BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:		
PROPOSED AMENDMENTS TO:	)	
35 Ill. Adm. Code 302.102 and 302.208(g)	)	R18-
WATER QUALITY STANDARDS	)	
FOR CHLORIDES	)	

NOTICE OF FILING

TO: Don Brown
Clerk of the Board
Illinois Pollution Control Board
100 West Randolph Street, Suite 11-500
Chicago, Illinois 60601
(Via Electronic Mail)

(See Persons on Attached Service List)

PLEASE TAKE NOTICE that I have today filed with the Office of the Clerk of the Illinois Pollution Control Board the attached **PETITION TO AMEND 35 ILL. ADM. CODE 302.102 and 302.208(g) WATER QUALITY STANDARDS FOR CHLORIDES, INCLUDING PROPOSED RULE LANGUAGE, AND 200 SIGNATURES IN SUPPORT OF THIS PETITION,** copies of which are herewith served upon you.

Respectfully submitted,

Huff & Huff, Inc.

By: [signature]
Senior Consultant

Dated: May 21, 2018

James E. Huff, P.E.
HUFF & HUFF, INC.
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James.huff@gza.com
630-684-4444

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INTRODUCTION

This Petition is intended to present the body of available information on the toxicity of chlorides to aquatic species under winter-time temperatures experienced in Illinois streams. Based upon this information, much of it new data, alternative winter water quality standards are proposed for Illinois streams.

STATEMENT OF REASONS

The Illinois Pollution Control Board (Board), in R08-9 (Sub docket D) adopted water quality standards on the Chicago Area Waterways (CAWS) and the Lower Des Plaines River (LDPR), including for chlorides. With the exception of the Chicago Sanitary & Ship Canal (CSSC), the Board adopted a chloride water quality standard of 500 mg/L from May 1st through November 30th, and the same standard for the remainder of the year, effective three years after the effective date of those rules. The intent of the three-year delay was "to allow time for the work group to develop a proposal to address chloride and a water body wide variance." (Final Notice Opinion and Order of the Board, R80-9, p 32.)

The focus of the various work groups has been on developing and implementing Best Management Practices (BMPs) to reduce the application of highway de-icing salts, the principal cause of elevated chlorides during the winter (and spring) months in the receiving streams. Elevated chlorides are not unique to the CAWS and LDPR during the winter months; elevated chloride concentrations occur on all urban streams in Illinois. The General Use Water Quality Standard for chlorides, as found in 302.208(g), is 500 mg/L, identical to what the Board has adopted for the CAWS and LDPR, excluding the CSSC.

More efficient application of sodium chloride for highway de-icing is being implemented. However, as the 500 mg/L standard is a *not-to-exceed* standard, the question is: can BMPs achieve the necessary reduction under the worst storm events? For example, on the North Branch of the Chicago River, data from 2004 to 2014 reveal a maximum chloride concentration of 1,134 mg/L, necessitating a reduction of 55 percent in salt application during the worst events. (Huff, October 2015.) It is appropriate to question whether simply implementing BMPs can consistently achieve this type of reduction. For smaller streams, the required reductions can be even greater. For example, Hickory Creek at Vine Street reached 1,476 mg/L in 2014, necessitating a reduction of 66 percent in salt application during the worst storm events to achieve 500 mg/L. (Huff, Feb 2015.) Despite these elevated winter concentrations some of the impacted waterways still host aquatic communities who score at the upper end of the moderately impaired category of the state aquatic life scale. This observation supports the position that elevated winter concentrations are less destructive to aquatic communities than during elevated warm weather concentrations

While focusing on efficient utilization of de-icing salts is appropriate, there are concerns that implemented alone, BMPs will not achieve the target of 500 mg/L for these worst storm events. These concerns were the bases behind assembling a group of municipalities and sanitary districts, industries, The Salt Institute, a watershed group, and the Illinois Tollway to fund additional research on cold-temperature toxicity of chlorides. The results from these additional toxicity tests form the basis behind this Rulemaking request, as the findings show chlorides are less toxic at colder temperatures thereby justifying a relaxed chloride standard during the colder months. Illinois already utilizes a similar approach for ammonia for which there are less stringent winter standards, so there is precedent for such an approach. In addition, the Board adopted higher winter chloride standards for the CSSC in R08-9 (Subdocket D).

Given the current water quality violations, chlorides are identified as a cause of impairment for nearly all urban streams in Illinois. The ones not identified as impaired due to chlorides are likely due to the lack of sufficient monitoring. The impact of chlorides being identified as a cause of impairment is a serious impediment to future growth of any kind in the urban areas of Illinois. If increased pavement, housing, or parking lots are planned, then the required de-icing salts will need to be more than offset within the watershed. Finding these offsets is getting more difficult BMPs are being implemented and the offsets come at an additional cost. Alternatives to chloride de-icing are not technically feasible on a region-wide basis, when considering safety and mobility. This has been demonstrated by the Connecticut Department of Transportation, that for a seven-year period used a mixture of sand-salt (7:2) and compared the accidents to a seven-year period with just salt and found a 19 percent increase in nonfatal injuries and a 33 percent increase in accidents with the sand-salt mixture compared to just salt.[1] So while a reduction in salt usage is certainly an achievable goal, it is technically infeasible to reduce its use for de-icing practices sufficiently to consistently meet the 500 mg/L water quality standard.

Another consideration would simply shut down the highway system during snow events where there would be a potential to exceed the water quality standard. From the information generated in the Technical Support Document (Attachment 2), this would vary from an average one storm per year to over five storm events, and the duration of each shut down would for multiple days. Nationwide, a one- day shutdown of the snowbelt states would yield a loss of $2.6

[1] Mahoney, JU. D.S. Larsen, and E. Jackson. Reduction in nonfatal injury crashes after implementation of anti-icing technology. Transportation Research Record: *Journal of the Transportation Research Board,* No. 2613. Transportation Research Board of the National Academies, Washington, D.C., 2017, pp. 77-86. See Attachment 4

billion per day, and a loss of retail of $870 million per day.[2] Not only would this be economically unreasonable, the social impacts would not be acceptable to the citizens of Illinois.

I. History and background to the present proceeding

The 500 mg/L Illinois general use water quality standard for chloride was adopted by the Board in 1972 in R71-14, based on the testimony of a "recognized expert in fish biology," that 500 mg/L would be a safe limit. (Opinion of the Board, March 7, 1972.) This Illinois General Use Water Quality Standard has remained in effect for the past 45 years.

U.S. EPA in 1988 published the *Ambient Water Quality Criteria for Chloride-1988* (EPA 440/5-88-001, February 1988) that recommended a four-day limit of 230 mg/L and a one-hour average limit of 860 mg/L that should not be exceeded more than once every three years on the average.

However, nearly all of the toxicity data developed for chlorides have been generated at summer-type temperatures, and do not accurately reflect the toxicity of chlorides at winter temperatures. This proposal sets forth the findings of both a literature search and toxicity testing with the four most sensitive aquatic species (Fingernail clams, mayflies, Amphipod, and *C. dubia*) at 10°C. In addition, recognizing that if the Board is to entertain changes to the winter chloride water quality standard, it is appropriate to entertain changing the chloride water quality standard for the summer months as well.

A. Purpose and Effect of Regulatory Proposal

The Board's existing 500 mg/L General Use Standard for chlorides is exceeded in all urban streams during snow melt periods in Illinois. For the CAWS and LDPR, the winter 500 mg/L water quality limit goes into effect on December 1, 2019. Other urban watersheds are also working on seeking watershed variances from the 500 mg/L standard. As noted in the introduction, the compliance plans are centered around BMPs for de-icing practices. This is a sound and necessary approach that will reduce chloride concentrations in our waterways; however, it is not likely to consistently achieve the 500 mg/L standard in many of the urban streams.

This petition will demonstrate that the 500 mg/L chloride standard is not required to meet the applicable requirements for protection of aquatic species in Illinois streams during the winter months.

This work was undertaken to improve the understanding of chloride toxicity under winter temperatures. The results show that chlorides are less toxic at colder temperatures, and therefore higher water quality standards can be derived for the winter months, similar to the approach Illinois has taken with ammonia. If the proposed chloride water quality standards are

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[2] Benefit-Cost of Various Winter Maintenance Strategies, Project 99006/CR13-03, Western Transportation Institute, September 2015. See Attachment 5.

adopted, it is expected that many streams will be able to achieve the water quality standards through the implementation of BMPs.

Specifically, the proposed standard consists of the following amendments.

1. Remove Chloride from Section 302.208(g), Numeric Standards for Chemical Constituents, Single-Value Standards: Based on the difference in chloride toxicity at colder temperatures, it is appropriate to draft a new section to include both summer and winter chloride standards.

   g) Single-value standards apply at the following concentrations for these substances:

Constituent	Unit	Standard
~~Chloride (total)~~	~~mg/L~~	~~500~~

2. Add Section 302.214 Chlorides
   a. From May 1st to November 30th:
      i. an acute chloride standard of 860 mg/L shall not be exceeded more than once every three years on the average, except for those waters for which a zone of initial dilution (ZID) has been approved by the Agency pursuant to Section 302.102.
      ii. a chronic chloride standard of 230 mg/L shall not be exceeded more than once every three years by the arithmetic average of at least four consecutive samples collected over any period of four days, except for those waters for which a zone of initial dilution (ZID) has been approved by the Agency pursuant to Section 302.102.
   b. From December 1st to April 30th:
      i. an acute chloride standard of 1,010 mg/L shall not be exceeded more than once every three years on the average, except for those waters for which a zone of initial dilution (ZID) has been approved by the Agency pursuant to Section 302.102.
      ii. a chronic chloride standard of 640 mg/L shall not be exceeded more than once every three years by the arithmetic average of at least four consecutive samples collected over any period of four days. The samples used to demonstrate attainment or lack of attainment with a chloride standard must be collected in a manner that assures an average representative of the sampling period.

II. Technical Feasibility and Economic Justification

A. The Board and the Agency have always supported science-based standards, and this proposed regulatory rule change is consistent with this approach. New research, financially supported by the consortium that was assembled to examine the chloride standards, forms the basis for the proposed changes. This work was undertaken because the current chloride water quality standard is neither technically feasible to achieve nor ecologically or economically justified. The Agency has promoted a pathway forward of watershed variances, relying on Best Management Practices to achieve a 500 mg/L, while at the same time USEPA is promoting even more restrictive water quality standards. However, there was no testimony in the CAWS proceedings that achieving the 500 mg/L winter chloride standard was technically feasible, economically reasonable, or ecologically justified. Proceeding with the Agency's watershed approach will require the regulated community to continue striving to achieve an unachievable standard until someone comes up with an alternative approach, which is exactly what this proposal is intended to do.

B. The temperatures in the waters in Illinois are colder in the winter months. Yet, nearly all of the aquatic toxicity testing conducted prior to the testing contained in this Petition is at temperatures experienced during the summer months, with the majority of studies being conducted at what would be considered maximum temperatures experienced in Illinois streams. Many aquatic organisms are absent from the water column at colder temperatures, while others become dormant, so there is no growth or reproduction during the winter for many aquatic species. These facts were not taken into consideration when developing chronic chloride water quality criteria.

C. In summary, the expectation is that if the proposed winter water quality standards are adopted, the watershed approach based on implementing BMPs will become technically feasible and economically reasonable for many urban streams in Illinois as supported by the stream data presented in the Technical Support Document (Attachment 2). A summer chloride standard has also been proposed herein, based on the most recent ambient water quality criteria published by USEPA. No effort to determine if the summer proposed number is technically feasible or economically justified has been completed. The summer number was simply included so the proceedings could address chloride standards in their entirety.

D. There may well be a need for a spring standard as well, based on some intermediate temperature, such as 15°C; however, the science behind such a proposal is not currently available. Stormwater design practices currently employed include retention basins near the outfalls to streams. These basins accumulate salt over the winter, although the mechanism behind this accumulation is poorly understood. The result is through the spring months, a *tail* of elevated chlorides is released from these basins, and background chloride levels are not reached until near the beginning of summer, depending upon the winter application of salt and spring precipitation. In newer urban areas where these retention basins are commonly employed, it is unlikely that the streams will achieve the proposed summer water quality standard during the spring months, and this will need to be explored during the regulatory proceedings.

III. Facts in Support

Several Attachments are included herein to support the proposed changes. Attachment 1 is the USEPA 1988 publication, *Ambient Water Quality Criteria for Chloride-1988.* This document summarizes the state of toxicity data collected through 1988, and one will note that temperature was not considered in deriving the chloride criteria; rather, a review of the sources shows nearly all tests were conducted above 20°C (69°C). This document serves as the support for the proposed summer limits, without further discussion from the Petitioner.

Attachment 2 is a Technical Support Document prepared to support this petition. This document includes a summary of a literature review of colder temperature effects on chloride toxicity. As many chronic metrics (indicators) are either dormant or greatly retarded at colder temperatures, chronic effects are reduced from exposure to chlorides. For example, reproduction of *daphnia* at 10°C does not occur over a 96-hour test, independent of the chloride concentration. The same is true for other chronic indicators, such as weight gain, length change, etc. With the exception of the very large streams, de-icing chloride spikes tend to be short-term (less than 96 hours) episodic events. For the larger streams, recovery under the larger storm events can extend longer than 96 hours, but at declining concentrations over as long as eleven days.

Attachment 2 also includes Dr. David Soucek's report on the toxicity of three of the four most sensitive aquatic species (Fingernail clams, mayflies, and Amphipod) at 10°C. The findings indicate that chronic effects are not observed at 10°C over the standard duration of such tests (96-hour period of time). However, if the exposure is extended chronic effects can be observed, but at higher chloride concentrations of exposure. Similarly, the acute toxicity of chlorides is reduced at lower temperatures.

Also included in Attachment 2 are reports from New England Bioassay, a subsidiary of GZA, on *C. dubia,* the final of the four most sensitive aquatic species. Acute toxicity was found to occur at higher chloride concentrations at 10°C. Over the 96-hour chronic toxicity testing, no chronic effects were observed due to the lack of reproduction at 10°C over this time period.

Finally, the Illinois EPA provided temperature data for all Illinois streams for the time period December 1st through April 30th, from 2002 to 2016. The 75th percentile temperature for all gauging stations in Illinois for this five-month period is 9.3°C, below the 10°C of which the aquatic toxicity testing was completed. The 75th percentile approach is similar to the ammonia water quality standard approach, although in this case, the entire state database was used. The testing temperature utilized for these current studies can be considered conservative for representing winter stream temperatures in Illinois. Even if at some location the 75th percentile temperature is nominally above 10°C, this would not have a material effect on the toxicity results, and the conservative nature by which water quality standards are derived would assure the aquatic community would be protected.

The Board has adopted a 500 mg/L winter chloride water quality standard for the CAWS and provided a three-year period for the regulated community to either figure out how to comply or seek regulatory relief. For the remainder of the State waterways, the 500 mg/L chloride standard has been in effect since the early 1970's, and we are further from compliance during winter snow melt today than we were in the 1970's. (See Attachment 3, the Illinois State Water Survey 2012 Report on The Sources, Distribution, and Trends of Chloride in the Waters of Illinois, by Kelly, et al.)

At the encouragement of the Illinois EPA, most of the urban watersheds are working toward watershed variances, committing to Best Management Practices (BMP). This is laudable and should be encouraged. However, this approach will not achieve a *not-to-exceed* 500 mg/L standard under the worst winter storm events. With Region V USEPA pushing for an even more restrictive year-around chloride standard, the economic impact becomes unreasonable, as Illinois will have to regulate the amount of salt applied for every storm event, without regard to the need for salt for safety purposes. Clearly, there is a *technical impracticability* argument with achieving the current water quality chloride standard, which would be exacerbated with a more restrictive chloride standard. The current watershed variance approach will not result in resolving the existing winter chloride exceedances.

IV. Statutory Basis

A. Environmental Protection Act

Section 5(c) of the Act gives the Board "authority to act for the State in regard to the adoption of standards for submission to the United States under any federal law respecting environmental protection. Such standards shall be adopted in accordance with Title VII of the Act" 415 ILCS 5/5(c)(2006)."

In the provisions specific to protection of waters of the State, Section 13(a) of the Act provides that:

> The Board, pursuant to procedures prescribed in Title VII of this Act, may adopt regulations to promote the purposes and provisions of this Title. Without limiting the generality of this authority, such regulations may among other things prescribe: (1)

> Water quality standards specifying among other things, the maximum short-term and long-term concentrations of various contaminants in the waters, the minimum permissible concentrations of dissolved oxygen and other desirable matter in the waters, and the temperature of such waters.

415 ILCS 5/13(a)(2006).

Section 27(a) of the Act confers general substantive rulemaking authority upon the Board, and the contents of this regulatory proposal are clearly within these general rulemaking powers of the Board, as well as the specific powers outlined above. This proposal is being filed as a regulatory proposal of general applicability pursuant to Sections 27 and 28 of the Act. 415 ILCS 5/27 and 28 (2006). It is not being proposed as an identical-in-substance, fast-track, or federally required rulemaking. In addition, this proposal is being filed as a general (rather than emergency or peremptory) rulemaking pursuant to Section 5-40 of the Illinois Administrative Procedure Act. 5 ILCS 100/5-40. In evaluating these proposed rules, the Board is required to take into account "the existing physical conditions, the character of the area involved, including the character of surrounding land uses, zoning classifications, the nature of the existing air quality, or receiving body of water, as the case may be, and the technical feasibility and economic reasonableness of measuring or reducing the particular type of pollution." 415 ILCS 5/27(a)(2006).

B. Clean Water Act

Pursuant to the Federal Water Pollution Control Act (hereinafter "Clean Water Act" or "CWA"), it is the primary responsibility of the States to set water quality standards for intrastate waters and submit changes to those standards to U.S. EPA for approval. 33 U.S.C. §1313. Section 101(a)(2) of the CWA provides that "it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983." 33 U.S.C. §1251(a)(2).

Under the terminology used in the federal law, the phrase "water quality standards" includes both the establishment of designated uses for all intrastate waters, as well as the promulgation of criteria necessary to protect these uses. Whereas in Illinois law the term "water quality standards" is often used to refer only to the specific numeric or narrative criteria that have been adopted to protect the existing designated uses. The CWA describes this obligation by the States to set water quality standards as follows:

> Whenever the State revises or adopts a new standard, such revised or new standard shall be submitted to the Administrator. Such revised or new water quality standard shall consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses. Such standards shall be such as to protect the public health or welfare, enhance the quality of water and *serve the purpose of this [Clean Water] Act.* Such standards shall be established taking into consideration their use and value for public water supplies, propagation of fish and wildlife,

> recreational purposes, and agricultural, industrial, and other purposes, and also taking into consideration their use and value for navigation. (Emphasis added).

33 U.S.C. §1313(c)(2)(A).

C. Federal Regulations Applicable to Water Quality Standards proposals and Use Attainability Analyses

In the federal regulations, U.S. EPA defines the meaning of "serves the purposes of this [Clean Water] Act" in the above provision (CWA Section 303(c)(2)(A)) to mean:

> That water quality standards should, ***wherever attainable***, provide water quality for the protection and propagation of fish, shellfish and wildlife and for recreation in and on the water and take into consideration their use and value of public water supplies, propagation of fish, shellfish, and wildlife, recreation in and on the water, and agricultural, industrial, and other purposes including navigation. Such standards serve the dual purposes of establishing the water quality goals for a specific water body and serve as the regulatory basis for the establishment of water-quality-based treatment controls and strategies beyond the technology-based levels of treatment required by sections 301(b) and 306 of the [CWA]. (Emphasis added).

40 C.F.R. §131.2.

In 40 C.F.R. Part 131, U.S. EPA has established the requirements for federal approval of State water quality standards pursuant to Section 303(c) of the Clean Water Act. U.S. EPA has provided the six minimum requirements for State water quality standards submissions in 40 C.F.R. § 131.6. These six minimum elements are:

(a) Use designations consistent with the provisions of Sections 101(a)(2) and 303(c)(2) of the [Clean Water] Act.
(b) Methods used and analyses conducted to support water quality standards revisions.
(c) Water quality criteria sufficient to protect the designated uses.
(d) An antidegradation policy consistent with §131.12.
(e) Certification by the State Attorney General … that the water quality standards were duly adopted pursuant to State law.
(f) General information which will aid [U.S. EPA] in determining the adequacy of the scientific basis of the standards which do not include the uses specified in Section 101(a)(2) of the [Clean Water] Act as well as information on general policies applicable to State standards which may affect their application and implementation.

V. Public Participation and Consultation with IEPA and USEPA

The approach of developing winter chloride water quality standards has evolved over the past several years as watersheds have worked toward implementing Best Management Practices for de-icing activities and the need to file for watershed variances because of the exceedances in the current 500 mg/L standard. USEPA Region V has funded research on chloride toxicity on the more sensitive species that suggest to Region V that the 500 mg/L chloride standard is too liberal, at summer maximum temperatures. The chloride stakeholders are well aware of concern over de-icing practices, and the difficult task ahead in achieving even appropriate chloride water quality standards through BMPs.

Both the Illinois EPA and USEPA were approached about the possibility of conducting colder temperature toxicity testing, without success. Therefore, Huff & Huff, Inc. sent a letter to municipalities, counties, and industries, The Salt Institute, watershed groups, the Illinois Tollway, and the Illinois DOT, explaining the need to conduct colder temperature toxicity testing and requesting funding for that purpose. Interest was sufficient that Huff & Huff, Inc. undertook this work with the funding provided by the consortium. The work plan for the toxicity testing was also provided to both the Illinois EPA and USEPA, requesting any comments, in August 2016. Only a phone call from Scott Twait at the Illinois EPA was received, during which he commented that other temperatures besides 10^{o}C should be evaluated, but no funding from the Illinois EPA was available for such additional testing. It was pointed out to Mr. Twait that the USEPA has always pushed for seasonal limits (specific calendar months) rather than relying on specific temperatures to set water quality standards, and Mr. Twait offered no justification for testing toxicity at other temperatures.

As the toxicity testing has progressed, the consortium has been kept advised through written progress reports (9/8/2016, 3/14/2017 and 9/16/2017), and presentations of the findings have routinely been given at the various watershed meetings throughout northeast Illinois. In summary, the stakeholders have been not only aware of the on-going research, but many of them have financially supported the research. Presentations have been made on the research findings at both the DuPage River Salt Creek Workgroup and Hickory Creek Watershed Planning Group over the two years the research was being conducted.

VI. Synopsis to Testimony

During the Board’s proceedings in this matter, Huff & Huff, Inc. will present two witnesses. James Huff, P.E., Senior Consultant will summarize the winter temperature data, the toxicity testing research that was conducted, and the computation of the proposed winter chloride acute and chronic standards. Mr. Huff has 47 years of experience in the development and compliance strategies implementation of water quality standards. Roger Klocek, a biologist with Huff & Huff, also with 47 years of aquatic biology experience will also testify on the details of the aquatic toxicity testing.

It is expected that Dr. David Soucek from the Illinois Natural History Survey will also testify on behalf of the Illinois Tollway describing the toxicity testing his team completed at the colder temperatures.

It is also expected that Stephan McCracken from the DuPage River/Salt Creek Workgroup will testify in support of the winter standard based on the biological quality observed in their waterways when compared to the chloride concentrations observed. Mr. McCracken will also likely present data on the spring tail of chlorides observed in urban streams.

It is also expected that a number of entities from the consortium will also testify in support of the proposed winter standards.

Finally, it is hoped U.S. EPA will take a more active role in these proceedings and I would expect the Agency will also testify, but beyond a need for more research, their position is unknown.

VII. Conclusion

The current general use chloride water quality standard is unattainable in urban streams in Illinois during the winter months. Cold temperature toxicity testing of chlorides developed in support of this Petition has demonstrated that at colder temperatures chlorides are less toxicity to aquatic organisms. Based on these findings, a new winter chloride standard is proposed for General Use waters, derived using the USEPA protocol for developing water quality standards.

This Petition satisfies the requirements of Section 102.202 of the Board's rules because the Petition:

- Details the language of the proposed rule change;
- Presents the facts that support the proposal including the environmental, technical, and economic justification;
- Includes a statement of the purpose and effect of the proposal;
- Includes a synopsis of the expected testimony;
- Describes the results of the current knowledge on cold temperature toxicity of chlorides and the findings of the research associated with request;
- Demonstrated the proposed rule change is consistent with federal law.

WHEREFORE, Petitioner, Huff & Huff, Inc. respectfully requests that the Illinois Pollution Control Board adopt revised chloride water quality standards for the winter months, as proposed herein.

HUFF & HUFF, INC.

Dated: May 21, 2018

By: James E. Huff, P.E.

James E. Huff, P.E.
Huff & Huff, Inc., a Subsidiary of GZA, Inc.
915 Harger Road
Oak Brook, IL 60523
James.Huff@gza.com

CERTIFICATE OF SERVICE

I, James E. Huff, the undersigned, on oath state the following:
That I have served the attached **PETITION TO AMEND 35 ILL. ADM. CODE 302.102 and 302.208(g) WATER QUALITY STANDARDS FOR CHLORIDES,** via electronic mail upon:

Don Brown
Clerk of the Board
Illinois Pollution Control Board
100 W. Randolph Street, Suite 11-500
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That my email address is James.Huff@gza.com.

That the number of pages in the email transmission is _____.

That the email transmission took place before 5:00 p.m. on the date of May 21, 2018.

HUFF & HUFF, INC.

Dated: May 21, 2018

By: [signature]
James E. Huff, P.E.

AFFIDAVIT OF E-MAIL SERVICE

I, the undersigned, on oath [or affirmation] state the following:

That I have served the attached **Petition to Amend 35 Ill. Adm. Code 302.102 and 302.208(g) Water Quality Standards for Chlorides, including Proposed Rule Language, and 200 Signatures in Support of this Petition** by email upon Mr. Don Brown, Clerk of the Board, at Don.Brown@illinois.gov.

That my e-mail address is James.Huff@gza.com

That the number of pages in the e-mail transmission is _____.

That the e-mail transmission took place before 5:00 p.m. on the date of May 21, 2018.

James E. Huff

[Notary Seal]

SUBSCRIBED AND SWORN TO BEFORE ME this 21st day of May, 2018.

Notary Public

MAUREEN T WUNDERLICH
Official Seal
Notary Public - State of Illinois
My Commission Expires Oct 2, 2020

PETITION SIGNATURES

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:

PROPOSED AMENDMENTS TO:)
35 Ill. Adm. Code 302.102 and 302.208(g)) R18-
WATER QUALITY STANDARDS)
FOR CHLORIDES)

PETITION IN SUPPORT OF PROPOSED AMENDMENTS TO THE CHLORIDE WATER QUALITY STANDARDS

The undersigned, recognizing the need for science based winter chloride water quality standards, support this petition for regulatory hearings on this matter and join as co-signatories of the petition.

	Name	Address	Signature
1.	JOSEPH E. BRGNIG	839 NEW BRITTON, CAROL STREAM, IL	[signature]
2.	James Knudsen	2917 Kelly Drive, Elgin, IL	[signature]
3.	Gregory Ulreich	1931 Ridgemore Dr., Bartlett, IL	[signature]
4.	Adam Frederick	1412 Pinetree Dr. Naperville IL	[signature]
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	Name	Address	Signature
1.	Ted Gray	P.O Box 473, Western Springs IL 60558	[signature]
2.	Jessi DeMartini	703 Cleveland Ave Batavia Il 60510	Jessi DeMartini
3.	John Kawka	610 Farnham Ln Wheaton IL 60187	[signature]
4.	[illegible]	2840 Walnut Manor Ct Crystal Lake 60012	[signature]
5.	Dennis Streicher	25154 Sheffield Rd. Glen Ellyn, IL	[signature]
6.	Nick Menninga	305 Wesley Ave, Oak Park 60302	[signature]
7.	Joanna Dochaluk	2S4W609 Patricia Ct, Naperville 60540	[signature]
8.	Lawrence C. Cox	1620 Tulane Dr. Naperville IL 60565	Lawrence C. Cox
9.	ERIC OTTO	1152 CLARENCE AVE., OAK PARK, IL 60304	[signature]
10.	Chris Reynolds	1633 Amy Ave Glendale Hts IL 60139	[signature]
11.	Rick Federighi	1840 Amelia Ln Addison, IL 60101	[signature]
12.	Garett Guthrie	299 Glen Elkin Rd. Bloomingdale, IL 60108	[signature]
13.	Jedd Anderson	721 Buttonwood Cir Naperville 60540	[signature]
14.	Robert Swanson	1745 N. Hermitage Ave Unit C, Chicago IL 60622	[signature]
15.	J. Paul Georgiou	1503 Center Avenue, Wheaton, IL 60189	[signature]
16.	Thomas Minor IV.	10325 67th Ct Tinley Park IL 60477	[signature]
17.	Jason Elias	650 N. Lombard Ave Lombard IL 60148	[signature]
18.	Dennis Haile	1466 Waterside dr DeKalb IL 60115	[signature]
19.	Danette Stout	215 Deerpath Dr Oswego 60543	Danette Stout
20.	Kristine Hocking	4936 Montgomery Ave, Downers Grove IL	[signature]
21.	Simon Christensen	101 S 13th St St. Charles IL	[signature]
22.	Seema Wadia	1804 N Washington, Wheaton IL 60187	[signature]
23.	Scott Soeke	520 N. Edgewood, LaGrange Pk 60526	[signature]
24.	Jessica Bryant	262 Sheffield Dr., Schaumburg, IL 60194	[signature]
25.	Jim Listwan	1601 S. 10th Ave Maywood IL 60153	[signature]
26.	Karen Clementi	5 Westleigh Ct., Montgomery IL 60538	Karen Clementi
27.	ROB Covey	2916 Kelly Dr, Elgin, IL 60124	Robert Covey

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	Name	Address	Signature
28.	RAY FANO	400 S. EAGLE ST. NAPERVILLE IL	[signature]
29.	Julie Lomax	5101 Walnut, Downers Grove IL	[signature]
30.	Amy Ries	4511 Oak Ave Brookfield IL 60513	[signature]
31.	DAN ROSENWINKEL	1015 E. WASHINGTON LOMBARD 60148	[signature]
32.	Keith Buell	52 Wheeler Rd Sugar Grove, IL	[signature]
33.	Mary Bressel	PO BOX 603 Downers Grove, IL	[signature]
34.	[illegible] Swayne	2057 Creekside, Wheaton IL	[signature]
35.	Stephen McCaslen	8361 Dolfor Cove Burr Ridge IL	[signature]
36.	NANCY CINATL	536 Wakeman Wheaton IL	[signature]
37.	DAVID GORMAN	5401 S. FAIRVIEW DOWNERS GROVE IL	[signature]
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Received, Clerk's Office 5/21/2018 ** R2018-032**

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:

PROPOSED AMENDMENTS TO:	)	
35 Ill. Adm. Code 302.102 and 302.208(g)	)	R18-
WATER QUALITY STANDARDS	)	
FOR CHLORIDES	)	

PETITION IN SUPPORT OF PROPOSED AMENDMENTS TO THE CHLORIDE WATER QUALITY STANDARDS

The undersigned, recognizing the need for science based winter chloride water quality standards, support this petition for regulatory hearings on this matter and join as co-signatories of the petition.

	Name	Address	Signature
1.	Philip J. Modaff	4410 Hatch Lane, Lisle, IL 60532	[illegible]
2.	Ron Turner	1711 Cascade ridge Dr. Plainfield	[illegible]
3.	Tim Davenport	1654 Amy Ave, Glendale Heights	[illegible]
4.	Brendan Bowers	585 Hobart dr. South Elgin	[illegible]
5.	James Dillon	562 Apache Lane, Carol Stream	[illegible]
6.	Frank Minniti	516 15th Ct. St. Charles	[illegible]
7.	Josh Larson	316 El Paso lane, Carol Stream	[illegible]
8.	Brian Evans	2859 Adam Ave Montgomery, Il	[illegible]
9.	ANTHONY FREELAND	535 S 10TH STREET, DEKALB IL.	[illegible]
10.	JASON PAULING	862 S. FAIRFIELD AVE ELMHURST, IL	[illegible]
11.	Jose A Cuevas	847 Sesi Ln West Chicago	[illegible]
12.	Saeid Barghi	333 Cherrywood Ct Vernon Hills, IL 60061	[illegible]
13.	RON ROEHN	37 William Ln Sandwich Ill 60548	[illegible]
14.	Michele Lopez	1450 Golfview Dr. Glendale Ht, Il 60139	[illegible]
15.	Laura Imburgia	3000333 Wiant Rd, West Chgo, IL 60185	Laura Imburgia
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	Name	Address	Signature
1.	Robert Vanlbyseghem	256 Pleasant Plains Dr. St. Charles	[signature]
2.	RICHARD BABICA	826 W COUNTRY DR BARTLETT	[signature]
3.	Tracey Roiniotis	2836 Weaver Lane Batavia IL	[signature]
4.	Nathan Landers	97 Old Post Rd Oswego	[signature]
5.	KIRK Nelson	1242 Hillsboro Dr. Batavia IL	[signature]
6.	HAL WRIGHT	45008 Thornapple Tree Rd Sugar Grove IL	[signature]
7.	BRIAN SCHIBER	158 EDGEWATER, SUGAR GROVE, IL	[signature]
8.	James Childress	43W050 Seavey Rd Sugar Grove, IL	[signature]
9.	Jennifer Hilkemann	1108 Western Ave, Geneva IL	[signature]
10.	DAVE MORRIS	765 FABYAN PARKWAY GENEVA	[signature]
11.	Diane Krupa	310 Southampton Dr. Geneva IL	[signature]
12.	JEREMY LaVELLE	315 HARMONY DR N. AURORA IL	[signature]
13.	Jacob Huggins	44W677 Scott Rd Sugar Grove IL	[signature]
14.	Nick Alford	5 Brandwine Ct. South Elgin IL	[signature]
15.	Mike Glock	322 John St North Aurora, IL	[signature]
16.	John Young	1334 Prairie St Aurora IL	[signature]
17.	DAVID AREVALO	1090 CASCADE DR AURORA IL	[signature]
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	Name	Address	Signature
1.	Dan Gancarz	1623 E Peachtree Dr. Arlington Hts IL	[signature]
2.	Jordan Kim	908 S. Chatham Ave. Elmhurst, IL 60126	[signature]
3.	Anthony Aladham	1 St. Moritz Ct, Elmhurst, IL 60126	[signature]
4.	William Doyle	11147 S. Artesian Chgo IL 60655	[signature]
5.	Brett Bilina	300 W. 60th St Apt A307, Westmont, IL	[signature]
6.	John Szabo	1311 S. 12th St St Charles, IL	[signature]
7.	Adam Lintner	11915 Duchess Ave, Mokena IL 60448	[signature]
8.	Clarita R. Lao	917 Brecker Ct, Bensenville, IL 60106	[signature]
9.	Paul Kovacs	1123 Book Rd. Naperville IL 60540	[signature]
10.	Greg Stuker	432 Spruce Dr. Naperville IL 60540	[signature]
11.	Cynthia M Williams	1112 W Fray St, Chicago, IL 60642	[signature]
12.	Adam Reinke	308 W. Elm St. Wheaton, IL 60189	[signature]
13.	Nicholas Lange	440 S Cathrine ave, lagrange, IL 60525	[signature]
14.	Dave M Callan	336 S Dee-brookside Ln Arlington Hts 60004	[signature]
15.	Kara Olson	627 Yosemite Ave #308 Naperville IL 60563	[signature]
16.	Carlos Tibbs	18615 Amlin Circle, Country Club Hills IL 60478	[signature]
17.	Michael Brink	10265 Kent St Westchester IL 60154	[signature]
18.	Laura Thompson	2553 N 46th Rd Somonauk, IL 60552	[signature]
19.	Casandra Herron	15416 W. 8th St, Chgo IL 60620	[signature]
20.	Ed Flores	100 Frankel W., New Lenox IL	[signature]
21.	Derek Stancell	6533 Taylor Woodridge IL	[signature]
22.	Wayde Tober	16638 Saddlewood Lockport IL	[signature]
23.	Darrion Johnson	1959 Tone Lane Aurora IL	[signature]
24.	Jocelyn Vana	845 Kingston Lane Bartlett, IL.	[signature]
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	Name	Address	Signature
1.	Mark Phipps	1339 Oakview Terrace, Woodstock, IL 60098	[signature]
2.	KURTIS MUTH	1366 SPRING ST, YORKVILLE, IL 60560	[signature]
3.	L. ERIC SCHOENY	403 MEADOWROSE LN YORKVILLE IL	[signature]
4.	Ken Schroth	1105 Callaway Dr. W. Shorewood	[signature]
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	Name	Address	Signature
1.	Bryan Wagner	2242 W. Chicago Ave. #203, 60622	[signature]
2.	Roger Zucchero	433 Annandale Glen Ellyn, 60137	[signature]
3.	Reed Panther	328 Cumnor Avenue, Glen Ellyn 60137	[signature]
4.	Anna Stockdale	1445 S. Lorraine Rd #311 Wheaton, IL 60189	[signature]
5.	Marty Turner	621 Maplewood Dr. Wheaton IL 60189	[signature]
6.	Rosa Zhao	2519 W. Grenshaw St. Chicago IL 60612	[signature]
7.	Mohammed [illegible]	107 Starwood Dr. Bolingbrook, IL	[signature]
8.	Atri Kallur	716 N Windermere Av, Villa Park, IL	[signature]
9.	Rich Jarmakowicz	7133 Knottingham Ln. Downers Grove	[signature]
10.	Chris Arman	6846 N. Mendota Chi Illinois	[signature]
11.	Kerry Brown	22567 Kingston Frankfort	[signature]
12.	Fred Nazar	1N181 Rowling Dr Wheaton, IL	[signature]
13.	Jason Talley	538 Talma Aurora IL	[signature]
14.	Al Rugieniius	930 Oldfield Rd DG	[signature]
15.	Chris Veow	9901 S Western Ave, 001 Chgo.	[signature]
16.	Jeff Allen	2291 S. Aldine Ct Mokena, IL	[signature]
17.	Pete Forznssver	922 Warren #403 D.G. IL	[signature]
18.	Ismail Attalla	111 S Walker Dr.	[signature]
19.	Tim Pollony	2660 Leyland Ln Aurora IL	[signature]
20.	David Healing	153 Crest Rd. Glen Ellyn IL	[signature]
21.	Aimee Lee	4616 Johnson Ave Western Springs	[signature]
22.	Jeff Friedrich	812 Manor [illegible] Joliet IL	[signature]
23.	Russ Gino	1004 Peregrine Way Hampshire	[signature]
24.	Barry Koper	1474 Radcliff Lane, 60502	[signature]
25.	John Clinnin	807 Stanbridge Pl. DG 60516	[signature]
26.	EG Hessenthaler	130 E. Randolph #2650 Chgo 60601	[signature]
27.	Phil Graffy	929 W Adams St, Chicago, IL 60	[signature]

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	Name	Address	Signature
28.	[illegible]	2430 Millington Ct Aurora, IL	[illegible]
29.	[illegible]	6051 Highland Ave Hanover IL	[illegible]
30.	JASON WEINBERG	2631 [illegible] CT LINDENHURST IL [illegible]	[illegible]
31.	Kurt B. [illegible]	631 Bombay [illegible] Dr,	[illegible]
32.		[illegible] Field IL 60461	
33.	[illegible]	224 S. MICH AVE, CHI [illegible]	[illegible]
34.	Jeff Schneberg	Dolling	[illegible]
35.	Brian [illegible]	2914 Prairie Road Madison	[illegible]
36.	Luis MONTGOMERY	1010 W. CAMPBELL ST. 60005	[illegible]
37.	JOE CATTALANO	2114 NIMITZ DR DES PLAINES 60018	[illegible]
38.	Amanda Mrugacz	182 Brompton Lane Unit A Sugar Grove 60554	[illegible]
39.	KimMarie Trostle	4N4 Arboretum Dr. Lombard 60148	KimMarie Trostle
40.	Erica [illegible]	820 Meadowlark Ln Glenview 60025	[illegible]
41.	Lamyu Griffin	2701 Ogden, Downers Grove	[illegible]
42.	JACEK TYSZKIEWICZ	1641 W. Moosehoart Rd Aurora	[illegible]
43.	Bridget Maliszewski	28W016 Hillview Drive Naperville	[illegible]
44.	Elizabeth Tafro	1511 Promenade Ln. Wheaton IL	[illegible]
45.	Brad Will	1336 E Bailey Rd, Naperville 60565	[illegible]
46.	Safi Qureshi	30W013 Willow Ct. Warrenville, IL 60555	[illegible]
47.	John Stevens	384 S. BERKLEY ELMHURST, IL	[illegible]
48.	Manuel Lao	917 [illegible] ct Bensenville	[illegible]
49.	Rodrigo T. Carlos	980 Longford Rd. Bartlett IL	[illegible]
50.	THOMAS COLEMAN	9127 S. Springfield Evergreen Park, IL	[illegible]
51.	RICHARD HANBA	1209 W SHERWIN AVE APT 601 CHICAGO, IL 60626	[illegible]
52.	David Cedeño	2614 N. Harding, Chgo, IL 60647	[illegible]
53.	Ahmad Hammad	10812 W. 133, orland Park, IL 60467	[illegible]
54.	Mustafa Hassan	1535 Fieldcrest West Chicago	[illegible]
55.	Kelsey Musich	1831 Constitution St. Sycamore, IL 60178	Kelsey Musich
56.	ELIAS AJAMI	4500 ROSLYN Rd. DOWNERS GROVE, IL.	[illegible]
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BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

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	Name	Address	Signature
1.	Eric Stein	6719 Bunker Hill Cir, Downers Grove	[signature]
2.	Cory Wilson	3517 N. Lakewood Ave., Chicago	[signature]
3.	Adam Kittler	4533 Grand Ave, Western Springs, IL	[signature]
4.	Jill Connolly	10717 S. Talman Ave. Chgo	[signature]
5.	Shane Coplin	1214 Tuscany Trail, Hampshire	[signature]
6.	Maureen Wheatfield	175 Bloomingbank Rd Riverside	[signature]
7.	Jay Wimmer	321 N. 3rd St Geneva	[signature]
8.	Dawn Erwin	520 4th St. Warren Springs, IL	[signature]
9.	Sandy [illegible]	4318 S Blanchan, Brookfield, IL	[signature]
10.	Richard Ray	1600 Oval Pine Ct Unit 1637 Willow Park	[signature]
11.	Jim Novak	4120 Valley View Rd Crystal Lake 60012	[signature]
12.	Matt Mackey	1133 W. Grace St. Apt #2S, Chicago, IL 60613	[signature]
13.	Anna Kluchenberg	5449 N Ashland Ave Chicago 60640	[signature]
14.	Margaret Panatera	1619 Valley Forge Place, Downers Grove, IL 60516	[signature]
15.	Evan Markowitz	51 W. Crystal Ave Lombard IL 60148	[signature]
16.	Lindsay Birt	235 W. Graham Ave Lombard IL 60148	[signature]
17.	Tim Kelly	17209 Arrowhead Dr, Lockport IL 60441	[signature]
18.	Laura DiMaggio	4432 Arthur Ave., Brookfield, IL 60513	[signature]
19.	Gerry Trzupek	3023 Fairfield Ln, Aurora, IL 60504	[signature]
20.	Kinzie Robertson	32404 Millard Cir, Warrenville, IL 60555	[signature]
21.	Tim Huff	559 W. Surf St # 100, Chicago, IL 60657	[signature]
22.	Horacio Chavez	322 . Main St. Lombard, 60148	[signature]
23.	Erin Hokanson	215 Plymouth Drive, Streamwood, IL 60107	[signature]
24.	Jeremy Reynolds	1014 Key Stone Avenue Northbrook 60062	[signature]
25.	Leilan Reich	959 N. Oakley Blvd. #N	[signature]
26.	Armando Hermosillo	1013 S Oakley BLVD Chicago IL 60612	[signature]
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	Name	Address	Signature
1.	Ron Hursh	526 N. Edgewood LaGrange Pk IL	[signature]
2.	James Barry	1202 Homestead Rd LaGrange PK	[signature]
3.	Dennis Beedy	10917 Martindale Dr. Westchester	[signature]
4.	Jean-Claude Roy	7721 Janes Ave Woodridge	[signature]
5.	Don Matheny	907 Linden Ct. Western Springs	[signature]
6.	Roger Hahn	5715 Ridgewood Dr. Western Springs	[signature]
7.	Ronald A. Wisthuff	409 S. Kensington Av LaGrange	[signature]
8.	Arthur Hill	34 Drexel Ave LaGrange IL	[signature]
9.	Lisa E Telomen	800 S Kensington Ave LaGrange IL	[signature]
10.	Jan Bondiman	493 W Dorchester, Elmhurst	[signature]
11.	Stephen Gorman	533 Eighth LaGrange IL	[signature]
12.	Deane M. Ruppert	4923 Commonwealth, Western Springs	[signature]
13.	Hal Miller	414 N. Grant, Hinsdale, IL	[signature]
14.	Dennis Kasmayer	916 58th La Grange IL	[signature]
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	Name	Address	Signature
1.	GERRY O'CARROLL	1208 CONNAMARA CT. WESTMONT IL 60559	Gerry O'Carroll
2.	Jane Strobeck	1208 Connamara Ct Westmont	[illegible]
3.	Mike Trost	11109 SARATOGA DR ORLAND PK	[illegible]
4.	Bonnie Prokopa	12857 S. Petrina [illegible]	[illegible]
5.	RYAN MCAULIFFE	1840 BURTON LANE PARK RIDGE	Ryan McAuliffe
6.	Tim Calkins	6530 N. Nixon	[illegible]
7.	Joe Calkins	728 N. Willow Rd	Joseph Call
8.	Tom Calkins	6014 S. Cortland	[illegible]
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	Name	Address	Signature
1.	Michelle Mackey	1133 W. Grace St, Chicago, IL 60613	
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ATTACHMENT 1
AMBIENT WATER QUALITY CRITERIA FOR CHLORIDE-1988

United States
Environmental Protection
Agency

Office of Water
Regulations and Standards
Criteria and Standards Division
Washington, DC 20460

EPA 440/5-88-001
February 1988

Water

EPA

Ambient Water Quality Criteria for Chloride—1988

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

CHLORIDE

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL RESEARCH LABORATORY
DULUTH, MINNESOTA

NOTICES

This document has been reviewed by the Criteria and Standards Division, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, and approved for publication.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

NTIS accession No. PB88-175 047

FOREWORD

Section 304(a)(1) of the Clean Water Act of 1977 (P.L. 95-217) requires the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document is a revision of proposed criteria based upon consideration of comments received from other Federal agencies, State agencies, special interest groups, and individual scientists. Criteria contained in this document replace any previously published EPA aquatic life criteria for the same pollutant(s).

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(1) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non–regulatory, scientific assessment of ecological effects. Criteria presented in this document are such scientific assessments. If water quality criteria associated with specific stream uses are adopted by a State as water quality standards under section 303, they become enforceable maximum acceptable pollutant concentrations in ambient waters within that State. Water quality criteria adopted in State water quality standards could have the same numerical values as criteria developed under section 304. However, in many situations States might want to adjust water quality criteria developed under section 304 to reflect local environmental conditions and human exposure patterns before incorporation into water quality standards. It is notuntil their adoption as part of State water quality standards that criteria become regulatory.

Guidance to assist States in the modification of criteria presented in this document, in the development of water quality standards, and in other water–related programs of this Agency has been developed by EPA.

