables 16 through 21 (e.g., three species, two unique ways to express the endpoints, and seven different endpoints), it is difficult to conduct a quick scan to identify which deicer has the greatest and which deicer has the least toxicological potential. A method was developed using all of the endpoints to rank the toxicity potential of the products tested. Separate rankings were developed for endpoints calculated on a "product mass" basis and on a "major salt mass" basis. Details of the ranking method are provided below:

- Each product was given a rank from 1 through 8, based upon the value of the toxicological endpoint.
- The product with the largest endpoint (e.g., low toxicity) was given a #1 ranking and the products with smaller endpoints (e.g., high toxicity) were given sequentially higher rankings.
- If two or more products had the same toxicological endpoint value, then an average ranking (e.g., rank 4 and 5 for two products with identical endpoints would be given a value of 4.5) was applied to both products. The subsequent ranked product would be given a subsequent rank # just as if the two products did not have the same toxicological value (e.g., the product after the two 4.5 ranked products would be given rank #6).
- This procedure was conducted for all seven endpoints and all test species. Rankings were then summed across all of the endpoints and all of the test species to provide a Total Rank Number.
- The product with the smallest Total Rank Number was then given a Relative Toxicological Rank of 1. Products with higher Total Rank Numbers were given sequentially higher rankings.

The results of the ranking process are provided in Table 25. The relative toxicological rank of the products was the same whether the toxicity data were expressed as "total product mass" or by "major salt mass." Ignoring the Beet 55 and the Apogee results, it can be seen that the sodium chloride based deicer contains the least potentially toxic salt (see Section 2.0) and it was also the least toxic deicer. Similarly, the deicing product with the most potentially toxic salt, potassium, was most toxic. In general, product toxicity ranking by salt was (from most to least toxic): K-acetate > $MgCl_2$ >

$CaCl_2$ > NaCl. However, the test results (see Section 4.0 for a discussion on this) also provide an indication that the inhibitor as well as the salt contribute to toxicity. This is clearly the case for Beet 55. Interpretation of a similar study conducted by the Insurance Corporation of British Columbia, 2000, suggests that the inhibitors in that study were the primary determinant of toxicity potential rather than the salt. It can be concluded that the ranking provided in Table 25 likely applies only to these products and that it cannot be assumed that the potential toxicity of a given product will be solely a function of the type of salt used in the deicer.

5.0 Discussion

The primary objective of this study was to conduct toxicity tests with deicer products in a controlled laboratory setting, using established testing protocols and testing organisms, to develop a ranking of toxicity potential of the deicers tested. This ranking is provided in Table 25. Toxicological endpoint data were also produced as part of this study (Tables 16 through 24). These endpoint data, when considering dilution with snowmelt and receiving water flows or volume, could be used to evaluate the potential for toxicity in a receiving water body with product application. When conducting this type of evaluation, several factors would need to be considered such as application rates, length of road that contributes runoff to the receiving water body, and site specific climatic factors.

Some general observations were noted as part of this study. Even though deicing products have high chemical oxygen demand imparted by the corrosion inhibitor, dissolved oxygen did not decline during testing as much as was originally anticipated and it does not appear that the oxygen concentrations measured as part of the toxicity test would have caused toxicity (see Table 26 and Appendix B). This suggests that inhibitor toxicity is not mediated by dissolved oxygen depletion. The exception to this is Beet 55 where dissolved oxygen declined to low and potentially toxic levels in the fathead minnow test. From an interpretation of the toxicity testing results, for each dose tested as well as the specific conductance and the estimated salt concentration for each dose, it can be concluded that the inhibitor causes toxicity to the test organism that is separate from salt type and concentration in the brine-inhibitor mixture. Regardless, results of the test also suggest that the type and mass of salt in a deicer can influence the toxicity potential of a given inhibitor since salts considered to be most toxic as pure solutions were also most toxic in inhibitor-salt brine mixtures. Product toxicity with respect to the primary salt could be ranked as follows (from most to least toxic): K-acetate > $MgCl_2$ > $CaCl_2$ > NaCl.

For an acute exposure period, fathead minnows and *Ceriodaphnia dubia* demonstrated largely equal sensitivity to deicing products. However, *Ceriodaphnia dubia* was more sensitive to chronic exposure periods. *Selenastrum capricornutum* appeared to be less sensitive than fathead minnow but more sensitive than *Ceriodaphnia dubia* to chronic exposure. For some products and species, results were very similar for acute and chronic exposure periods. For example, using acute and chronic LC50 values for survival as a basis of comparison, exposure to product past the acute exposure period did not cause additional toxicity for nearly all the products tested with fathead minnows except for Apogee and CF-7. This was also the case for *Ceriodaphnia dubia* for about half of the products tested. Apogee and CF-7 were more chronically toxic than the other products with respect to fathead minnows while Beet 55, FreezGard CI Plus, Meltdown Apex, and CF-7 were more chronically toxic to *Ceriodaphnia dubia.*

References

Adelman, I.R., and L.L., Jr. Smith (1976). Standard Test Fish Development. Part I. Fathead Minnows (*Pimephales promelas*) and Goldfish (*Carassius auratus*) as Standard Fish in Bioassays and Their Reaction to Potential Reference Toxicants. EPA-600/3-76-061A, U.S.EPA, Duluth, MN:77 p.

Aquatic Toxicology Group (1998). Brenda Mines Sulphate and Molybdenum Toxicity Testing. Proj. Rep. No. 2-11-825/826, Prepared for Noranda Mining and Exploration Inc., Brenda Mines Div., B.C.:222 p.

Aragao, M.A., and E.V. Pereira (2003). Sensitivity of *Ceriodaphnia dubia* of Different Ages to Sodium Chloride. Bull. Environ. Contam. Toxicol.70(6): 1247-1250

Ball, G.F.A, Herrington, P.R., Patrick, J.E. (2008). Environmental effects of emulsions. Land Transport New Zealand Research Report 343. 46 pp.

Birge, W.J., J.A. Black, A.G. Westerman, T.M. Short, S.B. Taylor, D.M. Bruser, and E.D. Wallingford (1985). Recommendations on Numerical Values for Regulating Iron and Chloride Concentrations for the Purpose of Protecting Warmwater Species of Aquatic Life in the Commonwealth of Kentucky. University of Kentucky, Lexington, KY:73 p.

Cooney J.D., DeGraeve G.M., Moore E.L., Lenoble B.J., Pollock T.L., Smith G.J. (1992). Effects of Environmental and Experimental Design Factors on Culturing and Toxicity Testing of *Ceriodaphnia dubia*. Environ. Toxicol. Chem. 11: 839-850.

Corsi, S.R., S.W. Geis, G. Bowman, G.G. Failey, and T.D. Rutter (2009). Aquatic Toxicity of Airfield-Pavement Deicer Materials and Implications for Airport Runoff. Environ. Sci. Technol. 43(1): 40-46

Cowgill U.M., Milazzo D.P. (1990). The Sensitivity of Two Cladocerans to Water Quality Variables: Salinity and Hardness. Archiv. Hydrobio. 120: 185-196.

Defourny, C. (2000). Environmental Risk Assessment of Deicing Salts. 8th World Salt Symposium, The Hague, Netherlands 2:767–770.

DeGraeve, G.M., J.D. Cooney, B.H. Marsh, T.L. Pollock, and N.G. Reichenbach (1992). Variability in the Performance of the 7-D *Ceriodaphnia dubia* Survival and Reproduction Test: An Intra- and Interlaboratory Study. Environ. Toxicol. Chem.11(6): 851-866.

D'Itri, F.M. (1992). Chemical Deicers and the Environment. Boca Raton: Lewis Publishers.

Elphick, J.R.F., Bergh, K D., and H.C. Bailey (2011). Chronic Toxicity to Chloride to Freshwater Species: Effects of Hardness and Implications for Water Quality Guidelines. Environ. Tox. and Chem. 30(1):239-246.

Evans, M.S. and Frick, C. (2001). The Effects of Road Salts on Aquatic Ecosystems. Technical report, Environment Canada Health Canada, 2001.

Fay, L. and Shi, X. (2011). Environmental Impacts of Chemicals for Snow and Ice Control: State of the Knowledge. Water Air and Soil Pollution. DOI 10.1007/s11270-011-1064-6.

Geis, S.W., K. Fleming, A. Mager, and L. Reynolds (2003). Modifications to the Fathead Minnow (*Pimephales promelas*) Chronic Test Method to Remove Mortality due to Pathogenic Organisms. Environ. Toxicol. Chem.22(10): 2400-2404.

Goodfellow, W. L., Ausley, L.W, Burton, D.T., Denton, D.L., Dorn, P.B., Grothe, D.R., Heber, M.A., Norberg-King, T.J., and J.H. Rodgers, Jr. 2000. Major Ion Goxicity in Effluents: A Review with Permitting Recommendations. Environmental Toxicology and Chemistry. 19(1): 175-182.

Harmon, S.M., W.L. Specht, and G.T. Chandler (2003). A Comparison of the Daphnids Ceriodaphnia dubia and Daphnia ambigua for Their Utilization in Routine Toxicity Testing in the Southeastern United States. Arch. Environ. Contam. Toxicol.45(1): 79-85.

Hoke R.A., Gala W.R., Drake J.B., Geisy J.P., Fleger S. (1992). Bicarbonate as a Potential Confounding Factor in Cladoceran Toxicity Assessments of Pore Water from Contaminated Sediments. Can J Fish Aquat Sci 49: 1633-1640.

Horner, R.R., and M.V. Brener (1992). Environmental Evaluation of Calcium Magnesium Acetate for Highway Deicing Applications. Resource Conservation & Recycling, 7, 213–237.

LaPerriere, J.D., and C.L. Rea (1989). Effects of Calcium Magnesium Acetate Deicer on Small Ponds in Interior Alaska. Lake and Res. Manage., 5(2), 49–57.

Laseir, P.J. and P.V. Winger (2004). Effects of Anions and Anion Mixtures on the Reproduction of *Ceriodaphnia dubia*. Poster by USGS Patuxent Wildlife Research Center.

Meyer, J.S., D.A. Sanchez, J.A. Brookman, D.B. McWhorter, and H.L. Bergman (1985). Chemistry and Aquatic Toxicity of Raw Oil Shale Leachates from Piceance Basin, Colorado. Environ. Toxicol. Chem.4:559-572

Mount, D.R., and D.D. Gulley (1992). Development of a Salinity/Toxicity Relationship to Predict Acute Toxicity of Saline Waters to Freshwater Organisms. Final Rep.GRI-92/0301, ENSR Contract No. 5091-253-2160, ENSR Consult. and Eng., Ft. Collins, CO: 146 p.

Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans (1997) .Statistical Models to Predict the Toxicity of Major Ions to *Ceriodaphnia dubia, Daphnia magna* and *Pimephales promelas* (Fathead Minnows). Environ. Toxicol. Chem. 16(10): 2009-2019.

NCASI (2009). The Potential Influence of Effluent-Related Dissolved Solids on Chronic Whole Effluent Toxicity Test Results with *Ceriodaphnia dubia* and *Selenastrum capricornutum*.

Insurance Corporation of British Columbia (2000). Anti Icers – Chemical Analysis and Toxicity Test Results. File #498-0954.

Pickering, Q.H., J.M. Lazorchak, and K.L. Winks (1996). Subchronic Sensitivity of One-, Four-, and Seven-Day-Old Fathead Minnow (Pimephales promelas) Larvae to Five Toxicants. Environ. Toxicol. Chem.15(3): 353-359.

Sanders, D.F. (1993). Site Water Bioassays for Huff and Huff, Incorporated, La Grange, IL. IPS Environmental and Analytical Services, Appleton WI (December 6 Memo to S. LaDieu, Huff & Huff Inc, LaGrange, IL): 67 p.

Schulte, E. E. and Kelling, K. A., (2004). Soil and applied potassium (A2521) (http://www.soils.wisc.edu/extension/pubs/A2521.pdf); last accessed on May, 2010.

Stark, J. (1999). Bioassay Report Chronic Toxicity Tests. Conducted November 12 Through 19, 1999. SF Analytical Laboratories Inc., Milwaukee, WI (December 7 Memo to S. LaDieu, Huff & Huff Inc., IL): 56 p.

Taylor, P.A., A.J. Stewart, and L. Holt (1988). Toxicity of Common Salts to Three Biotoxicity Test Organisms. Prepared for Presentation at American Institute of Chemical Engineers National Meeting: 8 p.

US EPA (1991). Technical Support Document for Water Quality Based Toxics Control. EPA 505-2-90-001.

US EPA (2002). Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. EPA-821-R-02-013. Fourth Edition, October 2002.

US EPA (2002b). Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. EPA-821-R-02-012. Fifth Edition, October 2002.

Tables

Table 1. Acute and chronic toxicological endpoints for studies conducted with salts and without corrosion inhibitors.

Chemical	Species	Test Endpoint	Test Duration	Concentration (mg/l)	Reference
NaCl	*Ceriodaphnia dubia*	EC50	7 Days	2340	Evans and Frick 2001
		IC25	7 Days	1010	Sanders 1993
				910	Stark 1999
		LC50	2 Days	2308	Cowgill and Milazzo 1990
				1590	Harmon et al. 2003
				790	Hoke et al. 1992
				2132	Mount et al. 1992
				1042	Mount et al. 1992
				1956	Mount et al. 1992
		LC50	7 Days	1794	Cowgill and Milazzo 1990
				1510	DeGraeve et al. 1992
		NOEC	7 Days	250	Aragao and Pereira 2003
				1800	Cooney et al. 1992
				740	DeGraeve et al. 1992
				440	Harmon et al. 2003
				1250	Sanders 1993
				1000	Stark 1999
	Pimephales promelas	EC50	7 Days	7210	Evans and Frick 2001
		IC25	7 Days	3100	Geis et al. 2003
				1600	Sanders 1993
				1470	Stark 1999
		LC50	2 Days	7690	Adelman and Smith 1976
				6510	Mount et al. 1992
			4 Days	7600	Adelman and Smith 1976
				6570	Birge et al. 1985
				11400	Meyer et al. 1985
				6390	Mount et al. 1992
			7 Days	5740	Aquatic Toxicity Group 1998
				5490	Beak International Inc. 1999
		NOEC	7 Days	4000	Pickering et al. 1996
				2500	Sanders 1993
				500	Stark 1999
				500	Taylor et al. 1988
$CaCl_2$	*Ceriodaphnia dubia*	EC50	7 Days	1440	Evans and Frick 2001
		LC50	2 Days	1830	Mount et al. 1997
				1794	Mount et al. 1997
				1830	Ball et al. 2008
	Pimephales promelas	EC50	7 days	9520	Evans and Frick 2001
		LC50	4 Days	4630	Ball et al. 2008
				4630	Mount et al. 1997
	Selenastrum capricornutum	EC50	3 Days	2900	Ball et al. 2008
				2700	Ball et al. 2008
$MgCl_2$	*Ceriodaphnia dubia*	LC50	2 Days	880	Mount et al. 1997
				962	Mount et al. 1997
	Pimephales promelas	LC50	2 Days	2840	Mount et al. 1997
		LC50	4 Days	2120	Mount et al. 1997
K_2SO_4	*Ceriodaphnia dubia*	LC50	2 Days	680	Mount et al. 1997
	Pimephales promelas	LC50	2 Days	860	Mount et al. 1997
		LC50	4 Days	680	Mount et al. 1997
K-Acetate	*Ceriodaphnia dubia*	IC25	6-7 days	43	Corsi et al. 2009
		LC50	2 Days	313	Corsi et al. 2009
	Pimephales promelas	IC25	7 Days	324	Corsi et al. 2009
		LC50	4 Days	421	Corsi et al. 2009
	Selenastrum capricornutum	IC25	4 Days	28.8	Corsi et al. 2009
KCl	*Ceriodaphnia dubia*	LC50	2 Days	630	Mount et al. 1997
	Pimephales promelas	LC50	2 Days	910	Mount et al. 1997
		LC50	4 Days	880	Mount et al. 1997
		LOEC	7 Days	1000	Pickering et al. 1996
		NOEC	7 Days	500	Pickering et al. 1996

Table 2. Acute and chronic toxicological endpoints for studies conducted with deicing products.

Deicing Chemical	Supplier	Species	Test Endpoint	Test Duration	Product Concentration (mg/L)	Chloride or Potassium in Product (% by Weight)	Reference
Potassium Acetate Deicer	not identified	*Ceriodaphnia dubia*	LC50	2 Days	421	not given	Corsi et al. 2009
		Ceriodaphnia dubia	IC25	6-7 Days	54.5		
		Pimephales promelas	LC50	4 Days	298		
		Pimephales promelas	IC25	7 Days	366		
		Selenastrum capricornutum	IC25	4 Days	19.9		
$MgCl_2$-Freezgard	Premium/IMC	*Ceriodaphnia dubia*	LC50	2 Days	4514	25	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	1634		
		Ceriodaphnia dubia	IC50	7 Days	2807		
		Selenastrum capricornutum	IC25	3 Days	1426		
		Selenastrum capricornutum	IC50	3 Days	3158		
IceBan	IceBan America	*Ceriodaphnia dubia*	LC50	2 Days	395	0.19	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	103		
		Ceriodaphnia dubia	IC50	7 Days	173		
		Selenastrum capricornutum	IC25	3 Days	186		
		Selenastrum capricornutum	IC50	3 Days	277		
$CaCl_2$-Liquidow	Dow	*Ceriodaphnia dubia*	LC50	2 Days	5454	23	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	2109		
		Ceriodaphnia dubia	IC50	7 Days	2971		
		Selenastrum capricornutum	IC25	3 Days	1039		
		Selenastrum capricornutum	IC50	3 Days	3424		
$CaCl_2$-Inhibited	Dow	*Ceriodaphnia dubia*	LC50	2 Days	3828	23	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	1841		
		Ceriodaphnia dubia	IC50	7 Days	2722		
		Selenastrum capricornutum	IC25	3 Days	1737		
		Selenastrum capricornutum	IC50	3 Days	2422		
$MgCl_2$ (80%) + IceBan (20%)	Premium	*Ceriodaphnia dubia*	LC50	2 Days	1530	18.6	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	644		
		Ceriodaphnia dubia	IC50	7 Days	1004		
		Selenastrum capricornutum	IC25	3 Days	1154		
		Selenastrum capricornutum	IC50	3 Days	4144		
NaCl (23%) + IceBan (20%)	Premium	*Ceriodaphnia dubia*	LC50	2 Days	2127	14.4	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	451		
		Ceriodaphnia dubia	IC50	7 Days	808		
		Selenastrum capricornutum	IC25	3 Days	1483		
		Selenastrum capricornutum	IC50	3 Days	4017		
$MgCl_2$ (50%) + IceBan (50%)	Premium	*Ceriodaphnia dubia*	LC50	2 Days	585	11.7	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	86		
		Ceriodaphnia dubia	IC50	7 Days	164		
		Selenastrum capricornutum	IC25	3 Days	298		
		Selenastrum capricornutum	IC50	3 Days	1090		
$CaCl_2$ (50%) + IceBan (50%)	America West	*Ceriodaphnia dubia*	LC50	2 Days	676	11.6	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	94		
		Ceriodaphnia dubia	IC50	7 Days	142		
		Selenastrum capricornutum	IC25	3 Days	556		
		Selenastrum capricornutum	IC50	3 Days	876		
K-Acetate	Cryotec	*Ceriodaphnia dubia*	LC50	2 Days	660	190,000 mg/L	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	158		
		Ceriodaphnia dubia	IC50	7 Days	240		
		Selenastrum capricornutum	IC25	3 Days	217		
		Selenastrum capricornutum	IC50	3 Days	318		
NaCl + Caliber (10%)	Minnesota Corn	*Ceriodaphnia dubia*	LC50	2 Days	3114	12.7	Insurance Corporation of British Columbia, July 2000, File 498-0954
		Ceriodaphnia dubia	IC25	7 Days	399		
		Ceriodaphnia dubia	IC50	7 Days	538		
		Selenastrum capricornutum	IC25	3 Days	1837		
		Selenastrum capricornutum	IC50	3 Days	2721		

Table 3. Testing conditions for *Ceriodaphnia dubia.*

1. Test type: Static renewal
2. Temperature (^oC): 25 ± 1 ^oC. Test temperatures must not deviate (i.e., maximum minus minimum temperature) by more than 3 ^oC during the test.
3. Light quality: Ambient laboratory illumination
4. Light intensity: 10-20 µE/m2/s, or 50-100 ft-c (ambient laboratory levels) (recommended)
5. Photoperiod: 16 h light, 8 h dark
6. Test chamber size: 30 mL
7. Test solution volume: 15 mL
8. Renewal of test solutions: Daily
9. Age of test organisms: Less than 24 h; and all released within a 8-h period
10. Number of neonates per test chamber: 1. Assigned using blocking by known parentage (Subsection 13.10.2.4)
11. Number of replicate test chambers per concentration: 10
12. Number of neonates per test concentration: 10
13. Feeding regime: Feed 0.1 mL each of YCT and algal suspension per test chamber daily
14. Cleaning: Use freshly cleaned glass beakers or new plastic cups daily
15. Aeration: None
16. Dilution water: Moderately hard synthetic water prepared using MILLIPORE MILLI-Q® or equivalent deionized water and reagent grade chemicals
17. Test duration: Until 60% or more of surviving control females have three broods (maximum test duration 7 days)
18. Endpoints: Survival and reproduction
19. Test acceptability criteria: 80% or greater survival of all control organisms and an average of 15 or more young per surviving female in the control solutions. 60% of surviving control females must produce three broods.

Table 4. Standardized testing conditions for fathead minnow.

1. Test type: Static renewal
2. Temperature (^{o}C): 25 ± 1 ^{o}C. Test temperatures must not deviate (i.e., maximum minus minimum temperature) by more than 3 ^{o}C during the test.
3. Light quality: Ambient laboratory illumination
4. Light intensity: 10-20 µE/m_2/s (50-100 ft-c)(ambient laboratory levels)
5. Photoperiod: 16 h light, 8 h darkness
6. Test chamber size: 250mL
7. Test solution volume: 200 mL
8. Renewal of test solutions: Daily
9. Age of test organisms: Newly hatched larvae less than 24 h old.
10. Number of larvae per test chamber: 10
11. Number of replicate chambers per concentration: 4
12. Number of larvae per concentration: 40
13. Source of food: Newly hatched *Artemia* nauplii (less than 24 h old)
14. Feeding regime: On days 0-6, feed 0.1 g newly hatched (less than 24-h old) brine shrimp nauplii three times daily at 4-h intervals or, as a minimum, 0.15 g twice daily at 6-h intervals (at thebeginning of the work day prior to renewal, and at the end of the work day following renewal). Sufficient nauplii are added to provide an excess.
15. Cleaning: Siphon daily, immediately before test solution renewal
16. Aeration: None.
17. Dilution water: Moderately hard synthetic water prepared using MILLIPORE MILLI-Q® or equivalent deionized water and reagent grade chemicals
18. Test duration: 7 days
19. Endpoints: Survival and growth (weight)
20. Test acceptability criteria: 80% or greater survival in controls; average dry weight per surviving organism in control chambers equals or exceeds 0.25 mg

Table 5. Standardized testing conditions for *Selenastrum capricornutum.*

1. Test type: Static non-renewal
2. Temperature (^oC): 25 ± 1 ^oC. Test temperatures must not deviate (i.e., maximum minus minimum temperature) by more than 3 ^oC during the test
3. Light quality: "Cool white" fluorescent lighting.
4. Light intensity: 86 ± 8.6 µE/m_2/s (400 ± 40 ft-c or 4306 lux).
5. Photoperiod: Continuous illumination.
6. Test chamber size: 125 mL or 250 mL.
7. Test solution volume: 50 mL or 100 $mL_{2.}$
8. Renewal of test solutions: None.
9. Age of test organisms: 4 to 7 days.
10. Initial cell density in test chambers: 10,000 cells/mL.
11. Number replicate chambers per concentration: 4
12. Shaking rate: 100 cpm continuous, or twice daily by hand
13. Aeration: None
14. Dilution water: Woods Hole Medium, synthetic water prepared using MILLIPORE MILLI-Q® or equivalent deionized water and reagent grade chemicals

Table 6. Formulation of moderately hard laboratory water and nutrient media and concentration of major ions in the diluent water used in the *Ceriodaphnia dubia* and fathead minnow tests (moderately hard laboratory water) and the *Selenastrum capricornutum* test (Woods Hole nutrient media).

Moderately Hard Laboratory Water

Chemical	Mass (g per 20 L)	Constituent Concentration (mg/L)						
		Mg	SO_4	Na	HCO_3	Ca	Cl	K
$MgSO_4$	1.2	12.1	47.9	0.0	0.0	0.0	0.0	0.0
$NaHCO_3$	1.92	0.0	0.0	26.3	69.7	0.0	0.0	0.0
KCl	0.08	0.0	0.0	0.0	0.0	0.0	1.9	2.1
$CaSO_4$*$2H_2O$	1.2	0.0	33.5	0.0	0.0	14.0	0.0	0.0
Na_2SeO_4	0.000048	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum		12.1	81.4	26.3	69.7	14.0	1.9	2.1

Woods Hole Nutrient Media

Nutrient Media	Constituent	g/L	Stock Nutrient Media Concentration (g/L)						
			Ca	NO_3	SO_4	Na	Cl	Mg	K
Media 1	$CaCl_2$	36.76	13.3	0	0	0	23.5	0	0
	$NaNO_3$	80.02	0	58.4	0	21.6	0	0	0
	$MgSO_4$*$7H_20$	36.97	0	0	14.4	0	0	3.6	0
	$NaHCO_3$	12.6	0	0	0	3.4	0	0	0.0
	K_2HPO_4	8.71	0	0	0	0	0	0	2.5
	Na_2SiO_3*$9H_20$	28.42	0	0	0	4.6	0	0	0
	Na_2EDTA	4.36	0	0	0	0.3	0	0	0
Media 2	$FeCl_2$*$6H_20$	3.15	0	0	0	0	1.0	0	0
Sum of Constituents (g/L) in Nutrient Media Stock			13.3	58.4	14.4	30.0	24.5	3.6	2.5
Concentration (mg/L) in 1 Liter of Diluent Water			13.3	58.4	14.4	30.0	25.4	3.6	2.5

(1) 1 mL of nutrient media #1 and 2 mL of nutrient media #2 are added to 1 L of distilled water to make up the growth media.

Table 7. Analytically determined concentrations of anions, cations, metals, nitrogenous and phosphorus-based compounds, chemical and biological oxygen demand, chlorine, and pH in deicing products and deicing product-brine mixtures. Concentrations are given for undiluted product or product-brine mixtures.