William A. Whittington
Director
Office of Water Regulations and Standards

ACKNOWLEDGMENTS

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CONTENTS

TABLES

Introduction

The major anthropogenic sources of chloride in surface waters are deicing salt, urban and agricultural runoff, and discharges from municipal wastewater plants, industrial plants, and the drilling of oil and gas wells (Birge et al. 1985; Dickman and Gochnauer 1978; Sonzogni et al. 1983). Beeton (1965) reported that concentrations of chloride had been rising in Lake Erie, Lake Ontario, and Lake Michigan since the early 1900s, and in Lake Huron since the 1950s, but Sonzogni et al. (1983) stated that the rate of change of chloride inputs to the Great Lakes had stabilized or decreased.

Chloride has long received special attention from researchers interested in fish. In 1937, Ellis discussed the concept that "fresh-water fish tolerate an osmotic pressure of the external medium equal to that of their own blood if the various salts and substances in the water are balanced against each other so as to exclude the specific toxic effects" and presented supporting data. Chloride has been used as a nutrient and prophylactic for fish (Hinton and Eversole 1979; Phillips 1944). It has also been suggested for use as a reference toxicant (Adelman and Smith 1976a,b; Threader and Houston 1983).

Because anthropogenic sources of chloride are unlikely to pose a threat to saltwater species, this document concerns effects on only freshwater species. Unless otherwise noted, all concentrations of chloride in water reported herein from toxicity and bioconcentration tests are expected to be essentially equivalent to dissolved chloride concentrations. All concentrations are expressed as chloride, not as the chemical tested. An understanding of the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985), hereinafter referred to as the Guidelines, and the response to public comment (U.S. EPA 1985a) is necessary in order to understand the following text, tables, and calculations. Results of such intermediate calculations as recalculated LC5Os and Species Mean Acute Values are given to four significant figures to prevent roundoff errors in subsequent calculations, not to reflect the precision of the value. The latest comprehensive literature search for information for this document was conducted in August 1985; some more recent information was included.

Acute Toxicity to Aquatic Animals

Data that may be used, according to the Guidelines, in the derivation of a freshwater Final Acute Value for chloride are presented in Table 1. When compared on'the basis of mg of chloride/L, the chlorides of potassium, calcium, and magnesium are generally more acutely toxic to aquatic animals than sodium chloride (Biesinger and Christensen 1972; Dowden 1961; Dowden and Bennett 1965; Hamilton et al. 1975; Patrick et al. 1968; Trama 1954). Only for sodium chloride, however, are enough data available to allow derivation of a water quality criterion. In addition, it seems likely that most anthropogenic chloride in ambient water is associated with sodium, rather than potassium, calcium, or magnesium (Dickman and Gochnauer 1978; Sonzogni et al. 1983).

Results listed in Table 1 from Dowden and Bennett (1965), Hamilton et al. (1975), and Kostecki and Jones (1983) were obtained from 24- and 48-hr tests, rather than the 96-hr tests specified in the Guidelines. Use of such results is considered acceptable for chloride because the acute values changed little from 24 to 48 or 96 hours, depending on the species, in acute toxicity tests on chloride. For example, ratios of 24-hr and 48-hr LC5Os for sodium chloride with a midge and a daphnid were 0.91 and 0.81, respectively (Dowden and Bennett 1965; Thornton and Sauer 1972). Reed and Evans (1981) obtained a ratio of 1.0 for 24-hr and 14-day LC5Os determined with the channel catfish, bluegill., and largemouth bass (Table 5). Adelman and Smith (1976a,b) and Adelman et al. (1976) obtained ratios of 24- and 96-hr LC5Os of 0.74 and 0.97 with goldfish and fathead minnows, respectively, in tests in which the fish were fed (Table 5).

Adult fingernail clams were more sensitive than juveniles (Anderson 1977), but for the American eel (Hinton and Eversole 1978) and the bluegill (Cairns and Scheier 1959) smaller organisms were slightly more sensitive than larger ones. No pronounced relationships have been observed between the acute toxicity of chloride to freshwater animals and hardness, alkalinity, or pH.

Species Mean Acute Values (Table 1) were calculated as geometric means of the acute values from tests on sodium chloride, and then Genus Mean Acute Values (Table 3) were calculated as geometric means of the Species Mean Acute Values. Of the twelve genera for which acute values are available. the most sensitive genus, Daphnia, was only 6 times more sensitive than the most resistant, Anguilla. Invertebrates were generally more sensitive than vertebrates. The Final Acute Value for chloride was calculated to be 1,720 mg/L using the procedure described in the Guidelines and the Genus Mean Acute Values in Table 3. The acute value for Daphnia pulex. is lower than the Final Acute Value.

Chronic Toxicity to Aquatic Animals

The available data that are usable according to the Guidelines concerning the chronic toxicity of chloride are presented in Table 2. In the life-cycle test with Daphnia pulex, survival was as good as in the control treatment at chloride concentrations up to 625 mg/L (Birge et al. 1985). At 314 mg/L. reproduction was as good as in the control, but at 441 and 625 mg/L, reproduction was reduced by 27 and 39%, respectively. Thus, the chronic limits are 314 and 441 mg/L, the chronic value is 372.1 mg/L, and the acute-chronic ratio is 3.951.

In an early life-stage test with rainbow trout, a chloride concentration of 2,740 mg/L killed all the exposed organisms (Spehar 1987). Survival was 54% at 1,324 mg/L, but was 97% or higher at 643 mg/L and at two lower concentrations and in the control treatment. The mean weights of the fish alive at the end of the test at 1,324 mg/L and the lower tested concentrations ***were*** within 5% of the mean weight of the fish in the control treatment. The chronic value and the acute-chronic ratio obtained with the rainbow trout were 922.7 mg/L and 7.308, respectively.

In an early life-stage test with the fathead minnow, Pimephales promelas, Dirge et al. (1985) found that weight was as good as in the control treatment up to a chloride concentration of 533 mg/L. Survival was reduced 9% by a concentration of 352 mg/L and was reduced 15% by 533 m2/L. The chronic value is 433.1 mg/L, and the acute-chronic ratio is 15.17,

The three acute-chronic ratios available for chloride are 7.308, 15.17, and 3.951 (Table 3). The geometric mean of these three is 7.594, which is used as the Final Acute-Chronic Ratio. Division of the Final Acute Value by the Final Acute-Chronic Ratio results in a Final Chronic Value of 226.5 mg/L, which is substantially lower than all three chronic values in Table 2.

Toxicity to Aquatic Plants

Data on the toxicity of chloride to aquatic plants show a wide range of sensitivities (Table 4). The alga, SDiro!vra setiformis, was extremely sensitive to the effects of chloride; inhibition of growth, chlorophyll, and fixation of ^{14}C occurred at 71 mg/L• (Shitole and Joshi 1984). Growth of

Netrium dieitus was affected at 200 mg/L, but the other sixteen tested species were affected by concentrations ranging from 642 to 36,400 mg/L. A Final Plant Value, as defined in the Guidelines, cannot be obtained because no test in which the concentrations of chloride were measured and the endpoint was biologically important has been conducted with an important aquatic plant species.

Eyster (1962) reported that a concentration of 0.18 mg/L stimulated the growth of many algae, and Sonzogni et al. (1983) discussed the possibility that concentrations above 10 mg/L might shift phytoplanktbn communities toward nuisance, taste-and-odor-causing blue-green algae. When chloride was added to a small stream at a concentration of 610 mg/L, the algal density decreased whereas the bacterial density increased.

Although most of the data on toxicity of chloride to freshwater plants has been obtained with sodium chloride, some evidence indicates that a similar cation-anion toxicity relationship exists for both aquatic plants and animals. Patrick et al. (1968) demonstrated that potassium chloride was 2.3 times more toxic to a diatom than sodium chloride (Table 4), although calcium chloride was 1.3 times less toxic than sodium chloride. Tuchman and Stoermer (Manuscript a,b) found that potassium chloride had a greater inhibitory effect on algal population dynamics and nutrient uptake than sodium chloride.

Bioaccumulation

No data that are usable according to the Guidelines are available concerning the accumulation of chloride by freshwater species.

Other Data

Additional data on the lethal and sublethal effects of chloride on freshwater species are presented in Table 5. Anderson (1944,1948) and

Biesinger and Christensen (1972) found the same cation-anion toxicity relationship that is apparent in Table 1. Sreenivasan et al. (1979) reported that the rotifer, Brachionus rubens, tolerates chloride up to at least 1,400 mg/L. Wallen et al. (1957) reported that magnesium chloride-was less toxic to the mosquitofish than sodium chloride; however, these tests were conducted in very turbid water and therefore the results might be atypical. A concentration of 13% sodium chloride in the diet of trout caused no ill effects, whereas 25 mg in gelatin capsules caused edema and death of brook trout

(Phillips 1944). Food consisting of 12% sodium .chloride did not affect growth of Atlantic salmon (Shaw et al. 1975). Hasan and Macintosh (1986) and Tomasso et al. (1980) reported that chloride reduced the acute toxicity of nitrite to fish.

Unused Data

Some data concerning the effects of chloride on aquatic organisms and their uses were not used because the tests were conducted with species that are not resident in North America (e.g., Coetzee and Hattingh 1977; Das and Srivastava 1978; Ferri and Sesso 1982; Katz and Ben-sAsson 1984; Meech and Thomas 1980; Schiewer 1974,1984; Stangenberg 1975; Vaidya and Nagabhushanam 1979). Jennings (1976) compiled data from other sources. Data were not used when chloride was a component of an effluent (Birge et al. 1985). Reports by Batterton et al. (1972), Hosiaisluoma (1976), and Palmer and Maloney (1955) provided no usable data on the toxicity of chloride. Arnold (1974), Davis et al. (1972), and Edmister and Gray (1948) did not adequately describe their test procedures or results or both.

Results of some laboratory tests were not used because the tests were conducted in distilled or deionized water without addition of appropriate salts (e.g., Kardatzke 1980,1981; Lee 1973; .Mahajan et al. 1979; Pappas and Pappas 1983; Stamper 1969; Thornton and Wilhm 1974,1975: Zaim and Newson 1979) or were conducted in chlorinated or "tap" water (e.g., Kumar and Srivastava 1981) Christensen (1971/72) and Christensen and Tucker (1976) exposed plasma or enzymes. Length of exposure was not reported by Batterton and Van Baalen (1971). High control mortalities occurred in tests reported by Lewis (1971) Tests conducted without controls (e.g., Vosjan and Siezen 1968) or with too few test organisms (e.g., Leblanc and Surprenant 1984) were also not used. **Hughes (1968,1973) did not adequately acclimate the test organisms.** Ten-day LC50s (Threader and Houston 1983) were not used because the fish had not been fed during the tests.

Many studies were not used because they addressed the metabolism, regulation, or transport, rather than toxicity. of chloride (e.g., Carrasquer et al. 1983; Castille and Lawrence 1981; De Renzis and Maetz 1973; Greenway and Setter 1979a,b; Hinkle et al. 1971; Konovalov 1984; McCormick and Naiman 1984; Ooshima and Oguri 1974; Perry et al. 1984; Shomer-Ilan and Waisel 1976; Sullivan et al. 1981; Ticku and Olsen 1977). Some references were not used because they were foreign-language reports for which no translation was available and no useful data could be obtained from the English abstracts (e.g., Frahm 1975; Mushak 1968; Schiewer 1976; Turoboyski 1960).

Summary

Although few data are available concerning the toxicity of any chloride salt other than sodium chloride, the data that are available indicate that, when compared on the basis of mg of chloride/L, the chlorides of potassium, calcium, and magnesium are generally more toxic to freshwater species than sodium chloride. Based on tests on sodium chloride, the acute sensitivities of freshwater animals to chloride ranged from 1,470 mg/L for Daphnia pulex to 11,940 mg/L for the American eel. Invertebrate species were generally more sensitive than vertebrates. Results from tests with a variety of species show that if freshwater animals do not die within the first 24 hr of the test, they probably will not die during periods ranging from 48 hr to 11 days. No relationships have been observed between the acute toxicity of chloride to freshwater animals and hardness, alkalinity, pH, or life—stage of the test organisms.

A life—cycle test with Daphnia pulex and early life—stage tests with the rainbow trout and fathead minnow produced chronic values of 372.1, 922.7, and 433.1 mg/L, respectively. The acute—chronic ratios were calculated to be 3.951 for Daphnia pulex, 7.308 for rainbow trout, and 15.17 for the fathead minnow. Freshwater plants were affected at concentrations of chloride ranging from 71 to 36,400 mg/L. No data are available concerning bioaccumulation of chloride by freshwater organisms.

National Criteria

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if-the four—day average concentration of dissolved chloride, when associated with sodium, does not exceed 230 mg/L more than once every three years on the average and if the one—hour average concentration does not exceed 860 mg/L more than once every three years on the average. This criterion probably will not be adequately protective when the chloride is associated with potassium, calcium, or magnesium, rather than sodiud In addition, because freshwater animals have a narrow range of acute susceptibilities to chloride, excursions above this criterion might affect a substantial number of species.

Implementation

As discussed in the Water Quality Standards Regulation (U.S. EPA 1983a) and the Foreword to this document, a water quality criterion for aquatic life has regulatory impact only after it has been adopted in a State water quality standard. Such a standard specifies a criterion for a pollutant that is consistent with a particular designated use. With the concurrence of the U.S. EPA, States designate one or more uses for each body of water or segment thereof and adopt criteria that are consistent with the use(s) (U.S. EPA 1983b,1987). In each standard a State may adopt the national criterion, if one exists, or, if adequately justified, a site—specific criterion.

Site—specific criteria may include not only site—specific criterion concentrations (U.S. EPA 1983b), but also site—specific, and possibly pollutant—specific, durations of averaging periods and frequencies of allowed excursions (U.S. EPA 1-985b). The averaging periods of "one hour" and "four days" were selected by the U.S. EPA on the basis of data concerning how rapidly some aquatic species react to increases in the concentrations of some pollutants, **and "three years" is the Agency's best scientific judgment of** the average amount of time aquatic ecosystems should be provided between excursions (Stephan et al. 1985; U.S. EPA 1985b). However, various species and ecosystems react and recover at greatly differing rates. Therefore, if adequate justification is provided, site—specific and/or pollutant—specific concentrations, durations, and frequencies may be higher or lower than those given in national water quality criteria for aquatic life.

Use of criteria, which have been adopted in State water quality standards, for developing water quality-based permit limits and for designing waste treatment facilities requires selection of an appropriate wasteload allocation model. Although dynamic models are preferred for the application of these criteria (U.S. EPA 1985b), limited data or other considerations might require the use of a steady-state model (U.S. EPA 1986). Guidance on mixing zones and the design of monitoring programs is also available (U.S. EPA 1985b,1987).

Table 1. Acute Toxicity of Chloride to Aquatic Animals

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (mg/L)[b]	Species Mean Acute Value (mg/L)[c]	Reference
			FRESHWATER SPECIES			
Snail, *Physa gyrina*	F, M	Sodium chloride	100	2,540	2,540	Birge et al. 1985
Snail, *Physa heterostropha*	S, U	Potassium chloride	-	451	-	Academy of Natural Sciences 1960; Patrick et al. 1968
Fingernail clam (adult >5 cm), *Musculium transversum*	S, M	Potassium chloride	263	168	-	Anderson 1977
Fingernail clam (adult >5 cm), *Musculium transversum*	S, M	Potassium chloride	243	254	-	Anderson 1977
Fingernail clam (juvenile <5 cm), *Musculium transversum*	S, M	Potassium chloride	263	472	-	Anderson 1977
Fingernail clam (juvenile <5 cm), *Musculium transversum*	S, M	Potassium chloride	243	907	-	Anderson 1977
Fingernail clam (juvenile <5 cm), *Musculium transversum*	S, M	Potassium chloride	234	1,655[d]	-	Anderson 1977
Cladoceran (1st instar), *Daphnia magna*	S, U	Sodium chloride	-	<2,562[e]	-	Anderson 1946

Table I (continued)

Species	Method[a]		Chemical	Hardness (mg/L as CaC0₃1_	LC50 or EC50 imq/L)[b]	Species Mean Acute Value imahl[c]	Reference
Cladoceron, Daphnia mono	S,	U	Potassium chloride		171		Dowden 1961
Cladoceron, Daphnia macula	S,	U	Calcium chloride		486		Dowden 1961
Cladoceran, Daphnia magna	S,	U	Sodium chloride		2,024		Dowden 1961
Cladoceron, Daphnia magna	S,	U	Calcium chloride		1,923		Dowden and Bennett 1965
Cladoceron, Daphnia moana	S,	U	Magnesium chloride		2,774		Dowden and Bennett 1965
Cladoceran, Daphnia mane	S.	U	Sodium chloride		3,583		Dowden and Bennett 1965
Cladoceran, Daphnia magna	S,	U	Potassium chloride	45	86		Biesinger and Christensen 1972
Cladoceran, Daphnia mane,	S,	U	Calcium chloride	45	92	-	Biesinger and Christensen 1972
Cladoceran, Daphnia movie	S,	U	Magnesium chloride	45	409	-	Biesinger and Christensen 1972
Cladoceran, Daphnia moons	S.	V	*Sodium* chloride	45	2,565	2,650	Biesinger and Christensen 1972

Table I. (continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$L	LC50 or EC50 (mg/1.)[b]	Species Mean Acute Value (mg/L)[c]	Reference
Cladoceran, Daphnia pulex	R, M	Sodium chloride	93	1,470	1,470	Birge et al. 1985
Isopod, Lirceus fontinalis	F, M	Sodium chloride	100	2,950	2,950	Birge et al. 1985
Caddisfly, Hydroptila (moist°	S, U	Sodium chloride	124	4,039[1]	4,039	Hamilton et al. 1975
Mosquito (larva), Culex sp.	S, U	Sodium chloride		6,222[1]	6,222	Bowden and Bennett 1965
Midge, Chironomus attenuatus	S, U	Sodium chloride		4,900	4,900	Thornton and Sauer 1972
Midge, Cricotopus trifascia	S, U	Potassium chloride	124	1,434		Hamilton et al. 1975
Midge, Cricotopus trifascia	S, U	Sodium chloride	124	3,795	3,795	Hamilton et al. 1975
American eel (55 mm), Anguilla rostrata	S, U	Sodium chloride	44	10,900		Hinton and Eversole 1978
American eel (97.2 mm), Anguilla rostrata	S, U	Sodium chloride	44	13,085	11,940	Hinton and Eversole 1979
Rainbow trout, Salmo gairdneri	R, U	Sodium chloride		3,336[g]		Kostecki and Jones 1983
Rainbow trout, Salmo gairdneri	F, M	Sodium chloride	46	6,743	6,743	Spehar 1987

Table I. (continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaC0_3$1_	LC50 or EC50 (mn/L)[4]	Species Mean Acute Value (mq/L)[c]	Reference
Goldfish, <u>Corassius ouratus</u>	S, U	Sodium chloride	-	8,388[g]		Bowden and Bennett 1965
Goldfish, <u>Corassius auratus</u>	S, M	Sodium chloride	149	9,455[h]	8,906	Threader and Houston 1983
Fathead minnow, <u>Pimephales promelap</u>	1, m	Sodium chloride	100	6,570	6,570	Birge et al 1985
Bluegill, <u>Lepomis macrochirus</u>	S, U	Potassium chloride	39	956		Troma 1954
Bluegill, <u>Lepomis macrochirus</u>	S, U	Calcium chloride	39	6,804		Troma 1954
Bluegill, <u>Lepomis macrochirus</u>	S, U	Sodium chloride	39	7,846		Troma 1954
Bluegill (3.9 cm), <u>Lepomis macrochirus</u>	S, U	Calcium chloride		6,080		Cairns and Scheier 1959
Bluegill (6.1 cm), <u>Le.pomis macrochirus</u>	S, U	Calcium chloride		6,080		Cairns and Scheier 1959
Bluegill (14.2 cm), <u>Lepomis macrochirus</u>	S, U	Calcium chloride		1,232		Cairns and Scheier 1959
Bluegill, <u>Lepomis macrochirus</u>	S, U	Potassium chloride	-	965		Academy of Natural Sciences 1960; Patrick et al. 1968

Table I. (continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (mg/L)[b]	Species Mean Acute Value (mg/L)[c]	Reference
Bluegill, *Lepomis macrochirus*	S, U	Calcium chloride		6,816		Academy of Natural Sciences 1960; Patrick et al. 1968
Bluegill, *Lepomis macrochirus*	S, U	Sodium chloride		7,897		Academy of Natural Sciences 1960; Patrick et al. 1968
Bluegill, *Lepomis macrochirus*	S, U	Potassium chloride		2,640g		Dowden and Bennett 1965
Bluegill, *Lepomis mocrochirus*	S, U	Calcium chloride		5,344[g]		Dowden and Bennett 1965
Bluegill, *Lepomis macrochirus*	S, U	Sodium chloride		8,616g		Dowden and Bennett 1965
Bluegill, *Lepomis mocrochirus*	f, M	Sodium chloride	100	5,870	5,870	Birge et al. 1985

a S = static; R = renewal; F = flow-through; U = unmeasured; M = measured.

b Concentrotion of chloride not the chemical

c Only data obtained with sodium chloride *were* used in calculation of Species Mean Acute Values Data for other salts are presented for comparison purposes only.

d Test temperature = 7°C; the other tests with this species were at 17°C.

e Not used in calculations because quantitative values are available for this species.

This value is from a 48-hr test (see text)

9 This value is from a 24-hr test (see text)

h This value was derived from the publiiihed graph

Table 2. Chronic *Toxicity of Chloride to Aquatic Animals*

Species	Test[a]	Chemical	Hardness (mg/L as CoC03I_	Limits (adil[b]	Chronic Value tmq/L1	Reference
			FRESHWATER SPECIES			
Cladoceran, Daphnia pulex	LC	Sodium chloride	100	314-441	372.1	Birge et al. 1985
Rainbow trout, Salmo goirdneri	ELS	*Sodium* chloride	46	643-1,324	922.7	Spehor 1987
Fathead minnow, Pimephales promelas	ELS	Sodium chloride	100	352-533	433.1	Birge et al. 1985

[a] LC = life-cycle or partial life-cycle; ELS = early life-stage.

[b] Measured concentrations of chloride.

Acute-Chronic Ratio

Species	Hardness (mg/L as CaC03 1_	Acute Value (ma/L)	Chronic Value (mil/L)	Ratio
Cladoceran, Daphnia pulex	100	1,470	372.1	3.951
Rainbow trout, Salmo goirdneri	46	6,743	922.7	7.308
Fathead minnow, Pimephales promelas	100	6,570	433.1	15.17

Table 3. Ranked Genus Mean Acute Values with Species Mean Acute—Chronic Ratios

Rank°	Genus Mean Acute Value	Species	Species Mean Acute Value	Species Mean Acute—Chronic Ratio°
		FRESHWATER SPECIES		
12	11,940	American eel, Anguilla rostrata	11,94(1	
11	8,906	Goldfish, Carassius auratus	8,906	
10	6,743	Rainbow trout, Salmo gairdneri	6,743	7.308
9	6,570	Fathead minnow, Pimepholes promelos	6,570	15.17
8	6,222	Mosquito, Culex sp.	6,222	
7	5,870	Bluegill, Lepomis mocrochirus	5,870	
6	4,900	Midge, Chironomus attenuatus	4,900	
5	4,039	Caddisfly, Hydroptila angusta	4,039	
4	3,795	Midge, Cricotopus trifascia	3,795	
3	2,950	Isopod, Lireus fontinalis	2,95(1	
2	2,54(1	Snail, Phyla gyring	2,54(1	

Table 3. (continued)

Rank[a]	Genus Wean Acute Value (■g/L)	Species	Species Mean Acute Value (mg/L)[b]	Species Mean Acute-Chronic Ratio[s]
	1,974	Cladoceran, Daphnia magna	2,650	
		Cladoceran, Daphnia pulex	1,470	3.951

Ranked from most resistont to most sensitive based on Genus Mean Acute Value.

b From Table

From Table 2.

Final Acute Value = 1,720 mg/L

Criterion Maximum Concentration = (1,720 mg/L) / 2 = 860.0 mg/L

Final Acute-Chronic Ratio = 7.594 (see text)

Final Chronic Value = (1,720 mg/L) / 7.594 = 226.5 mg/L

Table 4. Toxicity of Chloride to Aquatic Plants

Species	Chemical	Duration (days)	Effect	Concentration (mq/L)°	Reference
			FRESHWATER SPECIES		
Alga, Anacvstis nidulans	Sodium chloride	4	Growth inhibition	>24,300	Schiewer 1974
Alga, Anaboena variabilis	Sodium chloride	4	*Growth inhibition*	*14,300*	*Schiewer 1974*
Alga, Chlomvdomonas reinhardtii	Sodium chloride	3-6	Growth inhibition	3,014	Reynoso et al. 1982
Alga, Chlorella emersonii	Sodium chloride	8-14	Growth inhibition	7,000	Setter et al. 1982
Alga, Chlorello Fusco fusca	Sodium chloride	28	Growth inhibition	18,200	Kessler 1974
Alga, Chlorella fusca rubescens	Sodium chloride	28	Growth inhibition	24,300	Kessler 1974
Alga, Chlorella fusca vacuolota	Sodium chloride	28	Growth inhibition	24,300	Kessler 1974
Alga, Chlorella kessleri	Sodium chloride	28	Growth inhibition	18,200	Kessler 1974
Alga, Chlorella luteoviridis	Sodium chloride	28	Growth inhibition	36,401)	Kessler 1974

Table 4. (continued)

Species	Chemical	Duration (days)	Effect	Concentration (164/L0	Reference
Alga, Chlorella minutissima	Sodium chloride	28	Growth inhibition	12,100	Kessler 1974
Alga, Chlorella protothecoides	Sodium chloride	28	Growth inhibition	30,300	Kessler 1974
Alga, Chlorella soccharophilio	Sodium chloride	28	Growth inhibition	30,300	Kessler 1974
Alga, Chlorella yulgoris	Potassium chloride	90-120	Growth inhibition	23,800	De Jong 1965
Alga, Chlorella yulgoris	Sodium chloride	90-120	Growth inhibition	24,100	De Jong 1965
Alga, Chlorella vulgoris tertia	Sodium chloride	28	Growth inhibition	18,200	Kessler 1974
Alga, Chlorella vvlgaris vulciaris	Sodium chloride	28	Growth inhibition	24,300	Kessler 1974
Alga, Chlorello zofingiensis	Sodium chloride	28	Growth inhibition	12,100	Kessler 1974
Alga, Pithophora oedogonia	Sodium chloride	10	Inhibition of growth, chlorophyll, and ^{14}C fixation	886	Shitole and Joshi 1984
Alga, Spirogyra setiformis	Sodium chloride	10	Inhibition of growth, chlorophyll, and ^{14}C fixation	71	Shitole and Joshi 1984
Desmid, Netrium digitus	Sodium chloride	21	Growth inhibition	200	Hosiaisluoma 1976

Table 4. (continued)

Species	Chemical	Duration (days)	Effect	Concentration (mq/11[a])	Reference
Desmid, *Netrium diaitus*	Sodium chloride	21	Growth inhibition	250	Hosiaisluoma 1976
Diatom, *Nitzschio linearis*	Potassium chloride	5	EC50	642	Academy of Natural Sciences 1960; Patrick et al. 1968
Diatom, *Nitzschia linearis*	Calcium chloride	5	EC50	2,003	Academy of Natural Sciences 1960; Patrick et al. 1968
Diatom, *Nitzschia linearis*	Sodium chloride	5	EC50	1,482	Academy of Natural Sciences 1960; Patrick et ol. 1968
Eurasian watermilfoil, *Myriophyllum spicatum*	Sodium chloride	32	501, reduction in dry weight	3,617	Stanley 1974
Eurasian wotermilfoil, *Wyriophyllum spicatum,*	Sodium chloride	32	507, reduction in dry weight	4,964	Stanley 1974
Angiosperm (seed), *Potamogeton pectinatus*	Sodium chloride	28	Reduced germination	1,820	Teeter 1965
Angiosperm (9-wk old plants), *Potamogeton pectinatus*	Sodium chloride	35	Reduced dry weight	1,820	Teeter 1965
Angiosperm (13-wk old plants), *Potamogeton pectinatus*	Sodium chloride	35	Reduced shoots and dry weight	1,820	Teeter 1965

[a] Concentration of chloride, not the chemical

Table 5. Other Data on Effects of Chloride on Aquatic Organisms

Species	Chemical	Hardness (iligh as $CaCO_3$L	Duration	Effect	Concentration	Reference
			FRESHWATER SPECIES			
Alga, Chlorello pvrenoidosa	Sodium chloride	-	24 hr	Inhibited growth	301	Kalinkina, 1979; Kalinkina and Strogonov 1980 Kolinkina et al. 1978
Protozoan, Paramecium tetrourelia	Sodium chloride		5 days	177. reduction in cell division	350[b]	Cronkite et al 1985
Cladoceron (1st instar), Daphnia mono	Potassium chloride		16 hrLC50		179	Anderson 1944
Clodoceran (1st instar), Dophnio moano	Calcium chloride		16 hr	LC50	853	Anderson 1944
Cladoceran (1st instar), Daphnia maona	Sodium chloride		16 hr	LC50	3,747	Anderson 1944
Cladoceran, Daphnia macula	Potassium chloride		64 hr	Incipient inhibition	207	Anderson 1948
Cladoceron, Daphnia mono	Calcium chloride		64 hr	Incipient inhibition	589	Anderson 1948
Cladoceron, Daphnia magna	Magnesium chloride		64 hr	Incipient inhibition	555	Anderson 1948
Clodoceran, *Daphnia mono*	Sodium *chloride*		64 hr	Incipient *inhibition*	2,245	Anderson 1948
Cladoceran, Dophnio moon°	Potassium chloride	45	21 days	Reproductive impairment	44[c]	Biesinger and Christensen 1972

Table 5. (continued)

Species	Chemical	Hardness (mg/L as CoC0₃I_	Duration	Effect	Concentration (mgjL)G	Reference
Cladoceran, Daphnia moona	Calcium chloride	45	21 days	Reproductive impairment	206[c]	Biesinger and Christensen 19,72
Clodoceran, Daphnia magna	Magnesium chloride	45	21 days	Reproductive impairment	239[c]	Biesinger and Christensen 1972
Cladoceran, Daphnia magna	Sodium chloride	45	21 days	Reproductive impairment	I,062[c]	Biesinger and Christensen 1972
Caddisfly, Hydropfilo anctusta	Potassium chloride	124	48 hr	LC50	2,119	Hamilton et al. 1975
Goldfish, Carassius auratus	Sodium chloride		24 hr 96 hr -	LC50 (fed) LC50 (fed) Threshold LC50	6,037 4,453 4,442	Adelman and Sniith 1976o,b Adelman et al 1976
Shiners, Notropis sp.	Sodium chloride		5 days	Reduced survival	1,525	Von Horn et al. 1949
Fathead minnow (II wk), Pimephales promelas	Sodium chloride		24 hr 96 hr -	LC50 (fed) LC50 (fed) Threshold LC50	4,798 4,640 4.640	Adelman and Smith 1976a b Adelman et al. 1976
Channel catfish, Ictalurus punctatus	Sodium chloride	412	24 hr 14 days	LC50 (fed)	8,000 8,00(1	Reed and Evans 1981
Mosquitofish, Gambusia offinis	Potassium chloride	-	24 *hr* 96 hr	LC50[d]	4,800 442	Walle.n et al. 1957
Mosquitofish, Gambusia offinis	Calcium chloride	-	24 hr 9-6 hr	LC50[d]	8,576 8,576	Wallen et al 1957
Mosquitofish, Gambusia affinis	Magnesium chloride	-	24 hr 96 hr	LC50[d]	14,060 12,37(1	Wallen et al. 1957

Table 5. (continued)

Species	Chemical	Hardness (mg/L as CoC0₃1_	Duration	Effect	Concentration . (ma/L1·	Reference
Mosquitofish,	Sodium	-	24 hr	LC50[d]	11,040	Wallen et ol. 1957
Gambusia offinis	chloride		96 hr		10,710	
Bluogill,	Sodium	412	24 hr	LC50 (fed)	8,000	*Reed* and Evans *1981*
Lepomis mocrochirus	chloride		14 days		8,000	
Largemouth boss (juvenile),	Sodium	412	24 hr	LC50 (fed)	8,500	Reed and Evans 1981
Micropterus solmoides	chloride		14 days		8,500	

• Concentration of chloride, not the chemical.

b . This value was derived from the published graph.

• Concentrations not measured in test solutions. d

Turbidity = <25 to 320 mg/L.

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ATTACHMENT 2
TECHNICAL SUPPORT DOCUMENT
FOR A WINTER CHLORIDE WATER QUALITY STANDARD

Received, Clerk's Office 5/21/2018 ** R2018-032**

TECHNICAL SUPPORT DOCUMENT FOR A WINTER WATER QUALITY STANDARD

May 14, 2018

By

James E. Huff, P.E.

1. INTRODUCTION

The Illinois Pollution Control Board's General Use Water Quality Standard for chlorides has been 500 mg/L since the early 1970s. Since the adoption of this water quality standard, sales of de-icing salts in the United States have doubled, with a similar increase in chloride concentrations in the receiving streams (Kelly et al., 2012). In Docket R8-09 (Sub docket D), the Board expanded the 500 mg/L chloride water quality standard to include the Chicago Area Waterways (CAWS) and Lower Des Plaines River, excluding the Chicago Sanitary & Ship Canal, where site-specific standards were adopted. However, the Board provided three years before the chloride water quality standard would apply during the winter months to the CAWS and Lower Des Plaines River, in recognition of the current water quality exceedances of this 500 mg/L level. Chloride concentrations above the 500 mg/L level are not unique to these two waterways but occur during snow melt periods in all urban streams within Illinois.

The current focus in Illinois to address these chloride exceedances is in pursuing variances from the Board, with a commitment to developing and implementing Best Management Practices (BMPs) to reduce the application of highway de-icing salt. While implementing BMPs is a worthwhile activity, the potential to achieve a *not-to-exceed* limit of 500 mg/L in urban streams under the worst storm conditions is not realistic. As U.S. EPA has also proposed a more restrictive chloride water quality criterion, the 500 mg/L standard has a potential to be reduced to levels closer to 200 mg/L at some future date.

Toxicity testing for chlorides consistently has demonstrated the need for restrictive water quality standards; however, this laboratory testing has been conducted at water temperatures between 23 and 25°C, basically peak summer temperatures. Winter temperature studies are limited. We know that growth and reproduction for most aquatic organisms are limited and do not occur at colder water temperatures, which raises the question of the appropriateness of the many chronic concerns during the winter months.

In addition, some species are absent from the water column during the winter months. As part of the justification for the site-specific water quality standards in R8-09, Citgo presented data on its collection of Cladocera (water fleas, including *Ceriodaphnia*) from the Chicago Sanitary & Ship Canal. Cladocera population peaked in the summer and steadily declined as the water temperatures cool. By October 29th, no Cladocera were collected within the Chicago Sanitary & Ship Canal. This finding is not surprising when one considers the life cycle of zooplankton, as summarized in the next chapter.

Based on the work funded by Citgo as part of R8-09, questions were raised about the impact temperature has on the toxicity of chlorides. Huff & Huff solicited funding from a cross section of salt users to fund additional research on cold temperature toxicity of chlorides. The actual toxicity testing for three species (the amphipod *Hyalella azteca*, the fingernail clam *Sphaerium simile*, and mayfly *Neocloeon triangulifer)* was conducted by Dr. David Soucek and Amy Dickinson at the Illinois Natural History Survey, and the daphnia test (*Ceriodaphnia dubia*) was conducted by the New England Bioassay Laboratory in Manchester, Connecticut. The Illinois Natural History Survey is recognized as the leading research laboratory on aquatic toxicity of chlorides and sulfates.

Presented herein are the findings from this research, which includes a literature study, cold temperature toxicity testing on four of the most sensitive species to chlorides, as well as justification for using 10°C as the appropriate threshold for winter temperatures. Also included herein is an analysis of the duration of exposure to elevated chlorides and derivation of suggested winter water quality standards for chlorides.

2. SUMMARY OF LITERATURE

Found in Appendix A is a literature survey on the toxicity of chlorides, with a focus on temperature effects on this toxicity. There has been minimal research on the effect of temperature on the toxicity of chlorides. Chloride toxicity in general has focused on some of the most sensitive aquatic species, including *C. dubia, N. triangulifer, H. azteca and S. simile,* the same organisms that were studied under the current work. There has been speculation that at lower temperatures chlorides will display reduced toxic effects on aquatic organisms, based on decreased bioavailability of chlorides, reduced uptake rates, slower metabolic rates, and unknown physiological mechanisms. Larval dormancy or diapause brought on by lower temperatures has been speculated to result in reduced toxicity in some macroinvertebrates. Studies have shown greater percent survival at colder temperature to chironomid larvae exposed to elevated chlorides.

For *C. dubia*, reproduction capacity is reduced with temperature, as is growth rate. However, eggs produced in times of stress are capable of surviving sub-optimal conditions, which allows populations to survive through winters and times of drought. Once water temperatures decline to approximately 50°F (10°C) in streams, and the fall season daylight hours shorten, photosynthesis declines dramatically and the plankton food source (single-celled algae, phytoplankton) rapidly declines from water bodies. The zooplankton, such as water fleas, that rely on the single-celled algae as food also disappear from these waterways at the same time. Cladocerans (water fleas) including *Ceriodaphnia* produce "resting" (diapausing) eggs that are thickly shelled and resistant to complete drying, cold, heat and other extremes of conditions. The resting eggs are microscopic, rest in the sediment, and are often viable for years, (Kaya & Erdogan, 2013). In this protected egg state, water fleas are able to pass the winter and hatch when conditions are more favorable. Elevated chlorides experienced during winter months would likely have no effect on the hatchability of the resting eggs, (Bailey et al., 2004). Eggs will hatch when the waters warm to approximately 55°F (13°C). Research conducted with food additions during daphnia testing showed that toxicity is reduced when food quantity is increased.

In 2013, to support a site-specific chloride water quality standard on the Chicago Sanitary & Ship Canal, Huff & Huff, on behalf of Citgo, presented in R9-08 the results of plankton collections on the Canal. The 2013 results showed a dramatic decrease in plankton with no Cladocerans present in the colder months. Subsequently, Huff & Huff conducted collections in 2014 from May to November. *Ceriodaphnia* was not collected in 2014, and by the October 29th collection date, the entire order of Cladocera was absent from the Chicago Sanitary & Ship Canal collections. Similarly, the November 29, 2014 collection (at Western Avenue) was also totally void of the order of Cladocera. As the primary food source for Cladocerans (single-celled algae, phytoplankton) is also absent from the waterway during the winter months, the presence of free swimming adult Cladocerans during these months would be expected. As described in the complete literature search, studies with *C. dubia* have demonstrated that survivorship, age of first reproduction, the reproductive rate, and the growth rate are all temperature dependent. Further, eggs produced in times of stress are capable of surviving sub-optimal conditions which allows populations to survive through winter periods. Water hardness has also been shown to have a significant effect on the toxicity of chlorides, with increasing hardness reducing the toxic effects of chlorides.

Research on the amphipod *Hyalella azteca* demonstrated that eggs were not produced at temperatures below 15^{o}C, and that populations peaked during the summer months (Pickard and Benke 1996; Wen 1992). Toxicity experiments where the *H. azteca* were fed during the test duration demonstrated that the toxicity of chlorides is reduced with feeding on three different strains. (Soucek et al. 2013.)

Temperature also impacts the food quality available to macroinvertebrates. Studies with the mayfly *Neocloeon triangulifer* indicate they generally feed on fine particles of organic material found on the bottom of streams, composed of algae and microbes. However, at 10^{o}C, when food leaves, the *Neoc. triangulifer* died shortly after the experiment began, likely due to the reduction in available food and possibly on the assimilation and respiration and food conversion efficiency. At 10^{o}C, the time from egg deposition to adult emergence took approximately 270 days. In northern climates, *C triangulifer* overwinter mainly as eggs, which hatch in late spring (Sweeney et al. 1984).

The freshwater mussel, *Sphaerium simile,* or fingernail clams, are filter feeders. Their highest reproduction rates occur in late spring and early summer.

In summary, there has been limited research on the temperature effect on macroinvertebrates. The available literature supports the belief that at colder temperatures, chloride toxicity is reduced. As growth and reproduction slow with temperatures, and in many species essentially stop at colder temperatures, chloride’s chronic effects may well be even more reduced at colder temperatures.

3. SUPPORT FOR 10 DEGREE C WINTER TEMPERATURE

Illinois water quality standards have a winter ammonia standard, reflecting the effect of temperatures on ammonia toxicity. The Board's current chloride water quality standards include a winter chloride standard on the Chicago Sanitary & Ship Canal, as well as a three-year delay before the winter chloride standard goes into effect on the other Chicago area waterways and the Lower Des Plaines River. Based on the literature review in Appendix A, there is scientific justification for such an approach; however, additional toxicity testing with the more sensitive species to derive winter limits is appropriate. The first step in this process is selecting a representative winter temperature.

When deriving water quality standards for ammonia, the Illinois EPA utilizes the 75th percentile temperature for the receiving stream. That is, 75 percent of the temperature readings recorded are less than the 75th percentile value. This approach requires the Illinois EPA to calculate unique water quality standards for each stream, when calculating effluent limits. A similar approach could be used for chlorides, or in the alternative, the 75th percentile value for all streams in Illinois could be used, and for setting the temperature to be utilized for the additional toxicity testing. Included in Appendix B is an analysis of temperature data provided by the Illinois EPA from all of the Illinois sampling stations from 2002 to 2016. The 75th percentile temperature for the months from December 1st to April 30th for all Illinois stream temperature data is 9.3^{o}C based on the sorting of the Agency data into this winter period. Eliminating April from the inclusion of the winter months reduces the 75th percentile temperature to 5.9^{o}C. The first page of each sorting is included in Appendix B. The sorted complete temperature output for each period can be provided upon request.

Based on this finding, the toxicity testing conducted as part of this temperature was conservatively set at 10^{o}C.

4. DURATION OF ELEVATED CHLORIDES IN RECEIVING STREAMS

Elevated chlorides in Illinois streams are episodic events. The levels reached and the duration are functions of the amount of salt applied in response to a storm event, the subsequent temperatures, the base flow in the receiving streams, and antecedent period from the previous snow event (which determines the background chloride concentration before the storm runoff). The smaller the drainage area, the flashier the chloride response will be, typically with spikes of chlorides above 500 mg/L lasting one-to-two days. As the stream size increases, the duration where the chlorides will remain above 500 mg/L can last a week or more. However, these longer durations typically have a return interval longer than three years on most urban streams.

Three data sources for spikes in chlorides or surrogate measurements (conductivity or Total Dissolved Solids or TDS) were used to look at the duration of snow melt events. First, the Citgo Lemont Refinery has measured the chlorides concentration on the Chicago Sanitary & Ship Canal (CSSC) for over a decade. Second, the MWRDGC has monitored conductivity on many Chicago Area Waterways, each with an individually-derived chloride concentration. The third data source is from the DuPage River/Salt Creek Workgroup, which also has monitored conductivity, with correlation to chlorides. Each of these three datasets provides information on the duration to spikes above 500 mg/L chlorides on a variety of stream sizes. Each of the three is discussed below.

4.1 Lemont Refinery Chloride Monitoring on the Chicago Sanitary & Ship Canal

Presented in Appendix C is the Lemont Refinery's chloride data table for the winter months. The average concentration each winter ranged from a low of 128 mg/L (based on limited data in 2012) to 393 mg/L in 2014. More relevant to our analysis is the duration of elevated chlorides when such events occur. The CSSC represents the largest stream segment, especially associated with urban runoff, so the durations of elevated chlorides would be expected to be longer on this waterbody than all others in Illinois. The chronic water quality standard on the CSSC is 620 mg/L, so using this value, the following table was constructed:

Event	Estimated Duration above 620 mg/L Chlorides, days	Maximum Chloride Concentration Recorded, mg/L
2017	No Events over 620 mg/L	-
1/4/2016	4	660
12/25/2015	3	904
2/17/2015	5	638
2/25/2014	4	635
1/14/2014	10	720
3/7/2013	14	711
2/14/2013	4	640
2012	No Events over 620 mg/L	-
2/18/2011	6	1,099
11/15/2010	2	870
11/8/2010	2	684
2/26/2010	2	648
2/15/2010	4	833
3/6/2009	4	881
2/8/2008	11	896
12/21/2007	5	998
12/10/2007	6	717
3/2/2007	4	734
2/19/2007	4	695
2006	No Events over 620 mg/L	-

*Note the duration in days is an extrapolation; typically, samples were collected two days per week.

There were 18 events over the 11-year period, with exceedances of the 620 mg/L chronic standard, and the average duration was approximately 5 days. Three events had durations greater than 7 days, or a frequency of occurring once per 3.6 winter seasons. The acute standard on the CSSC is 990 mg/L, and documented exceedances occurred twice over the 11-year period, a recurrence frequency of once every 5.5 years.

4.2 MWRD Conductivity Monitoring on the Chicago Area Waterways

The Metropolitan Water Reclamation District of Greater Chicago (MWRD) has a series of conductivity probes throughout the CAWS, and data from 2007 through April 2017 were available for analysis. Using the MWRD conversion from conductivity to chlorides allows for more accurate estimates of duration. The results for the CSSC at Cicero, just above the discharge from the Stickney treatment plant, are summarized below:

Event	# of days 4-day running average above 620 mg/L Chlorides, days	Maximum Chloride Concentration Recorded, mg/L
Thru April 30, 2017	0	500
2016	0	465
2/15/2015	8	812
1/14/2014	9	916
3/6/2013	7	918
2/12/2013	3	822
2/19/2011	2	719
2010	0	612
12/26/2009	0	634
3/3/2008	0	690
2/12/2008	9	1,241
12/17/2007	11	860
3/1/2007	6	1,008

Over the eleven years on the CSSC at Cicero Avenue, the number of days when the new chronic standard of 620 mg/L was exceeded was 55 days, or an average of five days per year. The acute standard (990 mg/L) was exceeded twice over this period, or a recurrence interval of approximately every five years. Durations above the chronic standard longer than seven days occurred four times over the period of record, or a recurrence interval of once every 2.7 years. These results are similar to the Lemont Refinery’s data presented above.

On the North Branch of the Chicago River, Kinzie Street is just above the confluence with the Chicago River. This station has been monitored by the MWRD from 2007 to 2013. Using 640 mg/L for the chronic winter threshold and 1,010 mg/L for the acute threshold, which are derived later on in this technical report, yields the following on the North Branch of the Chicago River.

Event	# of days 4-day running average above 640 mg/L Chlorides, days	Maximum Chloride Concentration Recorded, mg/L
3/8/2013	1	876
3/1/2013	4	1,075
2012	0	644
2011	0	718
2010	0	699
2009	0	690
2/9/2008	11	1,160
12/13/2007	3	914
2/27/2007	8	1,092

Over the seven years, the number of days when the chronic winter level of 640 mg/L was exceeded was 27 days, or an average of four days per year. An acute value of 1,010 mg/L was exceeded in three events over this seven-year period, or a recurrence interval of approximately every 2.3 years. Durations above the chronic standard longer than seven days occurred twice over the period of record, or a recurrence interval of once every 3.5 years.

For the Cal-Sag Channel, the MWRD has robust records at Cicero Avenue, from 2007 to 2017 for conductivity. Like the North Branch, this station is downstream of one of the major water reclamation facilities.