Constituent[(2)]	Units	Watershed Cl : Inhibitor + Salt (NaCl)	Beet 55: Inhibitor + Salt (NaCl)	Boost ($CaCl_2$)	Road Guard Plus ($CaCl_2$)	FreezGard CI Plus ($MgCl_2$)	Meltdown Apex ($MgCl_2$)	CF-7 (K-Acetate)	Apogee (Glycerol)
Alkalinity, total as $CaCO_3$	mg/L	640	4,000	1,280	2,400	4,200	1,840	174,000	4,000
Aluminum	mg/L	<0.64	1.6	8.2	0.82	<0.64	<0.64	<1.6	<1.6
Arsenic	mg/L	0.64	0.13	0.5	<0.24	2.8	0.8	<0.60	<0.24
Barium	mg/L	<0.14	<0.5	13.2	64	<0.14	<0.14	<0.36	<0.14
Biochemical Oxygen Demand (5-day)	mg/L	3,400	67,000	22,000	26,000	3,200	1,440	<1	520,000
Boron	mg/L	26	18	48	66	600	300	50	18.2
Cadmium	mg/L	<0.07	0.036	<0.07	<0.07	<0.07	<0.07	<0.18	<0.07
Calcium	mg/L	2.80	93	148,000	120,000	760	1,080	1.36	16.0
Chemical Oxygen Demand	mg/L	16,000	170,000	68,000	102,000	30,000	36,000	168,000	980,000
Chloride	mg/L	176,000	130,000	260,000	260,000	300,000	260,000	860	30,000
Chlorine (total residual)	mg/L	11[(3)]	12[(3)]	6800[(3)]	380[(3)]	<7[(3)]	<0.28[(3)]	<0.28[(3)]	0.36[(3)]
Chromium	mg/L	<0.150	0.072	<0.150	<0.150	<0.150	<0.150	<0.380	<0.150
Cobalt	mg/L	<0.060	0.240	0.110	0.058	0.088	<0.060	0.142	<0.060
Copper	mg/L	0.24	0.13	0.64	0.46	<0.01	<0.01	0.64	0.24
Cyanide, total	mg/L	0.186	0.100	0.116	0.116	<0.040	<0.040	<0.040	<0.040
Hardness, total as $CaCO_3$	mg/L	9	400	380,000	340,000	420,000	440,000	3	460
Magnesium	mg/L	0.6	50	4,000	11,400	96,000	108,000	<2.40	112
Nickel	mg/L	<0.20	0.88	<0.20	<0.20	<0.20	<0.20	<0.50	<0.20
Nitrate + Nitrite as N	mg/L	110	130	68	198	9.8	24	6.4	8.2
Nitrogen, total kjeldahl as N	mg/L	36	4600	6000	3800	800	360	<30	<30
Nitrogen, ammonia as N	mg/L	3.2	31	4600	780	30	26	1.44	0.4
Phosphate as P, Ortho	mg/L	1.14	6.6	18.2	<0.18	192	<0.36	380	480
Phosphorus as P, total	mg/L	2	33	78	16.6	186	<0.28	440	640
Potassium	mg/L	240	1,700	17,800	10,600	980	1,220	220,000	60
Sodium	mg/L	112,000	94,000	5,600	10,200	1,580	2,400	112	28,000
Specific Conductance, @ 25 ^{o}C	umhos/cm	360,000	300,000	400,000	360,000	320,000	360,000	480,000	116,000
Zinc	mg/L	<0.28	3.5	9.0	1.78	1.64	<0.28	<0.68	<0.28
pH[(1)]	s.u.	6.74	7.73	4.85	7.74	7.89	7.72	9.59	5.67

(1) Measured according to PNS methods. pH measured in a solution consisting of four parts deionized water and one part deicing product or salt brine-inhibitor mixture.

(2) All chemicals in this table are as undiluted salt brine-corroson ihibitor stock solutions. Solutions were submitted to the analytical laboratory as 20:1 dilutions except for Beet 55 which was a 10:1 dilution. Numers provided by the analytical laboratory were either multiplied by 20 or 10 to produce undiluted stock solution chemistry.

(3) Method detection limits were raised for total residual chlorine analysis because the analytical method is colorimetric and the product color made detection problematic. Results should be considered estimated.

Table 8. Dosing, chemistry, and toxicity testing results for Watershed CI (NaCl) from Rivertop Renewables.

Test Species	Dose	***Dosing*** Product Dose (g/L)	Product Dose (mL of Stock in 1 L)	***Basic Chemistry*** Na (mg/L)[3]	Cl (mg/L)	Specific Conductance (us/cm)	***Toxicity Testing Results*** Percent Survival or Mean # of Cells[1] 48 or 96 Hours	Percent Survival or Mean # of Cells[1] 7 Day	Chronic Endpoint[2] 7 Day
Fathead Minnow	Control	0	0	26	2	307	97.5	97.5	0.352
	Dose 1	0.5	0.4	70	71	465	92.5	90.0	0.458
	Dose 2	3.0	2.3	289	415	1419	90.0	52.5	0.346
	Dose 3	6.0	4.7	552	828	2570	95.0	90.0	0.354
	Dose 4	12.0	9.4	1078	1655	4620	97.5	95.0	0.351
	Dose 5	24.0	18.8	2130	3308	8510	77.5	70.0	0.316
	Dose 6	48.0	37.6	4234	6614	15920	0	0	0
	Dose 7	72.0	56.4	6338	9921	24200	0	0	0
	Dose 8	144	113	12650	19839	42600	0	0	0
Ceriodaphnia dubia	Control	0	0	26	2	306	100	100	17.9
	Dose 1	0.005	0.004	27	3	280	100	100	13.7
	Dose 2	0.10	0.078	35	16	314	100	90	14.2
	Dose 3	0.25	0.196	48	36	373	100	100	15.0
	Dose 4	0.50	0.391	70	71	458	100	100	15.9
	Dose 5	1.0	0.8	114	140	483	100	90	13.4
	Dose 6	3.0	2.3	289	415	1387	100	100	9.40
	Dose 7	12.0	9.4	1078	1655	1524	100	0	0
	Dose 8	24.0	18.8	2130	3308	6330	0	0	0
Selenastrum capricornutum	Control	0	0	30	25	519	3.99	---	---
	Dose 1	1.0	0.78	118	163	895	4.24	---	---
	Dose 2	2.0	1.57	205	301	1241	4.35	---	---
	Dose 3	3.0	2.35	293	439	1592	4.36	---	---
	Dose 4	4.0	3.13	381	576	1960	4.31	---	---
	Dose 5	6.0	4.70	556	852	2820	4.31	---	---
	Dose 6	10.0	7.83	907	1403	4240	4.51	---	---
	Dose 7	15.0	11.7	1345	2092	5950	4.21	---	---
	Dose 8	30.0	23.5	2660	4158	10960	0.678	---	---

(1) Endpoint is percent survival for fathead minnows and *Ceriodaphnia dubia* and mean number of cells (expressed as millions of cells or 10^6 cells).
(2) Chronic endpoint for fathead minnow is weight (mg) and for *Ceriodaphnia dubia* it is mean young production per adult female.

(3) Mass of sodium chloride was 20.61% in the inhibitor-salt brine mixture (e.g., 20.61 grams of NaCl in 100 grams of inhibitor-salt brine mixture). Prior to mixture with inhibitor, the salt brine was 23.5% NaCl by weight (e.g., 23.5 grams of NaCl in 76.5 grams water). A total of 42.5 mL of inhibitor was added to a salt brine with a final solution volume of 850 mL.

Stock Solution Characteristics

Density	Na (mg/L)	Cl (mg/L)
1.278	112000	176000

Table 9. Dosing, chemistry, and toxicity testing results for Beet 55 (NaCl) from Smith Fertilizer and Grain.

Test Species	Dose	***Dosing*** Product Dose (g/L)	***Dosing*** Product Dose (mL of Stock in 1 L)	***Chemistry*** Na (mg/L)[3]	***Chemistry*** Cl (mg/L)[3]	***Chemistry*** Specific Conductance (us/cm)	***Toxicity Testing Results*** Percent Survival or Mean # of Cells[1] 48 or 96 Hours	***Toxicity Testing Results*** Percent Survival or Mean # of Cells[1] 7 Day	***Toxicity Testing Results*** Chronic Endpoint[2] 7 Day
Fathead Minnow	Control	0	0	26	2	307	97.5	97.5	0.390
	Dose 1	0.050	0.040	30	7	305	100	100	0.445
	Dose 2	0.250	0.197	45	27	371	100	92.5	0.413
	Dose 3	0.500	0.393	63	53	446	97.5	97.5	0.403
	Dose 4	1.00	0.785	100	104	638	100	97.5	0.352
	Dose 5	2.00	1.57	174	206	978	92.5	92.5	0.298
	Dose 6	6.00	4.72	469	615	2340	0	0	0
	Dose 7	12.0	9.45	915	1230	4280	0	0	0
	Dose 8	24.0	18.9	1798	2452	8140	0	0	0
	Dose 9	48.0	37.7	3570	4903	14550	0	0	0
	Dose 10	72.0	56.6	5342	7353	22900	0	0	0
Ceriodaphnia dubia	Control	0	0	26	2	304	100	100	17.7
	Dose 1	0.0005	0.0005	26	2	285	100	100	17.5
	Dose 2	0.001	0.0010	26	2	282	100	100	16.6
	Dose 3	0.002	0.0015	26	2	281	100	90	15.4
	Dose 4	0.004	0.005	27	3	288	100	80	16.3
	Dose 5	0.010	0.010	27	3	291	100	90	15.7
	Dose 6	0.100	0.080	34	12	320	100	90	12.1
	Dose 7	1.00	0.800	101	106	344	100	50	1.20
	Dose 8	3.00	2.35	247	307	1137	100	40	0.05
	Dose 9	10.0	7.85	764	1022	2940	100	0	0
	Dose 10	25.0	19.7	1873	2556	6900	0	0	0
Selenastrum capricornutum	Control	0	0	30	25	538	3.35	---	---
	Dose 1	0.050	0.039	34	30	529	4.225	---	---
	Dose 2	0.100	0.079	37	36	551	4.675	---	---
	Dose 3	1.00	0.786	104	128	1164	5.538	---	---
	Dose 4	2.00	1.57	178	230	1210	6.706	---	---
	Dose 5	4.00	3.14	325	434	1787	7.069	---	---
	Dose 6	6.00	4.71	473	638	2530	2.95	---	---
	Dose 7	10.0	7.86	769	1047	3880	0.128	---	---
	Dose 8	15.0	11.8	1138	1558	5490	0.054	---	---
	Dose 9	30.0	23.6	2246	3090	990	0.011	---	---
	Dose 10	60.0	47.1	4462	6154	18260	0	---	---

(1) Endpoint is percent survival for fathead minnows and *Ceriodaphnia dubia* and mean number of cells (expressed as millions of cells or 10^6 cells) for *Selenastrum capricornutum* .

(2) Chronic endpoint for fathead minnow is weight (mg) and for *Ceriodaphnia dubia* it is mean young production per adult female.

(3) Mass of sodium chloride was 16.71% in the inhibitor-salt brine mixture (e.g., 16.71 grams of NaCl in 100 grams of inhibitor-salt brine mixture). Prior to mixture with inhibitor, the salt brine was 23.5% NaCl by weight (e.g., 23.5 grams of NaCl in 76.5 grams water). A total of 255 mL of inhibitor was added to a salt brine with a final solution volume of 850 mL giving a 30% (v/v) inhibitor concentration.

Stock Solution Characteristics

Density	Na (mg/L)	Cl (mg/L)
1.273	94,000	130,000

Table 10. Dosing, chemistry, and toxicity testing results for FreezGard CI Plus ($MgCl_2$) from North American Salt.

Test Species	Dosing			Chemistry			Toxicity Testing Results		
							Percent Survival or Mean # of Cells(1)		Chronic Endpoint(2)
	Dose	Product Dose (g/L)	Product Dose (mL of Stock in 1 L)	Mg (mg/L)	Cl (mg/L)	Specific Conductance (us/cm)	48 or 96 Hours	7 Day	7 Day
Fathead Minnow	Control	0	0	12	2	301	97.5	97.5	0.420
	Dose 1	0.03	0.023	14	9	307	97.5	95.0	0.458
	Dose 2	0.10	0.078	20	25	338	90.0	87.5	0.477
	Dose 3	0.30	0.233	34	72	460	92.5	92.5	0.476
	Dose 4	0.50	0.388	49	118	555	95.0	95.0	0.528
	Dose 5	1.0	0.775	87	234	925	87.5	87.5	0.434
	Dose 6	8.0	6.20	607	1862	5060	0	0	0
	Dose 7	40.0	31.0	2989	9304	19470	0	0	0
	Dose 8	100	77.5	7454	23258	40600	0	0	0
Ceriodaphnia dubia	Control	0	0	12	2	306	100	100	17.9
	Dose 1	0.050	0.039	16	14	312	100	100	10.8
	Dose 2	0.100	0.078	20	25	343	100	100	15.1
	Dose 3	0.150	0.116	23	37	332	100	100	12.4
	Dose 4	0.250	0.194	31	60	332	100	100	5.20
	Dose 5	0.500	0.388	49	118	436	100	90	1.70
	Dose 6	8.00	6.20	607	1862	1443	100	0	0
	Dose 7	40.0	31.0	2989	9304	12540	0	0	0
	Dose 8	100	77.5	7454	23258	22000	0	0	0
Selenastrum capricornutum	Control	0	0	4	25	519	3.99	---	---
	Dose 1	1.0	0.78	78	258	1090	3.49	---	---
	Dose 2	2.0	1.55	152	491	1683	2.68	---	---
	Dose 3	4.0	3.10	301	956	2870	2.00	---	---
	Dose 4	8.0	6.20	599	1886	5130	1.10	---	---
	Dose 5	20.0	15.5	1492	4677	11210	0.003	---	---

(1) Endpoint is percent survival for fathead minnows and *Ceriodaphnia dubia* and mean number of cells (expressed as millions of cells or 10^6 cells) for *Selenastrum capricornutum* .
(2) Chronic endpoint for fathead minnow is weight (mg) and for *Ceriodaphnia dubia* it is mean young production per adult female.

Stock Solution Characteristics

Density	Mg (mg/L)	Cl (mg/L)
1.290	96000	300000

Table 11. Dosing, chemistry, and toxicity testing results for Meltdown Apex ($MgCl_2$) by Envirotech Services, Inc.

Test Species	Dosing			Chemistry			Toxicity Testing Results		
	Dose	Product Dose (g/L)	Product Dose (mL of Stock in 1 L)	Mg (mg/L)	Cl (mg/L)	Specific Conductance (us/cm)	Percent Survival or Mean # of Cells(1) 48 or 96 Hours	Percent Survival or Mean # of Cells(1) 7 Day	Chronic Endpoint(2) 7 Day
Fathead Minnow	Control	0	0	12	2	301	97.5	97.5	0.420
	Dose 1	0.06	0.05	17	14	324	87.5	85	0.439
	Dose 2	0.20	0.16	29	42	423	90	80	0.486
	Dose 3	0.60	0.47	62	123	692	92.5	92.5	0.459
	Dose 4	1.00	0.78	96	203	872	97.5	95	0.439
	Dose 5	2.00	1.55	180	405	1420	77.5	70	0.497
	Dose 6	16.00	12.40	1352	3227	7570	0	0	0
	Dose 7	80.00	62.02	6710	16126	32700	0	0	0
	Dose 8	200.00	155.04	16756	40312	697000	0	0	0
Ceriodaphnia dubia	Control	0	0	12	2	306	100	100	17.9
	Dose 1	0.050	0.04	16	12	313	100	100	9.9
	Dose 2	0.100	0.08	20	22	341	100	100	3.0
	Dose 3	0.150	0.12	25	32	384	100	100	1.4
	Dose 4	0.250	0.19	33	52	456	100	100	10.6
	Dose 5	0.500	0.39	54	103	640	100	90	3.3
	Dose 6	8.000	6.20	682	1614	1863	60	0	0
	Dose 7	40.000	31.01	3361	8064	9050	0	0	0
	Dose 8	100.000	77.52	8384	20157	27100	0	0	0
Selenastrum capricornutum	Control	0	0	4	25	519	3.99	---	---
	Dose 1	1.0	0.78	87	227	1219	3.49	---	---
	Dose 2	2.0	1.55	171	429	1755	2.68	---	---
	Dose 3	4.0	3.10	339	832	3390	2.00	---	---
	Dose 4	8.0	6.20	673	1638	5530	1.10	---	---
	Dose 5	20.0	15.50	1678	4056	11990	0.003	---	---

(1) Endpoint is percent survival for fathead minnows and *Ceriodaphnia dubia* and mean number of cells (expressed as millions of cells or 10^6 cells) for *Selenastrum capricornutum* .

(2) Chronic endpoint for fathead minnow is weight (mg) and for *Ceriodaphnia dubia* it is mean young production per adult female.

Stock Solution Characteristics

Density	Mg (mg/L)	Cl (mg/L)
1.29	108000	260000

Table 12. Dosing, chemistry, and toxicity testing results for Road Guard Plus ($CaCl_2$) from Tiger Chemical.

Test Species	Dosing			Chemistry			Toxicity Testing Results		
							Percent Survival or Mean # of Cells(1)		Chronic Endpoint(2)
	Dose	Product Dose (g/L)	Product Dose (mL of Stock in 1 L)	Ca (mg/L)	Cl (mg/L)	Specific Conductance (us/cm)	48 or 96 Hours	7 Day	7 Day
Fathead Minnow	Control	0	0	14	2	307	97.5	97.5	0.352
	Dose 1	1.00	0.76	106	200	973	97.5	95.0	0.354
	Dose 2	2.00	1.53	197	399	1557	80.0	72.5	0.325
	Dose 3	3.00	2.29	289	597	220	35.0	22.5	0.196
	Dose 4	6.00	4.58	564	1193	3960	0	0	0
	Dose 5	9.00	6.87	838	1788	5690	0	0	0
	Dose 6	12.0	9.16	1113	2384	6360	0	0	0
Ceriodaphnia dubia	Control	0	0	14	2	306	100	100	17.9
	Dose 1	0.100	0.08	23	22	350	100	100	23.2
	Dose 2	0.250	0.19	37	52	432	100	100	23.9
	Dose 3	0.500	0.38	60	101	587	100	80	17.2
	Dose 4	1.50	1.15	151	300	1204	100	100	18.2
	Dose 5	6.00	4.58	564	1193	3540	100	100	2.50
	Dose 6	12.0	9.16	1113	2384	7180	0	0	0
	Dose 7	50.0	38.2	4594	9926	25400	0	0	0
Selenastrum capricornutum	Control	0	0	13	25	519	3.99	---	---
	Dose 1	1.00	0.76	105	224	1093	5.26	---	---
	Dose 2	2.00	1.53	196	422	1661	5.77	---	---
	Dose 3	4.00	3.05	380	819	3020	4.94	---	---
	Dose 4	6.00	4.58	563	1216	4170	0.80	---	---
	Dose 5	8.00	6.11	746	1613	4310	0.22	---	---
	Dose 6	12.0	9.16	1112	2407	7370	0.36	---	---

(1) Endpoint is percent survival for fathead minnows and *Ceriodaphnia dubia* and mean number of cells (expressed as millions of cells or 10^6 cells) for *Selenastrum capricornutum* .
(2) Chronic endpoint for fathead minnow is weight (mg) and for *Ceriodaphnia dubia* it is mean young production per adult female.

Stock Solution Characteristics

Density	Ca (mg/L)	Cl (mg/L)
1.31	120000	260000

Table 13. Dosing, chemistry, and toxicity testing results for Boost (CaCl2) from America West.

Test Species	Dose	Product Dose (g/L)	Product Dose (mL of Stock in 1 L)	Ca (mg/L)	Cl (mg/L)	Specific Conductance (us/cm)	Percent Survival or Mean # of Cells(1) 48 or 96 Hours	Percent Survival or Mean # of Cells(1) 7 Day	Chronic Endpoint(2) 7 Day
Fathead Minnow	Control	0	0	14	2	307	97.5	97.5	0.352
	Dose 1	1.00	0.76	127	200	952	97.5	80.0	0.404
	Dose 2	2.00	1.53	240	399	1607	97.5	82.5	0.328
	Dose 3	3.00	2.29	353	597	2270	90.0	77.5	0.263
	Dose 4	6.00	4.58	692	1193	4240	27.5	12.5	0.070
	Dose 5	9.00	6.87	1031	1788	5950	0	0	0
	Dose 6	12.0	9.16	1370	2384	7830	0	0	0
Ceriodaphnia dubia	Control	0	0	14	2	306	100	100	17.9
	Dose 1	0.100	0.08	25	22	338	100	90	20.7
	Dose 2	0.250	0.19	42	52	428	100	100	20.3
	Dose 3	0.500	0.38	70	101	594	100	100	18.9
	Dose 4	1.50	1.15	183	300	1255	100	80	13.1
	Dose 5	6.00	4.58	692	1193	3730	90	70	2.60
	Dose 6	12.0	9.16	1370	2384	7650	0	0	0
	Dose 7	50.0	38.2	5663	9926	26600	0	0	0
Selenastrum capricornutum	Control	0	0	13	25	519	3.99	---	---
	Dose 1	1.00	0.76	126	224	1158	4.69	---	---
	Dose 2	2.00	1.53	239	422	1755	4.36	---	---
	Dose 3	4.00	3.05	465	819	3180	3.37	---	---
	Dose 4	6.00	4.58	691	1216	4380	2.85	---	---
	Dose 5	8.00	6.11	917	1613	5680	0.64	---	---
	Dose 6	12.0	9.16	1369	2407	7060	0.37	---	---

(1) Endpoint is percent survival for fathead minnows and *Ceriodaphnia dubia* and mean number of cells (expressed as millions of cells or 10^6 cells) for *Selenastrum capricornutum* .

(2) Chronic endpoint for fathead minnow is weight (mg) and for *Ceriodaphnia dubia* it is mean young production per adult female.

Stock Solution Characteristics

Density	Ca (mg/L)	Cl (mg/L)
1.31	148000	260000

Table 14. Dosing, chemistry, and toxicity testing results for CF-7 (Potassium Acetate) from Cryotec.

Test Species	Dosing: Dose	Dosing: Product Dose (g/L)	Dosing: Product Dose (mL of Stock in 1 L)	Chemistry: K (mg/L)	Chemistry: Specific Conductance (us/cm)	Toxicity Testing Results: Percent Survival or Mean # of Cells[(1)] 48 or 96 Hours	Percent Survival or Mean # of Cells[(1)] 7 Day	Chronic Endpoint[(2)] 7 Day
Fathead Minnow	Control	0	0	2	307	97.5	97.5	0.352
	Dose 1	0.020	0.016	6	337	95	95	0.355
	Dose 2	0.050	0.039	11	301	87.5	80	0.389
	Dose 3	0.100	0.078	19	328	87.5	72.5	0.368
	Dose 4	0.200	0.156	36	373	95	87.5	0.335
	Dose 5	0.500	0.391	88	525	80	77.5	0.3830
	Dose 6	1.000	0.781	174	777	90	70	0.3465
	Dose 7	2.000	1.56	346	1218	70	12.5	0.2833
	Dose 8	4.000	3.13	690	2180	0	0	0.0000
Ceriodaphnia dubia	Control	0	0	2	306	100	100	17.9
	Dose 1	0.0025	0.002	3	275	100	100	11.6
	Dose 2	0.0075	0.006	3	281	100	90	5.1
	Dose 3	0.010	0.008	4	281	100	80	1.8
	Dose 4	0.050	0.039	11	301	100	80	2.8
	Dose 5	0.200	0.156	36	373	90	80	1.9
	Dose 6	0.500	0.391	88	526	100	70	4.1
	Dose 7	1.000	0.781	174	768	100	100	4.3
	Dose 8	2.000	1.56	346	1240	0	0	0
Selenastrum capricornutum	Control	0	0	3	519	3.985	---	---
	Dose 1	0.0025	0.0020	3	530	3.556	---	---
	Dose 2	0.0075	0.0059	4	507	3.425	---	---
	Dose 3	0.0100	0.0078	4	509	3.188	---	---
	Dose 4	0.0500	0.0391	11	524	2.669	---	---
	Dose 5	0.2000	0.1563	37	599	2.908	---	---
	Dose 6	0.5000	0.3906	88	746	2.249	---	---
	Dose 7	1.0000	0.7813	174	986	0.123	---	---
	Dose 8	2.0000	1.56	346	1449	0.020	---	---

(1) Endpoint is percent survival for fathead minnows and *Ceriodaphnia dubia* and mean number of cells (expressed as millions of cells or 10^6 cells) for *Selenastrum capricornutum* .

(2) Chronic endpoint for fathead minnow is weight (mg) and for *Ceriodaphnia dubia* it is mean young production per adult female.

Stock Solution Characteristics

Density	K (mg/L)	Cl (mg/L)
1.28	220,000	860

Table 15. Dosing, chemistry, and toxicity testing results for Apogee (Glycerol) by Envirotech.

Test Species	Dose	Product Dose (g/L)	Product Dose (mL of Stock in 1 L)	Specific Conductance (us/cm)	Percent Survival or Mean # of Cells[1] 48 or 96 Hours	Percent Survival or Mean # of Cells[1] 7 Day	Chronic Endpoint[2] 7 Day
Fathead Minnow	Control	0	0	301	97.5	97.5	0.420
	Dose 1	0.05	0.04	281	92.5	85.0	0.478
	Dose 2	0.25	0.20	302	100	27.5	0.343
	Dose 3	0.50	0.40	325	95.0	10.0	0.125
	Dose 4	1.00	0.80	383	92.5	2.50	0.050
	Dose 5	2.00	1.61	444	100	10.0	0.200
	Dose 6	4.00	3.21	588	95.0	10.0	0.083
	Dose 7	10.0	8.03	1086	90.0	5.00	0.050
	Dose 8	20.0	16.1	1843	90.0	7.50	0.058
Ceriodaphnia dubia	Control	0	0	306	100	100	17.9
	Dose 1	0.00050	0.00040	271	80	40	6.0
	Dose 2	0.0010	0.00080	274	100	100	14.8
	Dose 3	0.0020	0.0016	274	100	100	13.4
	Dose 4	0.0030	0.0024	278	100	80	9.7
	Dose 5	0.0040	0.0032	273	100	100	13.1
	Dose 6	0.0050	0.0040	276	100	100	8.3
	Dose 7	0.100	0.0803	286	90	90	10.1
	Dose 8	1.00	0.803	363	100	100	14.8
	Dose 9	3.00	2.41	565	100	90	1.5
	Dose 10	10.0	8.03	1285	100	80	0.0
Selenastrum capricornutum	Control	0	0	519	3.99	---	---
	Dose 1	0.0100	0.008	500	3.40	---	---
	Dose 2	0.0200	0.016	502	3.39	---	---
	Dose 3	0.0400	0.032	504	3.58	---	---
	Dose 4	0.0600	0.048	508	3.40	---	---
	Dose 5	0.0800	0.064	509	2.94	---	---
	Dose 6	0.100	0.080	507	2.81	---	---

(1) Endpoint is percent survival for fathead minnows and *Ceriodaphnia dubia* and mean number of cells (expressed as millions of cells or 10^6 cells) for *Selenastrum capricornutum* .