Event	# of days 4-day running average above 640 mg/L Chlorides, days	Maximum Chloride Concentration Recorded, mg/L
2017	0	341
2016	0	454
2015	0	646
2014	0	387
2011	0	551
2/25/2010	2	723
2009	0	568
2008	0	668
2007	0	622

Over the nine years, the number of days when the chronic winter level of 640 mg/L was exceeded was 2 days, or an average of once every 4.5 years. An acute value of 1,010 mg/L has not been exceeded on the Cal-Sag at Cicero over the nine-year period of record, with a maximum estimated chloride of 723 mg/L that occurred on February 25, 2010.

A summary of the MWRD data on the Chicago Area Waterways indicates that most elevated chloride periods last less than seven days, with the peak duration above some chronic level of 11 days.

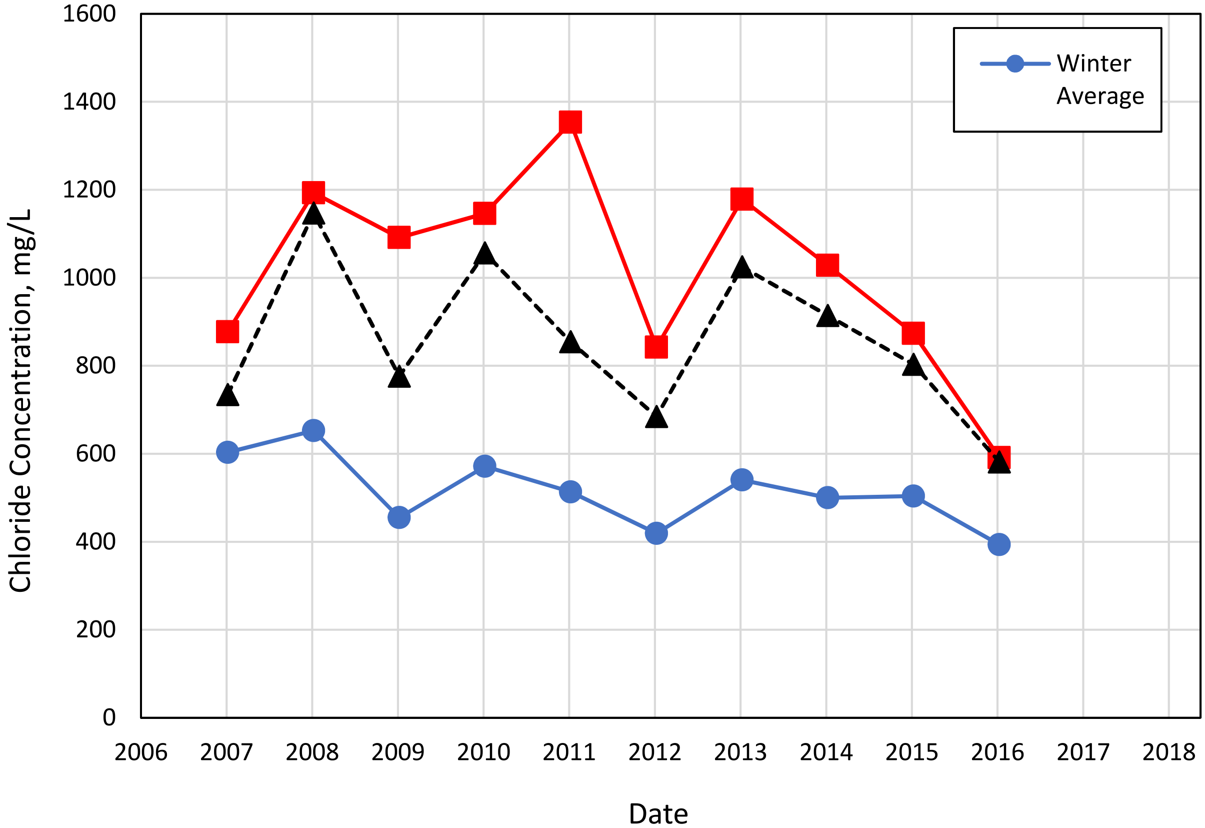
4.3 DuPage River and Salt Creek Conductivity Data

The DuPage River/Salt Creek Workgroup (DRSCW) has monitored conductivity and chlorides on its waterways since 2007, and their data provide an excellent picture of intermediate-sized streams in urban areas. Salt Creek at Wolf River reflects closer to the downstream end, and below the Fullersburg Woods Dam, so the chloride spikes are dampened to a minor degree at this location. This stream also receives considerable wastewater effluents from the municipalities along the waterway. The following table summarizes the winter days above 640 mg/L and the maximum estimated chlorides.

Event	Estimated Duration above 640 mg/L Chlorides, days	Maximum Chloride Concentration Recorded, mg/L
2016	0	591
3/25/2015	5	771
3/12/2015	13	861
2/9/2015	9	874
3/13/2014	10	1,028
1/11/2014	5+	931
12/21/2013	2	742
3/7/2013	14	1,178
2/13/2013	1	645
2/8/2013	5	811
2/27/2011	6	815
2/16/2011	4+	990
1/19/2011	1+	**1,353**
2/23/2010	21	1,146
2/11/2010	7	894
2/10/2009	2	670
3/1/2008	11	984
2/9/2008	26	1,193
2/12/2007	4	877

The durations at this station are longer than at the other stations tabulated, and this may be due to the dam immediately upstream, retarding the flushing of the chlorides. However, the dam would also dampen the peak chloride concentrations. Overall there appears to be a declining trend in both peak chlorides and in the durations; however, some of this recent improvement may be attributed to the milder winters the last two years. Figure 1 clearly depicts this trend, including in the winter average chloride concentrations.

Figure 1: ANNUAL CHLORIDE CONCENTRATION - WINTER MONTHS (2007-2016)
SALT CREEK AT WOLF ROAD



DRSCW also monitored the East Branch of the DuPage River at Hobson Road (HR) in Woodridge and Unincorporated, DuPage County, Illinois from 2008 to 2015. The results are presented in the following table.

Event	Estimated 4-Day Duration above 640 mg/L Chlorides, days	Maximum Chloride Concentration Recorded, mg/L
2/9/2015	4	819
3/22/2014	8	859
2/20/2014	2	987
2/20/2013	6	1,097
2012	0	788
1/19/2011	3	980
2/23/2010	8	1172
2/11/2010	3	782
2009	0	513
2/5/2008	17	1,017

The peak recorded chloride was 1,172 mg/L at Hobson Road and the longest duration above 640 mg/L was17 consecutive days, back in 2008. Since 2008, eight consecutive days is the longest duration above 640 mg/L.

On the West Branch of the DuPage River, the DRSCW has monitored at Arlington Drive (AD) in Hanover Park, DuPage County, Illinois from 2007 to 2015, with the following chloride winter spikes.

Event	Estimated 4-Day Duration above 640 mg/L Chlorides, days	Maximum Chloride Concentration Recorded, mg/L
2015	0	589
3/8/2014	1	696
2/19/2014	2	812
3/8/2013	3	758
2012	0	612
1/29/2011	3	731
2010	0	719
2009	0	750
2/9/2008	6	826
2007	0	599

The West Branch is the furthest west, and the least urbanized compared to the East Branch and Salt Creek. The peak chloride over the nine years was 826 mg/L, so no exceedances of the proposed acute standard of 1,010 mg/L. Five events exceeded 640 mg/L for a 4-day period, or less than one event annually.

5. RESULTS OF COLD TEMPERATURE TOXICITY TESTING

5.1 *Ceriodaphnia dubia* Test Results at 10°C and 25°C

Appendix D includes three reports from New England Bioassay on the results of testing *C. dubia* at 10°C and at 25°C and the report from the Natural History Survey. The first report describes the result of acute toxicity testing using standard USEPA protocol over a 48-hr period at the two temperatures. The 25°C temperature is the standard temperature specified by the USEPA protocol and reflects near maximum summer temperatures in most Illinois streams. The results of this first acute test are summarized below:

Date	Test Species	Test Temp	48 hr LC_{50}, as Cl, mg/L
3/1/17	*C. dubia*	10°C	>1,518
3/1/17	*C. dubia*	25°C	<759

This first acute testing indicated that at 10°C, chloride toxicity is reduced by at least a factor of two.

The first chronic test was conducted at 10°C for the USEPA specified 168 hours (7 days). In the *C. dubia* test protocol, chronic effects are measured based on reproduction (number of offspring over 7 days). Chloride concentrations varied from the control (moderately hard fresh water) to levels of 2,883 mg/L. No offspring were produced in the control (low chlorides), nor any other of the tests, not surprising as reproduction slows with reduced temperature and at colder temperatures stops. From this, one could conclude there is no chronic effect at temperatures less than 10°C. The acute toxicity results from these same 10°C tests yielded a 48-hour LC_{50} of 2,124 mg/L, or 2.8 times the acute test reported above at 25°C.

Additional acute and chronic tests were completed in the fall of 2017 to fine tune the previous results and to address a longer duration for the chronic testing. The chloride dilutions were adjusted to allow for more accurate computations of the LC_{50}. The acute results are presented below:

Date	Test Species	Test Temp	48 hr LC_{50}, as Cl, mg/L
11/8/17	*C. dubia*	10°C	2,197
11/8/17	*C. dubia*	25°C	1,165

Like the previous results, reducing the temperature to 10°C resulted in reducing the acute toxicity to *C. dubia*, this time by a factor of 1.9.

Chronic tests were set up for a 35-day duration, at both 25°C and at 10°C, at eleven different chloride concentrations. In the 25°C test, reproduction occurred within the first 7 days, and at the lower chloride concentrations reproduction essentially stopped after the first 14 days at 25°C, but reproduction continued at higher chloride concentrations through 21 days. The offspring per female declined with increasing chlorides at 25°C. Also, the percent survival with exposure duration were similar up to chloride concentrations of 1,214 mg/L, and by 28 days, all of the test organisms had died in the 25°C exposure, presumably from old age.

In the 10°C tests, reproduction did not occur at any chloride concentration for the first 14 days, and then at a low number of offspring compared to the 25°C tests. At 10°C, survival continued throughout the full 35 days at all concentrations up to the 1,214 mg/L.

Using the standard USEPA test duration of seven days, no chronic effects from chlorides were observed, as there was no reproduction in the first 7 days at 10°C. The No-Observable Effects Concentration based on the full 35 days was computed at 782 mg/L chlorides at 10°C, compared to 607 mg/L for the 25°C test; at 10°C the chronic effect from a full 35 days of elevated exposure is 1.29 times less toxic than at 25°C. Caution should be exercised when using these longer chronic exposure tests, as 35 days of elevated chlorides does not reflect what occurs in Illinois streams, as discussed in the previous section.

5.2 *Sphaerium simile* (Fingernail Clam)

Approximately 300 adult clams were collected from Spring Creek, near Loda, IL in Iroquois County in April 2017 and then brought back to the INHS laboratory to release juveniles, which were acclimated to 25°C and 10°C temperatures and used for testing. The 96-hr acute toxicity test yielded an LC_{50} of 1,673 mg/L for 25°C and >2,920 mg/L at 10°C. In fact, there was 100 percent survival at 2,920 mg/L chlorides at 10°C, after four days.[1] No chronic effects were observed at 10°C as measured by weight change.

From these results, the acute toxicity for the Fingernail Clam at 10°C is greater than 1.75 times the acute concentration measured in the standard 25°C test.

5.3 *Neocloeon triangulifer* (Mayfly)

Acute and chronic tests were conducted for 14 days at both 25°C and 10°C. The LC_{50} for the 25°C test was 1,359 mg/L compared to 1,960 mg/L, at 10°C. The acute toxicity was reduced by a factor of 1.44 when the exposure temperature is adjusted to winter time temperatures.

For the chronic effects, which are based on weight gain, the LC_{50} was calculated at 998 mg/L at 25°C and greater than 1,466 mg/L at 10°C. The chronic effects are reduced by a factor of greater than 1.34 as the temperature is adjusted to winter time temperatures for the Mayfly. In fact, there were no chronic effects at 10°C up to the maximum chloride concentration tested (1,466 mg/L), so the 1.34 factor is conservative.

[1] When the exposure to elevated chlorides was extended to 28 days, the survival was essentially the same at 25°C as the survival at 10°C.

5.4 *Hyalella azteca* (Burlington Strain) Amphipod

There are two genetically distinct "strains" of *Hyalella azteca.* Most laboratories utilize the "US lab" strain; however, this southern strain does not do well under lab conditions at 10°C. The Burlington strain or northern strain from Canada, was evaluated, and they survived well at 10°C, which was not the case with the "southern strain." So after the initial testing with both strains, the Burlington strain was utilized.

The acute testing for 96 hours revealed an LC_{50} of 1,733 mg/L at 25°C. At 10°C, the LC_{50} was reported at 2,185 mg/L, or a factor at 1.26 less toxic at winter temperatures. Chronic tests at 10°C over a 28-day period were not successful, with poor survival, even in the controls. At 25°C, the chronic LC_{50} was calculated at 949 mg/L chlorides.

5.5 Discussion

As demonstrated in the previous section, spikes in duration for chlorides are a function of the stream size and percent urbanization. For smaller and intermediate streams, durations longer than four days occurs less than once per year. For the large streams, durations extending between 11 and 14 days occur on the order of once every ten years. Certainly, chronic tests conducted over a 28 or 35-day time period do not represent conditions that occur in Illinois. The standard USEPA acute and chronic test periods are more appropriate, especially considering the margin of safety in the calculation method utilized by USEPA, as presented in the next section.

6. DERIVATION OF WATER QUALITY STANDARDS

Under federal regulation, 40CFR131.5(c), one of the minimum requirements for water quality standards is that the criteria be sufficient to protect the designated uses. In 1985, the USEPA published *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (Stephen, et al., 1985). This document outlines the methodology for deriving water quality criteria, and notes for the chronic criteria, that a four-day averaging period is appropriate, and that a 20 to 30-day period is unacceptable. The four-day period was intended to "prevent increased adverse effects on sensitive life stages by limiting the durations and magnitudes of exceedences of the CCC." (CCC is the Criterion Continuous Concentration, or chronic criteria.) (pg. 5.)

Stephens, et al., goes on to note that, "most bodies of water could tolerate exceedences once every three years on the average. In situations in which exceedences are grouped, several exceedences might occur in one or two years, but then there will be, for example, 10 to 20 years during which no exceedences will occur." (pg 6). This is consistent with the data presented in the previous section, where there are years with no exceedences and other years when exceedences are more frequent.

This EPA document notes that, "Whenever adequately justified, a national criterion may be replaced by a site-specific criterion," (pg 6).

Using the toxicity data published in the 1988 *Ambient Water Quality for Chlorides,* and then modifying the results for certain species based on the current 10^oC research, winter water quality criteria for chlorides can be derived. Table 1 presents a listing of the Chloride Genus and Species Mean Acute Values, ranked from the most tolerant to chlorides to the least tolerant species. The ones modified based on the current research are footnoted and are summarized below:

- Fingernail clam, *Musculium sp.* was adjusted upwards by a factor of 1.75 based on the 10^oC result from the Fingernail clam *Sphaerium simile.*
- Amphipod *Hyalella azteca* Burlington strain, Mayfly *Neocloeon triangulifer,* Fingernail clam *Sphaerium simile* and *Ceriodaphnia dubia* utilized the acute toxicity results from the 10^oC studies described in this report.
- The three species of daphnia (*D. magna, pulex* and *affinis*) were adjusted to 10^oC utilizing the 1.3 ratio of the acute toxicity of *Ceriodaphnia dubia* at 10^oC compared to the 25^oC results. The justification for this is that *C. dubia* is in the same family as the three *Daphnia* species and has a similar life history to the three *Daphnia. C.dubia* is known to be a more sensitive test species to a wide variety of toxicants, compared to *Daphnia* (Scott and Crunkilton 2000, Rojíčková-Padrtová et al. 1998, Von Der Ohe and Liess, 2004). Moreover, The three *Daphnia* species have a Genus Mean Acute Value (GMAV) of 2,326 for chloride while *Ceriodaphnia dubia* has a GMAV of 1,542 at 25°C. The *C.dubia* is greater than 1.5 times as sensitive to chloride so adjusting the GMAV of the *Daphnia* species by a 1.3 ratio is conservative for chloride at 10°C.

TABLE 1

CHLORIDE GENUS and SPECIES MEAN ACUTE VALUES (GMAV, SMAV) IN MG/L

Rank, R	Genus species	SMAV	GMAV	Cumulative Probability, P
34	*Anguilla* American eel *Anguilla rostrata*	17,160.60	17,161	0.9714
33	*Cambarus* Crayfish *Cambarus* ***sp.***	16,203.20	16,203	0.9429
32	*Fundulus* Plains killifish *Fundulus kansae*	14,897.10	14,897	0.9143
31	*Libellulidae* Dragonfly *Libellulidae* sp.	14,843.40	14,843	0.8857
30	*Gasterosteus* Threespine stickleback *Gasterosteus aculeatus*	13,452.60	13,453	0.8571
29	*Poecilia* Guppy *Poecilia reticulata*	11,860	11,860	0.8286
28	*Gambusia* Mosquitofish *Gambusia affinis*	9,933.40	9,933	0.8000
27	*Lepomis* Green sunfish *Lepomis cyanellus*	9,974.90	9,157	0.7714
26	*Notropis* Red shiner *Notropis lutrensis*	8,971.10	8,971	0.7429
25	Bluegill *Lepomis macrochirus*	8,406.50	8,406	0.7143
23	*Oncorhynchus* Rainbow trout *Oncorhynchus mykiss*	8,042.60	8,043	0.6571
22	*Ameiurus* Black bullhead *Ameiurus melas*	7,442.40	7,442	0.6286
21	*Pimephales* Fathead minnow *pimephales promelas*	6,515.30	6,515	0.6000
20	Amphipod, *Hyalella azteca*	6,398	6,398	0.5714
19	*Tubifex* Tubificid worm *Tubifex tubifex*	6,218.6	6,219	0.5429
18	*Cyprinella* Bannerfin shiner *Cyprinella leedsi*	6,111	6,111	0.5143
17	*Chironomus* Midge *Chironomus dilutus*	6,072	6,072	0.4857
16	*Rana* Bullfrog (tadpole) *Rana catesbeiana*	5,897	5,897	0.4571
15	Aquatic worm, Lumbriculus variegatus	5,444	5,444	0.4286
14	*Pseudacris* Chorus frog *Pseudacris* ***sp.***	4,686	4,686	0.4000
13	*Nephelopsis* Leech *Nephelopsis obscura*	4,369	4,369	0.3714
12	*Diaptomus* Copepod *Diaptomus clavipes*	3,946.1	3,946	0.3429
11	*Lirceus* Isopod *Lirceus fontinalis*	3,890.7	3,891	0.3143
10	*Gyraulus* Snail *Gyraulus parvus*	3,727.7	3,728	0.2857
9	Fingernail clam, *Musculium sp. 1/*	3,378	3,151	0.2571
8	*Physa* Snail *Physa gyrina*	3,350	3,350	0.2286
7	*Villosa* Mussel *Villosa delumbis*	3,821.1	3,086	0.2000
	Villosa iris	2,491.6		
6	*Hyalella* Amphipod *Hyalella azteca*	5,077.7	3,331	0.1714
	Hyalella Amphipod Burlington strain *Hyallela azteca* 3/\	2,185		
5	*Daphnia* Cladoceran *Daphnia ambigua 2/*	2,145	3,023	0.1429
	Daphnia pulex 2/	2,627		
	Daphnia magna 2/	4,905		
4	*Sphaerium* Fingernail clam *Sphaerium simile 3/*	2,920	2,920	0.1143
3	*Lampsilis* Mussel *Lampsilis fasciola*	2,907.1	2,835	0.0857
	Lampsilis siliquoidea	2,764.4		
2	*Ceriodaphnia* Cladoceran *Ceriodaphnia dubia 3/*	2,197	2,197	0.0571
1	Mayflies *Neocloeon triangulifer 3/*	1,960	1,960	0.0286

Source; Stephens, 2009

GMAV = Genus Mean Acute Value, SMAV = Species Mean Acute Value

Number of Data Points, N =34

Cumulative Probability, P = R / (N + 1)

1/ Adjusted to 10 degrees C by multiplying by 1.75 based on *Sphaerium* results

2/ Adjusted to 10 degrees C based on C. dubia results, by multiplying by 1.3

3/ Used 10 degree C data

Under the EPA protocol, the four most sensitive species then drive the resulting acute water quality criterion, or Criterion Maximum Concentration (CMC), although the number of species also enters the calculations. The four most sensitive species based on Table 1 are:

- Mayfly *Neocloeon triangulifer*
- *Ceriodaphnia dubia*
- *Lampsilis* Mussel
- *Sphaerium* Fingernail clam *Sphaerium simile*

Three out of four of these most sensitive species were part of the current research at 10^{o}C, as the *Hyalella* Amphipod moved up to the sixth most sensitive species with the 10^{o}C result. One species utilized, the *Lampsilis* Mussel was not adjusted to 10^{o}C, resulting in an additional safety factor in the resulting computations.

Table 2 presents the computations of the CMC and CCC. The CMC, or acute criterion for a winter chloride standard is 1,040 mg/L. The CCC, or chronic criterion, was derived by utilizing the Acute Chronic Ratio of 3.178, and the Final Acute Value of 2,028 mg/L. (The CMC has a safety factor of 2 applied, yielding the 1,010 mg/L.) The CCC computed is 640 mg/L, and this would be the recommended 4-day chronic water quality criterion for winter-time chlorides. Note, as no chronic effects were reported at 10^{o}C, using the ratio method for deriving the chronic standard is a conservative approach.

TABLE 2
RECALCULTION VALUES FOR
CHICAGO SANITARY AND SHIP CANAL

Rank	GMAV	Type, Genus species	Cumulative Probability, P	$Ln(GMAV)^2$	Ln(GMAV)	$P^{1/2}$
4	2,920	Sphaerium Fingernail clam Sphaerium simile	0.1143	62.799	7.925	0.338
3	2,764.4	Lampsilis siliquoidea	0.0857	59.211	7.695	0.293
2	2,197	Ceriodaphnia Cladoceran Ceriodaphnia dubia	0.0571	57.467	7.581	0.239
1	1,960	Mayflies	0.0286	57.467	7.581	0.169
			Σ P	**$\Sigma(\ln(GMAV)^2)$**	**Σ ln(GMAV)**	**$\Sigma P_{1/2}$**
			0.286	**236.944**	**30.781**	**1.039**
					$(\Sigma \ln(GMAV))^2/_4$	**$(\Sigma P^{1/2})^2/_4$**
					236.865	**0.270**

$S_2 = [\Sigma(\ln(GMAV)^2) - (\Sigma \ln(GMAV))^2/_4] / [\Sigma P - (\Sigma P^{1/2})^2/_4]$

$S_2 = [S(\Sigma P^{1/2})]^2 = [\ 236.944 - 236.865\ ] / [\ 0.286 - 0.27\ ]$ S_2
$= [S(\Sigma P^{1/2})]^2 = 4.964$

$S = S(\Sigma P^{1/2}) = 2.228$

L = [Σ ln(GMAV) - S*(Σ P1/2)] / 4

L = [30.781 - 2.228*1.039] / 4 **L**
= 7.117

$A = S*(0.05)^{1/2} + L$

A = 2.228*0.05^(1/2) + 7.117
A = 7.615

FAV = e^A = exp(A) FAV
= exp(7.615) **FAV =**
2,028

FCV = Chronic Toxicity =FAV / ACR ACR
for invertebrates is 3.178
FCV = 638

	Rounded Values
Criterion Max Concentration (CMC) = FAV/2= 1014 mg/L	**1010 mg/L**
Criterion Chronic Concentration (CCC) = FCV= 638 mg/L	**640 mg/L**

7. COMPARISON OF PROPOSED WINTER STANDARDS TO RESEARCH RESULTS

Four species were selected for evaluation at winter temperature chloride toxicity evaluation, and the results were presented in Section 5. The derivation of the winter chloride standard was straight forward, using the USEPA protocol, as discussed in the previous section. The chronic derivation is not as straight forward, as no chronic effects were observed using the standard USEPA toxicity test protocol, making derivation of a chronic standard subject to more best professional judgment. Using the USEPA Acute:Chronic ratio of 3.178 was therefore a conservative approach, which yielded a chronic water quality criterion of 640 mg/L.

As described in Section 5, a number of extended exposure tests were conducted. The *C. dubia* test where the organisms were exposed to elevated chlorides for 35 days yielded a No-observable Effects Concentration of 782 mg/L chlorides at 10^{o}C, above the 640 mg/L computed chronic criterion, so the laboratory testing of *C. dubia* demonstrates that this sensitive species would readily be protected if the 640 mg/L criterion was adopted as a winter standard for chlorides.

For the Fingernail clam toxicity testing, run for 28 days of exposure to various chloride concentrations, no chronic effects were detected with concentrations of 1,000 mg/L chlorides at 10^{o}C. This result also demonstrates that a chronic criterion of 640 mg/L chlorides in the winter would be protective of this sensitive species.

The third sensitive species, the Mayfly *neocloeon triangulifer,* showed no chronic effects found in chloride concentrations up to 750 mg/L. At the highest dose of exposure, 1,500 mg/L chlorides, no chronic effects were observed, but survival declined to 55 perecent (compared to 0 percent survival at 25^{o}C). Again, the computed chronic criterion of 640 mg/l is protective of this sensitive species.

The final species evaluated, the amphipod *Hyalella azteca* (Burlington strain) did not survive well at 10^{o}C, with only about a 50% survival rate at 7 to 10 days, independent of the chloride concentration. However, based on the acute testing at the two temperatures, at 25^{o}C the 96-hour LC_{50} was 1,733 mg/L versus 2,185 mg/L at 10^{o}C, or a ratio of 1.26. Applying this same ratio to the 28-day chronic test at 25^{o}C result of 516 mg/L yields an estimated chronic value at 10^{o}C of 650 mg/L from 28 days of exposure to chlorides. Again, this sensitive species will be protected with a 4-day chronic criterion of 640 mg/L chlorides.

In summary, using the acute-to-chronic ratio, as described in the previous section results in a conservative chronic water quality criterion, which will be protective of the most sensitive species.

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APPENDIX A
LITERATURE SEARCH

1.0 INTRODUCTION

Sodium chloride (NaCl) is used throughout the United States as a roadway deicer due to its effectiveness and affordability. The use of NaCl as a roadway deicer can lead to high concentrations of chloride within runoff, which can in turn lead to extensive salinization of receiving waters (Cañedo-Argüelles et al. 2013). In the Chicago area, a normal winter averages 20-30 snowstorms requiring winter maintenance involving deicer application (Salt Institute 2004). The Chicago area has also seen a significant increase in chloride concentrations present within waterways since the 1970s due to increases in deicer application rates (Kelly et al. 2012). These increases in chloride concentrations within aquatic systems may pose significant risks to aquatic taxa due to disruptions in the osmotic balance between organisms and their environment, necessitating the exclusion or excretion of these ions (Nazari et al. 2015). In 1988, to diminish the risks that salinization poses to aquatic biota, the United States Environmental Protection Agency (U.S. EPA) set acute and chronic chloride standards of 860 mg/L and 230 mg/L, respectively (using NaCl as the chloride source) (Benoit 1988). These standards were calculated based on data from 14 studies and spanned 12 species of varying life stages. The 1988 standards were derived using standard laboratory controlled temperatures, between 20-25ºC. Very few studies of the effects of chlorides have been completed in-situ and even fewer at actual winter temperatures. This gap in the literature limits the understanding of the effects of chlorides during the time of year they are often deployed as a component of roadway deicer. The life histories of the most sensitive organisms vary, as they belong to several different groups and additional studies are needed to address the differing metabolisms and life stages experienced during the winter. While there are other reviews regarding the effects of chloride on aquatic biota from roadway deicer applications (see Farag & Harper 2014; Cui et al. 2015; Nazari et al. 2015) here we summarize the current state of toxicity research and draw attention to the need for research regarding the influence of temperature on chloride toxicity.

2.0 BACKGROUND

Ceriodaphnia dubia belongs to the Daphniidae family and Cladocera sub-order. Daphnia are commonly known as water fleas. *C.dubia* is present in a variety of aquatic environments including lakes and ponds and is a commonly used taxa in toxicological bioassays. *C.dubia* reproduce using cyclic parthenogenesis which is a mode of reproduction that alternates between asexual and sexual phases, dependent on environmental factors. Daphnia populations consist almost entirely of females for the majority of the year (U.S. EPA 2002a; U.S. EPA 2002b). Factors such as overcrowding, lack of food, oxygen depletion, or seasonal changes can cause daphnia to switch from parthenogenesis (asexual reproduction) to sexual reproduction (Kleiven et al 1992). Life history characteristics of *C. dubia* including survivorship, age of first reproduction, reproductive rate, and growth rate, have been demonstrated to be temperature dependent, with lower temperatures extending the duration of life spans but reducing reproductive capacity (theoretical number of offspring that could be produced) and growth rate (Cowgill et al. 1985; Anderson and Benke 1994). The eggs produced during sexual reproduction are encased in an ephippia which is a tough covering resistant to drying (U.S. EPA 2002a; U.S. EPA 2002b). The eggs produced in times of stress are capable of surviving sub-optimal conditions which allows populations to survive through winter and periods of drought (Bailey et al. 2004).

The amphipod *Hyalella azteca* belongs to the Amphipod order and Hyalellidae family. It is commonly found in ponds, lakes, and rivers and is the most widespread species of amphipod (Pickard and Benke 1996).[2] It has a short life cycle and reaches sexual maturity in the laboratory at approximately 25-40 days (Othman and Pascoe 2001). The population density was found to be lowest in winter with a peak biomass in August and September in southern Alberta, Canada (Wen 1992). Reproduction is continuous from spring to fall. In one laboratory experiment, in temperatures of less than 15ºC, eggs were not produced (Pickard and Benke 1996). Another study demonstrated that growth and reproduction were optimum at temperatures between 20 and 26ºC (March 1977).

Neocloeon triangulifer (previously Centroptilum triangulifer) belongs to the order Ephemeroptera (mayfly) and Baetidae family. *N. triangulifer* is a parthenogenetic mayfly that is found in slow-flow areas of small to medium sized streams (Funk et al. 2006). The offspring of *N. triangulifer* are female clones (Funk et al. 2006, Soucek and Dickinson 2015). They are nymphs for approximately 3-4 weeks in ideal conditions prior to emerging as adults. *N. triangulifer* larvae failed to reach adulthood at high temperatures (30ºC) and produced the greatest number of eggs at 14ºC (Herrera, L., 2017, Chou personal communication). *N. triangulifer* were shown to exhibit larval development that took 27 days at 25°C and 179 days at 10°C, yet were shown to exhibit inverse relationships between temperature and adult size, and fecundity (Sweeney & Vannote 1984).

The freshwater mollusk, *Sphaerium simile*, is commonly referred to as a fingernail clam. It occurs in depositional substrates such as sand or mud in lakes and rivers. *S. simile* are filter feeders, siphoning floating particulate organic materials. *S. simile* are hermaphroditic and reproduction occurs throughout the year, with the highest reproduction occurring in late spring and summer (Zumoff 1973). *Sphaerium* incubate their young in brood sacs and release them as juveniles. *Sphaerium* brooding is asynchronous, meaning multiple broods in different stages of development occur simultaneously, in separate brood sacs (Thorp and Covich 2010).

[2] It is now known that H. azteca is a species complex. See Soucek et al. 2013 for info and citations plus comparison of Cl toxicity to two separate genetically distinct “strains”

3.0 STATE OF CURRENT RESEARCH

The effects of chloride on aquatic systems and the fauna they support, due largely to the widespread use of roadway deicers, has received considerable attention in the literature (Farag & Harper 2014, Cui et al. 2015, Nazari et al. 2015). Generally, such research has focused on identifying the acute and chronic toxicity of chloride to organisms through laboratory bioassays. Typically, acute toxicity tests are completed to identify the LC_{50} (Lethal Concentration). Chronic toxicity tests are used to characterize the LC_{50} when individuals are exposed to toxicants for longer periods of time, typically ranging from one week to two months depending on the study organism (Stephen et al. 2010). Chronic tests are also used to identify the EC (Effective Concentration) or IC (Inhibition Concentration) values for life history traits such as reproduction and growth. Such tests have expanded to address how chloride toxicity may be influenced by other environmental factors including water hardness (Elphick et al. 2010; Soucek et al. 2011) and when chloride occurs in mixture with other toxicants (Johnson 2014). However, fewer studies have used in-situ toxicity testing to develop a well resolved understanding of whether the acute and chronic toxicity of aquatic organisms derived from laboratory studies are ecologically relevant. Furthermore, there is a lack of research aimed at understanding how chloride toxicity may differ due to differences in water temperature, despite common observations in toxicity testing of a positive relationship between temperature and toxicity (Heugens et al. 2001).

3.1 <u>LABORATORY TOXICITY TESTING</u>

Since the U.S. EPA's development of the ambient water quality criteria for chloride (Benoit 1988), the majority of studies attempting to discern the toxicity of chloride to aquatic organisms have done so through laboratory bioassay testing methodologies. Many of these studies have been performed on a short list of macroinvertebrates, including *C. dubia*, *N. triangulifer*, *H. azteca*, and *S. simile*, which are generally more sensitive to chloride than their vertebrate counterparts as well as many other macroinvertebrates (Benoit 1988; Soucek et al. 2011; Struewing et al. 2015). The standards developed to perform these chloride toxicity tests are all conducted at temperatures near 25°C (23ºC for Hyalella). Recently, the most prevalent species used for chloride toxicity testing has been *C. dubia*. Recent studies have found that the acute 48-hour LC_{50} for *C. dubia* has been found to range from 1,068 mg Cl^-/L to 1,520 mg Cl^-/L, depending on water hardness (between 80-100 mg/L $CaCO_3$ in these studies) and feeding regime (Elphick et al. 2011; Soucek et al. 2011; Struewing et al. 2015). Chronic toxicity tests performed with *C. dubia* have revealed seven-day LC_{50} values between 954 and 1,054 mg Cl^-/L (DeGraeve et al. 1992; Struewing et al. 2015). Chronic toxicity as measured by the effect on reproduction for *C. dubia* has been measured at IC_{25} of between 600 and 697 mg Cl^-/L (Elphick et al. 2011; Struewing et al. 2015).

Another species that has received recent attention for chloride toxicity testing is *N. triangulifer*. Soucek and Dickinson (2015) determined that the 96-hour LC_{50} was 1,062 mg Cl^-/L and that the EC_{20} for percent pre-emergent nymphs and percent survival to pre-emergent nymph stage were 165 and 190 mg Cl^-/L, respectively. Another study, however, found a much lower LC_{50} value of 399 mg Cl^-/L at similar water hardness to the study by Soucek and Dickinson (2015), but feeding regimes were vastly different across studies (Struewing et al. 2015).

Another organism that has been used in chloride toxicity studies is the amphipod crustacean, *H. azteca*. Elphick et al. (2011) determined that the 96-hour LC_{50} for *H. azteca* was 1,068 mg Cl^-/L and that the 28-day IC_{50} for weight was 2,298 mg Cl^-/L. Alternatively, another study determined one and four-week LC_{50}s for a *H. azteca* strain to be 1,510 and 1,200 mg Cl^-/L, respectively (Bartlett et al. 2012). Soucek, et al. (2013) reported on the effect of test duration and feeding on three strains of *H. azteca* when exposed to chlorides over a 96-hour test period. The LC_{50}s reported are presented below for the three species:

Population	96-hr LC_{50} Unfed at 23ºC	96-hr LC_{50} Fed at 23ºC
US Lab	2,937 mg/L Cl^-	3,032 mg/L Cl^-
Burlington	1,530 mg/L Cl^-	1,741 mg/L Cl^-
Clear Pond	1,174 mg/L Cl^-	2,117 mg/L Cl^-

Finally, the fingernail clam species *S. simile* has also been used in chloride toxicity studies. This species has been found to be one of the most sensitive species to chloride with a 96-hour LC_{50} of 740 mg Cl^-/L (at 51 mg/L hardness) (Soucek et al. 2011).

Some concern has stemmed from the use of restricted life stages in these toxicity tests as some research has shown that some freshwater species (e.g. snails and chironomids) have similar chloride tolerances across all life stages, but in other species, mature individuals can be much more tolerant of higher salinities (Kefford et al. 2007). However, a study by Aragao and Pereira (2003) did not show differences in toxicity to *C. dubia* neonates of different age ranges. Furthermore, there has been a push to expand chloride toxicity research to include many other organisms to develop the most inclusive standards and to derive toxicity standards based on the species pool present at a given site. Aside from *C. dubia*, there have been many other daphnids used in chloride toxicity studies, including those which were used to develop the current U.S. EPA chloride standards. Using the species *Daphnia magna* and *Daphnia pulex*, the genus average 48-hour LC_{50} was 1,974 mg Cl^-/L, and the chronic threshold effecting reproduction was mg Cl^-/L for *D. pulex* (Benoit 1988). Since then, *D. magna* has been shown during a 96-hour test to have an acute and chronic LC_{50} of 2,955 mg Cl^-/L and 2,617 mg Cl^-/L, respectively (Struewing et al. 2015), although the chronic test was only for 48 hours. This study also determined the chronic IC_{25} on *D. magna* weight was 1,668 mg Cl^-/L, suggesting that *D. magna* are considerably more tolerant to chloride toxicity than *C. dubia*. This finding was supported in a study that found that *D. magna* can become acclimated to concentrations as high as 3,642 mg Cl^-/L (Martínez-Jerónimo & Martínez-Jerónimo (2007). In a study by Harmon et al. (2003) *D. ambigua* was shown to have a 48-hour LC_{50} of 1,214 mg Cl^-/L, making its tolerance to chloride similar to that of *C. dubia*. Additionally, a unicolonial hybrid of *D. pulex* and

Daphnia pulicaria was used to demonstrate that food quantity is positively correlated with the chronic LC_{50} for the species (Brown & Yan 2015). Some work with other freshwater fauna has extended beyond determining toxicity with standard endpoints, including a study by Sala et al. (2016), which assessed chloride toxicity to *Hydropsyche exocellata* using biomarkers and behavior to identify some signs of increased tolerance due to acclimation. Another study by Beggel and Geist (2015) demonstrated that glochidia of the freshwater mussel *Anadonta anatina* exhibited a 24-hour LC_{50} of 2,505 mg Cl^{-}/L, and that successful attachment of glochidia to fish hosts was negatively correlated with chloride concentration.

While such standardized methodologies have generally produced consistent, reliable measurements of toxicity endpoints (LC_{50}, EC_{20}, etc.) across laboratories (DeGraeve et al. 1992), these studies may be limited in their value for determining how chloride affects aquatic organisms when they are subjected to variability in other abiotic conditions (e.g. water temperature, hardness, co-occurring ions, etc.). Consequently, recent studies of chloride toxicity have incorporated these abiotic conditions related to water quality that may diminish or exacerbate the effects of chloride. One such factor that has received attention from many researchers is water hardness, considered to be a surrogate representing the concentration of other ions (Elphick et al. 2011). The acute chloride toxicity of *C. dubia* was shown to increase from an LC_{50} of 977 mg Cl^{-}/L at 25 mg/L hardness to 1,836 mg Cl^{-}/L at 800 mg/L hardness, (Linton & Soucek 2008). In addition, a study by Lasier and Hardin (2010) revealed that the chronic IC_{50} of *C. dubia* increased from 342 mg Cl^{-}/L to 653 mg Cl^{-}/L when the water hardness was increased by 50 mg/L $CaCO_3$. These results were similar to a study by Elphick et al. (2011), yet their research extended further by conducting tests at more intervals of varying hardness and calculated the Water Quality Objective (WQO) for chloride as a function of hardness. These results indicated that in waters that are very soft, (less than 40 mg/L $CaCO_3$) the U.S. EPA chronic toxicity standards may not be sufficient to protect *C. dubia*. Other studies have identified that this ameliorating effect of hardness on chloride toxicity spanned beyond cladocerans to freshwater clams (*S. simile* and *Musculium transversum*) and worms (*Tubifex tubifex*) (Soucek et al. 2011).

Other studies have demonstrated reductions in chloride toxicity to cladocerans (*C. dubia* and *Daphnia magna*) in solutions containing multiple cations (Mount et al. 1997). Recent research regarding reductions in chloride toxicity to *C. dubia* (NaCl source) due to increased water hardness has demonstrated that this effect is predominantly due to the presence of calcium (Ca) ions, rather than due to the total water hardness (Mount et al. 2016). It is also of note that toxicity standards and many continued toxicity tests on the effects of chloride are based on additions of chloride from NaCl because it is the most common source of exposure and sodium ions are suspected to have less of a toxic effect than other cations like potassium (K) and magnesium (Mg) (Mount et al. 1997). This has been supported by research suggesting that increasing the concentration of sodium cations can reduce chloride toxicity (Lasier & Hardin, 2010). Furthermore, a study by Struewing et al. (2015) revealed that the chronic and acute toxicities for *C. dubia* and *Daphnia* *magna* were much lower for chloride when it was added in solution with NaCl as opposed to KCl, however, *N. triangulifer* exhibited the opposite pattern.[3]

In addition to studies that have addressed how water hardness affects chloride toxicity, other studies have incorporated how toxicity is influenced by the presence of other toxic anions such as sulfate and bicarbonate, which are also common pollutants. The majority of this work has been concentrated on determination of the toxicity of chloride and sulfate when they occur in mixtures. An early study in this course of research found that the amphipod *H. azteca* exhibited increased 96-hour survival when sulfate was kept constant at 80 mg/L and chloride concentrations were increased from 5 to 67 mg/L (Soucek & Kennedy 2005). A subsequent study revealed that at low chloride concentrations, this same increase in the acute LC_{50} for sulfate-exposed *H. azteca* was observed; however, at higher chloride concentrations (100 to 500 mg Cl^-/L), the acute LC_{50}s for *H. azteca* and *C. dubia* decreased (Soucek 2007). Conversely, a more recent study by Soucek et al. (2011) did not demonstrate a significant relationship between the 48-hour chloride LC_{50} for *C. dubia* and sulfate concentration in dilution water. This work has been expanded to incorporate the influence of carbonate on chloride and sulfate toxicity, an ion which can exhibit strong toxic effects, yet has received less attention in the literature (Farag & Harper 2014). Chronic Cl^-, SO_4^{2-}, and HCO_3^- exposures were shown to generally exhibit simple additive toxic effects on *C. dubia* reproduction when they occurred in mixtures according to a study by Lasier and Hardin (2010). In contrast, more recent research has demonstrated that the toxic effects of these contaminants were greater than additive, though there is some debate regarding the most appropriate ways in which to determine effects of these contaminants when they occur in mixtures (Johnson 2014).

These studies demonstrate complexities in the toxicity of chloride to aquatic macroinvertebrates due to other aspects of water quality that can vary substantially across geographic locations, suggesting the need for development of site-specific chloride standards. In response to this potential for U.S. EPA-defined toxicity standards to not be appropriate at sites given their individual physiochemical properties, the Iowa Department of Natural Resources developed new standards in which the acute and chronic values are normalized based on the hardness and sulfate concentration at a given site (Iowa DNR 2009). This approach of refining standards based on site-specific properties may be valuable in continuing to revise standards given new research on other water quality characteristics that influence chloride toxicity.

3.2 **<u>IN-SITU TOXICITY STUDIES</u>**

Salinization of aquatic systems is known to be extensive in the United States, with one of the most substantial contributions coming from chloride (largely supplied by the dissociation of NaCl from roadway de-icing and mining activities) (Cañedo-Argüelles et al. 2013). Furthermore, elevated chloride concentrations in aquatic systems have been demonstrated to occur in areas far removed from sources of chloride pollution, such as urbanized areas, due to diffuse

[3] David Soucek's laboratory has confirmed Struewing's results in a paper soon to be published.

surface flows (Hill & Sadowski 2016). While the aforementioned controlled laboratory-based studies are valuable for developing baseline observations of chloride toxicity and to isolate the responses of individuals that are exposed to singular additional stressors (e.g. variation in water temperature, hardness, etc.), laboratory-based ecotoxicolgical studies are frequently criticized for their potential lack in ecological relevance, as these studies do not reflect how species may respond to elevated toxicant concentrations while being subjected to a whole host of environmental abiotic and biotic stressors (Cairns 1992; Chapman 2002; Filser 2008). While laboratory-derived LC_{50} values have been shown to be closely correlated with the maximum concentrations at which the species are observed in the field, this finding does not explain the occurrence of healthy populations at such concentrations (Kefford et al. 2004). Therefore, studies must be done to determine if they reflect the responses of these species to chloride contamination in the field.

To address these criticisms and develop a more well resolved understanding of how aquatic species respond to increased chloride concentrations in the wild, researchers have used several strategies. One such strategy has been to use field collected water samples to conduct bioassays of chloride toxicity. This was done in Wisconsin streams throughout the year to identify toxicity to *C. dubia* at observed field concentrations within the year (Corsi et al. 2010). It was found that measured chloride toxicity was similar when using field collected water samples to findings derived from standardized laboratory bioassays as the LC_{50} was found to be approximately 1,800 mg Cl^-/L and the IC_{25} for reproduction was approximately 1,050 mg Cl^-/L. Another study by Gardner & Royer (2010) found that the LC_{50} for *Daphnia pulex* was lower when conducting the chloride toxicity tests using filtered stream water from Indiana streams (1,812 mg Cl^-/L) than it was when using an artificial freshwater medium (2,042 mg Cl^-/L), suggesting that unmeasured characteristics of the stream water may exacerbate chloride toxicity. Hardness is a likely cause of this difference, but the hardness levels in the two tests were not reported. This finding is in contrast to a study in which groundwater with the same chloride concentration as laboratory-prepared test water was less toxic to the freshwater sediment-dwelling mussel species, *Lampsilis siliquoidea* (Roy et al. 2015), as well as by a study which found that glochidia viability in *Lampsilis fasciola* increased from an EC_{50} of 285 mg Cl^-/L in reconstituted water to 1,265 mg Cl^-/L in natural stream water (Gillis 2011).

Another strategy that has been implemented to more closely replicate chloride experiments in a natural setting has been through mesocosm experiments. In a study by Benbow and Merritt (2004), the researchers determined the acute toxicities of four macroinvertebrate species (*H. azteca*, *Callibaetis fluctuans*, *Physella integra*, and *Chaoborus americanus*) to chloride through the addition of road salt mixtures under three different test conditions. The test conditions included standard laboratory containers and containers situated next to a wetland, both of which contained filtered pond water, as well as mesocosm PVC containers within the wetland. The study revealed that mortality occurred more frequently *in the controls* of the mesocosm experiment than under the laboratory or outside test conditions, suggesting that a baseline mortality level expected to occur in the field may not be captured in controlled laboratory experiments. However, generally the mortality seen across chloride concentrations for each species demonstrated mortality rates were similar among test conditions, indicating that laboratory-based toxicity tests can reveal reasonable estimates of chloride toxicity to species in the field. While this study does tackle the question of whether laboratory-based toxicity studies accurately portray the responses of species to chloride toxicity when they occur in nature, the constant concentration of chloride maintained within the mesocosms does not represent the way in which elevated chloride concentrations occur under field conditions. Rather than a steady flow of chloride, waterbodies tend to experience flashes of high concentrations which quickly subside. For example, it was found that while streams spanning a gradient of urbanization in southeastern Indiana experienced spikes in chloride concentrations following winter storms frequently exceeded 300 mg Cl^-/L (above the U.S. EPA chronic toxicity standard), the spikes returned to levels below toxicity standards in a matter of hours, making these waterways unlikely to violate toxicity standards (Gardner & Royer, 2010). Another mesocosm study by Marshall and Bailey (2004) sought to replicate this flash of high concentrations of chloride and determine how its effects compare to the same quantity of salt released at a constant rate. The researchers found that there were larger reductions in total macroinvertebrate abundance when chloride was added to the mesocosms in four pulse concentrations of 3,500 mg/L NaCl (length of pulse varied from four to 13 hours) when compared to a continuous concentration of 1,500 mg/L NaCl, both over a five-day period. Despite this finding, there is not a thorough understanding of how the toxicity thresholds of freshwater invertebrates may vary depending on whether the same elevated concentration is held constant over the entire period of time necessary to exceed the U.S. EPA toxicity standard, compared to when that same peak concentration is reached only in a brief flash. There is, however, research suggesting that there may be inter-site variation among the tolerances of freshwater macroinvertebrate species to salinity via acclimation to higher salt concentrations when exposed over long periods of time (Hart et al. 1991; Dunlop et al. 2005; Dunlop et al. 2008).