(2) Chronic endpoint for fathead minnow is weight (mg) and for *Ceriodaphnia dubia* it is mean young production per adult female.

Stock Solution Characteristics

Density	Biochemical Oxygen Demand (mg/L)
1.25	520,000

Table 16. Summary of acute and chronic toxicological endpoints expressed as grams of deicing product per liter of diluent. Tests conducted with the species *Ceriodaphnia dubia* .

Test Species: *Ceriodaphnia dubia*

Product	Supplier	Toxicological Endpoint as Product (grams product/liter of diluent)						
		Acute NOEC (survival)	Acute LC50 (survival)	Chronic NOEC (survival)	Chronic LC50 (survival)	Chronic NOEC (young production)	Chronic IC25 (young production)	Chronic IC50 (young production)
Watershed Cl: Inhibitor + Salt (NaCl)	Rivertop Renewables	12.0	17.0	3.00	4.81	1.00	0.990	3.43
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	10.0	15.8	0.100	0.580	0.010	0.071	0.368
FreezGard CI Plus ($MgCl_2$)	North American Salt	8.00	17.9	0.500	1.68	0.100	0.131	0.198
Meltdown Apex ($MgCl_2$)	Envirotec Services	0.500	7.45	0.500	1.68	<0.050	0.028	0.060
Road Guard Plus ($CaCl_2$)	Tiger Chemical	6.00	8.49	6.00	6.87	1.50	1.94	3.54
Boost ($CaCl_2$)	America West	6.00	7.89	1.50	4.99	1.50	1.22	2.91
CF-7 (K-Acetate)	Cryotec	1.00	1.29	1.00	0.53	<0.0025	0.0018	0.0045
Apogee (Glycerol)	Envirotec Services	>10.0	>10.0	>10.0	>10.0	1.00	0.0003	1.44
Reference Toxicant (NaCl-mg/L)		---					0.838	2.19

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.

LC50: Lethal concentration with 50 percent survival. Concentration at which there is 50 percent survival.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (reproduction) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (reproduction) compared to controls.

Table 17. Summary of acute and chronic toxicological endpoints expressed as grams of deicing product per liter of diluent. Tests conducted with the species fathead minnow.

Test Species: Fathead Minnow

Product	Supplier	Toxicological Endpoint as Product (grams product/liter of diluent)						
		Acute NOEC (survival)	Acute LC50 (survival)	Chronic NOEC (survival)	Chronic LC50 (survival)	Chronic NOEC (growth)	Chronic IC25 (growth)	Chronic IC50 (growth)
Watershed Cl : Inhibitor + Salt (NaCl)	Rivertop Renewables	12.0	29.5	12.0	27.9	24.0	24.9	32.6
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	2.00	3.24	2.00	3.04	1.00	1.71	3.19
FreezGard CI Plus ($MgCl_2$)	North American Salt	1.00	2.15	1.00	2.24	1.00	2.30	4.20
Meltdown Apex ($MgCl_2$)	Envirotec Services	1.00	4.22	1.00	3.69	2.00	5.50	9.00
Road Guard Plus ($CaCl_2$)	Tiger Chemical	2.00	2.70	1.00	2.39	2.00	2.46	3.30
Boost ($CaCl_2$)	America West	3.00	4.88	2.00	4.03	3.00	2.68	4.15
CF-7 (K-Acetate)	Cryotec	1.00	1.67	0.20	0.74	2.00	2.06	2.71
Apogee (Glycerol)	Envirotec Services	10	>20.0	0.050	0.140	0.250	0.258	0.386
Reference Toxicant (NaCl-g/L)		---					0.937	8.39

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.

LC50: Lethal concentration with 50 percent survival. Concentration at which there is 50 percent survival.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (growth) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (growth) compared to controls.

Table 18. Summary of acute and chronic toxicological endpoints expressed as grams of deicing product per liter of diluent. Tests conducted with the species *Selenastrum capricornutum* .

Test Species: *Selenastrum capricornutum*

Product	Supplier	Toxicological Endpoint as Product (grams product/liter of diluent)		
		NOEC (growth)	IC25 (growth)	IC50 (growth)
Watershed Cl : Inhibitor + Salt (NaCl)	Rivertop Renewables	15.0	19.2	23.8
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	6.00	5.14	6.45
FreezGard CI Plus ($MgCl_2$)	North American Salt	2.00	4.41	8.50
Meltdown Apex ($MgCl_2$)	Envirotec Services	1.00	1.62	4.03
Road Guard Plus ($CaCl_2$)	Tiger Chemical	4.00	4.57	5.18
Boost ($CaCl_2$)	America West	2.00	4.42	6.61
CF-7 (K-Acetate)	Cryotec	0.010	0.030	0.560
Apogee (Glycerol)	Envirotec Services	<0.1000	0.0778	>0.1000

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (growth) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (growth) compared to controls.

Table 19. Summary of acute and chronic toxicological endpoints expressed as milligrams of the primary deicing salt per liter of diluent. Tests conducted with the species *Ceriodaphnia dubia* .

Test Species: *Ceriodaphnia dubia*

Product	Supplier	Chemical Used for Endpoint Calculation	Stock Concentration (grams salt/liter of product)[2]	Toxicological Endpoint as Primary Salt (milligrams salt/liter of diluent)[1]						
				Acute NOEC (survival)	Acute LC50 (survival)	Chronic NOEC (survival)	Chronic LC50 (survival)	Chronic NOEC (young production)	Chronic IC25 (young production)	Chronic IC50 (young production)
Watershed Cl : Inhibitor + Salt (NaCl)	Rivertop Renewables	Na + Cl	288	2705	3826	676	1084	225	223	773
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	Na + Cl	224	1760	2782	17.6	102	1.76	12.4	64.8
FreezGard CI Plus ($MgCl_2$)	North American Salt	Mg + Cl	396	2456	5491	153	516	30.7	40.2	60.8
Meltdown Apex ($MgCl_2$)	Envirotech Services	Mg + Cl	368	142.6	2125	143	479	<14.30	7.99	17.0
Road Guard Plus ($CaCl_2$)	Tiger Chemical	Ca + Cl	380	1740	2461	1740	1993	435	562	1027
Boost ($CaCl_2$)	America West	Ca + Cl	408	1869	2456	467	1554	467	380	905
CF-7 (K-Acetate)	Cryotec	K	221	172.5	223	173	91.4	0.4314	0.311	0.776
Apogee (Glycerol)	Envirotech Services	not applicable								
Reference Toxicant (NaCl-mg/L)				1900	2190	>2000	>2000	500	838	2900

1. Toxicological endpoint as salt:

Endpoint as salt=(milligrams salt/liter of product)*(grams product/liter of diluent)*(liter of product/grams of product), where: (liter of product/grams of product)=1/product density and (grams product/liter of diluent) is the endpoint.

Product density was either provided on material safety data sheets or was measured for salt brine-inhibitor solutions prepared in the laboratory.

Endpoint can be NOEC, LC50, IC25,or IC50.

2. Sum of the primary cation and anion of the product (e.g., sum of sodium and chloride for Watershed Cl).

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.
LC50: Lethal concentration with 50 percent survival. Concentration at which there is 50 percent survival.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (reproduction) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (reproduction) compared to controls.

Table 20. Summary of acute and chronic toxicological endpoints expressed as grams of the primary deicing salt per liter of diluent. Tests conducted with the species fathead minnow.

Test Species: Fathead Minnow

Product	Supplier	Chemical Used for Endpoint Calculation	Stock Concentration (grams salt/liter of product)[2]	Toxicological Endpoint as Primary Salt (milligrams salt/liter of diluent)[1]						
				Acute NOEC (survival)	Acute LC50 (survival)	Chronic NOEC (survival)	Chronic LC50 (survival)	Chronic NOEC (growth)	Chronic IC25 (growth)	Chronic IC50 (growth)
Watershed Cl : Inhibitor + Salt (NaCl)	Rivertop Renewables	Na + Cl	288	2705	6659	2705	6285	5410	5613	7349
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	Na + Cl	224	352	570	352	535	176	302	562
FreezGard CI Plus ($MgCl_2$)	North American Salt	Mg + Cl	396	307	660	307	688	307	707	1290
Meltdown Apex ($MgCl_2$)	Envirotech Services	Mg + Cl	368	285	1204	285	1053	571	1569	2567
Road Guard Plus ($CaCl_2$)	Tiger Chemical	Ca + Cl	380	580	783	290	693	580	715	956
Boost ($CaCl_2$)	America West	Ca + Cl	408	934	1520	623	1255	934	836	1293
CF-7 (K-Acetate)	Cryotec	K	221	173	288	34.5	128	345	356	467
Apogee (Glycerol)	Envirotech Services	not applicable								
Reference Toxicant (KCl-mg/L)				---	---	800	1050	800	937	1030
Reference Toxicant (NaCl-mg/L)				7700	8290	---	---	---	---	---

1. Toxicological endpoint as salt:

Endpoint as salt=(milligrams salt/liter of product)*(grams product/liter of diluent)*(liter of product/grams of product), where: (liter of product/grams of product)=1/product density and (grams product/liter of diluent) is the endpoint.

Product density was either provided on material safety data sheets or was measured for salt brine-inhibitor solutions prepared in the laboratory.

Endpoint can be NOEC, LC50, IC25, IC50

2. Sum of the primary cation and anion of the product (e.g., sum of sodium and chloride for Watershed Cl).

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.

LC50: Lethal concentration with 50 percent survival. Concentration at which there is 50 percent survival.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (growth) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (growth) compared to controls.

Table 21. Summary of acute and chronic toxicological endpoints expressed as grams of the primary deicing salt per liter of diluent. Tests conducted with the species *Selenastrum capricornutum* .

Test Species: *Selenastrum capricornutum*

Product	Supplier	Chemical Used for Endpoint Calculation	Stock Concentration (grams salt/liter of product)[2]	Toxicological Endpoint as Primary Salt (milligrams salt/liter of diluent)[1]		
				NOEC (growth)	IC25 (growth)	IC50 (growth)
Watershed Cl : Inhibitor + Salt (NaCl)	Rivertop Renewables	Na + Cl	288	3381	4330	5357
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	Na + Cl	224	1056	904.2	1136
FreezGard CI Plus ($MgCl_2$)	North American Salt	Mg + Cl	396	614	1353	2609
Meltdown Apex ($MgCl_2$)	Envirotech Services	Mg + Cl	368	285.3	461.2	1151
Road Guard Plus ($CaCl_2$)	Tiger Chemical	Ca + Cl	380	1160	1326	1502
Boost ($CaCl_2$)	America West	Ca + Cl	408	622.9	1378	2060
CF-7 (K-Acetate)	Cryotec	K	221	1.73	5.16	96.7
Apogee (Glycerol)	Envirotech Services	not applicable				
Reference Toxicant (NaCl-Mg/L)				>1000	741	---

1. Toxicological endpoint as salt:

Endpoint as salt=(milligrams salt/liter of product)*(grams product/liter of diluent)*(liter of product/grams of product), where: (liter of product/grams of product)=1/product density and (grams product/liter of diluent) is the endpoint.

Product density was either provided on material safety data sheets or was measured for salt brine-inhibitor solutions prepared in the laboratory.

Endpoint can be NOEC, LC50, IC25, IC50

2. Sum of the primary cation and anion of the product (e.g., sum of sodium and chloride for Watershed Cl).

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (growth) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (growth) compared to controls.

Table 22. Summary of acute and chronic toxicological endpoints expressed as milliliters of deicing product per liter of diluent. Tests conducted with the species *Ceriodaphnia dubia* .

Test Species: *Ceriodaphnia dubia*

Product	Supplier	Toxicological Endpoint as Product (milliliters of product/liter of diluent)(1)						
		Acute NOEC (survival)	Acute LC50 (survival)	Chronic NOEC (survival)	Chronic LC50 (survival)	Chronic NOEC (young production)	Chronic IC25 (young production)	Chronic IC50 (young production)
Watershed Cl : Inhibitor + Salt (NaCl)	Rivertop Renewables	9.4	13.3	2.3	3.8	0.8	0.8	2.7
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	7.9	12.4	0.1	0.5	0.01	0.06	0.29
FreezGard CI Plus ($MgCl_2$)	North American Salt	6.2	13.9	0.4	1.3	0.1	0.1	0.2
Meltdown Apex ($MgCl_2$)	Envirotech Services	0.4	5.8	0.4	1.3	<0.039	0.022	0.046
Road Guard Plus ($CaCl_2$)	Tiger Chemical	4.6	6.5	4.6	5.2	1.1	1.5	2.7
Boost ($CaCl_2$)	America West	4.6	6.0	1.1	3.8	1.1	0.9	2.2
CF-7 (K-Acetate)	Cryotec	0.8	1.0	0.8	0.4	<0.0020	0.0014	0.0035
Apogee (Glycerol)	Envirotech Services	>8.03	>8.03	>8.03	>8.03	0.8032	0.0002	1.1586

(1)Endpoint as milliliters of product/liter of diluent= (endpoint as grams product/liter of diluent)*(1/density of product)

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.

LC50: Lethal concentration with 50 percent survival. Concentration at which there is 50 percent survival.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (reproduction) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (reproduction) compared to controls.

Table 23. Summary of acute and chronic toxicological endpoints expressed as milliliters of deicing product per liter of diluent. Tests conducted with the species fathead minnow.