The aforementioned studies attempting to determine how species respond to elevated chloride concentrations have only addressed the responses of individual species. Therefore, these studies do not reveal how the presence of chlorides will influence the composition of communities and the ecosystem functions they provide. A mesocosm study sought to identify the response of aquatic biota beyond the individual level by using streamside channels that continuously pumped freshwater from the adjacent stream and concurrently a salt solution to maintain a constant chloride solution within the channel (Cañedo-Argüelles et al. 2012). This study revealed that at a salt treatment totaling a conductivity of 5 mS/cm (approximately 1,700 mg Cl^-/L), after 72 hours of exposure, there was a significant reduction in the richness and diversity of macroinvertebrate species. Another study using a mesocosm approach identified that as chloride concentration increased from 20 to 780 mg Cl^-/L the abundance of zooplankton decreased, which in turn lead to slight increases in phytoplankton abundance, suggesting the possibility of chloride contamination to cause trophic cascades in natural communities (Jones et al. 2016). Field-based studies attempting to bridge the gap between individual species responses to toxicity and ecosystem level consequences are few and have been largely correlative, and therefore unable to ascertain whether any relationships among species with chloride concentrations are due solely to the presence of chloride. For example, a study by Blasius and Merritt (2002) assessed differences among leaf litter processing and functional feeding group diversity at sites upstream and downstream of major road salt sources. However, differences among the sites were more closely associated with increased sediment loads at downstream sites, rather than differences in chloride concentrations, which were minimal across sites. That said, a few studies have found a negative relationship between macroinvertebrate species density or richness and chloride concentration at wetlands sites spanning regional and continental scales (Cuffney et al. 2010; Preston & Ray 2016). Another study took this correlative approach at a regional scale and identified changes in macroinvertebrate communities at salinities as low as 0.8 mS/cm (Horrigan et al. 2005).

3.3 WATER TEMPERATURE AND CHLORIDE TOXICITY

A property of the aquatic environment that has been shown to influence the tolerance of aquatic organisms to toxicants is temperature. As macroinvertebrates are ectothermic, ambient water temperature plays a critical role in the physiological processes that occur within the organism. Therefore, it is likely that for many toxicants that disrupt physiological processes, such as chloride which influences the osmotic balance of organism, that temperature could be an interacting effect leading to differential toxicodynamics (Heugens et al. 2001; Noyes et al. 2009). Furthermore, chloride concentrations are often much higher in aquatic systems during the coldest months of the year due to the application of roadway deicers (Cañedo-Argüelles et al. 2013). Despite these facts and the prevalence of research regarding the effects of temperature on other toxicodynamics (Heugens et al. 2001), there has been very little research regarding whether temperature can influence the tolerance of biota to elevated chloride concentrations (Nazari et al. 2015).

Aside from the necessity to determine whether any reduction in chloride toxicity can be attributed to decreased temperature, it is critical to understand the mechanism through which the toxicity is reduced; toxicity reductions at low temperatures could theoretically be due to decreased bioavailability of chloride, reduced uptake rates, slower metabolic rates, or some unknown physiological mechanism. While it has been claimed that chloride could be less bioavailable at low temperatures because of the decreased solubility of chloride salts (Cui et al. 2015), this is unlikely to be the primary driver of reduced toxicity because NaCl is not significantly more soluble at higher temperatures. However, if chloride pollution is predominantly from KCl or $CaCl_2$, increased temperature could result in higher solubility and therefore more bioavailable chloride. Temperature may also influence the effects of chloride on organisms because ambient temperature is known to affect physiological rates within ectothermic organisms, therefore influencing activity levels and metabolism (Heugens et al. 2001). If temperatures are low, activity levels and metabolism will decrease, which could lead to reductions in chloride uptake compared to under higher temperatures (Cairns et al. 1975). For example, larval dormancy or diapause brought on by low temperatures may be responsible for reduced toxicity in some macroinvertebrates. In a study by Silver et al. (2009), it was found that chironomid larvae (*Chironomus riparius*) at 22°C, experienced 35 percent survival in water with no NaCl, whereas at NaCl concentrations of 3,035, 6,070, and 12,140 mg Cl^-/L, survival was less than 10%. However, at 10°C, survival was greater than 50 percent at 0 and 3,035 mg Cl^-/L and below 20 percent at 10,000 and 20,000 mg Cl^-/L. A subsequent study demonstrated a positive relationship between temperature and toxicity, however, neither study tested for any delayed effects of chloride following the larval stage (Lob & Silver 2012). It is also possible that temperature could exert an effect on osmoregulation, a phenomenon that has been studied in other aquatic organisms (e.g. Handeland et al. 1998), but not well understood in macroinvertebrates (Cairns et al. 1975).

3.4 CONSIDERATIONS FOR THE DETERMINATION OF TOXICITY STANDARDS

The abundance of literature identifying the influence of temperature on the toxicity of ammonia, pesticides, and metals to aquatic organisms (Heugens et al. 2001; Noyes et al. 2009) demonstrates the need to study whether chloride toxicity is also influenced by temperature, a hypothesis that has been largely untested. To do this, chloride effects can be studied on aquatic macroinvertebrates using standard toxicity testing procedures (ASTM 2002; EPA (a) 2002; EPA (b) 2002), but with the addition of conducting the tests at lower temperatures that are more representative of winter and early conditions when chloride concentrations are typically the highest within streams. Many aquatic organisms have slower growth and reproduction rates, longer generation times, and prolonged life expectancies at lower temperatures (Bottrell 1975; Anderson & Benke, 1994).

Determining chronic toxicity standards is of particular concern because temperature can exert significant control over the life cycle of aquatic macroinvertebrates, with low temperatures suppressing metabolism, generally prolonging the lifespan, but reducing growth and reproductive rates of organisms. For example, the time span used to measure chronic toxicity for many species (often a week), may not be long enough for individuals to produce offspring at low temperatures; therefore, it would be impossible to determine the effect of chloride on reproduction across a range of temperatures. Anderson and Benke (1994) found that *Ceriodaphnia dubia* took 24 days at 10ºC for first egg production. Additionally, if growth was the metric used to determine chronic toxicity, differences in temperature may result in a mismatch in organismal development, making it difficult to identify whether impacts on growth from such studies are due to chloride toxicity or an artifact of differential growth rates at different life stages across temperatures.

In many cases, toxicity tests should be conducted for longer time frames that are inclusive of a larger proportion of the organism's life cycle at lower temperatures in order to verify that the measured response to chloride is not obscured by the physiological state of the organism after a given length of time, but rather represents the response at a given stage in its life cycle (Nørhave et al. 2014). If upon pursuing these tests for prolonged time periods it is determined that the time needed to discern the effect of temperature on chloride toxicity is impractical for some species, it may be necessary to exclude such species from being used in developing toxicity standards.

4.0 FUTURE RESEARCH NEEDS

The majority of recent research regarding the toxicity of chloride to aquatic macroinvertebrates from laboratory and in-situ studies suggests that the current toxicity standards are sufficient to protect aquatic species. However, due to the interaction of chloride with other aspects of water quality (e.g. water temperature), the current toxicity standards may be inappropriate for winter temperature. To incorporate these potential interacting factors with chloride toxicity into toxicity standards, there are several areas of research that must be pursued further, especially in regard to the influence of temperature on toxicity. First, it is necessary to conduct laboratory bioassay toxicity tests using standardized protocols on some of the most chloride sensitive taxa that are widely distributed in the United States (e.g. *C. dubia*, *H. azteca*, *N. triangulifer*, and *S. simile*), but with the addition of conducting the tests at lower temperatures. By using standardized protocols, this could eliminate some of the variability in determination of toxicity metrics (e.g. LC_{50}, EC_{20}, etc.) by reducing the number of confounding factors such as water hardness, feeding regime, and length of exposure. This type of testing at different temperatures would also allow for the development of standards that more accurately represent the conditions organisms experience throughout the year. Following any identification of a relationship between chloride toxicity and temperature from these tests, it may be necessary to conduct these tests for longer time periods, more inclusive of the entire life cycle of the organisms tested, as temperature can have a significant impact on the life history of aquatic invertebrates (Nørhave et al. 2014). Conducting such tests would eliminate the potential to overestimate any protective mechanisms of low temperatures on chloride toxicity.

Furthermore, in-situ studies have provided some valuable information on the effects of chloride on aquatic species in natural settings, one of which being that laboratory-based toxicity bioassays are a reasonable way to determine the sensitivity of aquatic macroinvertebrates to chloride. However, these field studies are still lacking in replicating the winter-time conditions during which organisms are subjected to the highest concentrations. As this lack of winter mesocosm/field studies is due to impracticality in many cases, laboratory studies must be designed in ways that will replicate field conditions as closely as possible. One way that laboratory studies could simulate the effects of chloride contamination in nature would be to replicate the common winter scenario in which a large pulse of chloride enters a stream briefly after a storm, then quickly returns to normal levels (Gardner & Royer, 2010). Studies should be designed under the same standardized procedures described above but with the addition of subjecting the individuals to elevated chloride concentrations for a short period of time (i.e. less time than would be necessary to trigger a violation of chronic toxicity standards) and then return the individuals to low chloride concentrations for the duration of the test. This would allow researchers to identify how long concentrations must be elevated to trigger the responses identified in chronic toxicity tests, thus informing future decision making regarding toxicity standards.

While there is an abundance of literature regarding chloride toxicity to aquatic organisms, the research is lacking in identifying the role that temperature may play in toxicity. Therefore, studies must be conducted to bridge this knowledge gap to develop toxicity standards that are sufficient in protecting biota, while not being overly stringent as this could result in unnecessary funds being directed to monitor and maintain streams which are in exceedance of chloride toxicity standards which do not pose significant risks to the aquatic systems.

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APPENDIX B
ANALYSIS OF TEMPERATURE DATA PROVIDED BY THE ILLINOIS EPA

TABLE 1
75th PERCENTILE TEMPERATURE (9.3ºC) FOR WINTER MONTHS FOR ALL ILLINOIS STREAM TEMPERATURE DATA

75th Percentile ▪ 12-1 to 4-30 ▪ 9.3 degrees C				
Station Code	**Collection Date**	**Result Value**	**Method Code**	**Sample Medium**
AD-02	1/28/2003	-0.1	170.1	WATER
AD-02	3/17/2003	11.8	170.1	WATER
AD-02	4/10/2003	9.4	170.1	WATER
AD-02	1/13/2004	2.6	170.1	WATER
AD-02	2/18/2004	2.6	170.1	WATER
AD-02	4/8/2004	14.6	170.1	WATER
AD-02	12/9/2004	8.8	170.1	WATER
AD-02	2/23/2005	7.3	170.1	WATER
AD-02	3/24/2005	8.8	170.1	WATER
AD-02	12/7/2005	1.3	170.1	WATER
AD-02	1/25/2006	4.7	170.1	WATER
AD-02	2/24/2006	4.1	170.1	WATER
AD-02	3/31/2006	12.4	170.1	WATER
AD-02	12/6/2006	2.3	170.1	WATER
AD-02	1/25/2007	4.0	170.1	WATER
AD-02	3/5/2007	6.2	170.1	WATER
AD-02	4/5/2007	14.4	170.1	WATER
AD-02	1/12/2009	2.6	170.1	WATER
AD-02	3/2/2009	4.1	170.1	WATER
AD-02	4/8/2009	10.8	170.1	WATER
AD-02	2/1/2010	-0.2	170.1	WATER
AD-02	3/9/2010	8.6	170.1	WATER
AD-02	4/8/2010	17.7	170.1	WATER
AD-02	1/26/2011	0.4	170.1	WATER
AD-02	2/15/2011	1.8	170.1	WATER
AD-02	4/6/2011	13.2	170.1	WATER
AD-02	1/10/2012	5.0	170.1	WATER
AD-02	2/29/2012	10.4	170.1	WATER
AD-02	3/28/2012	18.0	170.1	WATER
AD-02	12/4/2012	11.3	170.1	WATER
AD-02	1/8/2013	0.4	170.1	WATER
AD-02	3/13/2013	7.4	170.1	WATER
AD-02	4/4/2013	9.6	170.1	WATER
AD-02	1/23/2014	-0.3	170.1	WATER
AD-02	2/24/2014	4.2	170.1	WATER
AD-02	4/16/2014	11.2	170.1	WATER
AD-02	12/2/2014	6.1	170.1	WATER
AD-02	1/26/2015	3.6	170.1	WATER
AD-02	3/11/2015	5.5	170.1	WATER
AD-02	4/2/2015	15.5	170.1	WATER
AD-02	12/1/2015	9.3	170.1	WATER
AD-02	1/25/2016	0.3	170.1	WATER
AD-02	2/17/2016	0.9	170.1	WATER
AD-02	3/29/2016	13.2	170.1	WATER
AK-02	1/8/2003	3.8	170.1	WATER
AK-02	2/19/2003	2.5	170.1	WATER
AK-02	3/20/2003	12.7	170.1	WATER
AK-02	4/30/2003	18.0	170.1	WATER
AK-02	12/2/2003	6.1	170.1	WATER
AK-02	1/29/2004	0.6	170.1	WATER
AK-02	3/10/2004	7.5	170.1	WATER
AK-02	4/22/2004	18.5	170.1	WATER
AK-02	1/10/2005	7.1	170.1	WATER
AK-02	2/3/2005	4.5	170.1	WATER
AK-02	3/10/2005	6.4	170.1	WATER
AK-02	4/5/2005	12.6	170.1	WATER
AK-02	4/27/2005	12.9	170.1	WATER

TABLE 2
75th PERCENTILE TEMPERATURE (5.9ºC) FOR WINTER MONTHS (EXCLUDING APRIL) FOR ALL ILLINOIS STREAM TEMPERATURE DATA

75th Percentile ▪ 12-1 to 3-31 ▪ 5.9 degrees C				
Station Code	**Collection Date**	**Result Value**	**Method Code**	**Sample Medium**
AD-02	1/28/2003	-0.1	170.1	WATER
AD-02	3/17/2003	11.8	170.1	WATER
AD-02	1/13/2004	2.6	170.1	WATER
AD-02	2/18/2004	2.6	170.1	WATER
AD-02	12/9/2004	8.8	170.1	WATER
AD-02	2/23/2005	7.3	170.1	WATER
AD-02	3/24/2005	8.8	170.1	WATER
AD-02	12/7/2005	1.3	170.1	WATER
AD-02	1/25/2006	4.7	170.1	WATER
AD-02	2/24/2006	4.1	170.1	WATER
AD-02	3/31/2006	12.4	170.1	WATER
AD-02	12/6/2006	2.3	170.1	WATER
AD-02	1/25/2007	4.0	170.1	WATER
AD-02	3/2/2009	4.1	170.1	WATER
AD-02	2/1/2010	-0.2	170.1	WATER
AD-02	3/9/2010	8.6	170.1	WATER
AD-02	1/26/2011	0.4	170.1	WATER
AD-02	2/15/2011	1.8	170.1	WATER
AD-02	1/10/2012	5.0	170.1	WATER
AD-02	2/29/2012	10.4	170.1	WATER
AD-02	3/28/2012	18.0	170.1	WATER
AD-02	12/4/2012	11.3	170.1	WATER
AD-02	1/8/2013	0.4	170.1	WATER
AD-02	3/13/2013	7.4	170.1	WATER
AD-02	1/23/2014	-0.3	170.1	WATER
AD-02	2/24/2014	4.2	170.1	WATER
AD-02	1/26/2015	3.6	170.1	WATER
AD-02	3/11/2015	5.5	170.1	WATER
AD-02	12/1/2015	9.3	170.1	WATER
AD-02	1/25/2016	0.3	170.1	WATER
AD-02	2/17/2016	0.9	170.1	WATER
AD-02	3/29/2016	13.2	170.1	WATER
AK-02	1/8/2003	3.8	170.1	WATER
AK-02	2/19/2003	2.5	170.1	WATER
AK-02	3/20/2003	12.7	170.1	WATER
AK-02	12/2/2003	6.1	170.1	WATER
AK-02	1/29/2004	0.6	170.1	WATER
AK-02	3/10/2004	7.5	170.1	WATER
AK-02	1/10/2005	7.1	170.1	WATER

APPENDIX C
LEMONT REFINERY CHLORIDE DATA FOR THE WINTER MONTHS

ATTACHMENT 1

CHICAGO SANITARY & SHIP CANAL CHLORIDE LEVELS AT ROMEOVILLE, ABOVE LEMONT REFINERY OUTFALL

Influent Chloride,		Influent Chloride		Influent Chloride,		Influent Chloride,		Influent Chloride,		Influent Chloride,		Influent Chloride,		Influent Chloride,		Influent Chloride,		Influent Chloride		Influent Chloride		Influent Chloride		Influent Chloride		
Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	Date	mg/L	
1/10/05	835	1/2/06	330	1/1/07	174	1/7/08	562	1/2/09	342	1/1/10	344	01/03/11	369			1/1/2013	132	1/2/2014	390	1/1/2015	178	1/1/2016	523	1/2/2017	321	
1/12/05	492	1/6/06	320	1/5/07	158	1/11/08	272	1/5/09	297	1/4/10	350	01/07/11	391			1/3/2013	139	1/7/2014	593	1/6/2015	215	1/4/2016	660	1/6/2017	251	
1/13/05	580	1/9/06	314	1/8/07	113	1/18/08	270	1/9/09	270	1/6/10	301	01/10/11	291			1/8/2013	156	1/9/2014	670	1/8/2015	388	1/5/2016	233	1/9/2017	243	
1/14/05	274	1/13/06	276	1/12/07	133	1/21/08	256	1/12/09	300	1/8/10	278	01/14/11	288			1/10/2013	161	1/14/2014	720	1/13/2015	388	1/7/2016	229	1/13/2017	229	
1/17/05	242	1/16/06	226	1/15/07	250	1/25/08	252	1/16/09	436	1/11/10	223	01/17/11	407			1/15/2013	83	1/16/2014	600	1/15/2015	305	1/11/2016	248	1/16/2017	327	
1/19/05	250	1/20/06	215	1/19/07	239	1/28/08	514	1/19/09	470	1/15/10	311	01/21/11	264			1/17/2013	164	1/21/2014	520	1/20/2015	355	1/12/2016	251	1/20/2017	277	
1/21/05	235	1/23/06	220	1/22/07	203	2/1/08	556	1/23/09	331	1/18/10	267	01/24/11	521			1/22/2013	156	1/23/2014	610	1/22/2015	415	1/14/2016	244	1/23/2017	261	
1/24/05	430	1/27/06	413	1/26/07	384	2/4/08	625	1/26/09	282	1/22/10	297	01/28/11	277			1/24/2013	164	1/28/2014	465	1/27/2015	305	1/15/2016	256	1/27/2017	223	
1/31/05	634	1/30/06	308	1/29/07	286	2/8/08	896	1/30/09	224	1/25/10	342	01/31/11	348			1/29/2013	156	2/4/2014	400	1/29/2015	323	1/18/2016	313	1/30/2017	214	
2/4/05	413	2/3/06	288	2/2/07	225	2/11/08	848	2/2/09	298	1/29/10	281	02/04/11	353			1/31/2013	260	2/6/2014	372	2/3/2015	400	1/19/2016	332	2/3/2017	222	
2/11/05	416	2/6/06	252	2/5/07	227	2/15/08	666	2/6/09	214	2/1/10	310	02/07/11	305			2/5/2013	207	2/11/2014	420	2/5/2015	328	1/21/2016	255	2/6/2017	226	
2/14/05	364	2/10/06	243	2/9/07	181	2/18/08	488	2/9/09	270	2/5/10	259	02/11/11	425			2/7/2013	264	2/13/2014	360	2/9/2015	428	1/22/2016	244	2/10/2017	179	
2/25/05	307	2/13/06	238	2/12/07	224	2/22/08	351	2/13/09	402	2/8/10	305	02/14/11	805			2/12/2013	569	2/18/2014	288	2/10/2015	575	1/25/2016	240	2/13/2017	172	
3/7/05	283	2/17/06	251	2/16/07	181	2/25/08	376	2/16/09	355	2/12/10	283	02/18/11	1,099			2/14/2013	640	2/20/2014	242	2/12/2015	705	1/26/2016	241	2/17/2017	177	
3/11/05	286	2/20/06	276	2/19/07	895	2/29/08	299	2/20/09	310	2/15/10	833	02/21/11	504			2/19/2013	375	2/25/2014	635	2/13/2015	386	1/28/2016	228	2/20/2017	175	
3/14/05	277	2/24/06	249	2/23/07	549	3/3/08	460	2/23/09	344	2/19/10	446	02/25/11	366			2/21/2013	325	2/27/2014	525	2/16/2015	366	1/29/2016	216	2/24/2017	176	
3/21/05	300	2/27/06	484	2/26/07	600	3/7/08	396	2/27/09	376	2/26/10	648	02/28/11	423			2/26/2013	264	3/4/2014	402	2/17/2015	638	2/2/2016	238	2/27/2017	189	
3/25/05	272	3/3/06	200	3/2/07	734	3/10/08	364	3/2/09	255	3/1/10	559	03/04/11	401			2/28/2013	418	3/6/2014	425	2/19/2015	460	2/4/2016	198	3/3/2017	113	
3/28/05	270	3/17/06	209	3/5/07	616	3/14/08	333	3/6/09	881	3/3/10	580	03/07/11	336			3/5/2013	659	3/11/2014	487	2/24/2015	400	2/5/2016	222	3/6/2017	169	
4/4/05	240	3/20/06	201	3/9/07	395	3/17/08	316	3/9/09	187	3/5/10	528	03/11/11	341			3/7/2013	711	3/13/2014	530	2/26/2015	325	2/8/2016	256	3/10/2017	156	
4/8/05	232	3/31/06	189	3/12/07	250	3/21/08	301	3/13/09	198	3/8/10	422	03/14/11	353			3/12/2013	450	3/18/2014	582	3/3/2015	293	2/9/2016	232	3/13/2017	179	
4/11/05	221	4/3/06	208	3/16/07	350	3/24/08	294	3/16/09	237	3/12/10	343	03/18/11	348			3/14/2013	298	3/20/2014	408	3/5/2015	423	2/11/2016	192	3/17/2017	188	
4/15/05	200	4/7/06	189	3/19/07	340	3/28/08	388	3/20/09	252	3/19/10	536	03/21/11	266			3/19/2013	398	3/25/2014	428	3/10/2015	413	2/12/2016	218	3/20/2017	568	
4/18/05	199	4/10/06	183	3/23/07	281	3/31/08	413	3/23/09	249	3/22/10	261	03/25/11	273			3/21/2013	275	3/27/2014	452	3/12/2015	463	2/15/2016	280	3/24/2017	290	
4/22/05	197	4/14/06	188	3/23/07	281	4/4/08	333	3/27/09	245	3/22/10	261	03/28/11	252			3/26/2013	282			3/17/2015	438	2/16/2016	224	3/27/2017	281	
4/25/05	196	4/17/06	190	3/26/07	415	4/7/08	328	3/30/09	237	3/26/10	259	04/01/11	267			3/28/2013	345			3/19/2015	400	2/18/2016	212	3/31/2017	194	
4/29/05	184	4/21/06	128	3/30/07	258	4/11/08	275	4/3/09	225	3/29/10	285	04/04/11	201							3/20/2015	350	2/19/2016	215			
		4/24/06	154	4/2/07	252	4/14/08	247	4/6/09	228	4/2/10	266	04/08/11	264							3/23/2015	359	2/22/2016	389			
		4/28/06	102	4/6/07	238	4/18/08	158	4/10/09	210	4/5/10	248	04/11/11	218							3/24/2015	352	2/23/2016	296			
				4/9/07	232	4/21/08	266	4/13/09	231	4/9/10	187	04/15/11	221							3/30/2015	403	2/25/2016	292			
				4/13/07	214	4/25/08	251	4/17/09	214	4/12/10	192	04/18/11	237							4/3/2015	395	2/26/2016	393			
				4/16/07	242	4/28/08	242	4/20/09	240	4/16/10	210	04/22/11	186							4/6/2015	347	2/29/2016	296			
				4/20/07	259			4/24/09	218	4/19/10	215	04/25/11	164							4/10/2015	384	3/1/2016	456			
				4/23/07	241			4/27/09	220	4/23/10	218	04/29/11	155							4/13/2015	272	3/3/2016	387			
				4/27/07	136					4/26/10	191									4/17/2015	270	3/4/2016	382			
				4/27/07	138					4/30/10	197									4/20/2015	274	3/7/2016	369			
				4/30/07	169															4/24/2015	231	3/8/2016	384			
																				4/27/2015	245	3/10/2016	411			
11/4/05	146	11/3/06	134	11/2/07	111	11/3/08	145	11/2/09	72	11/1/10	104											3/11/2016	411			
11/7/05	126	11/6/06	149	11/5/07	122	11/7/08	146	11/6/09	111	11/5/10	107			12/4/2012	121	12/3/2013	168	12/2/2014	140	12/4/2015	124	3/14/2016	344			
11/11/05	105	11/13/06	118	11/9/07	120	11/10/08	152	11/9/09	158	11/8/10	684			12/6/2012	139	12/5/2013	165	12/4/2014	165	12/7/2015	114	3/15/2016	332			
11/14/05	132	11/17/06	108	11/12/07	127	11/14/08	116	11/11/09	134	11/12/10	121			12/11/2012	130	12/10/2013	176	12/9/2014	183	12/11/2015	191	3/17/2016	288			
11/18/05	110	11/20/06	128	11/16/07	130	11/17/08	147	11/13/09	137	11/15/10	870			12/13/2012	145	12/12/2013	166	12/11/2014	175	12/14/2015	198	3/18/2016	295			
11/21/05	116	11/24/06	140	11/19/07	128	11/21/08	149	11/16/09	151	11/19/10	123			12/18/2012	124	12/17/2013	238	12/16/2014	188	12/18/2015	165	3/21/2016	300			
11/25/05	126	11/27/06	143	11/23/07	122	11/24/08	154	11/20/09	137	11/22/10	142			12/20/2012	133	12/19/2013	233	12/18/2014	173	12/21/2015	142	3/22/2016	273			
11/28/05	128	12/1/06	105	11/26/07	100	11/28/08	149	11/23/09	133	11/26/10	111			12/24/2012	116	12/24/2013	455	12/23/2014	172	12/24/2015	146	3/24/2016	271			
12/2/05	146	12/4/06	14	11/30/07	103	12/1/08	155	11/27/09	145	11/29/10	87			12/27/2012	115	12/26/2013	428	12/25/2014	165	12/25/2015	904	3/25/2016	290			
12/5/05	130	12/8/06	185	12/7/07	261	12/5/08	133	11/30/09	119	12/3/10	91					12/31/2013	410	12/30/2014	165	12/28/2015	154	3/28/2016	214			
12/9/05	183	12/11/06	236	12/10/07	717	12/8/08	244	12/4/09	119	12/6/10	111									12/29/2015	145	3/29/2016	207			
12/12/05	192	12/15/06	249	12/14/07	854	12/12/08	272	12/7/09	143	12/10/10	205									12/31/2015	267	3/31/2016	202			
12/16/05	406	12/18/06	200	12/17/07	404	12/15/08	277	12/9/09	144	12/13/10	177															
12/19/05	284	12/22/06	198	12/21/07	998	12/19/08	313	12/11/09	286	12/17/10	316											12/5/2016	91			
12/23/05	295	12/25/06	129	12/24/07	814	12/22/08	337	12/14/09	275	12/20/10	316											12/9/2016	150			
12/26/05	253	12/29/06	139	12/28/07	488	12/26/08	448	12/18/09	301	12/24/10	259											12/16/2016	234			
12/30/05	357			12/31/07	412	12/29/08	385	12/21/09	259	12/27/10	326											12/23/2016	326			
								12/25/09	412	12/31/10	525											12/28/2016	361			
								12/28/09	424													12/30/2016	372			
																										Totals
Average	274		211		305		333		258		311		347		128		301		393		342		290		231	
Maximum	835		484		998		896		881		870		1,099		145		711		720		904		660		568	
# of days over 500	3		0		9		7		1		9		4		0		4		10		5		2		1	55
Total days	43		44		53		49		52		53		33		34		26		33		48		55		25	548
% of days over 500	7.0%		0%		17.0%		14.3%		1.9%		17.0%		12.1%		0.0%		15.4%		30%		10%		4%		4%	10%
# of days over 620	2		0		5		4		0		4		1		0		3		3		3		1		0	26
% of days over 620	5%		0		9%		8%		0%		8%		3%		0%		12%		9%		6%		2%		0%	5%

APPENDIX D
NEW ENGLAND BIOASSAY REPORTS
AND NATURAL HISTORY SURVEY REPORT

New England Bioassay

A Division of GZA

GEOTECHNICAL

ENVIRONMENTAL

ECOLOGICAL

WATER

CONSTRUCTION MANAGEMENT

77 Batson Drive
Manchester, CT 06042
T: 860.643.9560
F: 860.646.7169
www.nebio.com

AQUATIC TOXICITY TEST REPORT

Chronic Toxicity Testing at 10°C and 25°C Using *Ceriodaphnia dubia*

October 26, 2016

Report Prepared by:

New England Bioassay
A Division of GZA GeoEnvironmental, Inc.
77 Batson Dr.
Manchester, CT 06042

Report Submitted to:

Huff & Huff, a Subsidiary of GZA
915 Harger Road, Suite 330
Oak Brook, IL 60523

October 26, 2016

Huff & Huff, a Subsidiary of GZA
915 Harger Road, Suite 330
Oak Brook, IL 60523-1486

RE: Results of Chronic Tests
Sample ID: Reagent Grade NaC1 NEB
Project Number: 81.0220523.00

Dear Ms. Herrera:

This report provides you with the results of the experimental chronic toxicity tests performed at New England Bioassay (NEB) laboratory for Huff and Huff. The toxicity tests were performed using the freshwater organism *Ceriodaphnia dubia* as the aquatic test species.

Chronic Toxicity Test Methods

The specific details of the *C.dubia* chronic toxicity test system are based on EPA guidelines (EPA, 1994; 2002b). For the chronic toxicity tests, young *C.dubia* 24-h old at test initiation) were continuously exposed for 7 days under static-renewal conditions to 9 concentrations of reagent grade sodium chloride [0.75 g/L, 1.25 g/L, 1.75 g/L, 2.25 g/L, 2.75 g/L, 3.25 g/L, 3.75 g/L, 4.25 g/L, and 4.75 g/L NaC1] mixed with laboratory-prepared moderately hard synthetic water. A synthetic laboratory water control was also set concurrently with each test.

C. dubia were individually exposed in 30-mL plastic cups containing 15 mL of test solution or control water. Ten replicate beakers were used for each test concentration and the dilution-water control (10 animals per concentration or control). Daphnids used in testing were blocked by parentage for each replicate (i.e., young from a single female were used for all replicate #1, #2, etc).

Test beakers were maintained under the specified conditions (mean test temperature of either 25° ± 1°C or 10° ± 1°C; photoperiod 16 h light and 8 h dark for both tests) in commercial environmental test chambers. Surviving *Ceriodaphnia* were transferred daily with a large-bore pipette to newly prepared test solutions containing food.

Temperature, dissolved oxygen, pH, and specific conductivity were measured daily on composite samples of newly prepared solutions. Temperature, dissolved oxygen, and pH were measured on one replicate of the 24-h-old test solutions at each concentration. Observations on the number of live and dead (or immobilized) animals were made daily. Reproduction also was monitored daily by counting the number of live and dead young per female when the adults were transferred to new test solutions. Young were discarded after counting. A summary of the chronic testing protocols can be found in Attachment A. The results of the chronic toxicity tests can be found in Tables 1 and 2. Raw data sheets and statistical analysis are found in Attachment B.

TABLE 1. RESULTS OF A 7-DAY CERIODAPHNIA DUBIA CHRONIC TEST AT 25°C USING REAGENT GRADE SODIUM CHLORIDE MEDIAN LETHAL CONCENTRATIONS (LC5o), DAILY SURVIVAL, AND MEAN REPRODUCTIVE DATA

Test Species (Test ID No.)	Lcso[b] (g/L NaC1)	95% Confidence Limits LCLC	UCL[C]
Test Dates: 26 September — 3 October 2016			
C. dubia (16-1442)	48 h: 2.6 g/L	2.5 g/L	2.8 g/L
	168 h: 1.9 g/L	1.6 g/L	2.2 g/L

Test Concentration (gIL Naa)	Daily Survival (%) 1	2	3	4	5	6	7	Sig.[e]	N	Total Young/female[d] 7-d Reproductive Data X	Sig!
LAB CONTROL[a]	100	100	100	100	90	90	90		10	10.4	
0.75	100	100	100	100	100	100	100	NS	10	22.1	NS
1.25	100	100	100	100	100	100	100	NS	10	9.9	NS
1.75	100	100	90	60	60	60	60	NS	10	2.1	*
2.25	100	100	100	90	70	70	30		10	0.1	*
2.75	50	30	10	10	10	10	0	*	10	0.0	*
3.25	40	0	0	0	0	0	0	*	10	0.0	
3.75	0	0	0	0	0	0	0		10	0.0	*
4.25	0	0	0	0	0	0	0	*	10	0.0	*
4.75	0	0	0	0	0	0	0	*	10	0.0	*

a Lab control water was laboratory-prepared moderately hard fresh water.

b Test duration was 168 h (7 days) for C. dubia
c LCL: Lower confidence limit. UCL: Upper confidence limit;
d N: number of females at start of test (1 female/replicate and 10 replicates/concentration); X: Mean;
e Sig.: NS: not significant at 0.05; *: significant at 1.05.

TABLE 2. RESULTS OF A 7-DAY CERIODAPHNIA DUBIA CHRONIC TEST AT 10°C USING REAGENT GRADE SODIUM CHLORIDE MEDIAN LETHAL CONCENTRATIONS (LCso), DAILY SURVIVAL, AND MEAN REPRODUCTIVE DATA

Test Species (Test ID No.)	LCso[b] (g/L NaC1)	95% Confidence Limits LCL[e]	95% Confidence Limits UCL[C]
Test Dates: 26 September —3 October 2016			
C. dubia (16-1441)	48 h: 2.9 g/L	2.8 g/L	3.0 g/L
	168 h: 2.1 g/L	1.8 g/L	2.3g/L

Test Concentration (g/L NaCl)	Daily Survival (%) 1	2	3	4	5	6	7	Sig.[e]	7-d Reproductive Data: Total Young/female[d] N	X	Sig.[e]
LAB CONTROL[a]	100	100	100	100	100	100	100	---	10	0.0	
0.75	100	100	100	100	100	100	100	NS	10	0.0	
1.25	100	100	100	100	100	100	100	NS	10	0.0	
1.75	100	100	90	90	80	80	80	NS	10	0.0	
2.25	100	100	90	80	70	70	40	*	10	0.0	
2.75	100	80	60	40	10	10	0	*	10	0.0	
3.25	100	0	0	0	0	0	0	*	10	0.0	
3.75	80	0	0	0	0	0	0	*	10	0.0	
4.25	20	0	0	0	0	0	0	*	10	0.0	
4.75	0	0	0	0	0	0	0	*	10	0.0	

[a] Lab control water was laboratory-prepared moderately hard fresh water.

[b]Test duration was 168 h (7 days) for C. dubia
[c]LCL: Lower confidence limit. UCL: Upper confidence limit;
[d]N: number of females at start of test (1 female/replicate and 10 replicates/concentration); X: Mean;
[e]Sig.: NS: not significant at 0.05; *: significant at 0.05.

Quality Assurance

Prior to performing the chronic toxicity test at 10° C, NEB performed an acute test on 13 September 2016 using *Ceriodaphnia* to ascertain that the test organisms could successfully survive at the lower temperature. Survival of the organisms was 100% after 48 h (NEB Test ID 16-1302). Test results are included in Attachment B.

A reference toxicant test using sodium chloride (NaC1) was conducted with in-house cultured *C. dubia* during September 2016. The chronic IC25 value was 1.22 g/L NaC1 which was within the acceptability limits for NaCl at our laboratory. A copy of the cumulative-summation chart can be found in Attachment C.

Conclusions

The chronic aquatic toxicity tests performed with *Ceriodaphnia* using sodium chloride at the specified test temperatures of 10°C and 25°C showed similar 48-h and 7-day LC50 results as well as similar survival C-NOEC and C-LOEC levels. While survival results were very similar for both tests, the organisms in the 10°C test did not produce any young during the 7 day test period in the control water or in any of the NaCl test concentrations. In the 25°C test, the laboratory water controls produced young but failed to meet the minimum acceptability criteria for reproduction (an average of 15 young per female with 60% of females producing 3 broods of young during the test period). Young production in the 0.75 g/L test concentration averaged 22.1 young per female with lower reproduction numbers noted in the 1.25 g/L, 1.75 g/L, and 2.25 g/L test concentrations in the 25°C test.

If you have any questions concerning this report, please contact the Lab Manager, Kim Wills at (860) 858-3153 or kimberly.wills@gza.com

Very truly yours,

Kim Wills
Manager — Aquatic Toxicity Laboratory

Received, Clerk's Office 5/21/2018 ** R2018-032**

Attachment A

Chronic Toxicity Test Protocol Summary

CERIODAPHNL4 DUBIA AQUATIC TOXICITY TEST REPORT

Test Reference Manual: EPA 821-R-02-013, "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Water to Freshwater Organisms", Fourth Edition

Test Method: *Ceriodaphnia dubia* Survival and Reproduction Test — 1002.0

Test Type: Modified Chronic Static Renewal Freshwater Test

Temperature : 25 ± 1°C and 10 ± 1°C

Light Quality: Ambient Laboratory Illumination

Photoperiod: 16 hours light, 8 hours dark

Test Chamber Size: 30 mL

Test Solution Volume: Minimum 15 mL

Renewal of Test Solutions: Daily, using most recent sample

Age of Test Organisms: Less than 24 hours

Number of Neonates Per Test Chamber: 1

Number of Replicate Test Chambers Per Treatment: 10

Number of Neonates Per Test Concentration: 10

Feeding Regime: Fed 0.1 mL each of YCT and algal suspension per exposure chamber daily.

Aeration: None

Dilution Water: Moderately hard synthetic freshwater

Test Concentrations: 0, 0.75, 1.25, 1.75, 2.25, 2.75, 3.25, 3.75, 4.25, and 4.75 g/L

Test Duration: Until 60% of control females have three broods - 7 days

End Points: Survival and reproduction.

Test Acceptability: Control Survival: > 80% Yes X No
Control Reproduction: Average > 15/control female Yes No X

Test Organism Source: New England Bioassay in-house cultures

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Attachment B

Raw Data Sheets and Statistical Analysis

NEW ENGLAND BIOASSAY ACUTE TOXICITY DATA FORM
COVER SHEET

CLIENT:	GZA/Huff & Huff	*C.dubia* TEST ID #	16-1302
ADDRESS:	915 Harger Road, Suite 330	COC #	n/a
	Oak Brook, IL 60523-1486	PROJECT #	81.0220523.00
SAMPLE TYPE:	10°C control		

INVERTEBRATES

TEST SET UP (TECH INIT) CW
TEST SPECIES *Ceriodaphnia dubia*
NEB LOT# Cd16(9-13)
AGE < 24 hours
TEST SOLUTION VOLUME (m1s) 30
NO. ORGANISMS PER TEST CHAMBER 5
NO. ORGANISMS PER CONTROL 20

LABORATORY CONTROL WATER (MHRCF)			Hardness mg/L $CaCO_3$	Alkalinity mg/L $CaCO_3$
ARTIFICIAL FW:	NEB BATCH #	C36-MH011	88	60

	DATE	TIME
TEST START:	9/13/16	1512
TEST END:	9/15/16	1500

RESULTS OF *Ceriodaphnia dubia*

48hr Survival (%)	100%

NOEC: NO OBSERVABLE EFFECT CONCENTRATION

Comments: Please run control at 10°C

REVIEWD BY: [signature]

DATE:

NEW ENGLAND BIOASSAY

Reference Toxicity Test Data Sheet

NEB Test #: 16-1302

Organism Age: <24 hours

Facility Name: New England Bioassay

Test Duration: 48 (hours)

Test Organism *Ceriodaphnia dubia*

Beginning Date: 9/13/16 Time: 1512

Sample ID: Huff and Huff 10° Control

Control Water Source: Laboratory Synthetic

.3ontrol Hardness: 88 ppm as $CaCO_3$

NaCl Conc. g/L	**Number of Surviving Organisms**			**Dissolved Oxygen (mg/L)**			**Temperature (°C)**			**pH**		
Initials	CW	KO	PD	CW	KO	PD	CW	KO	PD	CW	KO	PD
_	0	24	48	0	24	48	0	24	48	0	24	48
Control A	5	5	5	9.5	12.0	11.3	9.0	10.9	11.0	7.8	7.7	7.9
B	5	5	5			11.3			11.0			7.9
C	5	5	5			11.4			11 0			7.9
D	5	5	5			11.3			11.0			8.0

NEW ENGLAND BIOASSAY TOXICITY DATA FORM CHRONIC

COVER SHEET

CLIENT: GZA/Huff & Huff

ADDRESS: 915 Harger Road, Suite 330

Oak Brook, IL 60523-1486

SAMPLE TYPE: Sodium Chloride run at 10 degrees C

DILUTION WATER: Moderately Hard Lab Water

C.dubia TEST ID # 16-1441

COC # N/A

PROJECT # 81.0220523.00

INVERTEBRATES

TEST SET UP (TECH INIT) KO

TEST SPECIES *Ceriodaphnia dubia* NEB

LOT# Cd16 (RMH 21)

AGE < 24 hours

TEST SOLUTION VOLUME (mis) 15

NO. ORGANISMS PER TEST CHAMBER

NO. ORGANISMS PER CONCENTRATION 10

Laboratory Control Water (MHRCF)

Batch Number	Hardness mg/L $CaCO_3$	Alkalinity mg/L $CaCO_3$
C36-MH012	88	60

	DATE	TIME
TEST START:	9/26/16	1420
TEST END:	10/3/16	1557

Results of *Ceriodaphnia dubia* Chronic Test

		95% Confidence Limits
48 Hour LC50	2.9 g/L	2.8 g/L - 3.0 g/L
7 Day LC50 Survival	2.1 g/L	1.8 o_, _ 2.3 g/L
NOEC Survival LOEC	1.75 g/L	
Reproduction **NOE**L	2.25 g/L	
Reproduction LOEC	<0.75 g.L	
Reproduction IC25	0.75 g/L	
	Not estimated	

NOEC: NO OBSERVABLE EFFECT CONCENTRATI(LOEC: LOWEST OBSERVABLE EFFECT CONCENTRATION Comments:

REVIEWD BY: is

DATE: /610'Ce

NEW ENGLAND BIOASSAY - CHRONIC TOXICITY TEST BROOD DATA SHEET

CLIENT/SAMPLE: GZA/Huff & Huff - Sodium Chloride			
NEB PROJECT NUMBER: 81.0220523.00	NEB TEST NUMBER: 16-1441		COC#
TEST ORGANISM: *Ceriodaphnia dubia*	AGE: <24 hours		Lot # Cd16 (RMH 21)
START DATE: 9/26/16	TIME: 1420	END DATE: 10/3/16	TIME:

Effluent Concentration (g/L)	Culture Lot# Cd16 (RMH 21) Cup #	B2	B3	B4	B5	B6	B7	B8	B9	B10	I B11	Total Young	# Live Adults	Analyst-Transfer	Analyst-Counts
	Day Number	A	B	C	D	E	F	G	H	I	J				
NEB Lab Synthetic Diluent	0	V	V		VI./			VV	V		V./		10	KO	
	1	V	V	V	V	V	V	V	V	V	V		10	PD	
	2	V	V	V	V	V	V	V	V	V	V	0	10	KO	
	3	V	V	V	V	V	V	V	V	V	V	0	10	ER	ER
	4	V	V	1	V	V	1	1	V	1	V	0	10	PD	PD
	5	V		11			VIVI		1	1	1	0	10	CW	CW
	6	1	V	1	1	V	1	1	V	1	1	0	10	CB	CB
	7	V	V	V	V	V	I	1	1	V	V	0	10	KO	KO
														KO	KO
	totals	0	0	0	0	0	0	0	0	0	0	0	10		MG
0.75		A	B	C	D	E	F	G	H	I	J				
	0	V	V	V	I	V	V	V	./	V	V		10		
	1	V	V	V	V	V	V	V	V	V	V		10		
	2	V	V	V	V	V	V	V	V	V	V	0	10		
	3	V	I	V	V	V	V	V	V	V	V	0	10		
	4	V		1./	1	1	1	1	1		VI	0	10		
	5	1	1	I	1		11	V	V	1	V	0	10		
	6	1	1			VIIII			V	V	1	0	10		
	7	1	1	1	1	1	V	1	V	1	1	0	10		
	totals	0	0	0 I	0	0	0	0	0	0	0	0	10		
1.25		A	B	C	D	E	F	G	H	I	J				
	0	V	V	V	V	V	V	V	V	V	V		10		
	1	V	I	V	V	V	V	V	V	V	V		10		
	2	V	V	V	V	V	V	.7	V	V	V	0	10		
	3	V	V	./	V	V	V	V	V	I	V	0	10		
	4	V	1	1	1	1	1	1	1	V	1	0	10		
	5	1	1	1	I	1	1	1	1	1	1/x	0	9		
	6		VI	1	1	1	1	1	1	1	X	0	9		
	7	1	1	1	VI		1	1	1		IX	0	9		
	totals	0	0	0	0	0	0 ,_	0	0	0	0	0	9		

Notes:

Received, Clerk's Office 5/21/2018 ** R2018-032**

FACILITY NAME & ADDRESS: GZA/Huff & Huff - Sodium Chloride

NEB PROJECT NUMBER: 81.0220523.00 ORGANISM: *Ceriodaphnia dubia* STARTDATE: 9/26/16