Test Species: Fathead Minnow

Product	Supplier	Toxicological Endpoint as Product (milliliters of product/liter of diluent)(1)						
		Acute NOEC (survival)	Acute LC50 (survival)	Chronic NOEC (survival)	Chronic LC50 (survival)	Chronic NOEC (growth)	Chronic IC25 (growth)	Chronic IC50 (growth)
Watershed Cl : Inhibitor + Salt (NaCl)	Rivertop Renewables	9.4	23.1	9.4	21.8	18.8	19.5	25.5
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	1.6	2.5	1.6	2.4	0.8	1.3	2.5
FreezGard CI Plus ($MgCl_2$)	North American Salt	0.8	1.7	0.8	1.7	0.8	1.8	3.3
Meltdown Apex ($MgCl_2$)	Envirotech Services	0.8	3.3	0.8	2.9	1.6	4.3	7.0
Road Guard Plus ($CaCl_2$)	Tiger Chemical	1.5	2.1	0.8	1.8	1.5	1.9	2.5
Boost ($CaCl_2$)	America West	2.3	3.7	1.5	3.1	2.3	2.0	3.2
CF-7 (K-Acetate)	Cryotec	0.8	1.3	0.2	0.6	1.6	1.6	2.1
Apogee (Glycerol)	Envirotech Services	>16.1	>16.1	0.040	0.112	0.201	0.207	0.310

(1)Endpoint as miililiters of product/liter of diluent= (endpoint as grams product/liter of diluent)*(1/density of product)

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.

LC50: Lethal concentration with 50 percent survival. Concentration at which there is 50 percent survival.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (growth) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (growth) compared to controls.

Table 24. Summary of acute and chronic toxicological endpoints expressed as milliliters of deicing product per liter of diluent. Tests conducted with the species *Selenastrum capricornutum.*

Test Species: *Selenastrum capricornutum*

Product	Supplier	Toxicological Endpoint as Product (milliliters of product/liter of diluent)(1)		
		NOEC (growth)	IC25 (growth)	IC50 (growth)
Watershed Cl : Inhibitor + Salt (NaCl)	Rivertop Renewables	11.7	15.0	18.6
Beet 55: Inhibitor + Salt (NaCl)	Smith Fertilizer and Grain	4.71	4.04	5.07
FreezGard CI Plus ($MgCl_2$)	North American Salt	1.55	3.42	6.59
Meltdown Apex ($MgCl_2$)	Envirotech Services	0.78	1.25	3.13
Road Guard Plus ($CaCl_2$)	Tiger Chemical	3.05	3.49	3.95
Boost ($CaCl_2$)	America West	1.53	3.38	5.05
CF-7 (K-Acetate)	Cryotec	0.0078	0.0234	0.4377
Apogee (Glycerol)	Envirotech Services	<0.080	0.062	0.080

(1)Endpoint as miililiters of product/liter of diluent= (endpoint as grams product/liter of diluent)*(1/density of product)

NOEC: No observed effect concentration. Highest concentration at which there is no stastically significant toxicological effect compared to controls.

IC25: Inhibition concentration with 25 percent effect. Concentration at which there is a 25 percent reduction (growth) compared to controls.

IC50: Inhibition concentration with 50 percent effect. Concentration at which there is a 50 percent reduction (growth) compared to controls.

Table 25. Ranking of relative toxicological potential of seven deicing chemicals tested for acute and chronic toxicity. Ranking is based upon an aggregate measure of seven toxicity endpoints and three test species. Rank #1 is low relative toxicity potential while Rank #8 is high relative toxicity potential. Rankings are provided on a total product mass basis (a) and on the basis of mass of the major salt in product (b).

(a) Ranking by Total Product Mass

Product	Relative Toxicological Rank(1)
Watershed Cl: Inhibitor + Salt (NaCl)	1
Boost (CaCl2)	2
Road Guard Plus (CaCl2)	3
Beet 55: Inhibitor + Salt (NaCl)	4
FreezGard CI Plus (MgCl2)	5
Apogee (Glycerol)	6
Meltdown Apex (MgCl2)	7
CF-7 (K-Acetate)	8

(1) The ranking procedure was conducted as follows:

(a) Each product was given a rank from 1 through 8, based upon the value of the toxicological endpoint.

(b) The product with the largest endpoint (e.g., low toxicity) was given a #1 ranking and the products with smaller endpoints (e.g., high toxicity) were given sequentially higher rankings.

(c) If two or more products had the same toxicological endpoint value, then an average ranking (e.g., rank 4 and 5 for two products with identical endpoints would be given a value of 4.5) was applied to both products. The subsequent ranked product would be given a subsequent rank # just as if the two products did not have the same toxicological value (e.g., the product after the two 4.5 ranked products would be given rank #6).

(d) This procedure was conducted for all endpoints and all test species. Rankings were then summed for all of the endpoints and all of the test species to provide a Total Rank Number.

(e) The product with the smallest Total Rank Number was then given a Relative Toxicological Rank of 1, products with higher total rank numbers were given sequentially higher rankings.

(b) Ranking by Salt Mass

Product	Relative Toxicological Rank(1)
Watershed Cl (A1-NaCl)	1
Boost (CaCl2)	2
Road Guard Plus (CaCl2)	3
FreezGard CI Plus (MgCl2)	4
Meltdown Apex (MgCl2)	5
Beet 55 (Beet Juice-A3-NaCl): Inhibitor + Salt	6
CF-7 (K-Acetate)	7

(1) Ranking procedure is the same as described in Table a above except that only 7 products were evaluated as the Apogee product is a glycerol based product rather than a salt based product.

Table 26. Concentration of dissolved oxygen for test concentrations at or near the acute survival LC50 and the chronic survival IC50 for the three test species.

Product	C. dubia		Fathead Minnow		*Selenastrum Capricornutum*
	Dissolved Oxygen (mg/L)[(1)]				
	At Acute LC50	At Chronic IC50	At Acute LC50	At Chronic IC50	At IC50
Watershed Cl : Inhibitor + Salt (NaCl)	7.91	8.09	5.1	6.54	9.49
Beet 55: Inhibitor + Salt (NaCl)	4.26	7.69	1.70	6.24	9.64
FreezGard CI Plus ($MgCl_2$)	7.96	8.04	4.70	7.09	9.53
Meltdown Apex ($MgCl_2$)	8.07	8.19	7.20	7.38	8.14
Road Guard Plus ($CaCl_2$)	7.24	7.74	4.24	4.60	8.16
Boost ($CaCl_2$)	5.54	7.33	3.28	3.97	9.01
CF-7 (K-Acetate)	7.29	7.98	4.64	6.50	9.05
Apogee (Glycerol)	7.16	7.70	4.54	5.58	9.78

(1) The dissolved oxygen concentration was provided in the laboratory reports and identified as "old," meaning the test solution was 24 hours old prior to measurement. Dissolved oxygen reported in the table corresponds to the concentration closest to the reported LC50 and IC50. If an LC50 or IC50 was between two test concentrations, dissolved oxygen concentrations were averaged for the two reported test concentrations.

Figures

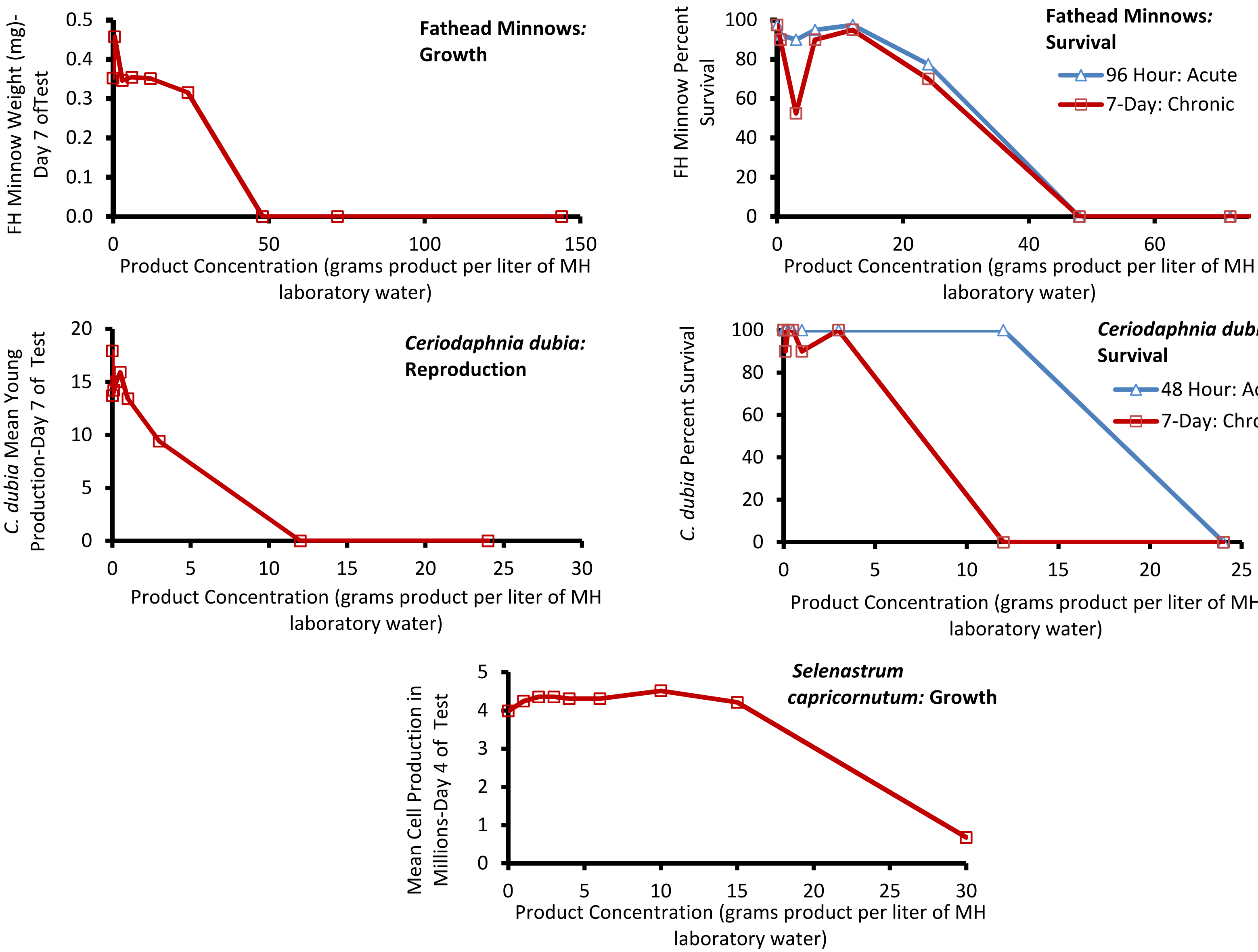

Figure 1. Results of chronic toxicity tests with deicing product Watershed Cl (NaCl) from Rivertop Renewables. Test species include fathead minnows, *Ceriodaphnia dubia* , and *Selenastrum capricornutum* . Chronic and acute data are shown for fathead minnows and *Ceriodaphnia dubia* . The *Selenastrum capricornutum* test is conducted for four days and has only one endpoint-number of cells.

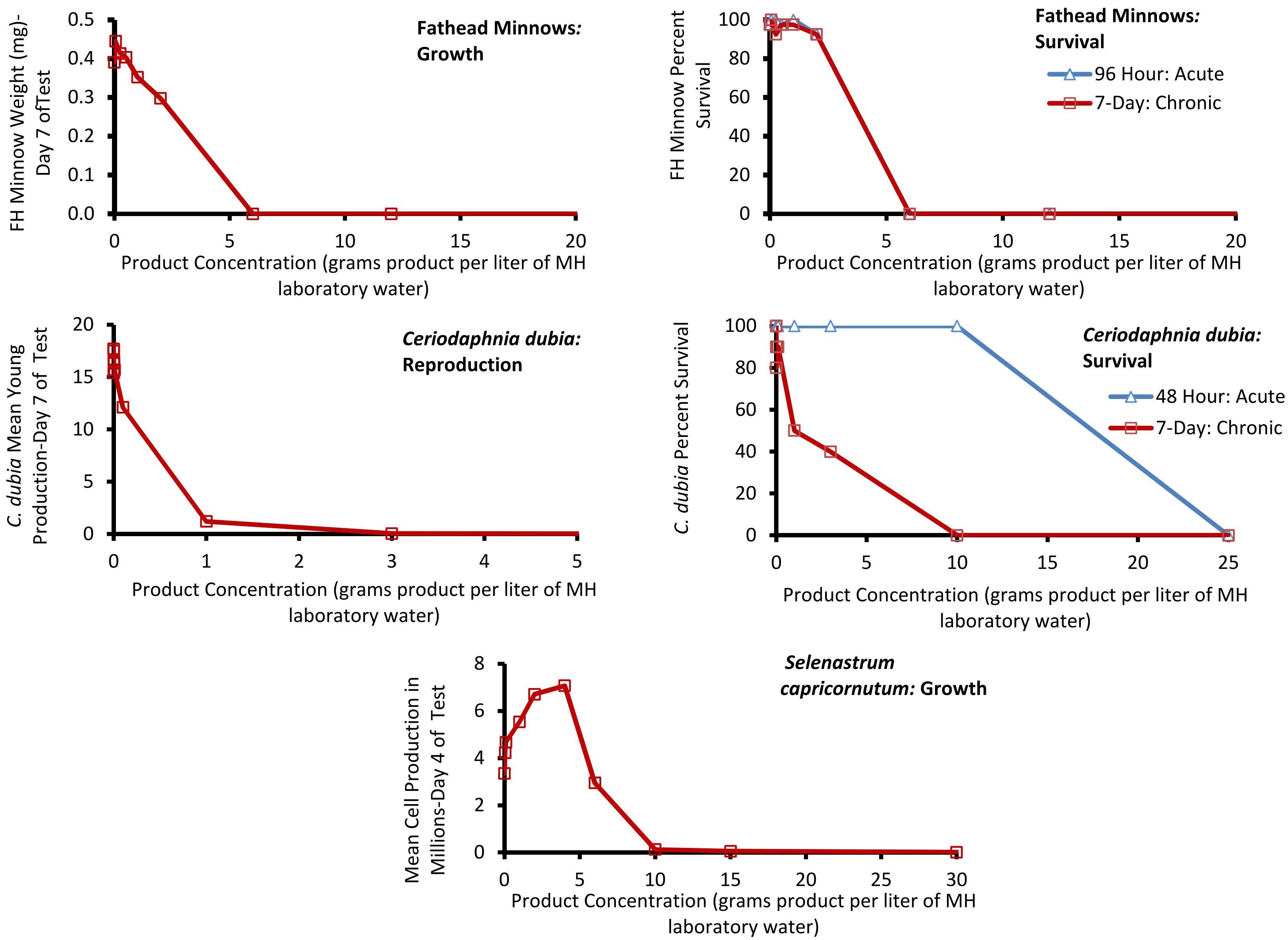

Figure 2. Results of chronic toxicity tests with deicing product Beet 55 (NaCl) from Smith Fertilizer and Grain. Test species include fathead minnows, *Ceriodaphnia dubia* , and *Selenastrum capricornutum* . Chronic and acute data are shown for fathead minnows and *Ceriodaphnia dubia* . The *Selenastrum capricornutum* test is conducted for four days and has only one endpoint-number of cells.