Effluent Concentration	Day Number	A	B	C	D	E I	F	G	H	I	J	Total !Ave Young	# Live Adults	Analyst-Transfer	Analyst-Counts
1.75	0	V	V	V	V	V	V	V	V	V	V		10		
	1	V	V		VJ	V	V	V	V	V	V		10		
	2	V	V	V	V	V	V	V	V	V	V	0	10		
	3	V	V		VEV		V	V	V	V	V	0	9		
	4		1./		1X		./../	1	1		1..i	0	9		
	5	V	V	V	X	V	V/x	V	V	V	1	0	8		
	6	V	V	../	X	V	X	V	V	V	V	0	8		
	7	V	V	1	X	V	X	V	V	V	V	0	8		
	totals	0	0	0	0	0	0	0	0	0	0	0	8		
		A	B		CD	E	F	G	H	I	J				
2.25	0	V	V	V	V	V	V	V	V	V	V		10		
	i	V	V	V		./../	V	V	V	V	V		10		
	2	V	V	V	V	V	V	V	V	V	V	0	10		
	3	V	V	V	V	V	V	V		VEIVV		0	9		
	4				1.7/xIIII				I	X	1	0	8		
	5	1	X	I	si/x	1	1	1	1	X	1	0	7		
	6			1XJXJ				1./	I	X	1	0	7		
	7					1XIXJ/xII					X.//x	0	4		
	totals	0	0	0	0	0	0	0	0	0	0	0	4		
		A	B		CD	E	F	G	H	I	J				
2.75	0	V	V	V	V	V	V	V	V	V	V		10		
	1	V	V	V	V	V	V	V	V	V	V		10		
	2	V	V	V	EV	V	V	V	IV	V	V	0	8		
	3	V	EV	V	X	V	V	V	X	ED V	V	0	6		
	4	1	X	I	X	I	1/x	1/x	X	X	1	0	4		
	5	J/x	X	I	X	..//x	X	X	X	X	1/x	0	1		
	6	X	X	I	X	X	X	X	X	X	X	0	1		
	7	X		XJ/x		X	X	X	X	X	X	0	0		
												0			
	totals	0	0	0	0	0	0	0	0	0	0	0	0		
		A	B		CD	E	F	G	H	I	J				
3.25	0	V	V	V	V	V	V	V	V	V	V		10		
	1	V	V	V	V	V	V	V	V	V	V		10		
	2	EV	EV	IV	EIV	EV	IV	EIV	EV	EIV	EV	0	0		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4	X	X.	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		

NEW ENGLAND BIOASSAY - CHRONIC TOXICITY TEST BROOD DATA SHEET

FACILITY NAME & ADDRESS: GZA/Huff & Huff - Sodium Chloride

NEB PROJECT NUMBER: 81.0220523.00 ORGANISM: *Ceriodaphnia dubia* [START DATE: 9/26/16

Effluent Concentration	Day Number	A	B	C	D	E	F	G	H	I	J	Total Live Young	# Live Adults	Analyst-Transfer	Analyst-Counts
3.75	0	V	V	V	V	V	V	V	V		V./		10		
	1	V	V			VIOV			V	V	V		8		
	2	EV	EV	DV	OV	X	EV	X	EV	EV	EV	0	0		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0_	0	0		000		0		
		A	B	C	D	E	F	G	H	I	J				
4.25	0	V	V			VVV1			V		V./		10		
	1	**El**	**El**	**E**	**,f**	**1**	**El**	**0**	**El**	**El**	**0**		2		
	2	X	X	X	El,/	EV	X	X	X	X	**X**	**0**	**0**		
	3	X	X	X	X	X	X	X	X	X	X	0	**0**		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	, 0	0	0	0		00	0	0		
		A	B	C	D	E	F	G	H	**I**	**J**				
4.75	**0**	**V**	**V**	**V**	**V**	**V**	**V**	**V**	**V**	**V**	**V**		**10**		
	1	**E**	**El**				**EEE**			**0E10**			**0**		
	2	X	X	X	X	X	X	X	X	X	X	0	**0**		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	**0**		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	**0**		
	totals				0000000				0	00		0	0		

NEB'S DATA SHEET FOR ROUTINE CHEMICAL AND PHYSICAL DETERMINATIONS

CLIENT/SAMPLE: GZA/Huff & Huff - Sodium Chloride
NEB PROJECT NUMBER: 81.0220523.00 TEST ORGANISM *Ceriadaphnia dubia*
DILUTION WATER SOURCE: Moderately Hard Lab Water START DATE: 9/26/16 TIME: 1420

ANALYST	KO	- PD	KO	ER	PD	CW	CB	
NEB Lab Synthetic Diluent - w	1	2	3	4	5	6	7	Remarks
Temp °C Initial	10.9	11.0	11.0	11.0	11.0	11.0	11.0	
D.O. mg/L Initial	9.4	9.8	9.4	9.6	9.4	9.4	10.1	
pH s.u. Initial	7.9	7.8	8.8	8.4	7.7	8.3	8.1	
Conductivity pS Initial	339	335	329	424	327	331	331	
Temp °C Final	11.0	11.0	11.0	9.5	11.0	11.0	11.0	
D.O. mg/L Final	12.0	11.4	10.3	11.3	10.7	12.2	11.1	
,pH s.u. Final	8.3	8.1	8.7	8.2	8.4	8.2	8.7	
Conductivity µS Final	372	358	410	352	356	345	341	
0.75 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	10.5	11.0	11.0	11.0	11.0	11.0	9.9	
D.O. mg/L Initial	9.5 _	10.0	9.5	9.6	9.5	9.7	10.1	
pH s.u. Initial	7.9	7.8	7.9	8.3	7.9	8.3	8.1	
Conductivity pS Initial	1,830	1,865	1,817	1,805	1,836	1,866	1,888	
Temp °C Final	11.0	11.0	11.0	9.0	10.6	11.0	11.0	
D.O. mg/L Final	12.2	11.4	11.0	12.3	11.8	12.3	11.9	
pH s.u. Final	8.5	8.1	8.5	8.3	8.4	8.3	8.6	
`Conductivity µS Final	1,757	1,812	1,797	1,803	1,833	1,819	1,817	
1.25 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	10.4	10.7	11.0	11.0	11.0	10.9	10.0	
D.O. mg/L Initial	9.6	10.2	9.5	9.5 _	9.6	9.7	10.1	
pH s.u. Initial	7.9	7.9	8.0	8.2	8.0	8.2	8.0	
Conductivity µS Initial	2,831	2,871	2,808	2,787	2,842	2,780	2,808	
Temp °C Final	11.0	11.0	11.0	9.0	10.4	11.0	11.0	
D.O. mg/L Final	12.3	11.4	11.1	12.7	12.1	12.5	12.2	
pH s.u. Final	8.5	8.1	8.5	8.2	8.5	8.3	8.6	
Conductivity pS Final	2,711	2,775	2,753	2,812	2,804	2,716	2,727	
1.75 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	10.1	10.3	11.0	11.0	11.0	10.9	10.0	
D.O. mg/L Initial	9.6	10.3	9.5	9.6	9.6	9.7	10.2	
pH s.u. Initial	8.0	7.9	8.0	8.2	8.0	8.2	8.0	
Conductivity pS Initial	3,813	3,861	3,730	3,758	3,760	3,670	3,791	
Temp °C Final	11.0	11.0	11.0	9.0	10.3	11.0	11.0	
D.O. mg/L Final	12.2	11.6	11.2	12.8	12.4	12.7	12.3	
pH s.u. Final	8.4	8.2	8.5	8.3	8.5	8.4	8.6	
Conductivity pS Final	3,652	3,776	3,668	3,716	3,723	3,587	3,579	

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NEWS DATA SHEET FOR ROUTINE CHEMICAL AND PHYSICAL DETERMINATIONS

FACILITY NAME & ADDRESS: NEB GZA/Huff & Huff - Sodium Chloride

PROJECT NUMBER: DILUTION WATER 81.0220523.00 TEST ORGANISM START *Ceriodaphnia dubia*

SOURCE: Moderately Hard Lab Water DATE: 9/26/16 TIME: 1420

2.25 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	10.3	10.4	11.0	11.0	10.9	10.8	10.0	
D.O. mg/L Initial	9.6	10.3	9.6	9.6	9.6	9.7	10.2	
pH s.u. Initial	8.0	7.9	8.0	8.2	8.0	8.2	8.0	
Conductivity pS Initial	4,808	4,736	4,730		4,807 L 4,650	4,708	4,799	
Temp °C Final	11.0	11.0	11.0	I 9.0	11.0	11.0	11.0	
D.O. m/L Final -	12.2	11.5	11.4	12.9	12.6	12.6	12.2	
pH s.u. Final	8.5	8.3	8.5	8.3	8.6	8.4	8.6	
Conductivity pS Final	4,483	4,384	4,731	4,603	4,613	4,455	4,650	

2.75 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	10.8	11.0	11.0	11.0	11.0	10.7	10.0	
D.O. mg/L Initial	9.9	10.1	9.9	9.8	9.6	9.9	10.2	
pH s.u. Initial	8.0	7.8	8.0	8.1	8.0	8.2	8.0	
Conductivity pS Initial	5,270	5,485	5,710	5,623	5,670	5,586	5,646	
Temp °C Final	11.0	11.0	11.0	9.0	11.0	11.0	11.0	
D.O. mg/L Final	12.1	11.5	11.3	12.7	12.5	12.8	12.3	
pH s.u. _ Final	8.5	8.1	8.5	8.3	8.7	8.5	8.6	
Conductivity pS Final	4,956	5,487	5,427	5,390	5,473	5,398	5,420	

3.25 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	10.9	11.0	11.0					
D.O. mg/L Initial	9.7	10.0	9.6					
pH s.u. Initial	8.0	7.8	8.0					
Conductivity pS Initial	6,522	6,546	6,540					
Temp °C Final	11.0	11.0						
D.O. mg/L Final	12.1	11.5						
pH s.u. Final	8.5	8.3						
Conductivity pS Final	6,183	6,254						

3.75 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	11.0	11.0	11.0					
D.O. mg/L Initial	9.8	9.9	9.6					
pH s.u. Initial	8.0	7.9	8.0					
Conductivity pS Initial	7,521	7,480	7,480					
Temp °C Final	11.0	11.0						
D.O. mg/L Final	12.1	11.7						
pH s.u. Final	8.4	8.4						
Conductivity pS Final	7,224	7.197						

Table of Random Permutations of 16 **C.dubia Test ID# 16-1441**

7	12	15	15	1	2	7	16	10	2	14	15	7	13	13	10	6	1	8	10
13	3	8	16	7	10	11	10	13	5	11	7	13	16	7	7	5	13	2	14
3	1	4	5	14	13	3	14	9	13	13	2	9	15	6	2	8	4	5	8
11	8	16	14	15	6	2	6	2	16	8	5	12	3	9	13	4	3	10	4
14	9	1	6	3	9	14	13	8	6	5	8	14	7	3	15	13	11	4	7
2	16	10	13	5	5	13	2	11	7	3	12	5	14	12	16	2	2	9	15
4	6	13	7	2	15	1	9	1	4	7	10	6	9	11	9	7	6	16	11
6	14	6	10	4	14	4	15	3	3	4	16	2	6	5	1	12	10	6	9
10	15	2	1	13	12	16	3	4	8	10	1	15	5	14	12	14	12	3	2
12	10	7	12	9	11	9	8	12	14	15	4	11	8	16	8	9	14	14	1
15	7	5	2	10	7	8	12	6	15	6	13	16	12	15	4	11	8	12	6
16	2	11	8	8	8	15	5	16	1	1	9	8	1	8	14	16	5	13	5
9	13	14	3	6	4	10	11	5	12	9	3	10	4	4	3	10	9	1	3
8	11	9	4	11	3	12	7	7	10	12	14	3	10	1	6	15	16	15	12
1	5	12	11	16	16	5	4	14	9	16	11	1	2	10	5	1	15	7	13
5	4	3	9	12	1	6	1	15	11	2	6	4	11	2	11	3	7	11	16

11	8	16	5	5	13	1	13	2	16	14	12	9	8	7	5	13	3	13	3
2	2	8	8	14	16	4	3	8	11	10	14	15	1	2	11	4	5	15	9
6	13	2	13	6	5	9	15	11	10	12	6	16	15	16	9	10	12	16	15
14	12	4	16	16	11	14	10	5	12	3	3	12	14	15	13	6	4	1	16
8	6	3	9	4	10	6	4	16	2	2	9	8	16	4	6	5	15	7	8
9	15	12	10	3	2	12	6	1	15	4	13	7	7	9	12	14	8	8	11
3	10	11	12	13	12	5	11	7	8	9	5	14	11	10	1	3	13	3	5
16	1	13	14	8	14	15	5	3	7	11	15	6	12	5	7	11	1	14	4
1	14	14	2	9	15	16	14	6	14	7	8	3	13	11	8	7	7	12	7
4	4	6	4	12	3	11	8	15	9	8	1	13	6	3	3	15	9	9	12
15	5	1	11	10	6	3	7	10	5	5	11	10	10	12	15	16	14	5	2
5	3	5	6	7	7	13	2	14	3	16	4	5	5	13	4	9	16	2	6
12	7	15	15	15	9	8	12	12	13	15	10	1	4	6	16	2	6	11	1
10	11	10	3	2	4	2	1	4	6	6	7	11	9	14	10	8	11	4	13
7	9	7	7	11	1	7	16	13	1	13	2	4	2	1	2	12	2	10	14
13	16	9	1	1	8	10	9	9	4	1	16	2	3	8	14	1	10	6	10

1	6	7	4	8	6	5	2	8	15	4	6	6	1	4	5	7	13	2	10
9	15	11	3	11	15	9	10	1	3	8	2	15	7	9	8	16	1	14	3
10	16	4	5	12	9	16	11	7	1	7	16	11	8	3	3	12	2	3	4
4	14	1	9	5	5	4	13	6	8	15	5	12	5	7	16	5	11	8	1
7	3	13	14	15	2	1	14	16	5	14	9	2	16	1	12	6	14	4	13
16	11	2	1	14	16	6	9	3	4	16	14	3	15	11	11	3	9	12	5
3	10	16	16	13	7	13	1	11	14	9	10	16	2	10	2	10	7	10	16
11	13	9	13	4	13	8	3	5	13	10	12	5	12	5	14	13	16	5	6
15	2	3	12	9	12	2	4	13	10	3	13	14	4	2	1	14	8	6	12
14	1	14	6	10	1	3	12	4	2	2	4	13	3	16	9	9	3	7	14
13	12	5	11	3	11	15	8	2	7	11	7	8	14	6	4	4	4	15	11
12	5	10	7	2	14	7	15	14	16	13	1	9	10	12	10	11	10	9	8
8	9	8	10	6	4	11	7	10	11	6	8	4	9	8	15	8	6	11	9
2	7	6	2	1	8	10	6	15	12	1	11	7	11	13	6	1	15	13	15
6	4	15	8	16	10	14	16	9	6	12	3	10	6	14	7	2	12	16	7
5	8	12	15	7	3	12	5	12	9	5	15	1	13	15	13	15	5	1	2

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13	4	10	4	16	13	16	13	5	3	6	14	1	16	8	7	2	3	3	12
5	14	4	6	8	2	15	1	13	14	16	4	15	4	3	12	12	1	4	7
2	2	2	15	14	16	9	12	16	6	10	15	14	9	10	1	14	8	8	16
7	12	15	8	12	3	5	14	7	12	5	13	16	1	7	5	11	2	9	3
6	9	7	14	9	14	10	11	15	11	12	1	12	12	14	16	3	11	11	8
14	5	16	7	10	8	11	8	14	13	7	11	6	3	11	4	4	6	6	9
15	11	8	9	7	12	8	7	1	15	9	3	3	7	13	11	10	4	5	1
11	6	6	1	4	1	3	16	12	5	4	9	13	13	6	8	15	9	1	14
4	10	3	16	2	11	7	9	6	9	1	8	4	11	5	2	16	10	12	4
1	8	1	13	1	15	4	4	11	4	2	16	5	8	1	9	5	12	16	6
9	7	14	2	6	4	14	10	9	8	15	10	7	10	9	10	6	14	10	11
12	1	9	10	15	5	2	15	10	2	14	2	8	2	4	13	8	5	15	5
3	3	12	11	5	9	6	6	3	10	13	12	9	6	2	15	7	15	7	13
10	15	11	5	13	7	12	5	2	7	11	5	10	15	12	3	1	13	13	10
8	13	13	3	3	10	13	2	4	1	8	6	11	14	15	6	9	16	2	2
16	16	5	12	11	6	1	3	8	16	3	7	2	5	16	14	13	7	14	15

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Ceriodaphnia dubia Culture Chart Pt # (z)CV-H-13u)

Brood mother source: (2-t4 N 2 GS' (3-1-\ Source's brood size: \ (Qty.) q-242-R,

Tech	PLG\		IACi	leic-	A- 0	ikti	A-0	ik-Or			Sir 1	-A1-t				
Date	0.1U		01–\S	11e	ci -0	"24	L I'22	1.25			9–)..C	.:.,.2c;				
Day acc.	0	1	2	3	4	5	6	7		8	9	10	11	12	13	14
ci Inlt																
1	N	N	Ni 1	Ai	iI	9';	N	si	1		Y					
2	N	N	\)	A	LI 1		N	Y	2		\1(	T1 Y-2-1)				
3	N	N	f \-) /1,		-3	-7	NiY		3			1 '7--7"				
4	N	N	N.,	Ni,	3	.---	NJ	y	4		"(	i3 -1 i ss				
5	N	N	N.)	N	LI	-7	k	\ ('	5			1-9 1'r;				
6	N	N	IV	A'	-3)7		.6/	y	6		/(	T \I (9	'			
7	N	N	\)	AI	(1	7	ki	y		7'	YI	-r z •				
8	N	N	1)		5	c I ,	iv	\(	8		y	T-1		,		
9	N	N				7	Ai	y ,	9	....	Y	'/2.z				
10	N	N	1\)	N	L-f	7	Ai	y	10		Y	Tci / 2-				i
11	N	N	K..)	N	---- s-)	cy	j1/4,;	\i	11		Y	TIC y1,7				
12	N	N	1\1	N	C			/	12		Y					
13	N	N	I'\)	i\)	`"(	-1	N	\) /	13		V	Y			_1	

Y = neonates present, and *criterion has been met* 20 neonates produced in otal by 3rd brood. N = no neonates

2B = two broods present. 2Y = two broods and criterion met: 20 neos by 3rd brood. X = brood mother dead ae = aborted eggs

✓ or P = neonates present after renewal on previous day (see time in log) = acceptable for acute testing only

T# = neonates used in test, replicate number of test noted (and brood counted). acc = *if acclimated* , H_2O type used w/ renewal this day

Test organism collection.

Project #	Symbols (✓ / P)	Tray diagram used? (Y/N)	Time period, neonates released	Collection date / time
Prt.."CC (0 ..'	T .	y	c -it> -I t 7 -1 - — c 2 6,- ilgy r 4 Si-e	2 1C-
	T i			
	T			
	T			
	T			
	T			

CETIS Analytical Report

Report Date: 18 Oct-16 11:59 (p 1 of 2)
Test Code: 16-1441 I 01-3095-9215

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 12-8279-8956
Analyzed: 18 Oct-16 11:40
Endpoint: 2d Survival Rate
Analysis: Untrimmed Spearman-Karber
CETIS Version: CETISv1.9 2
Official Results: Yes

Batch ID: 16-2170-0149
Start Date: 26 Sep-16 14:20
Ending Date: 03 Oct-16 15:57
Duration: 7d 2h
Test Type: Reproduction-Survival (7d)
Protocol: EPA/821/R-02-013 (2002)
Species: Ceriodaphnia dubia
Source: In-House Culture
Analyst:
Diluent: Laboratory Water
Brine: Not Applicable
Age: <24H

Sample ID: 18-9022-1325
Sample Date: 26 Sep-16
Receipt Date: 26 Sep-16
Sample Age: 14h
Code: 70AA7DOD
Material: Sodium chloride
Source: Huff & Huff
Station:
Client: GZA GeoEnvironmental
Project:

Spearman-Karber Estimates

Threshold Option	Threshold	Trim	Mu	Sigma	LC50	95% LCL	95% UCL
Control Threshold	0	0.00%	0.4596	0.0101	2.882	2.751	3.019

2d Survival Rate Summary

Calculated Variate(A/B)

Conc-gm/L	Code	Count	Mean	Min	Max	Std Err	Std Dev	CV%	%Effect	A	
0	**D**	10	1 0000	1.0000	1 0000	0.0000	0.0000	0.00%	0.0%	10	10
0 75		10	1 0000	1.0000	1.0000	0 0000	0.0000	0.00%	0.0%	10	10
1 25		10	1 0000	1.0000	1.0000	0 0000	0.0000	0.00%	0 0%	10	10
1.75		10	1.0000	1.0000	1.0000	0.0000	0.0000	0 00%	0 0%	10	10
2.25		10	1.0000	t0000	1 0000	0 0000	0.0000	0.00%	0.0%	10	10
2.75		10	0.8000	0.0000	1 0000	0.1333	0.4216	52.70%	20.0%	8	10
3.25		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
3.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
4.25		10	0 0000	0.0000	0 0000	0.0000	0.0000		100.0%	0	10
4.75		10	0 0000	0.0000	0.0000	0 0000	0.0000		100.0%	0	10

2d Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1 0000	1 0000	1.0000	1 0000	1 0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.75		1.0000	1.0000	1.0000	1 0000	1 0000	1.0000	1 0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.75		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1.0000
2.25		1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2.75		1.0000	1.0000	1.0000	0.0000	1.0000	1 0000	1.0000	0.0000	1.0000	1.0000
3.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.75		0 0000	0.0000	0 0000	0.0000	0 0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0 0000
4.75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

2d Survival Rate Binomials

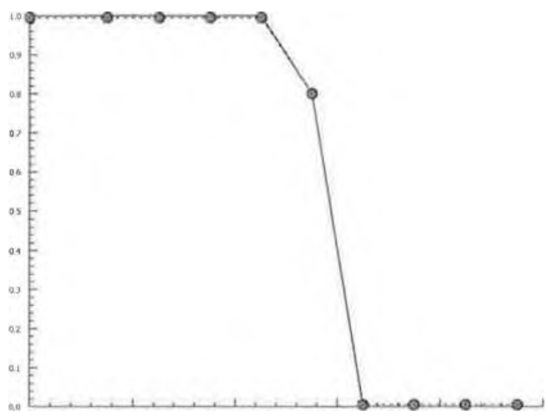
Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
0.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
2.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
2 75		0/1	1/1	1/1	0/1	1/1	1/1	1/1	0/1	0/1	1/1
3.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
3.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1

Received, Clerk's Office 5/21/2018 ** R2018-032**

Ceriodaphnia 7-d Survival and Reproduction Test | **New England Bioassay**

Analysis ID:	12-8279-8956	**Endpoint:**	2d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	18 Oct-16 11:40	**Analysis:**	Untrimmed Spearman-Karber	**Official Results:**	Yes

Graphics



CETIS Analytical Report

Report Date: 18 Oct-16 11:58 (p 1 of 3)
Test Code: 16-1441 I 01-3095-9215

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 20-5577-3980 | **Endpoint:** 7d Survival Rate | **CETIS Version:** CETISv1.9.2
Analyzed: 18 Oct-16 11:41 | **Analysis:** Linear Regression (GLM) | **Official Results:** Yes

Batch ID: 16-2170-0149 | **Test Type:** Reproduction-Survival (7d) | **Analyst:**
Start Date: 26 Sep-16 14:20 | **Protocol:** EPA/821/R-02-013 (2002) | **Diluent:** Laboratory Water
Ending Date: 03 Oct-16 15:57 | **Species:** Ceriodaphnia dubia | **Brine:** Not Applicable
Duration: 7d 2h | **Source:** In-House Culture | **Age:** <24H

Sample ID: 18-9022-1325 | **Code:** 70AA7DOD | **Client:** GZA GeoEnvironmental
Sample Date: 26 Sep-16 | **Material.** Sodium chloride | **Project:**
Receipt Date: 26 Sep-16 | **Source:** Huff & Huff
Sample Age: 14h | **Station:**

Linear Regression Options

Model Name	Link Function	Threshold Option	Thresh	Optimized	Pooled	Het Corr	Weighted
Log-Normal (Probit)	q=inv i:D[Tr]	Control Threshold	0.000001	Yes	Yes	No	Yes

Regression Summary

Iters	LL	AICc	BIC	Mu	Sigma	Adj R2	F Stat	Critical	P-Value	Decision(a:5%)
80	-5.318	20.64	17.54	0.3199	0.06671	0 9929				Lack of Fit Not Tested

Point Estimates

Level	gm/L	95% LCL	95% UCL
LC50	2 089	1.8	2 306

Test Acceptability Criteria — **TAC Limits**

Attribute	Test Stat	Lower	Upper	Overlap	Decision
Control Resp	1	0.8	>>	Yes	Passes Criteria

Regression Parameters

Parameter	Estimate	Std Error	95% LCL	95% UCL	t Stat	P-Value	Decision(a:5%)
Threshold	0.03515	0.0337	-0.03091	0.1012	1 043	0.3317	Non-Significant Parameter
Slope	14.99	4.423	6.322	23 66	3.389	0.0116	Significant Parameter
Intercept	-4 796	1.531	-7.797	-1.794	-3.131	0.0166	Significant Parameter

ANOVA Table

Source	Sum Squares	Mean Square	DF	F Stat	P-Value	Decision(a:5%)
Model	526	263	2	629.9	<1.0E-37	Significant
Residual	2.923	0.4175	7			

Residual Analysis

Attribute	Method	Test Stat	Critical	P-Value	Decision(a:5%)
Goodness-of-Fit	Pearson Chi-Sq GOF Test	2 922	14.07	0.8921	Non-Significant Heterogeneity
	Likelihood Ratio GOF Test	3.578	14.07	0.8269	Non-Significant Heterogeneity
Distribution	Shapiro-Wilk W Normality Test	0 9274	0 7607	0.4225	Normal Distribution
	Anderson-Darling A2 Normality Te	0.4009	2.492	0.3653	Normal Distribution

7d Survival Rate Summary — **Calculated Variate(A/B)**

Conc-gm/L	Code	Count	Mean	Min	Max	Std Err	Std Dev	CV%	%Effect	A	B
0	D	10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
0 75		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
1.25		10	0.9000	0.0000	1 0000	0 1000	0.3162	35.14%	10.0%	9	10
1.75		10	0.8000	0.0000	1.0000	0.1333	0.4216	52.70%	20.0%	8	10
2.25		10	0.4000	0 0000	1.0000	0 1633	0 5164	129.10%	60.0%	4	10
2.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
3.25		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
3.75		10	0 0000	0.0000	0 0000	0.0000	0 0000		100.0%	0	10
4.25		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
4.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10

Ceriodaphnia 7-d Survival and Reproduction Test | **New England Bioassay**

Analysis ID: 20-5577-3980 | **Endpoint:** 7d Survival Rate | **CETIS Version:** CETISv1.9.2
Analyzed: 18 Oct-16 11:41 | **Analysis:** Linear Regression (GLM) | **Official Results:** Yes

7d Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1.0000	1.0000	1 0000	1 0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.75		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1.0000	1 0000
1.25		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0 0000
1.75		1 0000	1 0000	1.0000	0.0000	1 0000	0 0000	1 0000	1 0000	1.0000	1.0000
2.25		1 0000	0 0000	1.0000	0.0000	0.0000	1 0000	1.0000	0 0000	0.0000	0.0000
2 75		0.0000	0.0000	0 0000	0.0000	0.0000	0 0000	0,0000	0.0000	0.0000	0.0000
3.25		0 0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.75		0.0000	0.0000	0.0000	0.0000	0.0000	0 0000	0.0000	0 0000	0.0000	0 0000
4.25		0.0000	0.0000	0 0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

7d Survival Rate Binomials

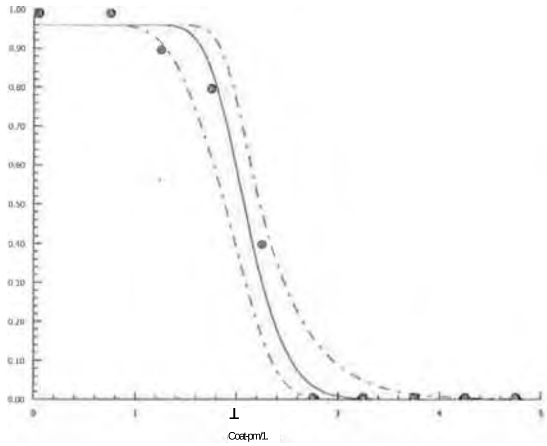
Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	**D**	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
0.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
2.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
2 75		0/1	1/1	1/1	0/1	1/1	1/1	1/1	0/1	0/1	1/1
3.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
3.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1

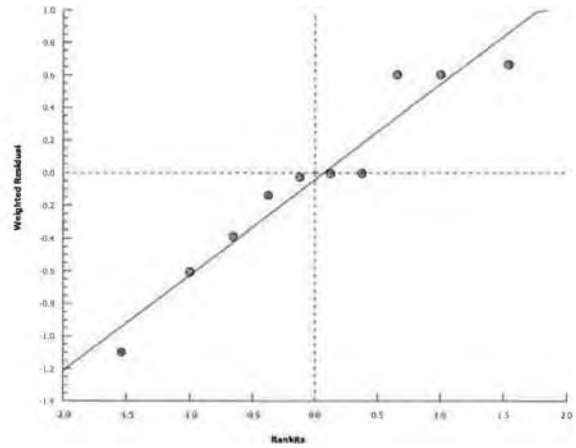
Ceriodaphnia 7-d Survival and Reproduction Test **New England Bioassay**

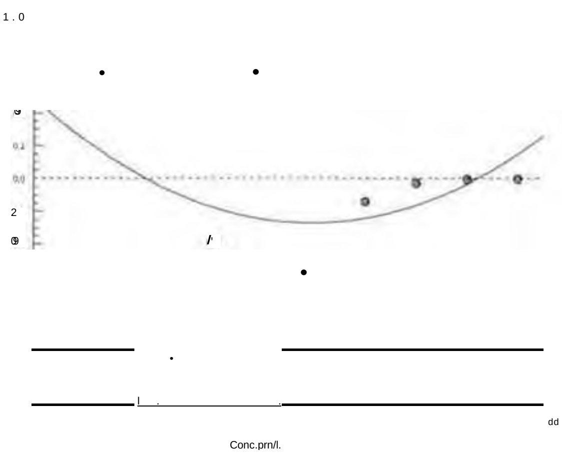
Analysis ID:	20-5577-3980	**Endpoint:**	7d Survival Rate	**CETIS Version:**	CETISv1 9.2
Analyzed:	18 Oct-16 11:41	**Analysis:**	Linear Regression (GLM)	**Official Results:**	Yes

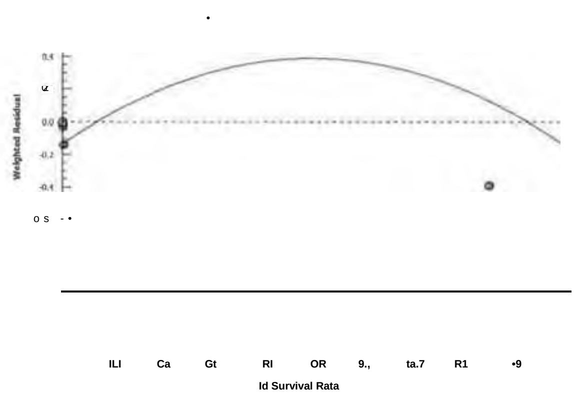
Graphics

Log-Normal: inv cD[Tr]=a+(3•log[x]









CETIS Analytical Report

Report Date: 18 Oct-16 11:59 (p 1 of 2)
Test Code: 16-1441 I 01-3095-9215

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 15-4090-4179	**Endpoint:** 7d Survival Rate	**CETIS Version:** CETISv1.9.2	
Analyzed: 18 Oct-16 11:41	**Analysis:** STP 2xK Contingency Tables	**Official Results:** Yes	

Batch ID: 16-2170-0149	**Test Type:** Reproduction-Survival (7d)	**Analyst:**
Start Date: 26 Sep-16 14:20	**Protocol:** EPA/821/R-02-013 (2002)	**Diluent:** Laboratory Water
Ending Date: 03 Oct-16 15:57	**Species:** Ceriodaphnia dubia	**Brine:** Not Applicable
Duration: 7d 2h	**Source:** In-House Culture	**Age:** <24H

Sample ID: 18-9022-1325	**Code:** 70AA7DOD	**Client:** GZA GeoEnvironmental
Sample Date: 26 Sep-16	**Material:** Sodium chloride	**Project:**
Receipt Date: 26 Sep-16	**Source:** Huff & Huff	
Sample Age: 14h	**Station:**	

Data Transform	Alt Hyp	NOEL	LOEL	TOEL	TU
Untransformed	C > T	1.75	2.25	1 984	

Fisher Exact/Bonferroni-Holm Test

Control vs	Group	Test Stat	P-Type	P-Value	Decision(a:5%)
Dilution Water	0.75	1 0000	Exact	1.0000	Non-Significant Effect
	1.25	0 5000	Exact	1 0000	Non-Significant Effect
	1.75	0.2368	Exact	0.7105	Non-Significant Effect
	2.25*	0.0054	Exact	0.0217	Significant Effect

Test Acceptability Criteria **TAC Limits**

Attribute	Test Stat	Lower	Upper	Overlap	Decision
Control Resp	1	0.8	>>	Yes	Passes Criteria

Data Summary

Conc-gm/L	Code	NR	R	NR + R	Prop NR	Prop R	%Effect
0	D	1 0	0	1 0	1	0	0 0%
0.75		1 0	0	1 0	1	0	0.0%
1.25		9	1	1 0	0 9	01	10.0%
1.75		8	2	1 0	0 8	02	20.0%
2.25		4	6	1 0	0 4	06	60.0%

7d Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1.0000	1 0000	1 0000	1 0000	1 0000	1 0000	1.0000	1.0000	1.0000	1.0000
0.75		1 0000	1 0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.25		1 0000	1 0000	1.0000	1 0000	1.0000	1 0000	1.0000	1.0000	1.0000	0.0000
1.75		1 0000	1.0000	1:0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1 0000
2.25		1 0000	0 0000	1 0000	0 0000	0 0000	1.0000	1.0000	0.0000	0.0000	0.0000

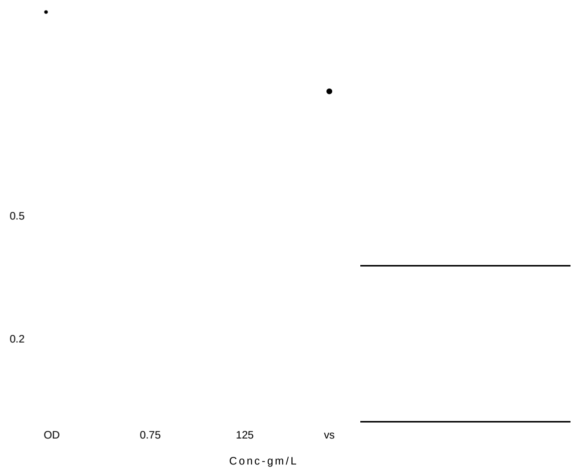
7d Survival Rate Binomials

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
0 75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/1
1 75		1/1	1/1	1/1	0/1	1/1	0/1	1/1	1/1	1/1	1/1
2.25		1/1	0/1	1/1	0/1	0/1	1/1	1/1	0/1	0/1	0/1

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 15-4090-4179	**Endpoint:** 7d Survival Rate	**CETIS Version:** CETISv1.9.2	
Analyzed: 18 Oct-16 11:41	**Analysis:** STP 2xK Contingency Tables	**Official Results:** Yes	

Graphics



Attachment C

Reference Toxicant Chart

NEW ENGLAND BIOASSAY TOXICITY DATA FORM CHRONIC
COVER SHEET

CLIENT: GZA/Huff & Huff
ADDRESS: 915 Harger Road, Suite 330
Oak Brook, IL 60523-1486
SAMPLE TYPE: Sodium Chloride run at 25 degrees C
DILUTION WATER: Moderately Hard Lab Water

C.dubia TEST ID # 16-1442
COC # N/A
PROJECT # 81.0220523.00

INVERTEBRATES

TEST SET UP (TECH INIT) KO
TEST SPECIES *Ceriodaphnia dubia* NEB
LOT# Cd16 (RMH 126)
AGE < 24 hours
TEST SOLUTION VOLUME (m1s) 15
NO. ORGANISMS PER TEST CHAMBER **1**
NO. ORGANISMS PER CONCENTRATION 10

Laboratory Control Water (MHRCF)

Batch Number	Hardness mg/L $CaCO_3$	Alkalinity mg/L $CaCO_3$
C36-MH012	88	60

	DATE	TIME
TEST START:	9/26/16	1454
TEST END:	10/3/16	1559

Results of ***Ceriodaphnia dubia*** Chronic Test

		95% Confidence Limits
48 Hour LC50	2.6 g/L	2.5 g/L-2.8g/L
7 Day LC50	1.9 g/L	1.6 g/L - 2.2 g/L
Survival NOEC	1.75 g/L	
Survival LOEC	2.25 g/L	
Reproduction NOEC	1.25 g/L	
Reproduction LOEC	1.75 g/L	
Reproduction IC25	1.1 g/L	

NOEC: NO OBSERVABLE EFFECT CONCENTRATIC LOEC: LOWEST OBSERVABLE EFFECT CONCENTRATION

Comments:

REVIEWD BY: [signature]

DATE: 10/26/16

CLIENT/SAMPLE: GZA/Huff & Huff - Sodium Chloride			
NEB PROJECT 81.0220523.00	NEB TEST NUMBER: 16-1442		COC 4
TEST ORGANISM: *Ceriodaphnia dubia*	AGE: <24 hours		Lot 4 Cd16 (RMH
START DATE: 9/26/16 1454	**END** 10/3/16		TIME:

Effluent Concentration (g/L)	Cup #	A2	A3	A4	A5	A6	A7	A8	A9	A10	Al 1	Toivtael Young	# Live Adults	Analyst-Transfer	Analyst -Counts
	Culture Lot#	Cd16 (RMEL													
	Day Numbe	Re {Kate													
		A	B	C	D	E	F	G	H	I	J				
NEB Lab Synthetic Diluent	0	V	V	V	V		VV	V	I	V	V		10	KO	
	1	V	V	V	V	V	V	I	V	V	V		10	PD	
	2	I	V	V	V	V	V	V	V	V	V	0	10	ER	
	3	4	6	4	6	4	6	6	4	4	5	49	10	ER	ER
	4	I	4	1	2	1	8	5	6	I	*V*	25	10	CB	CB
	5				VV/VIV					II/x	1	0	9	CW	CW
	6	1	1	1	1	1	2	1	2	X	1	4	9	CB	CB
	7	V	5	V	V	V	8	7	6	X	V	26	9	ER	ER
	totals	4	15	4	8	4	24	18	18	4	5	104	9		MG
0.75		A	B	C	D	E	F	G	H	I	J				
	0	V	V	V	V	V	V	V	V	I	V		10		
	1	V	V	V	',/	V	V	I	V	V	V		10		
	2	I	V	V	V	V	V	V	V	V	V	0	10		
	3	5	5	4	3	5	5	6	4	4	5	46	10		
	4	6	10	3	4	5	10	6	7	4	2	57	10		
	5	I	10	I	I	I	I	I	I	I	1	10	10		
	6	9	*1*	*1*	9	1	8	7	11	2	2	48	10		
	7	4	11	1	2	V	8	17	13	3	1	60	10		
	totals	24	36	8	18	10	31	36	35	13	10	221	10		
1.25		A	B	C	D	E	F	G	H	I	J				
	0	V	V	I	V	V	V	V	I	V	V		10		
	1	V	V	V	V	V	V	V	V	V	V		10		
	2	V	V	V	V	V	V	V	V		VI	0	10		
	3	5	4	3	3	3	2	3	5	3	4	35	10		
	4	4	3	1	3	1	3	2	2	5	I	23	10		
	5	*1*	*1*	*4*	*1*	*1*	*11*		*I*	*1*	*1*	*4*	*10*		
	6	3	*4*			*1111*		*3*	*5*	*1*	*1*	*15*	10		
	7	3	3	4	V	V	1	1	4	6	V	22	10		
	totals	15	14	11	6	4	6	9	16	14	4	99	10		

Notes:

FACILITY NAME & ADDRESS: GZA/Huff & Huff - Sodium Chloride

NEB PROJECT NUMBER: 81.0220523.00 ORGANISM: *Ceriodaphnia dubia* S'l AR l' DATE: 9/26/16

Effluent Concentration	Day Numbe	A	B	C	D	E	F	G	H	I	J	"rota! Live	# Live Adults	Analyst-Transfer	Analyst-Counts
		Replicate Young													
1.75	0	V	V	V	V	V	V	V	V	V	V		10		
	1	V	V	V	V	V	V	V	V		VV		10		
	2	V	V		VV	V	V	V	V	V	V	0	10		
	3	3	3	2	3		VITIs		4	1	1	17	9		
	4	1	1	.//x	V	1	X	I	1/x	I	si/x	0	6		
	5	2		1X	2	1	X	I	X		IX	4	6		
	6	1				1XIIXJ			X		iX	0	6		
	7				WX/V			/	X		'/X	0	6		
	totals	5	3	2	5	0	0	0	4	1	1	21	6		
2.25		A	B	C	D	E	F	G	fl	I	J				
	0	V		VV./			VV./		V		/V		10		
	1	V	V		V1V		V	V	./	V	V		10		
	2	V	V	V	V	V	V	V	V		V,/	0	10		
	3	V	V			VIVJ			V	V	V	0	10		
	4				I/xIIIIII				V	V	V	0	9		
	5		XI		lixII		1	V	I	V	V Ix	1	7		
	6			XIXII			V	V	V	V	X	0	7		
	7	X	snx	X	1/x	,/	s/	Vix	Vix	/	X	0	3		
	totals	0	0	1	0	0	0	0	0	0	0	1	3		
2.75		A	B	C	D	E	F	G	H	I	J				
	0	V	V	V	V	V	V	V	V	V	V		10		
	1	V	o	0	0	V	V	V	0	0	V		5		
	2	0	X	X	X	V	0	V	X	X	V	0	3		
	3	X	X	X	X	V	X	El	X	X		0	1		
	4	X	X	X	X	I	X	X	X	X	X	0	1		
	5	X	X	X	X	V	X	X	X	X	X	0	1		
	6	X	X	X	X	I	X	X	X	X	X	0	1		
	7				XXXV/x				X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		
3.25		A	B	C	D	E	F	G	H	I	J				
	0	V	V	V	V	V		V./	V	/	V		10		
	1	V				0000,/			V		0V		4		
	2		OX	X	X	X		X00			XEI	0	0		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		

FACILITY NAME & ADDRESS: GZA/Huff & Huff - Sodium Chloride

NEB PROJECT NUMBER: 81.0220523.00 1ORGANISM: *Ceriodaphnia dubia* START DATE: 9/26/16

Effluent Concentration	Day Numbe	Re•licate										Total Live Young	# Live Adults	Analyst-Transfer	Analyst -Counts
		A	B	C	D	E	F	G	H	I	J				
3.75	0	V	V		VV./		V	V	V	V	V		10		
	1	El	El	El	El		!DEE		E		CIE		0		
	2	X	X	X	X	X	X	X	X	X	X	0	0		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X		XX_	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		
		A	B	C	D	E	F	G	H	I	J				
4.25	0	V		V1V		V	V	V	V		V,/		10		
	1			CIEICI					0E00				0		
	2	X	X	X	X	X	X	X	X	X	X	0	0		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4				XXXXX				X	X	X	0	0		
	5				XXXXX				X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
													1		
	totals	0	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**		**0**	
		A	B	C	D	E	F	G	H	I	J				
4.75	**0**	**V**	**V**	**V**	**V**	**V**	**V**	**V**	**V**	**V**	**V**		**10**		
	1	**El**				**DECI**		**ID**		**000**			**0**		
	2	X	X		XX	X	X	X	**X**	**X**	**X**	**0**	**0**		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	**0**	**k**	
	6	X	X	X	X	X	X	X	X	X	X	0	**0**		
	7	X	X	X	X	X	X	X	X	X	X	0	**0**		
	totals	0	0	0	0	0	0	0	0	0	0	r0_0			

NEWS DATA SHEET FOR ROUTINE CHEMICAL AND PHYSICAL DETERMINATIONS

CLIENT/SAMPLE: GZA/Huff & Huff - Sodium Chloride
NEB PROJECT NUMBER: 81.0220523.00 TEST ORGANISM *Ceriodaphnia dubia*
DILUTION WATER SOURCE: Moderately Hard Lab Water START DATE: 9/26/16 TIME: 1454

ANALYST	KO	PD	ER	CB	PD	CW	CB	
NEB Lab Synthetic Diluent	1	2	3	4	5	6	7	Remarks
Temp cv Initial	24.0	25.0	24.6	24.6	24.1	25.1	24.5	
D.O. mg/L Initial	8.4	8.2	8.4	8.4	8.4	8.2	8.3	
pH s.u. Initial	8.0	8.1	6.9	8.2	7.8	7.7	8.1	
Conductivity uS Initial	329	326	320	329	322	329	321	
Temp °C Final	24.6	25.8	24.5	24.0	24.0	24.0	24.4	
D.O. mg/L Final	8.3	8.5	8.7	8.8	8.8	8.7	8.5	
pH s.u. Final	8.2	8.3	8.3	8.3	8.6	8.5	8.4	
Conductivity µS Final	365	385	359	358	346	339	372	
0.75 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	24.0	25.0	24.9	24.6	24.0	25.0	24.5	
D.O. mg/L Initial	8.4	8.2	8.4	8.4	8.4	8.3	8.3	
pH s.u. Initial	8.0	8.1	7.2	8.1	7.8	7.7	8.1	
Conductivity uS Initial	1,771	1,808	1,713	1,803	1,750	1,676	1,768	
Temp °C Final	24.6	25.6	24.4	24.0	24.0	24.0	24.4	
D.O. mg/L Final	8.4	8.6	8.8	8.9	8.8	8.8	8.5	
pH s.u. Final	8.5	8.4	8.3	8.4	8.6	8.5	8.3	
Conductivity uS Final	1,810	1,823	1,743	1,811	1,757	1,694	1,931	
1.25 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	24.0	25.1	24.9	24.5	24.0	25.0	24.6	
D.O. m _ Initial	8.4	8.2	8.3	8.4	8.4	8.3	8.3	
pH s.u. Initial	8.0	8.1	7.4	8.1	7.9	7.7	8.1	
Conductivity uS Initial	2,770	2,722	2,704	2,710	2,718	2,639	2,740	
Temp °C Final	24.8	25.5	24.4	24.0	24.0	24.0	24.5	
D.O. mg/L Final	8.2	8.5	8.9	8.9	8.8	8.7	8.5	
pH s.u. Final	8.4	8.4	8.3	8.4	8.5	8.5	8.3	
Conductivity uS Final	3,250	2,736	2,771	2,726	2,742	2,666	2,970	
1.75 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	24.0	25.1	24.9	24.4	24.0	25.0	24.6	
D.O. mg/L Initial	8.4	8.2	8.4	8.4	8.4	8.3	8.3	
pH s.u. Initial	8.0	8.1	7.6	8.1	7.9	7.8	8.1	
Conductivity [IS Initial	3,696	3,670	3,642	3,698	3,660	3,577	3,611	
Temp °C Final	24.8	25.9	24.6	24.0	24.0	24.0	24.5	
D.O. mg/L Final	8.2	8.6	9.1	9.0	8.8	8.8	8.5	
pH s.u. Final	8.3	8.4	8.4	8.5	8.5	8.5	8.3	
Conductivity AS Final	3,580	3,663	3,747	3,660	3,622	3,547	3,873	