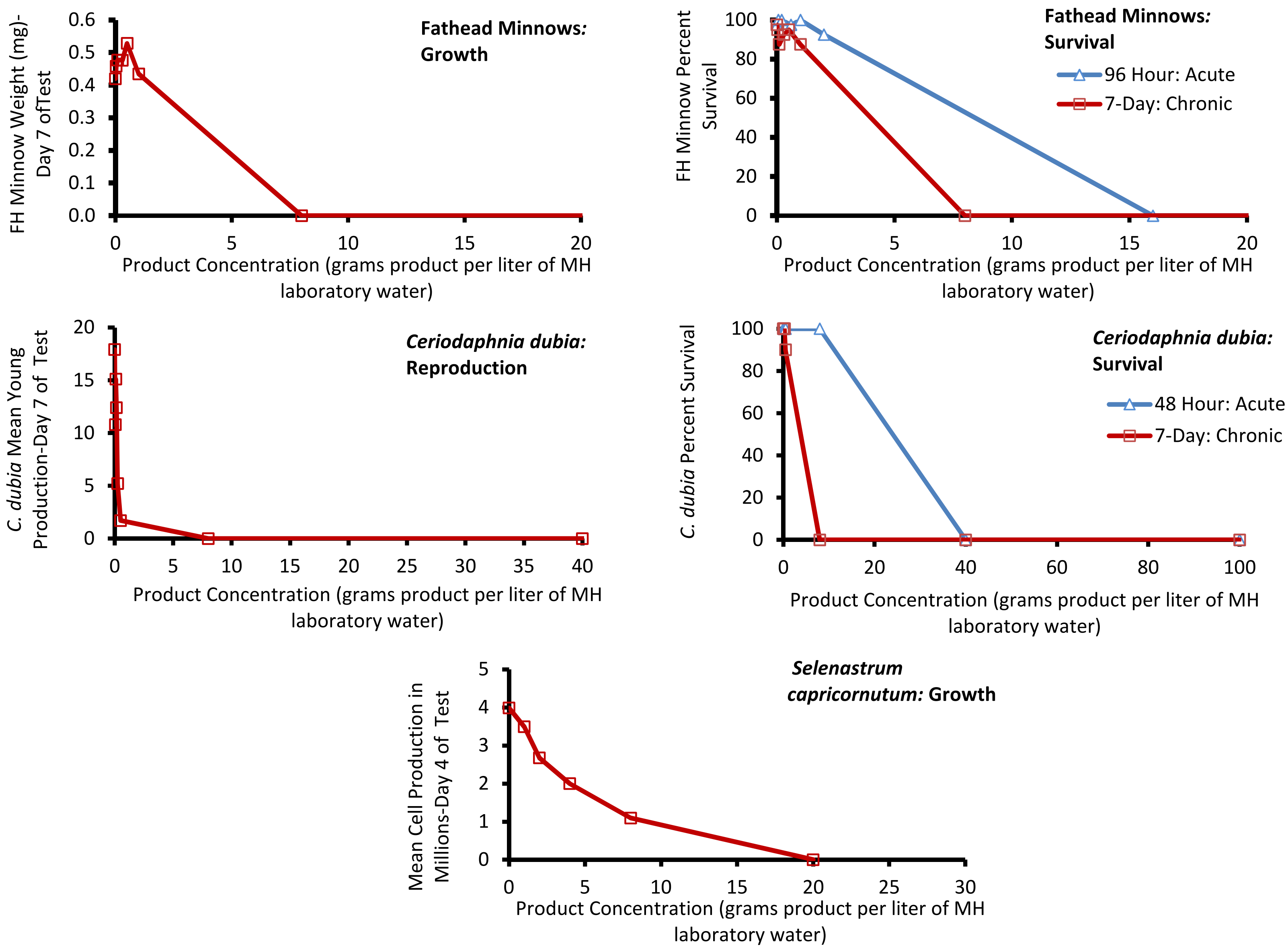

Figure 3. Results of chronic toxicity tests with deicing product FreezGard CI Plus ($MgCl_2$) from North American Salt. Test species include fathead minnows, *Ceriodaphnia dubia* , and *Selenastrum capricornutum* . Chronic and acute data are shown for fathead minnows and *Ceriodaphnia dubia* . The *Selenastrum capricornutum* test is conducted for four days and has only one endpoint-number of cells.

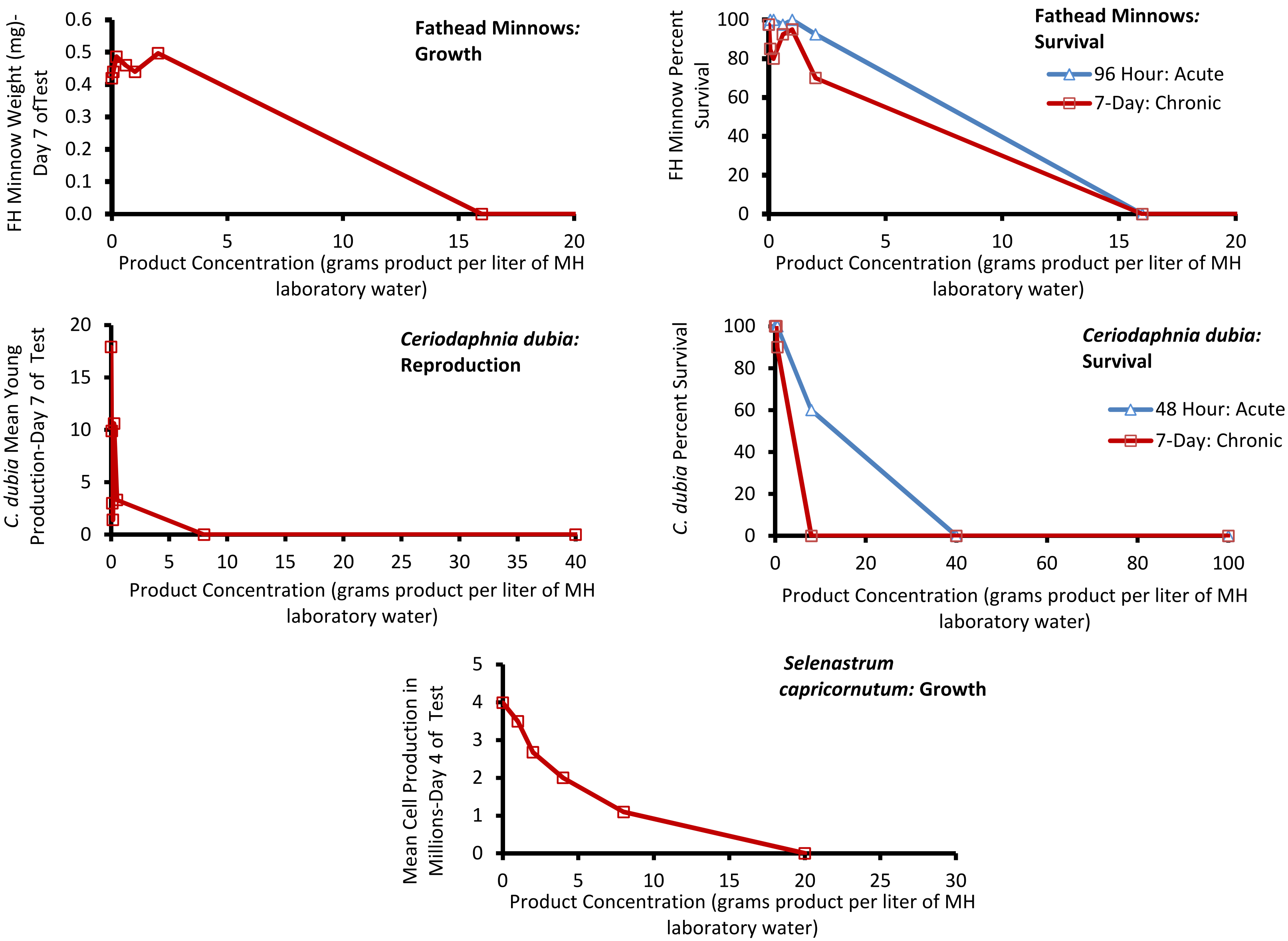

Figure 4. Results of chronic toxicity tests with deicing product Meltdown Apex ($MgCl_2$) by Envirotech Services, Inc. Test species include fathead minnows, *Ceriodaphnia dubia* , and *Selenastrum capricornutum* . Chronic and acute data are shown for fathead minnows and *Ceriodaphnia dubia* . The *Selenastrum capricornutum* test is conducted for four days and has only one endpoint-number of cells.

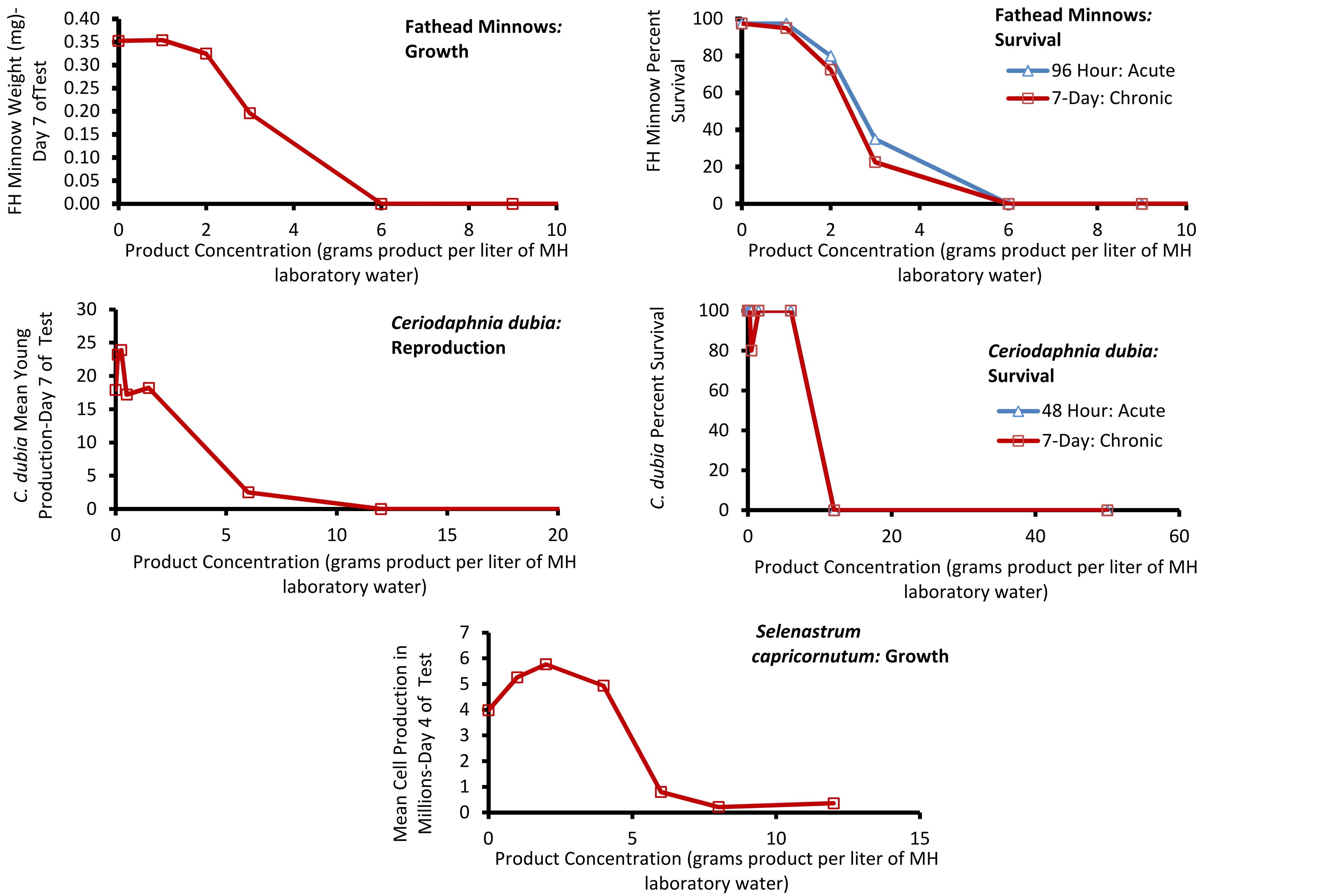

Figure 5. Results of chronic toxicity tests with deicing product Road Guard Plus ($CaCl_2$) from Tiger Chemical. Test species include fathead minnows, *Ceriodaphnia dubia*, and *Selenastrum capricornutum*. Chronic and acute data are shown for fathead minnows and *Ceriodaphnia dubia*. The *Selenastrum capricornutum* test is conducted for four days and has only one endpoint-number of cells.