Received, Clerk's Office 5/21/2018 ** R2018-032**

NEB'S DATA SHEET FOR ROUTINE CHEMICAL AND PHYSICAL DETERMINATIONS

FACILITY NAME & ADDRESS: NEB	GZA/Huff & Huff - Sodium Chloride		
PROJECT NUMBER: DILUTION	81.0220523.00	TEST ORGANISM START	*Ceriadaphnia dubia*
WATER SOURCE:	Moderately Hard Lab Water	DATE:	9/26/16 TIME: 1454

2.25 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	24.0	25.1	24.9	24.4	24.0	25.1	24.6	
D.O. mg/L Initial	8.4	8.2	8.3	8.4	8.5	8.3	8.3	
pH s.u. Initial	8.0	8.1	7.8	8.0	7.9	7.9	8.1	
Conductivity pS Initial	4,527	4,540	4,490	4,642	4,620	4,502	4,517	
'temp °C Final	24.7	26.0	24.6	24.0	24.0	24.0	24.6	
D.O. mg/L Final	8.2	8.5	9.2	9.1	8.8	8.8	8.7	
pH s.u. Final	8.2	8.4	8.4	8.5	8.5	8.5	8.3	
Conductivity pS Final	4,640	4,575	4,606	4,560	4,616	4,478	4,795	
2.75 g/L	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Remarks**
Temp °C Initial	24.5	25.0	25.0	24.5	24.0	25.0	24.6	
D.O. mg/L Initial	8.4	8.3	8.3	8.4	8.4	8.3	8.3	
pH s.u. Initial	8.0	8.0	7.9	8.0	7.9	7.9	8.1	
Conductivity pS Initial	5,507	5,500	5,470	5,512	5,510	5,400	5,438	
Temp °C Final	24.6	26.0	24.5	24.0	24.0	24.0	24.6	
D.O. mg/L Final	8.4	8.7	9.1	9.2	8.9	8.9	8.6	
pH s.u. Final	8.2	8.5	8.4	8.6	8.5	8.5	8.2	
Conductivity [IS Final	5,780	5,432	5,484	5,430	5,489	5,391	5,837	
3.25 g/L	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Remarks**
Temp °C Initial	24.7	25.1	25.0					
D.O. mg/L Initial	8.3	8.2	8.3					
pH s.u. Initial	8.0	8.0	7.9					
Conductivity µS Initial	6,396	6,390	6,350					
Temp °C Final	24.7	25.6						
D.O. mg/L Final	8.2	8.5						
pH s.u. Final	8.2	8.4						
Conductivity pS Final	6,900	6,436						
3.75 g/L	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Remarks**
Temp °C Initial	24.8	25.2						
D.O. mg/L Initial	8.3	8.2						
pH s.u. Initial	8.0	8.1						
Conductivity pS Initial	7,284	7,320						
Temp °C Final	24.6							
D.O. mg/L Final	8.3							
pH s.u. Final	8.2							
Conductivity pS Final	7,500							

7	12	15	15	1	2	7	16	10	2	14	15	7	13	13	10	6	1	8	10
13	3	8	16	7	10	11	10	13	5	11	7	13	16	7	7	5	13	2	14
3	1	4	5	14	13	3	14	9	13	13	2	9	15	6	2	8	4	5	8
11	8	16	14	15	6	2	6	2	16	8	5	12	3	9	13	4	3	10	4
14	9	1	6	3	9	14	13	8	6	5	8	14	7	3	15	13	11	4	7
2	16	10	13	5	5	13	2	11	7	3	12	5	14	12	16	2	2	9	15
4	6	13	7	2	15	1	9	1	4	7	10	6	9	11	9	7	6	16	11
6	14	6	10	4	14	4	15	3	3	4	16	2	6	5	1	12	10	6	9
10	15	2	1	13	12	16	3	4	8	10	1	15	5	14	12	14	12	3	2
12	10	7	12	9	11	9	8	12	14	15	4	11	8	16	8	9	14	14	1
15	7	5	2	10	7	8	12	6	15	6	13	16	12	15	4	11	8	12	6
16	2	11	8	8	8	15	5	16	1	1	9	8	1	8	14	16	5	13	5
9	13	14	3	6	4	10	11	5	12	9	3	10	4	4	3	10	9	1	3
8	11	9	4	11	3	12	7	7	10	12	14	3	10	1	6	15	16	15	12
1	5	12	11	16	16	5	4	14	9	16	11	1	2	10	5	1	15	7	13
5	4	3	9	12	1	6	1	15	11	2	6	4	11	2	11	3	7	11	16
																Re			
11	8	16	5	5	13	1	13	2	16	14	12	9	8	7	5		3	13	3
2	2	8	8	14	16	4	3	8	11	10	14	15	1	2	11		5	15	9
6	13	2	13	6	5	9	15	11	10	12	6	16	15	16	9		12	16	15
14	12	4	16	16	11	14	10	5	12	3	3	12	14	15	13		4	1	16
8	6	3	9	4	10	6	4	16	2	2	9	8	16	4	6		15	7	8
9	15	12	10	3	2	12	6	1	15	4	13	7	7	9	12		8	8	11
3	10	11	12	13	12	5	11	7	8	9	5	14	11	10	1		13	3	5
16	1	13	14	8	14	15	5	3	7	11	15	6	12	5	7		1	14	4
1	14	14	2	9	15	16	14	6	14	7	8	3	13	11	8		7	12	7
4	4	6	4	12	3	11	8	15	9	8	1	13	6	3	3		9	9	12
15	5	1	11	10	6	3	7	10	5	5	11	10	10	12	15		14	5	2
5	3	5	6	7	7	13	2	14	3	16	4	5	5	13	4		16	2	6
12	7	15	15	15	9	8	12	12	13	15	10	1	4	6	16		6	11	1
10	11	10	3	2	4	2	1	4	6	6	7	11	9	14	10		11	4	13
7	9	7	7	11	1	7	16	13	1	13	2	4	2	1	2		2	10	14
13	16	9	1	1	8	10	9	9	4	1	16	2	3	8	14		10	6	10
						Conc													
1	6	7	4	8	6		2	8	15	4	6	6	1	4	5	7	13	2	10
9	15	11	3	11	15		10	1	3	8	2	15	7	9	8	16	1	14	3
10	16	4	5	12	9		11	7	1	7	16	11	8	3	3	12	2	3	4
4	14	1	9	5	5		13	6	8	15	5	12	5	7	16	5	11	8	1
7	3	13	14	15	2		14	16	5	14	9	2	16	1	12	6	14	4	13
16	11	2	1	14	16		9	3	4	16	14	3	15	11	11	3	9	12	5
3	10	16	16	13	7		1	11	14	9	10	16	2	10	2	10	7	10	16
11	13	9	13	4	13		3	5	13	10	12	5	12	5	14	13	16	5	6
15	2	3	12	9	12		4	13	10	3	13	14	4	2	1	14	8	6	12
14	1	14	6	10	1		12	4	2	2	4	13	3	16	9	9	3	7	14
13	12	5	11	3	11		8	2	7	11	7	8	14	6	4	4	4	15	11
12	5	10	7	2	14		15	14	16	13	1	9	10	12	10	11	10	9	8
8	9	8	10	6	4	1	7	10	11	6	8	4	9	8	15	8	6	11	9
2	7	6	2	1	8	0	6	15	12	1	11	7	11	13	6	1	15	13	15
6	4	15	8	16	10	**4**	16	9	6	12	3	10	6	14	7	2	12	16	7
5	8	12	15	7	3	**12**	5	12	9	5	15	1	13	15	13	15	5	1	2
13	4	10	4	16	13	16	13	5	3	6	14	1	16	8	7	2	3	3	12
5	14	4	6	8	2	15	1	13	14	16	4	15	4	3	12	12	1	4	7
2	2	2	15	14	16	9	12	16	6	10	15	14	9	10	1	14	8	8	16
7	12	15	8	12	3	5	14	7	12	5	13	16	1	7	5	11	2	9	3
6	9	7	14	9	14	10	11	15	11	12	1	12	12	14	16	3	11	11	8
14	5	16	7	10	8	11	8	14	13	7	11	6	3	11	4	4	6	6	9
15	11	8	9	7	12	8	7	1	15	9	3	3	7	13	11	10	4	5	1
11	6	6	1	4	1	3	16	12	5	4	9	13	13	6	8	15	9	1	14
4	10	3	16	2	11	7	9	6	9	1	8	4	11	5	2	16	10	12	4
1	8	1	13	1	15	4	4	11	4	2	16	5	8	1	9	5	12	16	6
9	7	14	2	6	4	14	10	9	8	15	10	7	10	9	10	6	14	10	11
12	1	9	10	15	5	2	15	10	2	14	2	8	2	4	13	8	5	15	5
3	3	12	11	5	9	6	6	3	10	13	12	9	6	2	15	7	15	7	13
10	15	11	5	13	7	12	5	2	7	11	5	10	15	12	3	1	13	13	10
8	13	13	3	3	10	13	2	4	1	8	6	11	14	15	6	9	16	2	2
16	16	5	12	11	6	1	3	8	16	3	7	2	5	16	14	13	7	14	15

Ceriodaphnia dubia Culture Chart

Brood mother source: 04'114 e')0 | c1 Source's brood size: 2 9 (Qty.)

{-1 ▸ 44 q- 2t. •

	TetIACI	ii-q	Ao	-AV	I oc4k	i'a4	itt4			SLY	A-4 1				
Date	q-iii)		q-s	1-6	0..-....	i: 2A	ei .2:7-	13		C1--ki	Ct''				
Day acc.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	N	NI\		-11	3	1	Ali\i''		1	\I	\I				
2	N		N(-)	Ai	3	(e	Al	-I	2	ki fi Y rt	11 / i c(				
3	N		NN)	A,1	3	?	A)	el	3		17.. Y 1,				
4	N		N				Aj	N/	4		y I i??				
5	N		NNA1		LI	G	N	1	5	Y	--;--1 \i, V g				
6	N	N	1\j	11	IC	q	N	\/	6	Y	Y zp				
7	N		NO	Ai		7	A;	\I	7	\I	-rfe Y(6				
8	N		Nt-)	i'j<1		-7	Ai	\f	8	Y	T-/ 2-				
9	N		N		9	-1	/0	kJ-rS' y	9	y 1	y ci				
10	N	N		iv	y	7	A'	\'	10	V	7'1 Y ict				
11	N	N	11	Aj	3	5		y	ii	\i)	1—IC Y zo				
12	N	N	/\)	Al	Li	7	'')	Y	12		Y	\/			
13	N	N	N)	A'	\-I		T	,		13 __	Y 1				

Y= neonates present, and *criterion has been met* > 20 neonates produced in otal by 3rd brood. **N =** no neonates

2B = two broods present. **2Y =** two broods and criterion met: 20 neos. by 3rd brood. **X=** brood mother dead **ae =** aborted eggs

✓ or **P =** neonates present after renewal on previous day (see time in log). = acceptable for acute testing only

= neonates used in test, replicate number of test noted (and brood counted). **acc. =** *if acclimated* , H_2O type used w/ renewal **this day**

Test organism collection: Tray diagram used?

Project #	Symbols (P)	(YIN)	Time period, neonates released	Collection date I time
OVV<4-14-04-i--	T :	\i	el-25-16/,70c --- -241— /(6/0C)-00	/-2 k/W l2 c v
	T			
	T			
	T			
	T			
	T			

CETIS Analytical Report

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID:	12-4435-2782	**Endpoint:**	2d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	18 Oct-16 11:53	**Analysis:**	Untrimmed Spearman-Karber	**Official Results:**	Yes
Batch ID:	14-9463-9642	**Test Type:**	Reproduction-Survival (7d)	**Analyst:**	
Start Date:	26 Sep-16 14:54	**Protocol:**	EPA/821/R-02-013 (2002)	**Diluent:**	Laboratory Water
Ending Date:	03 Oct-16 15:59	**Species:**	Ceriodaphnia dubia In-House Culture	**Brine:**	Not Applicable
Duration:	7d 1h	**Source:**		**Age:**	<24H
Sample ID:	04-3364-2641	**Code:**	19D8DC91	**Client:**	GZA GeoEnvironmental
Sample Date:	26 Sep-16	**Material:**	Sodium chloride	**Project:**	
Receipt Date:	26 Sep-16	**Source:**	Huff & Huff		
Sample Age:	15h	**Station:**			

Spearman-Karber Estimates

Threshold Option	Threshold	Trim	Mu	Sigma	LC50	95% LCL	95% UCL
Control Threshold	0	0 00%	0.4197	0.01157	2.629	2.492	2.772

2d Survival Rate Summary

Calculated Variate(A/B)

Conc-gm/L	Code	Count	Mean	Min	Max	Std Err	Std Dev	CV%	%Effect	A	B
0	D	10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
0.75		10	1.0000	1.0000	1.0000	0.0000	0.0000	0 00%	0.0%	10	10
1 25		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
1.75		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
2.25		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
2.75		10	0.3000	0.0000	1.0000	0.1528	0.4830	161 00%	700%	3	10
3.25		10	0 0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
3 75		10	0 0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
4.25		10	0.0000	0.0000	0 0000	0.0000	0.0000		100.0%	0	10
4.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10

2d Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1 0000
0.75		1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1 0000	1.0000	1.0000	1.0000
1 75		1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1.0000	1.0000
2.25		1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1.0000	1.0000
2.75		0.0000	0.0000	0 0000	0.0000	1.0000	0 0000	1.0000	0.0000	0.0000	1.0000
3.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.75		0 0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.25		0 0000	0.0000	0.0000	0.0000	0 0000	0 0000	0.0000	0.0000	0.0000	0.0000
4.75		0.0000	0.0000	0 0000	0.0000	0.0000	0.0000	0.0000	0.0000	0 0000	0 0000

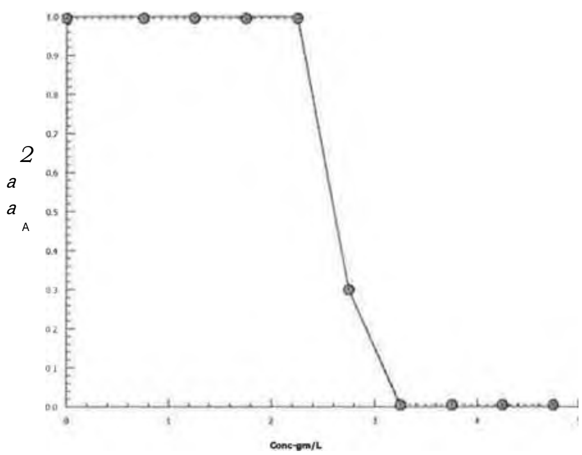
2d Survival Rate Binomials

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
0.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1 25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
2.25		0/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
2.75		0/1	0/1	0/1	0/1	1/1	0/1	1/1	0/1	0/1	1/1
3.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
3.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1

Ceriodaphnia 7-d Survival and Reproduction Test **New England Bioassay**

Analysis ID:	12-4435-2782	**Endpoint:**	2d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	18 Oct-16 11:53	**Analysis:**	Untrimmed Spearman-Karber	**Official Results:**	Yes

Graphics



CETIS Analytical Report

Report Date: 18 Oct-16 11:56 (p 1 of 3)
Test Code: 16-1442 116-3601-6968

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 06-9176-2121	**Endpoint:** 7d Survival Rate	**CETIS Version:** CETISv1.9.2
Analyzed: 18 Oct-16 11:53	**Analysis:** Linear Regression (GLM)	**Official Results:** Yes

Batch ID: 14-9463-9642	**Test Type:** Reproduction-Survival (7d)	**Analyst:**
Start Date: 26 Sep-16 14:54	**Protocol:** EPA/821/R-02-013 (2002)	**Diluent:** Laboratory Water
Ending Date: 03 Oct-16 15:59	**Species:** Ceriodaphnia dubia	**Brine:** Not Applicable
Duration: 7d 1h	**Source:** In-House Culture	**Age:** <24H

Sample ID: 04-3364-2641	**Code:** 19D8DC91	**Client:** GZA GeoEnvironmental
Sample Date: 26 Sep-16	**Material:** Sodium chloride	**Project:**
Receipt Date: 26 Sep-16	**Source:** Huff & Huff	
Sample Age: 15h	**Station:**	

Linear Regression Options

Model Name	Link Function	Threshold Option	Thresh	Optimized	Pooled	Het Corr	Weighted
Log-Normal (Probit)	q=inv	Control Threshold	0.1	Yes	Yes	No	Yes

Regression Summary

Iters	LL	AICc	BIC	Mu	Sigma	Adj R2	F Stat	Critical	P-Value	Decision(a:5/0)
17	-5 614	21.23	18.14	0.2866	0.0805	0.9914				Lack of Fit Not Tested

Point Estimates

Level	gm/L	95% LCL	95% UCL
LC50	1.934	1.588	2.159

Test Acceptability Criteria — **TAC Limits**

Attribute	Test Stat	Lower	Upper	Overlap	Decision
Control Resp	09	08	>>	Yes	Passes Criteria

Regression Parameters

Parameter	Estimate	Std Error	95% LCL	95% UCL	t Stat	P-Value	Decision(a:5%)
Threshold	0.0352	0.03612	-0.0356	0.106	0.9746	0 3622	Non-Significant Parameter
Slope	12.42	3.792	4 99	19.86	3.276	0.0136	Significant Parameter
Intercept	-3.56	1.238	-5.986	-1.134	-2.876	0.0238	Significant Parameter

ANOVA Table

Source	Sum Squares	Mean Square	DF	F Stat	P-Value	Decision(a:5%)
Model	492.5	246.3	2	522.6	<1.0E-37	Significant
Residual	3 298	0.4712	7			

Residual Analysis

Attribute	Method	Test Stat	Critical	P-Value	Decision(a:5%)
Goodness-of-Fit	Pearson Chi-Sq GOF Test	3 298	14.07	0.8561	Non-Significant Heterogeneity
	Likelihood Ratio GOF Test	3 923	14.07	0.7886	Non-Significant Heterogeneity
Distribution	Shapiro-Wilk W Normality Test	0.941	0 7607	0.5636	Normal Distribution
	Anderson-Darling A2 Normality Te	0.3601	2.492	0.4525	Normal Distribution

7d Survival Rate Summary — **Calculated Variate(A/B)**

Conc-gm/L	Code	Count	Mean	Min	Max	Std Err	Std Dev	CV%	%Effect	A	
0	D	10	0.9000	0.0000	1.0000	0.1000	0 3162	35.14%	0.0%	9	10
0.75		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	-11.11%	10	10
1.25		10	1.0000	1 0000	1.0000	0.0000	0.0000	0 00%	-11 11%	10	10
1.75		10	0.6000	0.0000	1.0000	0.1633	0 5164	86.07%	33.33%	6	10
2.25		10	0 3000	0.0000	1.0000	0.1528	0 4830	161.00%	66.67%	3	10
2.75		10	0 0000	0 0000	0 0000	0.0000	0.0000		100.0%	0	10
3.25		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
3.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		1000%	0	10
4.25		10	0.0000	0.0000	0 0000	0.0000	0.0000		100.0%	0	10
4.75		10	0.0000	0 0000	0.0000	0.0000	0.0000		100.0%	0	10

Ceriodaphnia 7-d Survival and Reproduction Test | **New England Bioassay**

Analysis ID:	06-9176-2121	**Endpoint:**	7d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	18 Oct-16 11:53	**Analysis:**	Linear Regression (GLM)	**Official Results:**	Yes

7d Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1 0000	1.0000	0.0000	1 0000
0.75		1.0000	1 0000	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1 0000	1.0000	1.0000	1.0000	1.0000	1 0000	1 0000	1 0000
1.75		1.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000
2.25		0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000	0.0000	1.0000	0.0000
2 75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0 0000
3.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.75		0 0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0 0000	0.0000	0 0000
4.75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0 0000

7d Survival Rate Binomials

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	**D**	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
0.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
2.25		0/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
2.75		0/1	0/1	0/1	0/1	1/1	0/1	1/1	0/1	0/1	1/1
3.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
3.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1

Ceriodaphnia 7-d Survival and Reproduction Test **New England Bioassay**

Analysis ID:	06-9176-2121	**Endpoint:** 7d Survival Rate		**CETIS Version:**	CETISv1 9.2
Analyzed:	18 Oct-16 11:53	**Analysis:** Linear Regression (GLM)		**Official Results:**	Yes

Graphics

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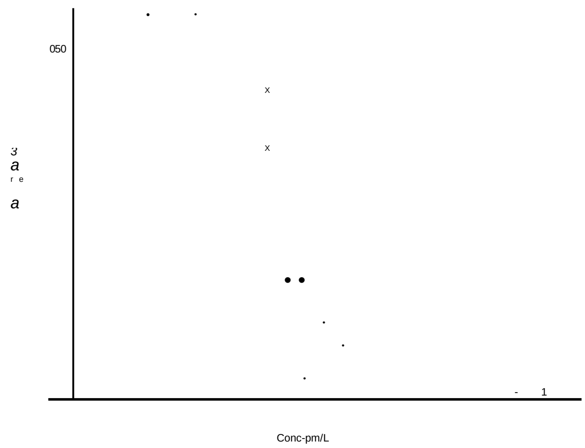
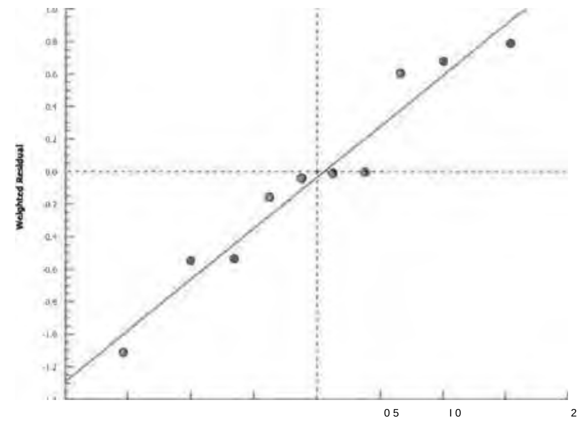
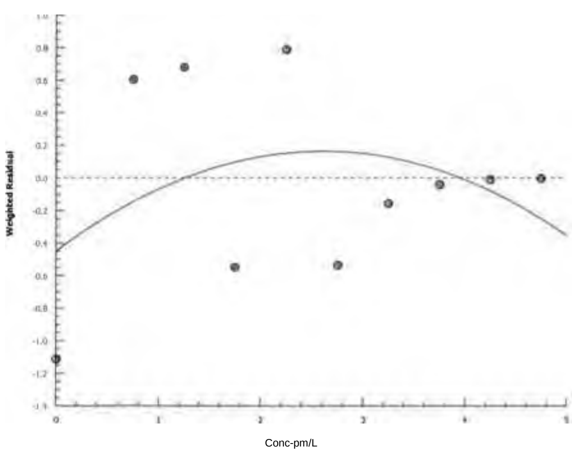
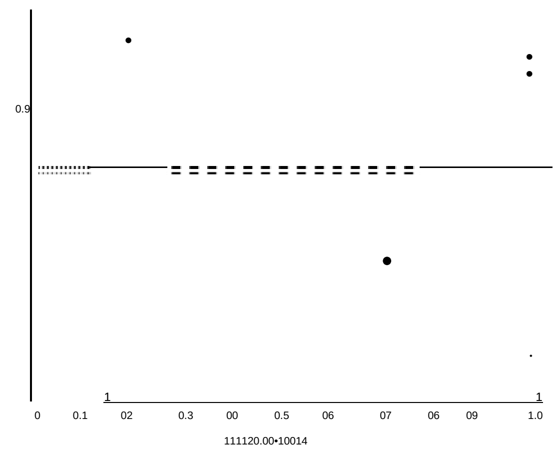








CETIS Analytical Report

Report Date: 18 Oct-16 11:56 (p 1 of 2)
Test Code: 16-1442116-3601-6968

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 17-2178-4252
Analyzed: 18 Oct-16 11:53
Endpoint: 7d Survival Rate
Analysis: STP 2xK Contingency Tables
CETIS Version: CETISv1.9.2
Official Results: Yes

Batch ID: 14-9463-9642
Start Date: 26 Sep-16 14:54
Ending Date: 03 Oct-16 15:59
Duration: 7d 1h
Test Type: Reproduction-Survival (7d)
Protocol: EPA/821/R-02-013 (2002)
Species: Ceriodaphnia dubia
Source: In-House Culture
Analyst:
Diluent: Laboratory Water
Brine: Not Applicable
Age: <24H

Sample ID: 04-3364-2641
Sample Date: 26 Sep-16
Receipt Date: 26 Sep-16
Sample Age: 15h
Code: 19D8DC91
Material: Sodium chloride
Source: Huff & Huff
Station:
Client: GZA GeoEnvironmental
Project:

Data Transform	Alt Hyp	NOEL	LOEL	TOEL	TU
Untransformed	C > T	1.75	2.25	1.984	

Fisher Exact/Bonferroni-Holm Test

Control vs	Group	Test Stat	P-Type	P-Value	Decision(a:5%)
Dilution Water	0.75	1.0000	Exact	1 0000	Non-Significant Effect
	1.25	1.0000	Exact	1 0000	Non-Significant Effect
	1.75	0.1517	Exact	0 4551	Non-Significant Effect
	2 25"	0.0099	Exact	0.0395	Significant Effect

Test Acceptability Criteria — TAC Limits

Attribute	Test Stat	Lower	Upper	Overlap	Decision
Control Resp	0.9	0.8	>>	Yes	Passes Criteria

Data Summary

Conc-gm/L	Code	NR	R	NR + R	Prop NR	Prop R	%Effect
0	D	9	1	1 0	0.9	01 0	0.0% -
0.75		10	0	1 0	1	0 04	11.11% -
1.25		10	0	1 0	1	0.7	11 11%
1 75		6	4	1 0	0.6		33.33%
2.25		3	7	1 0	0.3		66.67%

7d Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Reps	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0		1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	0.0000	1.0000
0.75		1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1.0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1.0000	1.0000	1.0000	1 0000	1 0000	1.0000	1.0000	1.0000
1.75		1.0000	1.0000	0.0000	1.0000	1.0000	0.0000	1 0000	0.0000	1.0000	0.0000
2.25		0.0000	0.0000	0.0000	0 0000	1 0000	1 0000	0 0000	0.0000	1.0000	0.0000

7d Survival Rate Binomials

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
0.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1 75		1/1	1/1	0/1	1/1	1/1	0/1	1/1	0/1	1/1	0/1
2.25		0/1	0/1	0/1	0/1	1/1	1/1	0/1	0/1	1/1	0/1

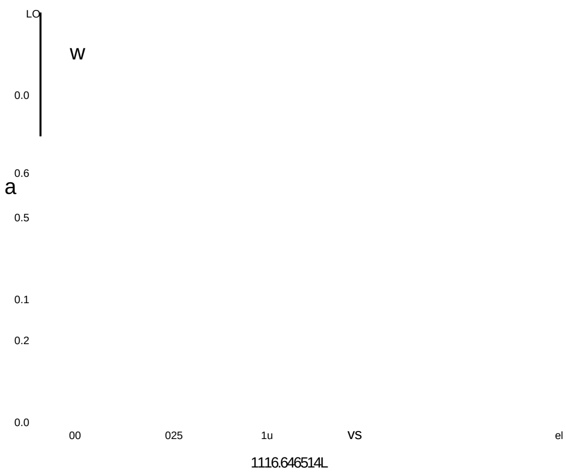
CETIS Analytical Report

Report Date: 18 Oct-16 11:56 (p 2 of 2)
Test Code: 16-1442 I 16-3601-6968

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 17-2178-4252	**Endpoint:** 7d Survival Rate	**CETIS Version:** CETISv1.9.2	
Analyzed: 18 Oct-16 11:53	**Analysis:** STP 2xK Contingency Tables	**Official Results:** Yes	

Graphics



CETIS Analytical Report

Report Date: 18 Oct-16 11:56 (p 1 of 2)
Test Code: 16-1442116-3601-6968

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 15-5979-5920 | **Endpoint:** Reproduction | **CETIS Version:** CETISv1 9 2
Analyzed: 18 Oct-16 11:54 | **Analysis:** Nonparametric-Control vs Treatments | **Official Results:** Yes

Batch ID: 14-9463-9642 | **Test Type:** Reproduction-Survival (7d) | **Analyst:**
Start Date: 26 Sep-16 14:54 | **Protocol:** EPA/821/R-02-013 (2002) | **Diluent:** Laboratory Water
Ending Date: 03 Oct-16 15:59 | **Species:** Ceriodaphnia dubia | **Brine:** Not Applicable
Duration: 7d 1h | **Source:** In-House Culture | **Age:** <241-I

Sample ID: 04-3364-2641 | **Code:** 19D8DC91 | **Client:** GZA GeoEnvironmental
Sample Date: 26 Sep-16 | **Material:** Sodium chloride | **Project:**
Receipt Date: 26 Sep-16 | **Source:** Huff & Huff
Sample Age: 15h | **Station:**

Data Transform	Alt Hyp	NOEL	LOEL	TOEL	TU	PMSD
Untransformed	C > T	1.25	1.75	1.479		63.46%

Steel Many-One Rank Sum Test

Control vs	Conc-gm/L	Test Stat	Critical	Ties	DF	P-Type	P-Value	Decision(a:5%)
Dilution Water	0.75	136	76	3	18	Asymp	0.9999	Non-Significant Effect
	1.25	106.5	76	2	18	Asymp	0.8352	Non-Significant Effect
	1.75*	66	76	2	18	Asymp	0.0058	Significant Effect
	2.25*	55	76	0	18	Asymp	3.1E-04	Significant Effect

Test Acceptability Criteria — TAC Limits

Attribute	Test Stat	Lower	Upper	Overlap	Decision
Control Resp	10.4	15	>>	Yes	Below Criteria
PMSD	0.6346	0.13	0.47	Yes	Above Criteria

ANOVA Table

Source	Sum Squares	Mean Square	DF	F Stat	P-Value	Decision(a:5%)
Between	3011.68	752 92	4	17.08	<1.0E-37	Significant Effect
Error	1984	44.0889	45			
Total	4995 68		49			

Distributional Tests

Attribute	Test	Test Stat	Critical	P-Value	Decision(a:1%)
Variances	Bartlett Equality of Variance Test	66.82	13.28	<1.0E-37	Unequal Variances
Distribution	Shapiro-Wilk W Normality Test	0.9623	0 9367	0 1108	Normal Distribution

Reproduction Summary

Conc-gm/L	Code	Count	Mean	95% LCL	95% UCL	Median	Min	Max	Std Err	CV%	%Effect
0	D	10	10.4	4.96	15.84	6 5	4	24	2.405	73.12%	0.00%
0.75		10	22.1	13.75	30.45	21	8	36	3 692	52.83%	-112.50%
1.25		10	9.9	6.537	13.26	10	4	16	1.487	47.49%	4.81%
1.75		10	2.1	0.6515	3.548	1 5	0	5	0.6403	96.42%	79.81%
2.25		10	0.1	-0.1262	0.3262	0	0	1	0.1	316.23%	99 04%

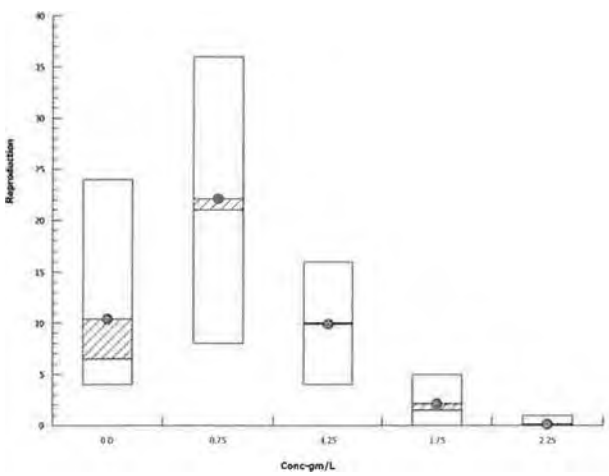
Reproduction Detail

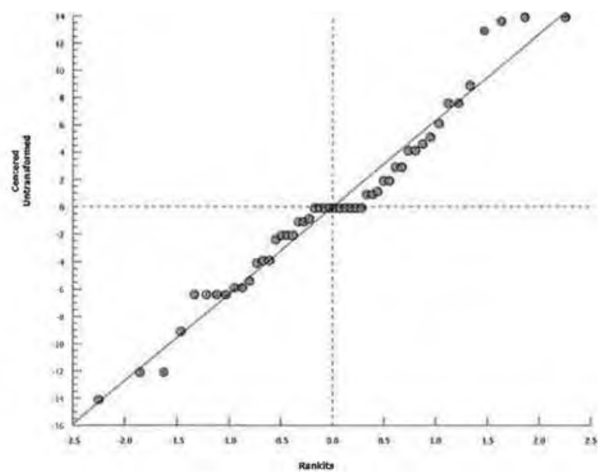
Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep?	Rep 8	Rep 9	Rep 10
0		4	15	4	8	4	24	18	18	4	5
0.75		24	36	8	18	10	31	36	35	13	10
1 25		15	14	11	6	4	6	9	16	14	4
1.75		5	3	2	5	0	0	0	4	1	1
2.25		0	0	1	0	0	0	0	0	0	0

Ceriodaphnia 7-d Survival and Reproduction Test **New England Bioassay**

Analysis ID: 15-5979-5920	**Endpoint:** Reproduction	**CETIS Version:** CETISv1 9.2
Analyzed: 18 Oct-16 11:54	**Analysis:** Nonparametric-Control vs Treatments	**Official Results:** Yes

Graphics





CETIS Analytical Report

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID: 05-5445-0343 **Endpoint:** Reproduction **CETIS Version:** CETISv1.9.2
Analyzed: 18 Oct-16 11:54 **Analysis:** Linear Interpolation (ICPIN) **Official Results:** Yes

Batch ID: 14-9463-9642 **Test Type:** Reproduction-Survival (7d) **Analyst:**
Start Date: 26 Sep-16 14:54 **Protocol:** EPA/821/R-02-013 (2002) **Diluent:** Laboratory Water
Ending Date: 03 Oct-16 15:59 **Species:** Ceriodaphnia dubia **Brine:** Not Applicable
Duration: 7d 1h **Source:** In-House Culture **Age:** <24H

Sample ID: 04-3364-2641 **Code:** 19D8DC91 **Client:** GZA GeoEnvironmental
Sample Date: 26 Sep-16 **Material:** Sodium chloride **Project:**
Receipt Date: 26 Sep-16 **Source:** Huff & Huff
Sample Age: 15h **Station:**

Linear Interpolation Options

X Transform	Y Transform	Seed	Resamples	Exp 95% CL	Method
Linear	Linear	1479707	200	Yes	Two-Point Interpolation

Test Acceptability Criteria

Attribute	Test Stat	TAC Limits Lower	Upper	Overlap	Decision
Control Resp	10.4	15	>>	Yes	Below Criteria

Point Estimates

Level	gm/L	95% LCL	95% UCL
IC25	1.07	0 9657	1.359
IC50	1.364	1.181	1.522

Reproduction Summary — **Calculated Variate**

Conc-gm/L	Code	Count	Mean	Min	Max	Std Err	Std Dev	CV%	%Effect
0	D	10	10.4	4	24	2.405	7 604	73.12%	0.0%
0.75		10	22.1	8	36	3.692	11.68	52.83%	-112.5%
1 25		10	9.9	4	16	1 487	4.701	47.49%	4.81%
1 75		10	2.1	0	5	0.6403	2.025	96.42%	79.81%
2.25		10	0.1	0	1	01	0.3162	316.20%	99.04%
2.75		10	0	0	0	0	0		100.0%
3.25		10	0	0	0	0	0		100.0%
3.75		10	0	0	0	0	0		100.0%
4.25		10	0	0	0	0	0		100 0%
4.75		10	0	0	0	0	0		100 0%

Reproduction Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Reps	Rep 6	Rep?	Rep 8	Rep 9	Rep 10
0		4	15	4	8	4	24	18	18	4	5
0.75		24	36	8	18	10	31	36	35	13	10
1 25		15	14	11	6	4	6	9	16	14	4
1.75		5	3	2	5	0	0	0	4	1	1
2 25		0	0	1	0	0	0	0	0	0	0
2.75		0	0	0	0	0	0	0	0	0	0
3.25		0	0	0	0	0	0	0	0	0	0
3.75		0	0	0	0	0	0	0	0	0	0
4.25		0	0	0	0	0	0	0	0	0	0
4.75		0	0	0	0	0	0	0	0	0	0

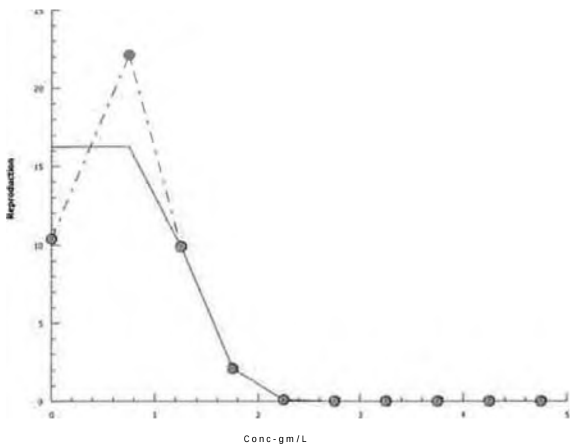
CETIS Analytical Report

Report Date: 18 Oct-16 11:56 (p 2 of 2)
Test Code: 16-1442 1 16-3601-6968

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

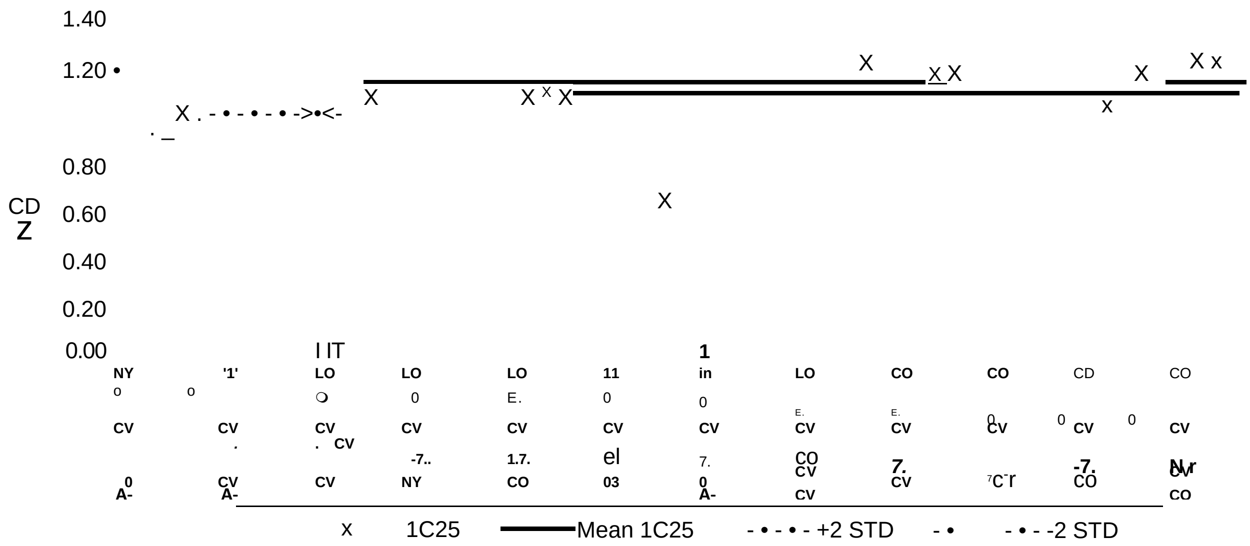
Analysis ID:	05-5445-0343	**Endpoint:**	Reproduction	**CETIS Version:**	CETISv1.9.2
Analyzed:	18 Oct-16 11:54	**Analysis:**	Linear Interpolation (ICPIN)	**Official Results:**	Yes

Graphics



New England Bioassay
Reference Toxicant Data: *Ceriodaphia dubia* Chronic Reproduction IC25

Reference Toxicant: Sodium chloride
Test Dates: Oct 2014 - Sept 2016



Test ID	Date	IC25	Mean IC25	STD	-2STD	+2STD	CV	CV National 75th%	CV National 90th%
14-1629	10/1/2014	1.17	1.15	0.10	0.95	1.34	0.08	0.45	0.62
14-1886	11/3/2014	1.03	1.14	0.10	0.94	1.34	0.09	0.45	0.62
14-1982	12/1/2014	1.17	1.15	0.07	1.01	1.30	0.06	0.45	0.62
15-79	1/5/2015	1.32	1.16	0.08	1.01	1.32	0.07	0.45	0.62
15-148	2/2/2015	1 05	1.16	0.08	1.00	1.32	0.07	0.45	0.62
15-378	3/23/2015	1.09	1.16	0.08	1.00	1.32	0.07	0.45	0.62
15-460	4/1/2015	1.00	1.15	0.09	0.98	1.32	0.08	0.45	0.62
15-602	5/1/2015	1.07	1.14	0.09	0.97	1.32	0.08	0.45	0.62
15-750	6/1/2015	110	1.14	0.09	0.97	1.32	0.08	0.45	0.62
15-955	7/1/2015	1.07	1.14	0.09	0 97	1.32	0.07	0 45	0.62
15-1211	8/3/2015	1.07	1.14	0.09	0.97	1.31	0.08	0.45	0.62
15-1375	9/9/2015	0.66	1.11	0.13	0.86	1 37	0.11	0.45	0.62
15-1540	10/1/2015	1.08	1.11	0.13	0.86	1.37	0.11	0.45	0.62
15-1691	11/2/2015	1.12	1.11	0.13	0.86	1.36	0.11	0.45	0.62
15-1897	12/28/2015	1.12	1.10	0.12	0.87	1.33	0.11	0.45	0.62
16-37	1/4/2016	1.23	1.11	0.12	0 87	1.34	0.11	0.45	0 62
16-138	2/1/2016	1.09	1.10	0.12	0.87	1 34	0.11	0.45	0.62
16-307	3/1/2016	1.12	1.10	0.12	0.87	1.33	0.11	0.45	0.62
16-463	4/1/2016	1.16	110	0.12	0.87	1.34	011	0.45	0.62
16-596	5/2/2016	119	1.10	0.12	0.87	1.34	011	0.45	0.62
16-707	6/1/2016	1.07	1.10	0.12	0.87	1.34	0.11	0.45	0.62
16-880	7/1/2016	1.20	1.10	0.12	0.87	1.34	0.11	0.45	0 62
16-1212	8/24/2016	1.24	1.10	0.12	0.86	1.34	0.11	0.45	0.62
16-1258	9/8/2016	1 22	1.11	0.12	0.87	1.35	011	0.45	0.62

New England Bioassay
A Division of GZA

GEOTECHNICAL
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AQUATIC TOXICITY TEST REPORT

Chronic Toxicity Testing at 10°C
Using *Ceriodaphnia dubia*

January 26, 2017

Report Prepared by:

New England Bioassay
A Division of GZA GeoEnvironmental, Inc.
77 Batson Dr.
Manchester, CT 06042

Report Submitted to:

Huff & Huff, a Subsidiary of GZA
915 Harger Road, Suite 330
Oak Brook, IL 60523

January 26, 2017

Huff & Huff, a Subsidiary of GZA
915 Harger Road, Suite 330
Oak Brook, IL 60523-1486

RE: Results of Chronic Tests
Sample ID: Reagent Grade NaCl
NEB Project Number: 81.0220523.00

Dear Ms. Herrera:

This report provides you with the results of the experimental chronic toxicity test performed at New England Bioassay (NEB) laboratory for Huff and Huff. The toxicity test was performed using the freshwater organism, *Ceriodaphnia dubia,* as the aquatic test species.

Chronic Toxicity Test Methods

The specific details of the *C.dubia* chronic toxicity test system are based on EPA guidelines (EPA, 1994; 2002b). For the chronic toxicity test, young *C.dubia* (≤ 24-h old at test initiation) were continuously exposed for 7 days under static-renewal conditions to 9 concentrations of reagent grade sodium chloride [0.75 g/L, 1.25 g/L, 1.75 g/L, 2.25 g/L, 2.75 g/L, 3.25 g/L, 3.75 g/L, 4.25 g/L, and 4.75 g/L NaCl] mixed with laboratory-prepared moderately hard synthetic water. A synthetic laboratory water control was also set concurrently with the test.

C. dubia were individually exposed in 30-mL plastic cups containing 15 mL of test solution or control water. Ten replicate beakers were used for each test concentration and the dilution-water control (10 animals per concentration or control). Daphnids used in testing were blocked by parentage for each replicate (i.e., young from a single female were used for all replicate #1, #2, etc).

Test beakers were maintained under the specified conditions (mean test temperature of 10° ± 1°C; photoperiod 16 h light and 8 h dark) in a commercial environmental test chamber. Surviving *Ceriodaphnia* were transferred daily with a large-bore pipette to newly prepared test solutions containing food.

Temperature, dissolved oxygen, pH, and specific conductivity were measured daily on composite samples of newly prepared solutions. Temperature, dissolved oxygen, and pH were measured on one replicate of the 24-h-old test solutions at each concentration. Observations on the number of live and dead (or immobilized) animals were made daily. Reproduction also was monitored daily by counting the number of live and dead young per female when the adults were transferred to new test solutions. Young were discarded after counting. A summary of the chronic testing protocols can be found in Attachment A. The results of the chronic toxicity test can be found in Table 1. Raw data sheets and statistical analysis are found in Attachment B.

TABLE 1. RESULTS OF A 7-DAY CERIODAPHNIA DUBIA CHRONIC TEST AT 10°C USING REAGENT GRADE SODIUM CHLORIDE MEDIAN LETHAL CONCENTRATIONS (LC_{50}), DAILY SURVIVAL, AND MEAN REPRODUCTIVE DATA

Test Species (Test ID No.)	LC_{50}[b] (g/L NaCl)	95% Confidence Limits LCL[c]	95% Confidence Limits UCL[c]
Test Dates: 4-11 January 2017			
C. dubia (17-24)	48 h: 3.5 g/L 168 h: 1.5 g/L	3.3 g/L 1.3 g/L	3.8 g/L 1.8 g/L

Test Concentration (g/L NaCl)	Daily Survival (%) 1	2	3	4	5	6	7	Sig.[e]	Young/female[d] N (7-d Reproductive Data)	X	Sig.[e]
LAB CONTROL[a]	100	100	100	100	100	100	90	---	10	0.0	--
0.75	100	100	100	100	100	100	100	NS	10	0.0	--
1.25	100	100	100	100	100	100	100	NS	10	0.0	--
1.75	100	90	90	80	0	0	0	*	10	0.0	--
2.25	100	100	70	60	40	20	0	*	10	0.0	--
2.75	100	90	50	20	0	0	0	*	10	0.0	--
3.25	100	80	30	10	0	0	0	*	10	0.0	--
3.75	70	30	0	0	0	0	0	*	10	0.0	--
4.25	20	0	0	0	0	0	0	*	10	0.0	--
4.75	0	0	0	0	0	0	0	*	10	0.0	--

[a] Lab control water was laboratory-prepared moderately hard fresh water.

[b] Test duration was 168 h (7 days) for C. dubia

[c] LCL: Lower confidence limit. UCL: Upper confidence limit;

[d] N: number of females at start of test (1 female/replicate and 10 replicates/concentration); X: Mean;

[e] Sig.: NS: not significant at 0.05; *: significant at 0.05.

Quality Assurance

A reference toxicant test using sodium chloride (NaCl) was conducted with in-house cultured *C. dubia* during January 2017. The chronic IC25 value was 1.22 g/L NaCl which was within the acceptability limits for NaCl at our laboratory. A copy of the cumulative-summation chart can be found in Attachment C.

Conclusions

The chronic aquatic toxicity test performed with *Ceriodaphnia* using sodium chloride at the specified test temperature of 10°C showed similar 48-h and 7-day LC50 results as well as similar survival C-NOEC (1.25 g/L versus 1.75 g/L) and C-LOEC levels (1.75 g/L versus 2.25 g/L) when compared with the original *Ceriodaphnia* test initially performed during 26 September - 3 October 2016 (NEB Test ID 16-1441). Organisms did not produce any young during the 7 day test period in the control water or in any of the NaCl test concentrations in either of the chronic toxicity tests conducted at 10°C. The reproduction C-NOEC was <0.75 g/L NaCl for both tests.

If you have any questions concerning this report, please contact the Lab Manager, Kim Wills at (860) 858-3153 or kimberly.wills@gza.com

Very truly yours,

Kim Wills
Manager – Aquatic Toxicity Laboratory

Attachment A

Chronic Toxicity Test Protocol Summary

Test Reference Manual:	EPA 821-R-02-013, "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Water to Freshwater Organisms", Fourth Edition
Test Method:	*Ceriodaphnia dubia* Survival and Reproduction Test – 1002.0
Test Type:	Modified Chronic Static Renewal Freshwater Test
Temperature :	10 ± 1°C
Light Quality:	Ambient Laboratory Illumination
Photoperiod:	16 hours light, 8 hours dark
Test Chamber Size:	30 mL
Test Solution Volume:	Minimum 15 mL
Renewal of Test Solutions:	Daily, using most recent sample
Age of Test Organisms:	Less than 24 hours
Number of Neonates Per Test Chamber:	1
Number of Replicate Test Chambers Per Treatment:	10
Number of Neonates Per Test Concentration:	10
Feeding Regime:	Fed 0.1 mL each of YCT and algal suspension per exposure chamber daily.
Aeration:	None
Dilution Water:	Moderately hard synthetic freshwater
Test Concentrations:	0, 0.75, 1.25, 1.75, 2.25, 2.75, 3.25, 3.75, 4.25, and 4.75 g/L
Test Duration:	7 days
End Points:	Survival and reproduction.
Test Acceptability:	Control Survival: ≥ 80% Yes X No _ Control Reproduction: Average ≥ 15/control female Yes __ No X
Test Organism Source:	New England Bioassay in-house cultures

Attachment B

Raw Data Sheets and Statistical Analysis

NEW ENGLAND BIOASSAY TOXICITY DATA FORM

CHRONIC COVER SHEET

CLIENT: GZA/Huff & Huff
ADDRESS: 915 Harger Road, Suite 330
Oak Brook, IL 60523-1486
SAMPLE TYPE: Sodium Chloride run at 10 degrees C
DILUTION WATER: Moderately Hard Lab Water

C.dubia TEST ID # 17-24
COC # N/A
PROJECT # 81.0220523.00

INVERTEBRATES

TEST SET UP (TECH INIT) KO
TEST SPECIES *Ceriodaphnia dubia*
NEB LOT# Cd16 (RMH 282)
AGE < 24 hours
TEST SOLUTION VOLUME (mls) 15
NO. ORGANISMS PER TEST CHAMBER 1
NO. ORGANISMS PER CONCENTRATION 10

Laboratory Control Water (MHRCF)

Batch Number	Hardness mg/L $CaCO_3$	Alkalinity mg/L $CaCO_3$
C36-MH015	86	60

	DATE	TIME
TEST START:	1/4/17	1526
TEST END:	1/11/17	1526

Results of *Ceriodaphnia dubia* Chronic Test

		95% Confidence Limits
48 Hour LC50	3.5 g/L	3.3 g/L - 3.8 g/L
7 Day LC50	1.5 g/L	1.3 g/L - 1.8 g/L
Survival NOEC	1.25 g/L	
Survival LOEC	1.75 g/L	
Reproduction NOEC	<0.75 g/L	
Reproduction LOEC	0.75 g/L	
Reproduction IC_{25}	Not estimated	

NOEC: NO OBSERVABLE EFFECT CONCENTRATI(LOEC: LOWEST OBSERVABLE EFFECT CONCENTRATION

Comments:

REVIEWD BY: [signature] DATE: 1/26/17

NEW ENGLAND BIOASSAY - CHRONIC TOXICITY TEST BROOD DATA SHEET

FACILITY NAME & ADDRESS:	GZA/Huff & Huff - Sodium Chloride				
NEB PROJECT NUMBER:	81.0220523.00	NEB TEST NUMBER:	17-24	COC #	N/A
TEST ORGANISM:	*Ceriodaphnia dubia*	AGE:	<24 hours		Lot # Cd16 (RMH 282)
START DATE:	1/4/17	TIME: 1526	END DATE: 1/11/17	TIME:	1526

g/L	Culture Lot# Cd16 (RMH 282)											Total Live Young	# Live Adults	Analyst-Transfer	Analyst-Counts
	Cup #	A1	A3	A4	A5	A6	A8	A9	A10	A12	A13				
	Day Number	A	B	C	D	E	F	G	H	I	J				
NEB Lab Synthetic Diluent	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10	KO	
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10	PD	
	2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10	CW	
	3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10	CW	CW
	4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10	CW	CW
	5	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10	KO	KO
	6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10	CW	CW
	7	✓	✓/x	✓	✓	✓	✓	✓	✓	✓	✓	0	9	KO	KO
	totals	0	0	0	0	0	0	0	0	0	0	0	9		MG
0.75		A	B	C	D	E	F	G	H	I	J				
	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	5	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	totals	0	0	0	0	0	0	0	0	0	0	0	10		
1.25		A	B	C	D	E	F	G	H	I	J				
	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	5	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	totals	0	0	0	0	0	0	0	0	0	0	0	10		

Notes: Adults producing no neonates were identified as non-reproducing females at test termination.

NEW ENGLAND BIOASSAY - CHRONIC TOXICITY TEST BROOD DATA SHEET

FACILITY NAME & ADDRESS: GZA/Huff & Huff - Sodium Chloride		
NEB PROJECT NUMBER: 81.0220523.00	ORGANISM: *Ceriodaphnia dubia*	START DATE: 1/4/17

Effluent Concentration	Day Number	Replicate A	B	C	D	E	F	G	H	I	J	Total Live Young	# Live Adults	Analyst-Transfer	Analyst-Counts
1.75	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	2	✓	✓	✓/x	✓	✓	✓	✓	✓	✓	✓	0	9		
	3	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	0	9		
	4	✓	✓	X	✓/x	✓	✓	✓	✓	✓	✓	0	8		
	5	✓/x	✓/x	X	X	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		
2.25		A	B	C	D	E	F	G	H	I	J				
	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0	10		
	3	✓	✓/x	✓	✓/x	✓	✓	✓	✓	✓	✓/x	0	7		
	4	✓	X	✓	X	✓/x	✓	✓	✓	✓	X	0	6		
	5	✓/x	X	✓	X	X	✓	✓/x	✓	✓	X	0	4		
	6	X	X	✓	X	X	✓/x	X	✓	✓/x	X	0	2		
	7	X	X	✓/x	X	X	X	X	✓/x	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		
2.75		A	B	C	D	E	F	G	H	I	J				
	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	2	✓	✓	✓/x	✓	✓	✓	✓	✓	✓	✓	0	9		
	3	✓/x	✓/x	X	✓	✓/x	✓	✓	✓/x	✓	✓	0	5		
	4	X	X	X	✓/x	X	✓/x	✓/x	X	✓	✓	0	2		
	5	X	X	X	X	X	X	X	X	✓/x	✓/x	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		
3.25		A	B	C	D	E	F	G	H	I	J				
	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	2	✓	✓	✓/x	✓	✓	✓	✓/x	✓	✓	✓	0	8		
	3	✓/x	✓	X	✓/x	✓/x	✓	X	✓	✓/x	✓/x	0	3		
	4	X	✓	X	X	X	✓/x	X	✓/x	X	X	0	1		
	5	X	✓/x	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		

FACILITY NAME & ADDRESS:	GZA/Huff & Huff - Sodium Chloride		
NEB PROJECT NUMBER: 81.0220523.00	ORGANISM: *Ceriodaphnia dubia*	START DATE:	1/4/17

Effluent Concentration	Day Number	A	B	C	D	E	F	G	H	I	J	Total Live Young	# Live Adults	Analyst-Transfer	Analyst-Counts
3.75	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓	✓/x	✓	✓	✓	✓	✓/x	✓/x	✓	✓		7		
	2	✓	X	✓/x	✓/x	✓/x	✓	X	X	✓	✓/x	0	3		
	3	✓/x	X	X	X	X	✓/x	X	X	✓/x	X	0	0		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		
4.25		A	B	C	D	E	F	G	H	I	J				
	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x	✓	✓		2		
	2	X	X	X	X	X	X	X	X	✓/x	✓/x	0	0		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		
4.75		A	B	C	D	E	F	G	H	I	J				
	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		10		
	1	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x	✓/x		0		
	2	X	X	X	X	X	X	X	X	X	X	0	0		
	3	X	X	X	X	X	X	X	X	X	X	0	0		
	4	X	X	X	X	X	X	X	X	X	X	0	0		
	5	X	X	X	X	X	X	X	X	X	X	0	0		
	6	X	X	X	X	X	X	X	X	X	X	0	0		
	7	X	X	X	X	X	X	X	X	X	X	0	0		
	totals	0	0	0	0	0	0	0	0	0	0	0	0		

CETIS Analytical Report

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID:	10-2321-1881	**Endpoint:**	2d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	17 Jan-17 13:34	**Analysis:**	Linear Regression (GLM)	**Official Results:**	Yes

Batch ID:	16-4962-3954	**Test Type:**	Reproduction-Survival (7d)	**Analyst:**	
Start Date:	04 Jan-17 15:26	**Protocol:**	EPA/821/R-02-013 (2002)	**Diluent:**	Laboratory Water
Ending Date:	11 Jan-17 15:26	**Species:**	Ceriodaphnia dubia	**Brine:**	Not Applicable
Duration:	7d 0h	**Source:**	In-House Culture	**Age:**	<24h

Sample ID:	21-2684-2912	**Code:**	7EC50C20	**Client:**	GZA GeoEnvironmental
Sample Date:	04 Jan-17	**Material:**	Sodium chloride	**Project:**	
Receipt Date:	04 Jan-17	**Source:**	Reference Toxicant		
Sample Age:	15h	**Station:**			

Linear Regression Options

Model Name	Link Function	Threshold Option	Thresh	Optimized	Pooled	Het Corr	Weighted
Log-Normal (Probit)	η=inv Φ[π]	Control Threshold	0.000001	Yes	Yes	No	Yes

Regression Summary

Iters	LL	AICc	BIC	Mu	Sigma	Adj R2	F Stat	Critical	P-Value	Decision(α:5%)
24	-6.9	23.8	20.71	0.5497	0.03814	0.9901				Lack of Fit Not Tested

Point Estimates

Level	g/L	95% LCL	95% UCL
LC50	3.545	3.262	3.762

Regression Parameters

Parameter	Estimate	Std Error	95% LCL	95% UCL	t Stat	P-Value	Decision(α:5%)
Threshold	0.03254	0.02314	-0.0128	0.07789	1.407	0.2023	Non-Significant Parameter
Slope	26.22	8.059	10.42	42.01	3.253	0.0140	Significant Parameter
Intercept	-14.41	4.509	-23.25	-5.574	-3.196	0.0151	Significant Parameter

ANOVA Table

Source	Sum Squares	Mean Square	DF	F Stat	P-Value	Decision(α:5%)
Model	568.4	284.2	2	451.2	<1.0E-37	Significant
Residual	4.409	0.6299	7			

Residual Analysis

Attribute	Method	Test Stat	Critical	P-Value	Decision(α:5%)
Goodness-of-Fit	Pearson Chi-Sq GOF Test	4.409	14.07	0.7316	Non-Significant Heterogeneity
	Likelihood Ratio GOF Test	4.969	14.07	0.6637	Non-Significant Heterogeneity
Distribution	Shapiro-Wilk W Normality Test	0.8248	0.7607	0.0290	Non-Normal Distribution
	Anderson-Darling A2 Normality Te	0.8007	2.492	0.0379	Non-Normal Distribution

2d Survival Rate Summary

			Calculated Variate(A/B)								
Conc-g/L	Code	Count	Mean	Min	Max	Std Err	Std Dev	CV%	%Effect	A	B
0	D	10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
0.75		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
1.25		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
1.75		10	0.9000	0.0000	1.0000	0.1000	0.3162	35.14%	10.0%	9	10
2.25		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	10	10
2.75		10	0.9000	0.0000	1.0000	0.1000	0.3162	35.14%	10.0%	9	10
3.25		10	0.8000	0.0000	1.0000	0.1333	0.4216	52.70%	20.0%	8	10
3.75		10	0.3000	0.0000	1.0000	0.1528	0.4830	161.00%	70.0%	3	10
4.25		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
4.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10

Ceriodaphnia 7-d Survival and Reproduction Test | **New England Bioassay**

Analysis ID: 10-2321-1881 | **Endpoint:** 2d Survival Rate | **CETIS Version:** CETISv1.9.2
Analyzed: 17 Jan-17 13:34 | **Analysis:** Linear Regression (GLM) | **Official Results:** Yes

2d Survival Rate Detail

Conc-g/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.75		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.75		1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2.25		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2.75		1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3.25		1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000
3.75		1.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000
4.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

2d Survival Rate Binomials

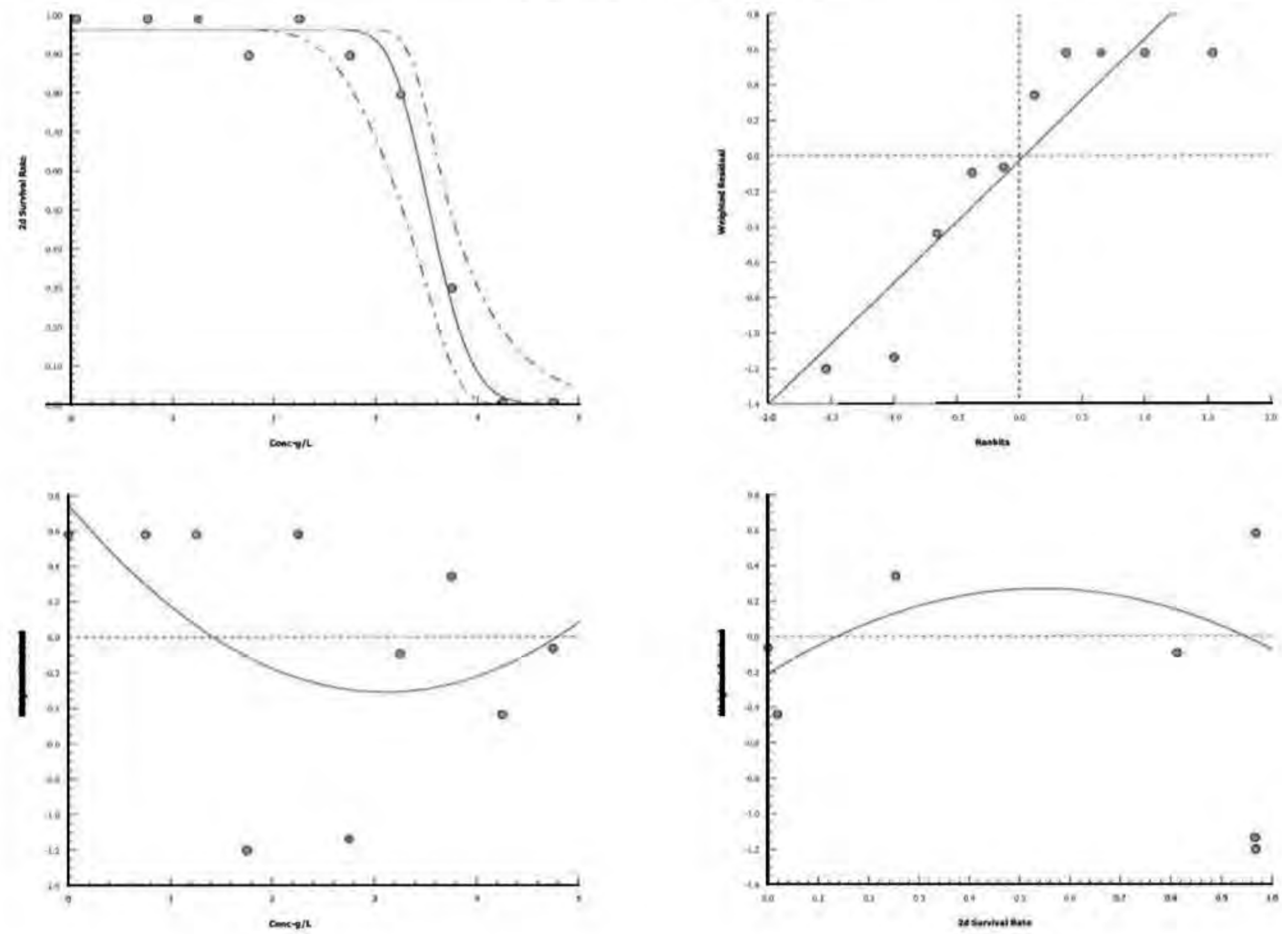
Conc-g/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
0.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.75		0/1	1/1	0/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
2.25		0/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
2.75		0/1	1/1	0/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
3.25		0/1	1/1	0/1	1/1	1/1	1/1	0/1	1/1	0/1	1/1
3.75		0/1	0/1	0/1	0/1	0/1	1/1	0/1	0/1	0/1	0/1
4.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1

Ceriodaphnia 7-d Survival and Reproduction Test | **New England Bioassay**

Analysis ID:	10-2321-1881	**Endpoint:**	2d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	17 Jan-17 13:34	**Analysis:**	Linear Regression (GLM)	**Official Results:**	Yes

Graphics

Log-Normal: inv Φ[π]=α+β·log[x]



Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

Analysis ID:	11-8828-4656	**Endpoint:**	7d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	17 Jan-17 13:34	**Analysis:**	Binomial Method	**Official Results:**	Yes
Batch ID:	16-4962-3954	**Test Type:**	Reproduction-Survival (7d)	**Analyst:**	
Start Date:	04 Jan-17 15:26	**Protocol:**	EPA/821/R-02-013 (2002)	**Diluent:**	Laboratory Water
Ending Date:	11 Jan-17 15:26	**Species:**	Ceriodaphnia dubia	**Brine:**	Not Applicable
Duration:	7d 0h	**Source:**	In-House Culture	**Age:**	<24h
Sample ID:	21-2684-2912	**Code:**	7EC50C20	**Client:**	GZA GeoEnvironmental
Sample Date:	04 Jan-17	**Material:**	Sodium chloride	**Project:**	
Receipt Date:	04 Jan-17	**Source:**	Reference Toxicant		
Sample Age:	15h	**Station:**			

Binomial/Graphical Estimates

Threshold Option	Threshold	Trim	Mu	Sigma	LC50	95% LCL	95% UCL
Control Threshold	0.1	0.00%	0.17	0	1.479	1.25	1.75

Test Acceptability Criteria

Attribute	Test Stat	TAC Limits Lower	TAC Limits Upper	Overlap	Decision
Control Resp	0.9	0.8	>>	Yes	Passes Criteria

7d Survival Rate Summary

Conc-g/L	Code	Count	Mean	Min	Max	Std Err	Std Dev	CV%	%Effect	A	B
			Calculated Variate(A/B)								
0	D	10	0.9000	0.0000	1.0000	0.1000	0.3162	35.14%	0.0%	9	10
0.75		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	-11.11%	10	10
1.25		10	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	-11.11%	10	10
1.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
2.25		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
2.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
3.25		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
3.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
4.25		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10
4.75		10	0.0000	0.0000	0.0000	0.0000	0.0000		100.0%	0	10

7d Survival Rate Detail

Conc-g/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.75		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2.75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.25		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4.75		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

002-570-915-7 CETIS™ v1.9.2.4 Analyst: QA:

Received, Clerk's Office 5/21/2018 ** R2018-032**

Ceriodaphnia 7-d Survival and Reproduction Test — **New England Bioassay**

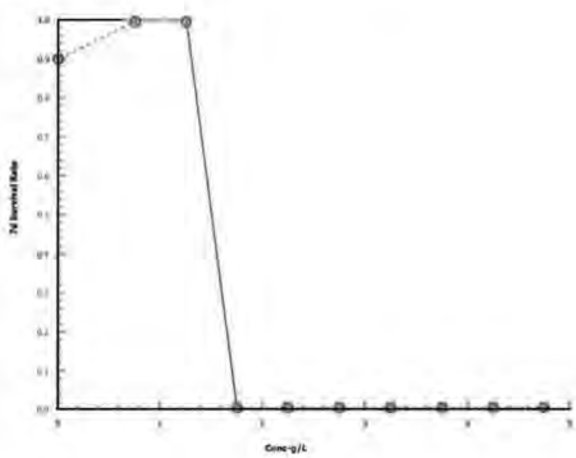
Analysis ID: 11-8828-4656 **Endpoint:** 7d Survival Rate **CETIS Version:** CETISv1.9.2

Analyzed: 17 Jan-17 13:34 **Analysis:** Binomial Method **Official Results:** Yes

7d Survival Rate Binomials

Conc-g/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
0.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.75		0/1	1/1	0/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
2.25		0/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
2.75		0/1	1/1	0/1	1/1	1/1	1/1	1/1	1/1	0/1	1/1
3.25		0/1	1/1	0/1	1/1	1/1	1/1	0/1	1/1	0/1	1/1
3.75		0/1	0/1	0/1	0/1	0/1	1/1	0/1	0/1	0/1	0/1
4.25		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
4.75		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1

Graphics



002-570-915-7 CETIS™ v1.9.2.4 Analyst: QA:

Ceriodaphnia 7-d Survival and Reproduction Test **New England Bioassay**

Analysis ID:	01-2901-2141	**Endpoint:**	7d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	17 Jan-17 13:34	**Analysis:**	STP 2xK Contingency Tables	**Official Results:**	Yes
Batch ID:	16-4962-3954	**Test Type:**	Reproduction-Survival (7d)	**Analyst:**	
Start Date:	04 Jan-17 15:26	**Protocol:**	EPA/821/R-02-013 (2002)	**Diluent:**	Laboratory Water
Ending Date:	11 Jan-17 15:26	**Species:**	Ceriodaphnia dubia	**Brine:**	Not Applicable
Duration:	7d 0h	**Source:**	In-House Culture	**Age:**	<24h
Sample ID:	21-2684-2912	**Code:**	7EC50C20	**Client:**	GZA GeoEnvironmental
Sample Date:	04 Jan-17	**Material:**	Sodium chloride	**Project:**	
Receipt Date:	04 Jan-17	**Source:**	Reference Toxicant		
Sample Age:	15h	**Station:**			

Data Transform	Alt Hyp	NOEL	LOEL	TOEL	TU
Untransformed	C > T	1.25	> 1.25	n/a	

Fisher Exact/Bonferroni-Holm Test

Control vs	Group	Test Stat	P-Type	P-Value	Decision(α:5%)
Dilution Water	0.75	1.0000	Exact	1.0000	Non-Significant Effect
	1.25	1.0000	Exact	1.0000	Non-Significant Effect

Test Acceptability Criteria

Attribute	Test Stat	TAC Limits Lower	TAC Limits Upper	Overlap	Decision
Control Resp	0.9	0.8	>>	Yes	Passes Criteria

Data Summary

Conc-g/L	Code	NR	R	NR + R	Prop NR	Prop R	%Effect
0	D	9	1	10	0.9	0.1	0.0%
0.75		10	0	10	1	0	-11.11%
1.25		10	0	10	1	0	-11.11%

7d Survival Rate Detail

Conc-g/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.75		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

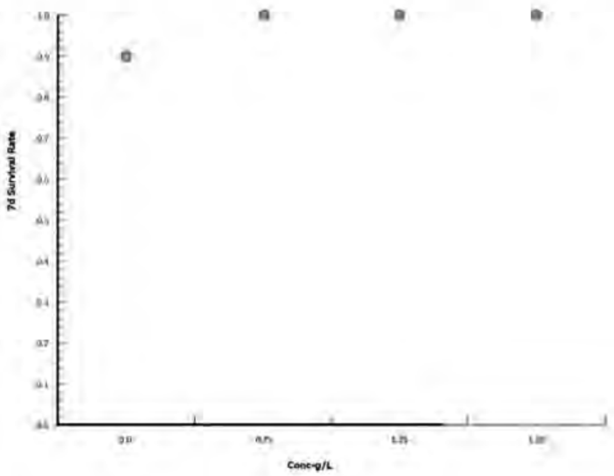
7d Survival Rate Binomials

Conc-g/L	Code	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
0	D	1/1	0/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
0.75		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
1.25		1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1

Ceriodaphnia 7-d Survival and Reproduction Test **New England Bioassay**

Analysis ID:	01-2901-2141	**Endpoint:**	7d Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	17 Jan-17 13:34	**Analysis:**	STP 2xK Contingency Tables	**Official Results:**	Yes

Graphics



NEB'S DATA SHEET FOR ROUTINE CHEMICAL AND PHYSICAL DETERMINATIONS

FACILITY NAME & ADDRESS: GZA/Huff & Huff - Sodium Chloride
NEB PROJECT NUMBER: 81.0220523.00 TEST ORGANISM *Ceriodaphnia dubia*
DILUTION WATER SOURCE: Moderately Hard Lab Water START DATE: 1/4/17 TIME: 1526

ANALYST	KO	PD	KO	CW	CW	KO	CW	
NEB Lab Synthetic Diluent	1	2	3	4	5	6	7	Remarks
Temp °C Initial	11.0	11.0	10.7	10.9	10.8	11.0	11.0	
D.O. mg/L Initial	9.6	9.8	9.8	9.8	10.4	10.6	10.2	
pH s.u. Initial	7.9	8.2	7.9	7.9	7.9	7.9	7.8	
Conductivity µS Initial	334	331	339	325	329	339	337	
Temp °C Final	11.0	11.0	11.0	10.6	10.9	11.0	11.0	
D.O. mg/L Final	11.8	11.8	11.7	11.8	11.6	11.8	12.2	
pH s.u. Final	8.6	8.7	8.8	9.0	8.5	8.6	8.8	
Conductivity µS Final	338	351	343	345	353	348	342	
0.75 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	11.0	10.6	10.6	10.8	10.2	10.8	11.0	
D.O. mg/L Initial	9.6	10.1	9.7	9.9	10.7	10.8	10.4	
pH s.u. Initial	7.9	8.1	7.9	8.0	7.9	7.9	7.8	
Conductivity µS Initial	1,708	1,787	1,816	1,796	1,826	1,843	1,790	
Temp °C Final	11.0	11.0	10.4	10.5	10.3	11.0	11.0	
D.O. mg/L Final	12.2	12.0	12.4	12.4	12.3	12.4	12.4	
pH s.u. Final	8.5	8.6	8.9	9.0	8.6	8.3	8.8	
Conductivity µS Final	1,706	1,818	1,783	1,771	1,834	1,785	1,759	
1.25 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	11.0	10.2	9.4	10.8	9.9	10.6	11.0	
D.O. mg/L Initial	9.7	10.3	10.1	9.9	10.7	10.8	10.7	
pH s.u. Initial	7.9	8.1	7.9	8.0	8.0	8.0	7.8	
Conductivity µS Initial	2,759	2,704	2,844	2,785	2,840	2,844	2,787	
Temp °C Final	11.0	10.8	10.3	10.3	10.2	11.0	11.0	
D.O. mg/L Final	12.3	12.2	12.6	12.6	12.6	13.0	12.7	
pH s.u. Final	8.6	8.6	9.0	9.0	8.7	8.4	8.8	
Conductivity µS Final	2,621	2,704	2,770	2,765	2,834	2,739	2,718	
1.75 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	11.0	10.1	9.2	10.9	9.7	10.4	10.8	
D.O. mg/L Initial	9.8	10.1	10.2	10.0	10.8	11.0	10.8	
pH s.u. Initial	7.9	8.1	7.8	8.0	8.0	8.0	7.9	
Conductivity µS Initial	3,777	3,583	3,838	3,739	3,809	3,779	3,715	
Temp °C Final	11.0	10.7	10.1	10.2	10.3	11.0	11.0	
D.O. mg/L Final	12.4	12.2	12.8	12.9	12.7	12.9	12.6	
pH s.u. Final	8.6	8.6	8.9	9.0	8.6	8.6	8.8	
Conductivity µS Final	3,514	3,669	3,713	3,712	3,782	3,581	3,683	

NEB'S DATA SHEET FOR ROUTINE CHEMICAL AND PHYSICAL DETERMINATIONS

FACILITY NAME & ADDRESS: GZA/Huff & Huff - Sodium Chloride
NEB PROJECT NUMBER: 81.0220523.00 TEST ORGANISM *Ceriodaphnia dubia*
DILUTION WATER SOURCE: Moderately Hard Lab Water START DATE: 1/4/17 TIME: 1526

2.25 g/L	1	2	3	4	5	6	7	Remarks
Temp °C Initial	11.0	10.2	9.2	10.9	9.9	10.5	10.9	
D.O. mg/L Initial	9.8	10.1	10.2	10.1	10.8	11.0	10.8	
pH s.u. Initial	7.9	8.0	7.8	8.0	8.0	8.0	7.9	
Conductivity µS Initial	4,447	4,360	4,656	4,624	4,698	4,735	4,668	
Temp °C Final	11.0	10.7	10.1	10.3	10.2	11.0	11.0	
D.O. mg/L Final	12.4	12.3	12.7	12.7	12.7	12.3	12.8	
pH s.u. Final	8.6	8.6	8.9	9.0	8.7	8.7	8.9	
Conductivity µS Final	4,370	4,424	4,531	4,663	4,684	4,508	4,634	
2.75 g/L	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Remarks**
Temp °C Initial	11.0	11.0	9.6	10.9	9.7	10.5		
D.O. mg/L Initial	9.7	10.1	10.3	10.1	10.8	11.0		
pH s.u. Initial	7.8	8.0	7.8	8.0	8.0	8.0		
Conductivity µS Initial	5,605	5,206	5,651	5,523	5,639	5,661		
Temp °C Final	11.0	11.0	10.3	10.3	10.6			
D.O. mg/L Final	12.5	11.8	12.6	12.7	12.8			
pH s.u. Final	8.6	8.6	9.0	9.0	8.8			
Conductivity µS Final	5,251	5,418	5,580	5,477	5,549			
3.25 g/L	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Remarks**
Temp °C Initial	11.0	11.0	9.3	10.8	10.0	10.3		
D.O. mg/L Initial	9.7	10.2	10.4	10.2	10.8	11.0		
pH s.u. Initial	7.9	7.9	7.8	8.0	8.0	8.0		
Conductivity µS Initial	6,307	6,184	6,533	6,426	6,612	6,519		
Temp °C Final	11.0	11.0	10.4	10.7	10.4			
D.O. mg/L Final	12.5	12.0	12.8	12.7	13.0			
pH s.u. Final	8.6	8.5	9.0	8.9	8.8			
Conductivity µS Final	6,155	6,230	6,250	6,300	6,469			
3.75g/L	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Remarks**
Temp °C Initial	11.0	11.0	9.1	10.7				
D.O. mg/L Initial	9.6	10.1	10.5	10.2				
pH s.u. Initial	7.8	7.9	7.9	8.0				
Conductivity µS Initial	7,168	7,192	7,602	7,385				
Temp °C Final	11.0	10.9	10.6					
D.O. mg/L Final	12.4	11.8	12.6					
pH s.u. Final	8.6	8.5	8.9					
Conductivity µS Final	6,870	7,238	7,366					

Table of Random Permutations of 16 C.dubia Test ID# 17-24

7	12	15	15	1	2	7	16	10	2	14	15	7	13	13	10	6	1	8	10
13	3	8	16	7	10	11	10	13	5	11	7	13	16	7	7	5	13	2	14
3	1	4	5	14	13	3	14	9	13	13	2	9	15	6	2	8	4	5	8
11	8	16	14	15	6	2	6	2	16	8	5	12	3	9	13	4	3	10	4
14	9	1	6	3	9	14	13	8	6	5	8	14	7	3	15	13	11	4	7
2	16	10	13	5	5	13	2	11	7	3	12	5	14	12	16	2	2	9	15
4	6	13	7	2	15	1	9	1	4	7	10	6	9	11	9	7	6	16	11
6	14	6	10	4	14	4	15	3	3	4	16	2	6	5	1	12	10	6	9
10	15	2	1	13	12	16	3	4	8	10	1	15	5	14	12	14	12	3	2
12	10	7	12	9	11	9	8	12	14	15	4	11	8	16	8	9	14	14	1
15	7	5	2	10	7	8	12	6	15	6	13	16	12	15	4	11	8	12	6
16	2	11	8	8	8	15	5	16	1	1	9	8	1	8	14	16	5	13	5
9	13	14	3	6	4	10	11	5	12	9	3	10	4	4	3	10	9	1	3
8	11	9	4	11	3	12	7	7	10	12	14	3	10	1	6	15	16	15	12
1	5	12	11	16	16	5	4	14	9	16	11	1	2	10	5	1	15	7	13
5	4	3	9	12	1	6	1	15	11	2	6	4	11	2	11	3	7	11	16

							rep				conc.								
11	8	16	5	5	13	1	**13**	2	16	14	**12**	9	8	7	5	13	3	13	3
2	2	8	8	14	16	4	**3**	8	11	10	**14**	15	1	2	11	4	5	15	9
6	13	2	13	6	5	9	**15**	11	10	12	**6**	16	15	16	9	10	12	16	15
14	12	4	16	16	11	14	**10**	5	12	3	**3**	12	14	15	13	6	4	1	16
8	6	3	9	4	10	6	**4**	16	2	2	**9**	8	16	4	6	5	15	7	8
9	15	12	10	3	2	12	**6**	1	15	4	**13**	7	7	9	12	14	8	8	11
3	10	11	12	13	12	5	**11**	7	8	9	**5**	14	11	10	1	3	13	3	5
16	1	13	14	8	14	15	**5**	3	7	11	**15**	6	12	5	7	11	1	14	4
1	14	14	2	9	15	16	**14**	6	14	7	**8**	3	13	11	8	7	7	12	7
4	4	6	4	12	3	11	**8**	15	9	8	**1**	13	6	3	3	15	9	9	12
15	5	1	11	10	6	3	**7**	10	5	5	**11**	10	10	12	15	16	14	5	2
5	3	5	6	7	7	13	**2**	14	3	16	**4**	5	5	13	4	9	16	2	6
12	7	15	15	15	9	8	**12**	12	13	15	**10**	1	4	6	16	2	6	11	1
10	11	10	3	2	4	2	**1**	4	6	6	**7**	11	9	14	10	8	11	4	13
7	9	7	7	11	1	7	**16**	13	1	13	**2**	4	2	1	2	12	2	10	14
13	16	9	1	1	8	10	**9**	9	4	1	**16**	2	3	8	14	1	10	6	10

1	6	7	4	8	6	5	2	8	15	4	6	6	1	4	5	7	13	2	10
9	15	11	3	11	15	9	10	1	3	8	2	15	7	9	8	16	1	14	3
10	16	4	5	12	9	16	11	7	1	7	16	11	8	3	3	12	2	3	4
4	14	1	9	5	5	4	13	6	8	15	5	12	5	7	16	5	11	8	1
7	3	13	14	15	2	1	14	16	5	14	9	2	16	1	12	6	14	4	13
16	11	2	1	14	16	6	9	3	4	16	14	3	15	11	11	3	9	12	5
3	10	16	16	13	7	13	1	11	14	9	10	16	2	10	2	10	7	10	16
11	13	9	13	4	13	8	3	5	13	10	12	5	12	5	14	13	16	5	6
15	2	3	12	9	12	2	4	13	10	3	13	14	4	2	1	14	8	6	12
14	1	14	6	10	1	3	12	4	2	2	4	13	3	16	9	9	3	7	14
13	12	5	11	3	11	15	8	2	7	11	7	8	14	6	4	4	4	15	11
12	5	10	7	2	14	7	15	14	16	13	1	9	10	12	10	11	10	9	8
8	9	8	10	6	4	11	7	10	11	6	8	4	9	8	15	8	6	11	9
2	7	6	2	1	8	10	6	15	12	1	11	7	11	13	6	1	15	13	15
6	4	15	8	16	10	14	16	9	6	12	3	10	6	14	7	2	12	16	7
5	8	12	15	7	3	12	5	12	9	5	15	1	13	15	13	15	5	1	2

13	4	10	4	16	13	16	13	5	3	6	14	1	16	8	7	2	3	3	12
5	14	4	6	8	2	15	1	13	14	16	4	15	4	3	12	12	1	4	7
2	2	2	15	14	16	9	12	16	6	10	15	14	9	10	1	14	8	8	16
7	12	15	8	12	3	5	14	7	12	5	13	16	1	7	5	11	2	9	3
6	9	7	14	9	14	10	11	15	11	12	1	12	12	14	16	3	11	11	8
14	5	16	7	10	8	11	8	14	13	7	11	6	3	11	4	4	6	6	9
15	11	8	9	7	12	8	7	1	15	9	3	3	7	13	11	10	4	5	1
11	6	6	1	4	1	3	16	12	5	4	9	13	13	6	8	15	9	1	14
4	10	3	16	2	11	7	9	6	9	1	8	4	11	5	2	16	10	12	4
1	8	1	13	1	15	4	4	11	4	2	16	5	8	1	9	5	12	16	6
9	7	14	2	6	4	14	10	9	8	15	10	7	10	9	10	6	14	10	11
12	1	9	10	15	5	2	15	10	2	14	2	8	2	4	13	8	5	15	5
3	3	12	11	5	9	6	6	3	10	13	12	9	6	2	15	7	15	7	13
10	15	11	5	13	7	12	5	2	7	11	5	10	15	12	3	1	13	13	10
8	13	13	3	3	10	13	2	4	1	8	6	11	14	15	6	9	16	2	2
16	16	5	12	11	6	1	3	8	16	3	7	2	5	16	14	13	7	14	15

Ceriodaphnia dubia Culture Chart

Lot # Cdlk (RMH 282) A

Huff + Huff 1-4-17

Brood mother source: RMH 278 A3 Source's brood size: 26 (Qty.)

Tech	MG	MG	MG	MG	MG		SJP	SJP		AH	AH	AH				
Date	12/26	12-27	12-28	12-29	12-30		1-1	1-2		1-3	1-4	1-5				
Day acc.	0	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Cup #																
1	N	N	N	4	N		2Y	N	1	T1 Y 18	T1 Y 23	Y				
2	N	N	N	4	N		2Y	N	2	T2 Y 17	~~T2~~ Y	Y				
3	N	N	N	5	N		2Y	N	3	T3 Y 19	T2 Y 11	Y				
4	N	N	N	4	N		2Y	N	4	T4 Y 19	T3 Y 13	Y				
5	N	N	N	N	6		2Y	N	5	Y	T4 Y 12	Y				
6	N	N	N	5	N		2Y	N	6	T5 Y 21	T5 Y 13	Y				
7	N	N	N	3	N		2Y	N X	7	→	→	→	→	→	→	→
8	N	N	N	N	5		2Y	N	8	T6 Y 22	T6 Y 16	Y				
9	N	N	N	5	N		2Y	N	9	T7 Y 22	T7 Y 13	Y				
10	N	N	N	4	N		2Y	N	10	T8 Y 20	T8 Y 14	Y				
11	N	N	N	4	N		2Y	N	11	T9 Y 19	Y	Y				
12	N	N	N	4	N		2Y	N	12	T10 Y 18	T9 Y 15	Y				
13	N	N	N	3	N		2Y	N	13	Y	(T1) T10 Y 19	Y				

Y = neonates present, and *criterion has been met:* ≥ 20 neonates produced in total by 3rd brood. **N** = no neonates

2B = two broods present. **2Y** = two broods and criterion met: ≥ 20 neos. by 3rd brood. **X** = brood mother dead **ae** = aborted eggs

✓ or **P** = neonates present after renewal on previous day (see time in log). **A→** = acceptable for acute testing only

T# = neonates used in test, replicate number of test noted (and brood counted). acc. = *if acclimated*, H_2O type used w/ renewal **this** day.

Test organism collection:

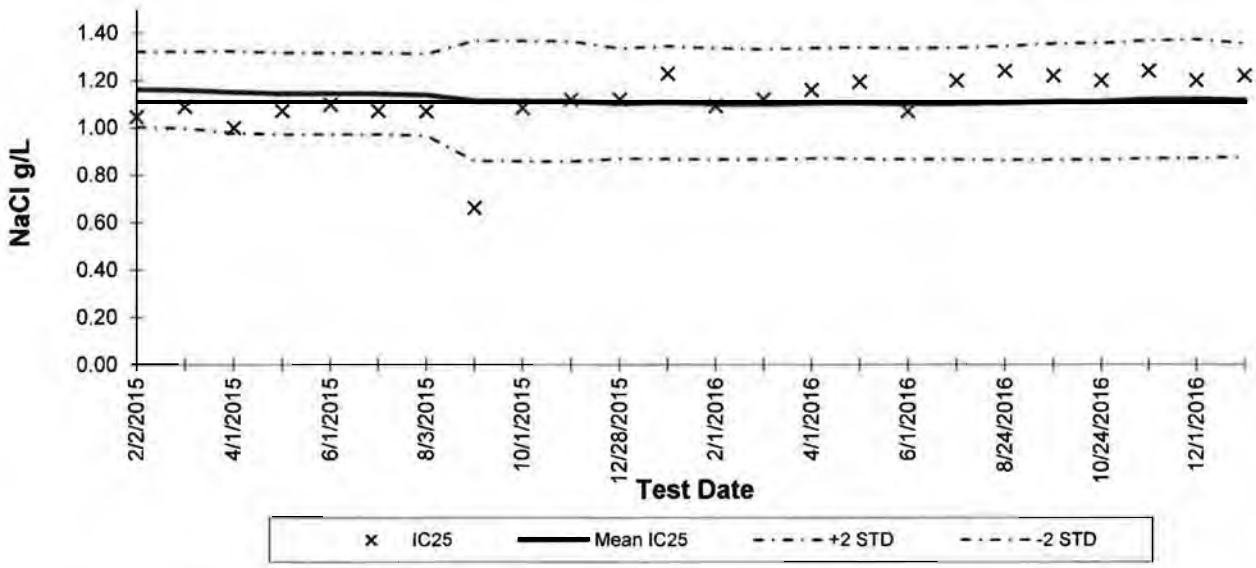
Project #	Symbols (✓ / P)		Tray diagram used? (Y/N)	Time period, neonates released	Collection date / time
81.0220523	T		Y	1-3-17/1605 → 1-4-17/0745	1-4-17/1115
00415743	(T)		Y	1-3-17/1605 → 1-4-17/0245	1-4-17/1230
	T				
	T				
	T				
	T				

Attachment C

Reference Toxicant Chart

New England Bioassay
Reference Toxicant Data: *Ceriodaphia dubia* Chronic Reproduction IC25

Reference Toxicant: Sodium chloride
Test Dates: Feb 2015 - Jan 2017



Test ID	Date	IC_{25}	Mean IC_{25}	STD	-2STD	+2STD	CV	CV National 75th%	CV National 90th%
15-148	2/2/2015	1.05	1.16	0.08	1.00	1.32	0.07	0.45	0.62
15-378	3/23/2015	1.09	1.16	0.08	1.00	1.32	0.07	0.45	0.62
15-460	4/1/2015	1.00	1.15	0.09	0.98	1.32	0.08	0.45	0.62
15-602	5/1/2015	1.07	1.14	0.09	0.97	1.32	0.08	0.45	0.62
15-750	6/1/2015	1.10	1.14	0.09	0.97	1.32	0.08	0.45	0.62
15-955	7/1/2015	1.07	1.14	0.09	0.97	1.32	0.07	0.45	0.62
15-1211	8/3/2015	1.07	1.14	0.09	0.97	1.31	0.08	0.45	0.62
15-1375	9/9/2015	0.66	1.11	0.13	0.86	1.37	0.11	0.45	0.62
15-1540	10/1/2015	1.08	1.11	0.13	0.86	1.37	0.11	0.45	0.62
15-1691	11/2/2015	1.12	1.11	0.13	0.86	1.36	0.11	0.45	0.62
15-1897	12/28/2015	1.12	1.10	0.12	0.87	1.33	0.11	0.45	0.62
16-37	1/4/2016	1.23	1.11	0.12	0.87	1.34	0.11	0.45	0.62
16-138	2/1/2016	1.09	1.10	0.12	0.87	1.34	0.11	0.45	0.62
16-307	3/1/2016	1.12	1.10	0.12	0.87	1.33	0.11	0.45	0.62
16-463	4/1/2016	1.16	1.10	0.12	0.87	1.34	0.11	0.45	0.62
16-596	5/2/2016	1.19	1.10	0.12	0.87	1.34	0.11	0.45	0.62
16-707	6/1/2016	1.07	1.10	0.12	0.87	1.34	0.11	0.45	0.62
16-880	7/1/2016	1.20	1.10	0.12	0.87	1.34	0.11	0.45	0.62
16-1212	8/24/2016	1.24	1.10	0.12	0.86	1.34	0.11	0.45	0.62
16-1258	9/8/2016	1.22	1.11	0.12	0.87	1.35	0.11	0.45	0.62
16-1553	10/24/2016	1.20	1.11	0.12	0.87	1.36	0.11	0.45	0.62
16-1592	11/1/2016	1.24	1.12	0.12	0.87	1.37	0.11	0.45	0.62
16-1734	12/1/2016	1.20	1.12	0.13	0.87	1.37	0.11	0.45	0.62
17-14	1/3/2017	1.22	1.12	0.12	0.88	1.36	0.11	0.45	0.62

New England Bioassay
A Division of GZA

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AQUATIC TOXICITY TEST REPORT

Acute Toxicity Testing at 10°C and 25°C Using *Ceriodaphnia dubia*

April 14, 2017

Report Prepared by:

New England Bioassay
A Division of GZA GeoEnvironmental, Inc.
77 Batson Dr.
Manchester, CT 06042

Report Submitted to:

Huff & Huff, a Subsidiary of GZA
915 Harger Road, Suite 330
Oak Brook, IL 60523

April 14, 2017

Huff & Huff, a Subsidiary of GZA
915 Harger Road, Suite 330
Oak Brook, IL 60523-1486

RE: Results of Acute Tests
Sample ID: Reagent Grade NaCl
NEB Project Number: 81.0220523.00

Dear Ms. Herrera:

This report provides you with the results of the experimental acute toxicity tests performed at New England Bioassay (NEB) laboratory for Huff and Huff. The toxicity tests were performed using the freshwater organism, *Ceriodaphnia dubia,* as the aquatic test species.

Acute Toxicity Test Methods

The specific details of the *C.dubia* acute toxicity test system are based on EPA guidelines (EPA, 1994; 2002b). For the acute toxicity test, young *C.dubia* (≤ 24-h old at test initiation) were continuously exposed for 48 hours under static conditions to 6 concentrations of reagent grade sodium chloride [1.25 g/L, 1.5 g/L, 1.75 g/L, 2.0 g/L, 2.25 g/L and 2.5 g/L NaCl] mixed with laboratory-prepared moderately hard synthetic water. A synthetic laboratory water control was also set concurrently with the test.