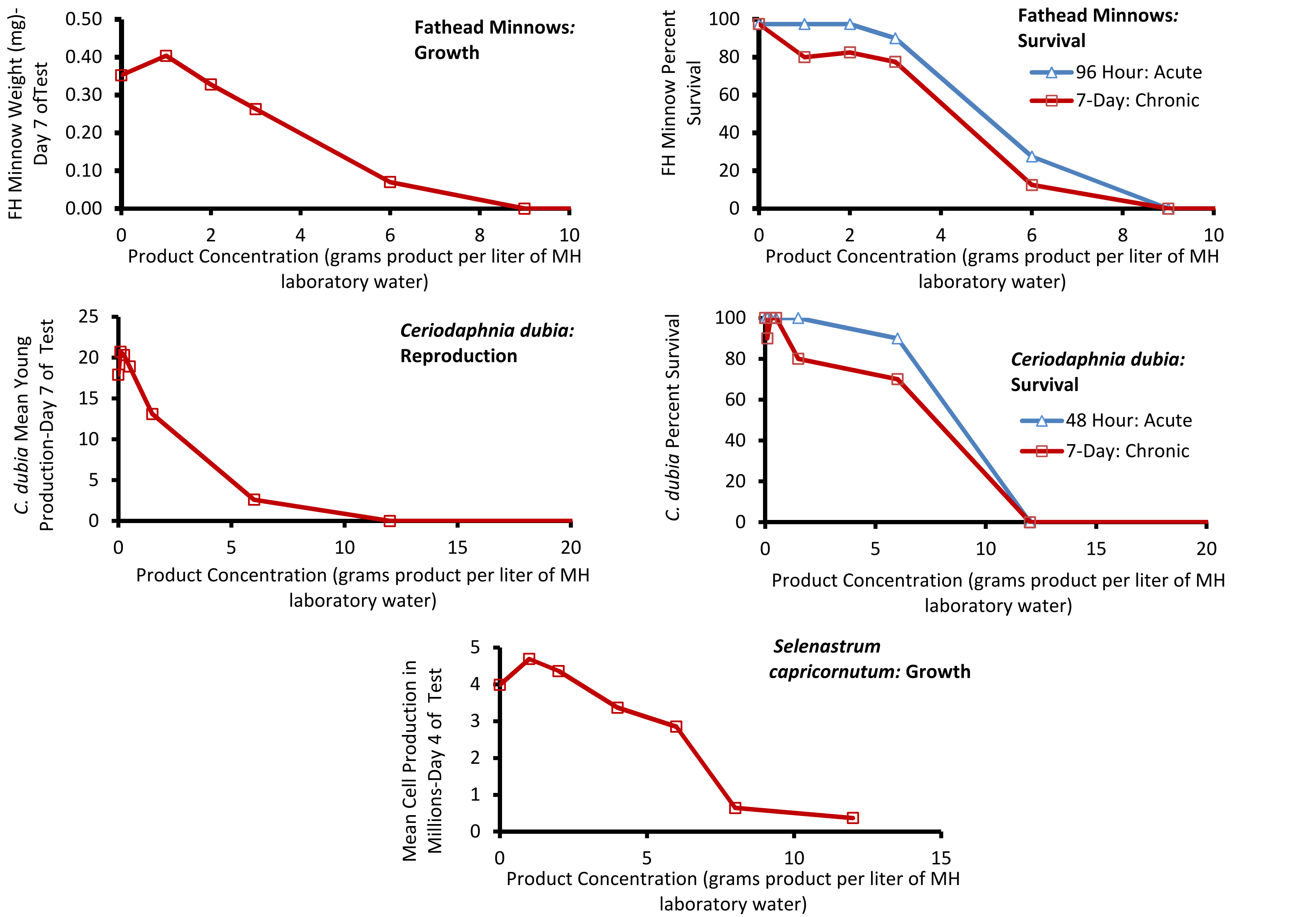

Figure 6. Results of chronic toxicity tests with deicing product Boost ($CaCl_2$) from America West. Test species include fathead minnows, *Ceriodaphnia dubia* , and *Selenastrum capricornutum* . Chronic and acute data are shown for fathead minnows and *Ceriodaphnia dubia* . The *Selenastrum capricornutum* test is conducted for four days and has only one endpoint-number of cells.

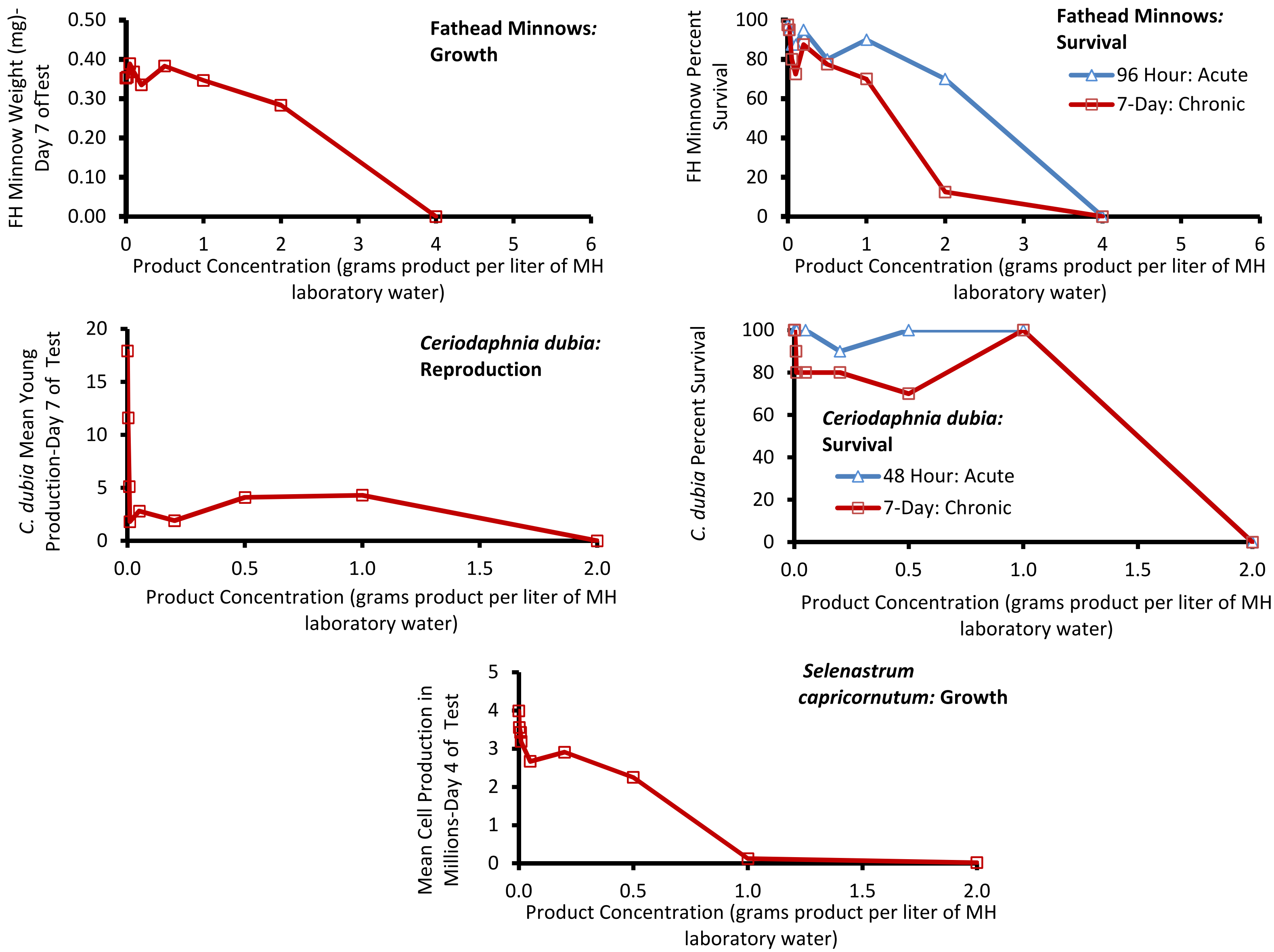

Figure 7. Results of chronic toxicity tests with deicing product CF-7 (Potassium Acetate) from Cryotec. Test species include fathead minnows, *Ceriodaphnia dubia* , and *Selenastrum capricornutum* . Chronic and acute data are shown for fathead minnows and *Ceriodaphnia dubia* . The *Selenastrum capricornutum* test is conducted for four days and has only one endpoint-number of cells.

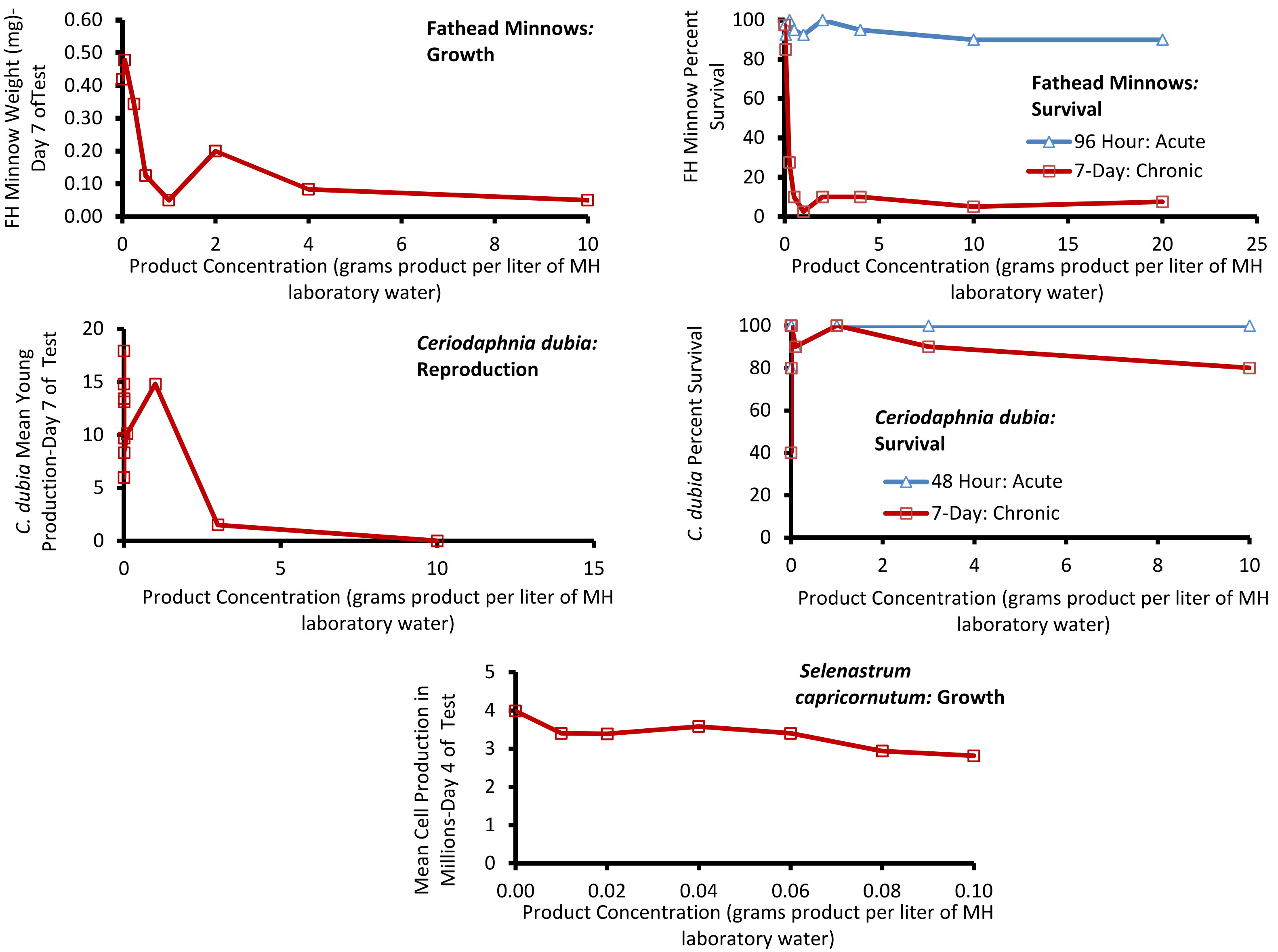

Figure 8. Results of chronic toxicity tests with deicing product Apogee (Glycerol) by Envirotech. Test species include fathead minnows, *Ceriodaphnia dubia* , and *Selenastrum capricornutum* . Chronic and acute data are shown for fathead minnows and *Ceriodaphnia dubia* . The *Selenastrum capricornutum* test is conducted for four days and has only one endpoint-number of cells.

CLEAR ROADS

research for winter highway maintenance

Lead state:
Minnesota Department of Transportation
Research Services & Library
395 John Ireland Blvd.
St. Paul, MN 55155