C. dubia were individually exposed in 30-mL plastic cups containing 25 mL of test solution or control water. Four replicate beakers were used for each test concentration and the dilution-water control (20 animals per concentration or control).

Test beakers were maintained under the specified conditions (mean test temperature of 10° ± 1°C and 25° ± 1°C; photoperiod 16 h light and 8 h dark) in an environmentally controlled testing room.

Temperature, dissolved oxygen and pH were measured daily on one replicate for days 0 and 24, and on each replicate at 48 hours. Observations on the number of live and dead animals were made daily. A summary of the acute testing protocols can be found in Attachment A. The results of the toxicity tests can be found in Table 1. Raw data sheets and statistical analysis are found in Attachment B.

TABLE 1. RESULTS OF 48-HR CERIODAPHNIA DUBIA ACUTE TESTS USING REAGENT GRADE SODIUM CHLORIDE

Test Date	Test Species	Test ID	Test Temperature	48hr LC50	48 hr NOAEL
3/1/17	C.dubia	17-279	10°C	> 2.5 g/L	2.5 g/L
3/1/17	C.dubia	17-280	25°C	< 1.25 g/L	<1.25 g/L

Quality Assurance

A reference toxicant test using sodium chloride (NaCl) was conducted with in-house cultured *C. dubia* during March 2017. The acute 48 hr LC50 value was 1.19 g/L NaCl which was within the acceptability limits for NaCl at our laboratory. A copy of the cumulative-summation chart can be found in Attachment C.

Conclusions

The NaCl test set at 10°C did not exhibit any toxicity to the C.dubia after 48 hours. The NaCl test set at 25°C did exhibit toxicity to the C.dubia at 48 hours, with significant mortality occurring in all test concentrations. If you have any questions concerning this report, please contact the Lab Manager, Kim Wills at (860) 858-3153 or kimberly.wills@gza.com

Very truly yours,

Kim Wills
Manager – Aquatic Toxicity Laboratory

Received, Clerk's Office 5/21/2018 ** R2018-032**

Attachment A

Acute Toxicity Test Protocol Summary

Test type:	Static non-renewal Static renewal (at 24 h)
Temperature (°C):	25 ± 1°C or 10 ± 1°C
Light quality:	Ambient laboratory illumination
Photoperiod:	16 hr light, 8 hr dark
Test chamber size:	Minimum 30 ml
Test solution volume:	Minimum 25 ml
Age of test organisms:	1-24 hours (neonates)
No. daphnids per test chamber:	5
No. of replicate test chambers per treatment:	4
Total no. daphnids per test concentration:	20
Feeding regime:	None
Aeration:	None
Dilution water:	moderately hard synthetic water (prepared using deionized water and reagent grade chemicals)
Number of dilutions:	6 plus a control
Effect measured:	Mortality - no movement of body or appendages on gentle prodding
Test acceptability:	90% or greater survival of test organisms in control solution

Attachment B

Raw Data Sheets and Statistical Analysis

Received, Clerk's Office 5/21/2018 ** R2018-032**

NEW ENGLAND BIOASSAY ACUTE TOXICITY DATA FORM COVER SHEET

CLIENT: Huff and Huff
ADDRESS: 915 Harger Road, Suite 330
Oak Brook, IL 60523-1486
SAMPLE TYPE: **10 °C Sodium Chloride**

C.dubia TEST ID: 17-279

TEST SOLUTION PREPERATION

Test Sol'n Vol:	400	ml
Control:	0	ml
1.25 g/L	5	ml
1.5 g/L	6	ml
1.75 g/L	7	ml
2.0 g/L	8	ml
2.25g/L	9	ml
2.5 g/L	10	ml

NaCl Lot Number: NaCl
NaCl Stock Concentration: 100 g/L
Stock Solution Volume: 2000 ml
NaCl Calculated: 200 g
NaCl Weighed: 200.0068 g

DILUTION WATER: MODERATELY HARD RECONSTITUTED FRESHWATER

MHRCF Lot # C37-MH004
Hardness 86 mg/L as $CaCO_3$
Alkalinity 60 mg/L as $CaCO_3$

Invertebrate
Type of Test: Definitive
Test Species: *Ceriodaphnia dubia*
NEB Lot#: Cd17 (3-1)
Age: <24 hours
TEST SOLUTION VOLUME: 30 ml
ORGANISMS PER TEST CHAMBER: 5
ORGANISMS PER CONCENTRATION: 20
ORGANISMS PER CONTROL: 20

START DATE: 3/1/17 AT 1626
END DATE: 3/3/17 AT 1602
TEST SETUP TECHNICIAN: PD

RESULTS OF *Ceriodaphnia dubia* 48 hr LC50 Test

Method	LC50 (g/L)	95% Confidence Limits (g/L)
Binomial	>2.5 g/L	2.5 g/L ±∞
Probit		
Trimmed Spearman Karber		
NOAEL	2.5 g/L	

NOAEL: No Observed Acute Effect Level

Comments:

REVIEWED BY: [signature] DATE: 4/14/17

Received, Clerk's Office 5/21/2018 ** R2018-032**

NEW ENGLAND BIOASSAY

Toxicity Test Data Sheet

NEB Test #: 17-279

Facility Name: New England Bioassay

Test Organism: *Ceriodaphnia dubia*

Sample ID: **10 °C Sodium Chloride**

Organism Age: <24 hours

Test Duration: 48 (hours)

Beginning Date: 3/1/17 Time: 1626

Dilution Water Source: Moderately Hard Lab Water

Dilution Hardness: 86 ppm as $CaCO_3$

NaCl Conc. g/L	Number of Surviving Organisms			Dissolved Oxygen (mg/L)			Temperature (°C)			pH		
Initials	PD	CW	PD	PD	CW	PD	PD	CW	PD	PD	CW	PD
	0	24	48	0	24	48	0	24	48	0	24	48
Control A	5	5	5	8.8	10.4	10.6	11.0	11.0	11.0	8.0	8.0	8.0
B	5	5	5			10.9			11.0			8.0
C	5	5	5			11.0			11.0			8.0
D	5	5	5			11.1			11.0			8.0
1.25 g/L A	5	5	5	8.8	10.6	11.2	11.0	11.0	11.0	8.0	8.0	8.0
B	5	5	5			11.1			11.0			8.0
C	5	5	5			11.1			11.0			8.0
D	5	5	5			11.1			11.0			8.0
1.5 g/L A	5	5	4	8.7	10.5	11.1	11.0	11.0	11.0	8.0	8.0	8.0
B	5	5	5			11.0			11.0			8.0
C	5	5	5			11.1			11.0			8.0
D	5	5	4			11.2			11.0			8.1
1.75 g/L A	5	5	5	8.7	10.7	11.1	11.0	11.0	11.0	8.0	7.9	8.0
B	5	5	5			11.0			11.0			8.0
C	5	5	5			11.0			11.0			8.0
D	5	5	5			11.1			11.0			8.0
2.0 g/L A	5	5	5	8.7	10.8	11.0	11.0	11.0	11.0	8.0	7.9	8.0
B	5	5	5			11.0			11.0			8.0
C	5	5	5			11.0			11.0			8.0
D	5	5	5			11.1			11.0			8.1
2.25 g/L A	5	5	4	8.7	10.7	11.0	11.0	11.0	11.0	8.0	7.9	8.0
B	5	5	4			10.9			11.0			8.0
C	5	5	4			11.1			11.0			8.0
D	5	5	5			11.1			11.0			8.1

LC50	Confidence Interval	A-NOEC	Computational Method
>2.5g/L	2.5 g/L ±∞	2.5 g/L	Graphical

NEW ENGLAND BIOASSAY
Toxicity Test Data Sheet

NEB Test #: 17-279

Facility Name: New England Bioassay

Test Organism: *Ceriodaphnia dubia*

Sample ID: **10 °C Sodium Chloride**

Organism Age: <24 hours

Test Duration: 48 (hours)

Beginning Date: 3/1/17 Time: 1626

Dilution Water Source: Moderately Hard Lab Water

Dilution Hardness: 86 ppm as $CaCO_3$

NaCl Conc. g/L	Number of Surviving Organisms			Dissolved Oxygen (mg/L)			Temperature (°C)			pH		
Initials	PD	CW	PD	PD	CW	PD	PD	CW	PD	PD	CW	PD
	0	24	48	0	24	48	0	24	48	0	24	48
2.5 g/L A	5	5	5	8.7	10.7	11.1	11.0	11.0	11.0	8.0	7.9	8.0
B	5	5	5			11.0			11.0			8.0
C	5	5	4			11.0			11.0			8.0
D	5	5	4			11.1			11.0			8.0

LC50	Confidence Interval	A-NOEC	Computational Method
>2.5g/L	2.5 g/L ±∞	2.5 g/L	Graphical

Ceriodaphnia 48-h Acute Survival Test — **New England Bioassay**

Analysis ID:	01-7675-3791	**Endpoint:**	48h Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	29 Mar-17 10:42	**Analysis:**	Nonparametric-Control vs Treatments	**Official Results:**	Yes
Batch ID:	05-7685-3341	**Test Type:**	Survival (48h)	**Analyst:**	
Start Date:	01 Mar-17 16:26	**Protocol:**	EPA/821/R-02-012 (2002)	**Diluent:**	Laboratory Water
Ending Date:	03 Mar-17 16:02	**Species:**	Ceriodaphnia dubia	**Brine:**	Not Applicable
Duration:	48h	**Source:**	In-House Culture	**Age:**	<24h
Sample ID:	12-3244-0359	**Code:**	49758C27	**Client:**	GZA GeoEnvironmental
Sample Date:	01 Mar-17	**Material:**	Sodium chloride	**Project:**	
Receipt Date:	01 Mar-17	**Source:**	Reference Toxicant		
Sample Age:	16h	**Station:**			

Data Transform	Alt Hyp	NOEL	LOEL	TOEL	TU	PMSD
Angular (Corrected)	C > T	2.5	> 2.5	n/a		13.39%

Steel Many-One Rank Sum Test

Control	vs	Conc-gm/L	Test Stat	Critical	Ties	DF	P-Type	P-Value	Decision(α:5%)
Dilution Water		1.25	18	10	1	6	Asymp	0.8571	Non-Significant Effect
		1.5	14	10	1	6	Asymp	0.3760	Non-Significant Effect
		1.75	18	10	1	6	Asymp	0.8571	Non-Significant Effect
		2	18	10	1	6	Asymp	0.8571	Non-Significant Effect
		2.25	12	10	1	6	Asymp	0.1598	Non-Significant Effect
		2.5	14	10	1	6	Asymp	0.3760	Non-Significant Effect

Test Acceptability Criteria

Attribute	Test Stat	TAC Limits Lower	Upper	Overlap	Decision
Control Resp	1	0.9	>>	Yes	Passes Criteria

ANOVA Table

Source	Sum Squares	Mean Square	DF	F Stat	P-Value	Decision(α:5%)
Between	0.14177	0.0236283	6	3.182	0.0222	Significant Effect
Error	0.155947	0.0074260	21			
Total	0.297716		27			

Distributional Tests

Attribute	Test	Test Stat	Critical	P-Value	Decision(α:1%)
Variances	Levene Equality of Variance Test	27.67	3.812	<1.0E-37	Unequal Variances
Variances	Mod Levene Equality of Variance Test	6.333	3.812	6.4E-04	Unequal Variances
Distribution	Shapiro-Wilk W Normality Test	0.8408	0.8975	6.1E-04	Non-Normal Distribution

48h Survival Rate Summary

Conc-gm/L	Code	Count	Mean	95% LCL	95% UCL	Median	Min	Max	Std Err	CV%	%Effect
0	D	4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.00%	0.00%
1.25		4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.00%	0.00%
1.5		4	0.9000	0.7163	1.0000	0.9000	0.8000	1.0000	0.0577	12.83%	10.00%
1.75		4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.00%	0.00%
2		4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.00%	0.00%
2.25		4	0.8500	0.6909	1.0000	0.8000	0.8000	1.0000	0.0500	11.76%	15.00%
2.5		4	0.9000	0.7163	1.0000	0.9000	0.8000	1.0000	0.0577	12.83%	10.00%

Angular (Corrected) Transformed Summary

Conc-gm/L	Code	Count	Mean	95% LCL	95% UCL	Median	Min	Max	Std Err	CV%	%Effect
0	D	4	1.345	1.345	1.346	1.345	1.345	1.345	0	0.00%	0.00%
1.25		4	1.345	1.345	1.346	1.345	1.345	1.345	0	0.00%	0.00%
1.5		4	1.226	1.007	1.445	1.226	1.107	1.345	0.06874	11.21%	8.85%
1.75		4	1.345	1.345	1.346	1.345	1.345	1.345	0	0.00%	0.00%
2		4	1.345	1.345	1.346	1.345	1.345	1.345	0	0.00%	0.00%
2.25		4	1.167	0.9772	1.356	1.107	1.107	1.345	0.05953	10.21%	13.28%
2.5		4	1.226	1.007	1.445	1.226	1.107	1.345	0.06874	11.21%	8.85%

Ceriodaphnia 48-h Acute Survival Test **New England Bioassay**

Analysis ID:	01-7675-3791	**Endpoint:**	48h Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	29 Mar-17 10:42	**Analysis:**	Nonparametric-Control vs Treatments	**Official Results:**	Yes

48h Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4
0	D	1.0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1.0000	1.0000
1.5		0.8000	1.0000	1.0000	0.8000
1.75		1.0000	1.0000	1.0000	1.0000
2		1.0000	1.0000	1.0000	1.0000
2.25		0.8000	0.8000	0.8000	1.0000
2.5		1.0000	1.0000	0.8000	0.8000

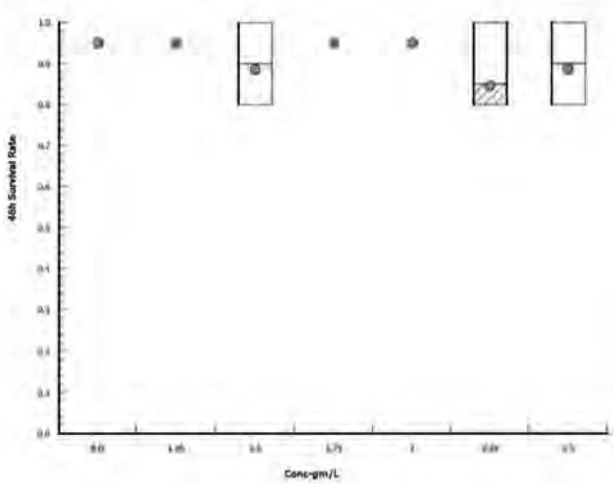
Angular (Corrected) Transformed Detail

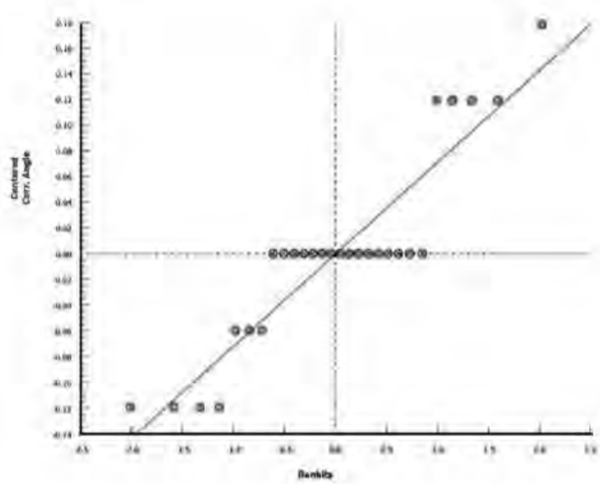
Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4
0	D	1.345	1.345	1.345	1.345
1.25		1.345	1.345	1.345	1.345
1.5		1.107	1.345	1.345	1.107
1.75		1.345	1.345	1.345	1.345
2		1.345	1.345	1.345	1.345
2.25		1.107	1.107	1.107	1.345
2.5		1.345	1.345	1.107	1.107

48h Survival Rate Binomials

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4
0	D	5/5	5/5	5/5	5/5
1.25		5/5	5/5	5/5	5/5
1.5		4/5	5/5	5/5	4/5
1.75		5/5	5/5	5/5	5/5
2		5/5	5/5	5/5	5/5
2.25		4/5	4/5	4/5	5/5
2.5		5/5	5/5	4/5	4/5

Graphics





CETIS Analytical Report

Report Date: 29 Mar-17 10:42 (p 1 of 2)
Test Code: 17-279 | 00-9968-0254

Ceriodaphnia 48-h Acute Survival Test — **New England Bioassay**

Analysis ID:	15-2188-6122	**Endpoint:**	48h Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	29 Mar-17 10:39	**Analysis:**	Linear Interpolation (ICPIN)	**Official Results:**	Yes

Batch ID:	05-7685-3341	**Test Type:**	Survival (48h)	**Analyst:**	
Start Date:	01 Mar-17 16:26	**Protocol:**	EPA/821/R-02-012 (2002)	**Diluent:**	Laboratory Water
Ending Date:	03 Mar-17 16:02	**Species:**	Ceriodaphnia dubia	**Brine:**	Not Applicable
Duration:	48h	**Source:**	In-House Culture	**Age:**	<24h

Sample ID:	12-3244-0359	**Code:**	49758C27	**Client:**	GZA GeoEnvironmental
Sample Date:	01 Mar-17	**Material:**	Sodium chloride	**Project:**	
Receipt Date:	01 Mar-17	**Source:**	Reference Toxicant		
Sample Age:	16h	**Station:**			

Linear Interpolation Options

X Transform	Y Transform	Seed	Resamples	Exp 95% CL	Method
Log(X)	Linear	1235453	200	Yes	Two-Point Interpolation

Test Acceptability Criteria

Attribute	Test Stat	TAC Limits Lower	Upper	Overlap	Decision
Control Resp	1	0.9	>>	Yes	Passes Criteria

Point Estimates

Level	gm/L	95% LCL	95% UCL
LC50	>2.5	n/a	n/a

48h Survival Rate Summary

Conc-gm/L	Code	Count	Calculated Variate(A/B) Mean	Min	Max	Std Err	Std Dev	CV%	%Effect	A	B
0	D	4	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	20	20
1.25		4	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	20	20
1.5		4	0.9000	0.8000	1.0000	0.0577	0.1155	12.83%	10.0%	18	20
1.75		4	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	20	20
2		4	1.0000	1.0000	1.0000	0.0000	0.0000	0.00%	0.0%	20	20
2.25		4	0.8500	0.8000	1.0000	0.0500	0.1000	11.76%	15.0%	17	20
2.5		4	0.9000	0.8000	1.0000	0.0577	0.1155	12.83%	10.0%	18	20

48h Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4
0	D	1.0000	1.0000	1.0000	1.0000
1.25		1.0000	1.0000	1.0000	1.0000
1.5		0.8000	1.0000	1.0000	0.8000
1.75		1.0000	1.0000	1.0000	1.0000
2		1.0000	1.0000	1.0000	1.0000
2.25		0.8000	0.8000	0.8000	1.0000
2.5		1.0000	1.0000	0.8000	0.8000

48h Survival Rate Binomials

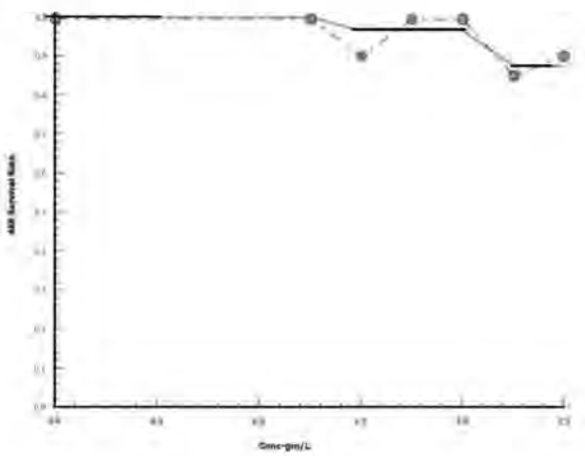
Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4
0	D	5/5	5/5	5/5	5/5
1.25		5/5	5/5	5/5	5/5
1.5		4/5	5/5	5/5	4/5
1.75		5/5	5/5	5/5	5/5
2		5/5	5/5	5/5	5/5
2.25		4/5	4/5	4/5	5/5
2.5		5/5	5/5	4/5	4/5

CETIS Analytical Report

Ceriodaphnia 48-h Acute Survival Test **New England Bioassay**

Analysis ID:	15-2188-6122	**Endpoint:**	48h Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	29 Mar-17 10:39	**Analysis:**	Linear Interpolation (ICPIN)	**Official Results:**	Yes

Graphics



NEW ENGLAND BIOASSAY ACUTE TOXICITY DATA FORM COVER SHEET

CLIENT: Huff and Huff
ADDRESS: 915 Harger Road, Suite 330
Oak Brook, IL 60523-1486
SAMPLE TYPE: **25 °C Sodium Chloride**

C.dubia TEST ID: 17-280

TEST SOLUTION PREPERATION

Test Sol'n Vol:	400	ml
Control:	0	ml
1.25 g/L	5	ml
1.5 g/L	6	ml
1.75 g/L	7	ml
2.0 g/L	8	ml
2.25g/L	9	ml
2.5 g/L	10	ml

NaCl Lot Number: NaCl17 (3-1)
NaCl Stock Concentration: 100 g/L
Stock Solution Volume: 2000 ml
NaCl Calculated: 200 g
NaCl Weighed: 200.0069 g

DILUTION WATER: MODERATELY HARD RECONSTITUTED FRESHWATER

MHRCF Lot #: C37-MH004
Hardness: 86 mg/L as $CaCO_3$
Alkalinity: 60 mg/L as $CaCO_3$

Invertebrate
Type of Test: Definitive
Test Species: *Ceriodaphnia dubia*
NEB Lot#: Cd17 (3-1)
Age: <24 hours
TEST SOLUTION VOLUME: 30 ml
ORGANISMS PER TEST CHAMBER: 5
ORGANISMS PER CONCENTRATION: 20
ORGANISMS PER CONTROL: 20

START DATE: 3/1/17 AT 1540
END DATE: 3/3/17 AT 1535
TEST SETUP TECHNICIAN: PD

RESULTS OF *Ceriodaphnia dubia* 48 hr LC50 Test

Method	LC50 (g/L)	95% Confidence Limits (g/L)
Binomial	<1.25 g/L	0 - 1.25 g/L
Probit		
Trimmed Spearman Karber		
NOAEL	<1.25 g/L	

NOAEL: No Observed Acute Effect Level

Comments:

REVIEWED BY: [signature] DATE: 4/14/17

NEW ENGLAND BIOASSAY
Toxicity Test Data Sheet

NEB Test #: 17-280
Organism Age: <24 hours
Facility Name: New England Bioassay
Test Duration: 48 (hours)
Test Organism: *Ceriodaphnia dubia*
Beginning Date: 3/1/17 Time: 1540
Sample ID: **25 °C Sodium Chloride**
Dilution Water Source: Moderately Hard Lab Water
Dilution Hardness: 86 ppm as $CaCO_3$

NaCl Conc. g/L	Number of Surviving Organisms			Dissolved Oxygen (mg/L)			Temperature (°C)			pH		
Initials	PD	CW	PD	PD	CW	PD	PD	CW	PD	PD	CW	PD
	0	24	48	0	24	48	0	24	48	0	24	48
Control A	5	5	5	8.1	10.6	8.3	25.0	25.4	24.6	8.2	7.9	7.7
B	5	5	5			8.2			24.8			7.9
C	5	5	5			8.2			24.9			8.0
D	5	5	5			8.2			24.6			8.1
1.25 g/L A	5	5	2	8.1	9.9	8.2	25.2	25.4	24.6	8.1	8.0	8.0
B	5	5	2			8.2			24.8			8.0
C	5	5	0			8.2			24.8			8.0
D	5	5	3			8.2			24.5			8.0
1.5 g/L A	5	5	3	8.1	8.6	8.2	25.2	25.6	24.5	8.1	7.9	8.0
B	5	5	2			8.2			24.8			8.0
C	5	5	3			8.2			24.8			8.1
D	5	5	2			8.2			24.6			8.1
1.75 g/L A	5	5	0	8.1	8.7	8.2	25.1	25.7	24.6	8.1	8.0	8.1
B	5	5	4			8.2			24.7			8.1
C	5	5	1			8.2			24.6			8.1
D	5	5	1			8.2			24.4			8.1
2.0 g/L A	5	4	3	8.1	8.7	8.4	25.2	25.5	24.0	8.1	8.0	8.0
B	5	5	0			8.3			24.0			8.0
C	5	5	0			8.3			24.0			8.1
D	5	4	1			8.3			24.1			8.1
2.25 g/L A	5	5	4	8.2	8.2	8.3	25.1	25.4	24.1	8.1	8.0	8.1
B	5	5	1			8.3			24.2			8.1
C	5	5	0			8.2			24.2			8.1
D	5	4	1			8.2			24.1			8.1

LC50	Confidence Interval	A-NOEC	Computational Method
<1.25 g/L	0 - 1.25 g/L	<1.25 g/L	Graphical

NEW ENGLAND BIOASSAY
Toxicity Test Data Sheet

NEB Test #: 17-280

Facility Name: New England Bioassay

Test Organism: *Ceriodaphnia dubia*

Sample ID: **25 °C Sodium Chloride**

Organism Age: <24 hours

Test Duration: 48 (hours)

Beginning Date: 3/1/17 Time: 1540

Dilution Water Source: Moderately Hard Lab Water

Dilution Hardness: 86 ppm as $CaCO_3$

NaCl Conc. g/L	Number of Surviving Organisms			Dissolved Oxygen (mg/L)			Temperature (°C)			pH		
Initials	PD	CW	PD	PD	CW	PD	PD	CW	PD	PD	CW	PD
	0	24	48	0	24	48	0	24	48	0	24	48
2.5 g/L A	5	4	0	8.1	8.3	8.2	25.2	25.5	24.0	8.0	8.0	8.1
B	5	4	2			8.2			24.0			8.1
C	5	5	2			8.3			24.0			8.1
D	5	5	3			8.2			24.0			8.1

LC50	Confidence Interval	A-NOEC	Computational Method
<1.25 g/L	0 - 1.25 g/L	<1.25 g/L	Graphical

Ceriodaphnia 48-h Acute Survival Test — New England Bioassay

Analysis ID:	12-7752-8256	**Endpoint:**	48h Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	29 Mar-17 10:47	**Analysis:**	Parametric-Control vs Treatments	**Official Results:**	Yes
Batch ID:	21-0647-2995	**Test Type:**	Survival (48h)	**Analyst:**	
Start Date:	01 Mar-17 15:40	**Protocol:**	EPA/821/R-02-012 (2002)	**Diluent:**	Laboratory Water
Ending Date:	03 Mar-17 15:35	**Species:**	Ceriodaphnia dubia	**Brine:**	Not Applicable
Duration:	48h	**Source:**	In-House Culture	**Age:**	
Sample ID:	20-8442-4652	**Code:**	7C3DCBCC	**Client:**	GZA GeoEnvironmental
Sample Date:	01 Mar-17	**Material:**	Sodium chloride	**Project:**	
Receipt Date:	01 Mar-17	**Source:**	Reference Toxicant		
Sample Age:	16h	**Station:**			

Data Transform	Alt Hyp	NOEL	LOEL	TOEL	TU	PMSD
Angular (Corrected)	C > T	< 1.25	1.25	n/a		42.71%

Dunnett Multiple Comparison Test

Control vs	Control II	Test Stat	Critical	MSD	DF	P-Type	P-Value	Decision(α:5%)
Dilution Water	1.25*	3.646	2.448	0.487	6	CDF	0.0038	Significant Effect
	1.5*	2.816	2.448	0.487	6	CDF	0.0237	Significant Effect
	1.75*	3.924	2.448	0.487	6	CDF	0.0020	Significant Effect
	2*	4.501	2.448	0.487	6	CDF	5.2E-04	Significant Effect
	2.25*	3.924	2.448	0.487	6	CDF	0.0020	Significant Effect
	2.5*	3.646	2.448	0.487	6	CDF	0.0038	Significant Effect

Test Acceptability Criteria

Attribute	Test Stat	TAC Limits Lower	TAC Limits Upper	Overlap	Decision
Control Resp	1	0.9	>>	Yes	Passes Criteria

ANOVA Table

Source	Sum Squares	Mean Square	DF	F Stat	P-Value	Decision(α:5%)
Between	2.13954	0.35659	6	4.509	0.0044	Significant Effect
Error	1.66071	0.0790815	21			
Total	3.80025		27			

Distributional Tests

Attribute	Test	Test Stat	Critical	P-Value	Decision(α:1%)
Variances	Levene Equality of Variance Test	1.562	3.812	0.2074	Equal Variances
Variances	Mod Levene Equality of Variance Test	0.5847	3.812	0.7386	Equal Variances
Distribution	Shapiro-Wilk W Normality Test	0.9352	0.8975	0.0833	Normal Distribution

48h Survival Rate Summary

Conc-gm/L	Code	Count	Mean	95% LCL	95% UCL	Median	Min	Max	Std Err	CV%	%Effect
0	D	4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.00%	0.00%
1.25		4	0.3500	0.0000	0.7504	0.4000	0.0000	0.6000	0.1258	71.90%	65.00%
1.5		4	0.5000	0.3163	0.6837	0.5000	0.4000	0.6000	0.0577	23.09%	50.00%
1.75		4	0.3000	0.0000	0.8512	0.2000	0.0000	0.8000	0.1732	115.47%	70.00%
2		4	0.2000	0.0000	0.6501	0.1000	0.0000	0.6000	0.1414	141.42%	80.00%
2.25		4	0.3000	0.0000	0.8512	0.2000	0.0000	0.8000	0.1732	115.47%	70.00%
2.5		4	0.3500	0.0000	0.7504	0.4000	0.0000	0.6000	0.1258	71.90%	65.00%

Angular (Corrected) Transformed Summary

Conc-gm/L	Code	Count	Mean	95% LCL	95% UCL	Median	Min	Max	Std Err	CV%	%Effect
0	D	4	1.345	1.345	1.346	1.345	1.345	1.345	0	0.00%	0.00%
1.25		4	0.6203	0.1751	1.065	0.6847	0.2255	0.8861	0.1399	45.10%	53.89%
1.5		4	0.7854	0.6004	0.9704	0.7854	0.6847	0.8861	0.05813	14.80%	41.62%
1.75		4	0.565	-0.03724	1.167	0.4636	0.2255	1.107	0.1892	66.99%	58.00%
2		4	0.4502	-0.04551	0.9459	0.3446	0.2255	0.8861	0.1558	69.20%	66.54%
2.25		4	0.565	-0.03724	1.167	0.4636	0.2255	1.107	0.1892	66.99%	58.00%
2.5		4	0.6203	0.1751	1.065	0.6847	0.2255	0.8861	0.1399	45.10%	53.89%

CETIS Analytical Report

Ceriodaphnia 48-h Acute Survival Test — **New England Bioassay**

Analysis ID:	12-7752-8256	**Endpoint:**	48h Survival Rate	**CETIS Version:**	CETISv1.9.2
Analyzed:	29 Mar-17 10:47	**Analysis:**	Parametric-Control vs Treatments	**Official Results:**	Yes

48h Survival Rate Detail

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4
0	D	1.0000	1.0000	1.0000	1.0000
1.25		0.4000	0.4000	0.0000	0.6000
1.5		0.6000	0.4000	0.6000	0.4000
1.75		0.0000	0.8000	0.2000	0.2000
2		0.6000	0.0000	0.0000	0.2000
2.25		0.8000	0.2000	0.0000	0.2000
2.5		0.0000	0.4000	0.4000	0.6000

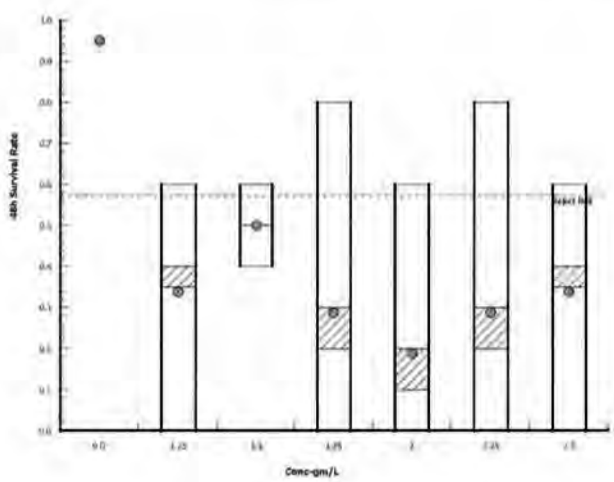
Angular (Corrected) Transformed Detail

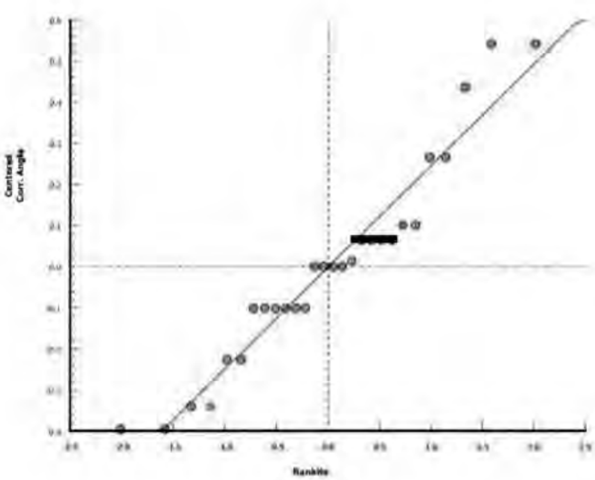
Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4
0	D	1.345	1.345	1.345	1.345
1.25		0.6847	0.6847	0.2255	0.8861
1.5		0.8861	0.6847	0.8861	0.6847
1.75		0.2255	1.107	0.4636	0.4636
2		0.8861	0.2255	0.2255	0.4636
2.25		1.107	0.4636	0.2255	0.4636
2.5		0.2255	0.6847	0.6847	0.8861

48h Survival Rate Binomials

Conc-gm/L	Code	Rep 1	Rep 2	Rep 3	Rep 4
0	D	5/5	5/5	5/5	5/5
1.25		2/5	2/5	0/5	3/5
1.5		3/5	2/5	3/5	2/5
1.75		0/5	4/5	1/5	1/5
2		3/5	0/5	0/5	1/5
2.25		4/5	1/5	0/5	1/5
2.5		0/5	2/5	2/5	3/5

Graphics





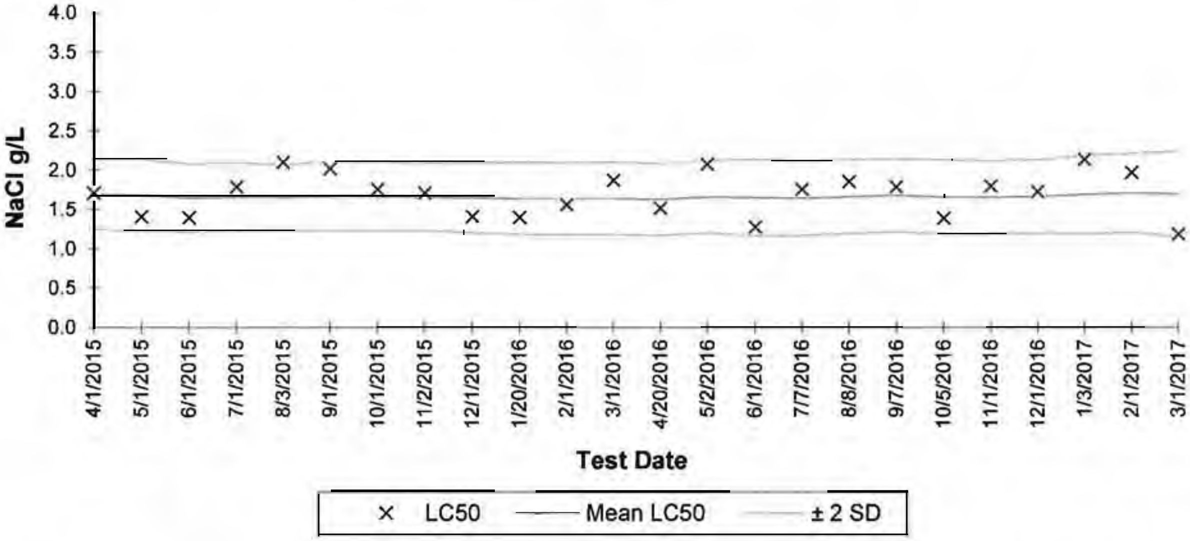
002-570-915-7 CETIS™ v1.9.2.4 Analyst: QA:

Attachment C

Reference Toxicant Chart

New England Bioassay
Reference Toxicant Data: *Ceriodaphnia dubia* 48-hour LC50

Reference Toxicant: Sodium chloride
Testing Dates: April 2015 - March 2017



Test ID	Date	LC_{50}	Mean LC_{50}	STD	-2 STD	+2 STD	CV	CV National 75th %	CV National 90th %
15-408	4/1/2015	1.7	1.7	0.2	1.2	2.1	0.13	0.29	0.34
15-545	5/1/2015	1.4	1.7	0.2	1.2	2.1	0.14	0.29	0.34
15-700	6/1/2015	1.4	1.6	0.2	1.2	2.1	0.13	0.29	0.34
15-896	7/1/2015	1.8	1.7	0.2	1.2	2.1	0.13	0.29	0.34
15-1078	8/3/2015	2.1	1.7	0.2	1.2	2.1	0.13	0.29	0.34
15-1293	9/1/2015	2.0	1.7	0.2	1.2	2.1	0.13	0.29	0.34
15-1453	10/1/2015	1.8	1.7	0.2	1.2	2.1	0.13	0.29	0.34
15-1684	11/2/2015	1.7	1.7	0.2	1.2	2.1	0.13	0.29	0.34
15-1772	12/1/2015	1.4	1.6	0.2	1.2	2.1	0.13	0.29	0.34
16-107	1/20/2016	1.4	1.6	0.2	1.2	2.1	0.14	0.29	0.34
16-134	2/1/2016	1.6	1.6	0.2	1.2	2.1	0.14	0.29	0.34
16-298	3/1/2016	1.9	1.6	0.2	1.2	2.1	0.14	0.29	0.34
16-563	4/20/2016	1.5	1.6	0.2	1.2	2.1	0.14	0.29	0.34
16-592	5/2/2016	2.1	1.7	0.2	1.2	2.1	0.14	0.29	0.34
16-703	6/1/2016	1.3	1.7	0.2	1.2	2.1	0.15	0.29	0.34
16-885	7/7/2016	1.8	1.6	0.2	1.2	2.1	0.14	0.29	0.34
16-1156	8/8/2016	1.9	1.7	0.2	1.2	2.1	0.14	0.29	0.34
16-1252	9/7/2016	1.8	1.7	0.2	1.2	2.1	0.14	0.29	0.34
16-1466	10/5/2016	1.4	1.7	0.2	1.2	2.1	0.14	0.29	0.34
16-1586	11/1/2016	1.8	1.7	0.2	1.2	2.1	0.14	0.29	0.34
16-1730	12/1/2016	1.7	1.7	0.2	1.2	2.1	0.14	0.29	0.34
17-5	1/3/2017	2.1	1.7	0.2	1.2	2.2	0.15	0.29	0.34
17-147	2/1/2017	2.0	1.7	0.3	1.2	2.2	0.15	0.29	0.34
17-274	3/1/2017	1.2	1.7	0.3	1.2	2.2	0.16	0.29	0.34

INSTITUTE FOR THE HISTORY OF NATURAL SCIENCES REPORT

Progress update 12/04/17

Fingernail clams:

-Collected ~300 adult clams in April 2017 from Spring Creek, near Loda, IL, Iroquois County.

-Juvenile clams released in laboratory were acclimated to reconstituted water and appropriate test temperature (25 and 10 °C).

-For each temperature, the test system provided for two water volume additions per day for the duration of the test to ensure sufficient dissolved oxygen and minimized ammonia.

-Because of limited juveniles for testing, acute and chronic tests were conducted concurrently with mortality data from day 4 used to estimate median lethal concentrations (LC50s).

-Overall average % measured Cl/nominal Cl for both tests combined was 96.5 (min = 90.6; max = 101.4)

-25 °C test:

Fingernail clam (*Sphaerium simile)* sodium chloride acute and chronic data (25 C)							
nominal Cl	measured Cl acute	measured Cl chronic	% surv. acute	% surv. chron.	dry weight chron. (mg)	96-h LC50 (mg Cl/L)	28-d LC50 (mg Cl/L)
27.56	27	26	100	100	10.048	1673	1672
100	98	98	100	100	9.928	(unreliable)	(unreliable)
300	292	290	100	100	9.480		
600	573	581	100	100	8.700		
1000	989	988	100	100	8.692		
3000	2831	2831	0	0			

-For the chronic dry weight data, ANOVA detected a significant difference among treatments, but post-hoc pair-wise comparisons failed to detected significant differences from the control. In addition weight did not decrease relative to controls sufficiently in Cl treatments to permit calculation of a 20% effect concentration (EC20).

-10 °C test:

Fingernail clam (*Sphaerium simile)* sodium chloride acute and chronic data (10 C)							
nominal Cl	measured Cl acute	measured Cl chronic	% surv. acute	% surv. chron.	dry weight chron. (mg)	96-h LC50 (mg Cl/L)	28-d LC50 (mg Cl/L)
27.56	27	26	100	100	9.240	>2920	1664
100	99	97	100	100	9.160		(unreliable)
300	289	290	100	100	8.476		
600	568	572	100	100	9.656		
1000	978	970	100	100	9.488		
3000	2920	2855	100	0			

-Controls grew less at 10 °C than at 25 °C, and no dose dependent response was observed for weight.

-While temperature appeared to affect the acute response of *S. simile* to NaCl, we were unable to detect an influence of temperature on chronic response.

Mayflies:

-Conducted acute and chronic (14-d) tests at both temperatures (25 and 10 °C).

- For acute tests, overall average % measured Cl/nominal Cl for both tests combined was 99.65 (min = 92.2; max = 104.2)

-- For chronic tests, overall average % measured Cl/nominal Cl for both tests combined was 99.0 (min = 94.2; max = 110.6)

-Acute data:

Mayfly (*Neocloeon triangulifer)* sodium chloride acute data (25 C)				
nominal Cl	measured Cl acute	# dead (of 20)	96-h LC50 (mg Cl/L)	95% C.L.
27.6	27.7	0	1359	1249 - 1478
560	543	0		
750	783	0		
1053	1063	2		
1492	1503	14		
2120	2140	20		

Mayfly (*Neocloeon triangulifer)* sodium chloride acute data (10 C)				
nominal Cl	measured Cl acute	# dead (of 20)	96-h LC50 (mg Cl/L)	95% C.L.
27.6	25.8	1	1960	1640 - 2343
276	268	0		
524	533	1		
1021	1029	1		
2014	2003	9		
4000	4071	20		

Chronic data:

Mayfly (*Neocloeon triangulifer)* sodium chloride chronic data (25 C)					
nominal Cl	measured Cl acute	% survival	dry weight/ind (mg)	weight std. dev	14-d LC50 (mg Cl/L)
27.6	27	95	0.069	0.037	998
100	100	100	0.09	0.034	(905 - 1101)
200	202	100	0.095	0.039	weight EC20 (mg Cl/L)
400	395	95	0.049	0.022	326
750	732	95	0.03	0.017	(201 - 529)
1500	1484	0	na		

Mayfly (*Neocloeon triangulifer)* sodium chloride chronic data (10 C)					
nominal Cl	measured Cl acute	% survival	dry weight/ind (mg)	weight std. dev	14-d LC50 (mg Cl/L)
27.6	27	100	0.004	nc	>1466
100	99	89	0.006	nc	
200	198	75	0.080	nc	weight EC20 (mg Cl/L)
400	391	95	0.010	nc	nc
750	723	90	0.010	nc	
1500	1466	55	0.046		

Amphipods:

-We culture two genetically distinct "strains" of *Hyalella azteca*. Most ecotox labs culture and test "US Lab" strain. This is a southern species, and it did not do well at 10 °C in initial experiments. A couple of labs in Canada culture and test with the "Burlington" strain. This is a northern species.

-We conducted control tests with Burlington strain at 10 °C and they survived well (but see below). Acute and chronic testing were/will be conducted with the Burlington strain for this project.

-We used 23 °C as the upper temperature for *Hyalella* because that is the typical acute test temperature for this species.

-Both acute tests have been completed (data below).

- For acute tests, overall average % measured Cl/nominal Cl for both tests combined was 102.3 (min = 96.9; max = 113.1)

-Acute data:

Amphipod (*Hyalella azteca (* Burlington strain)) sodium chloride acute data (23 C)				
nominal Cl	measured Cl acute	# dead (of 20)	96-h LC50 (mg Cl/L)	95% C.L.
27.6	29.0	1	1733	1592 - 1887
741	785	1		
1047	1098	0		
1484	1550	5		
2108	2173	18		
3000	3084	20		

Amphipod (*Hyalella azteca (* Burlington strain)) sodium chloride acute data (10 C)				
nominal Cl	measured Cl acute	# dead (of 20)	96-h LC50 (mg Cl/L)	95% C.L.
27.6	27.0	0	2185	2013 - 2372
741	745	0		
1047	1055	0		
1484	1492	1		
2108	2100	7		
3000	3008	20		

-Chronic data:

-We have conducted a 28-d chronic at 23 °C.

-For the chronic tests at 23°C, overall average % measured Cl/nominal Cl was 96.5% (min = 91.7; max = 109.2)

-Data for 23 °C test are below.

-We have been having difficulty with control survival for *Hyalella* at 10 °C. Two tests we have started have had ~50% survival within 7-10 days. Therefore we will attempt to use older organisms (~14-d) to start a test to allow young amphipods to grow stronger prior to acclimation to cold temperature and testing.

Amphipod (Hyalella azteca) sodium chloride chronic data (23 C)				
nominal Cl	measured Cl	% survival	dry weight/ind (mg)	28-d LC50 (mg Cl/L)
27.56	26	82	0.204	949 (829 - 1087)
187	177	76	0.167	28-d EC20 (survival; mg Cl/L)
375	364	82	0.185	744 (617 - 897)
750	745	63	0.079	28-d EC20 weight mg Cl/L)
1500	1480	6	0.038	516 (357 - 745)
2000	1956	0	na	

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ATTACHMENT 3
Illinois State Water Survey 2012 Report on The Sources, Distribution, and Trends of chloride in the Waters of Illinois

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Impacts of Road Salt Runoff on Water Quality of the Chicago, Illinois, Region

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Key Terms: ***Road Salt, Chloride, Water Quality***

ABSTRACT

Road salt runoff has heavily impacted the water quality of surface water and groundwater in the Chicago, IL, region. High salt contents in surface water and groundwater pose a significant threat to aquatic ecosystems and to infrastructure and industrial operations. Almost all of the rivers and streams monitored have had significant increases in chloride (Cl) and sodium (Na) concentrations since the mid-1970s. Rates of Cl increase for several of the streams are in excess of 10 mg/L/yr. Concentrations of Cl and Na are significantly higher during the winter months as a result of direct runoff from freshly salted roadways. In recent years, Cl and Na concentrations have increased most rapidly in the Fox River Basin west of the Chicago metropolitan area, where land use is rapidly changing from rural to urban. Chloride and Na concentrations are also increasing in shallow aquifers in the Chicago region. Surface waters currently have approximately equimolar concentrations of Cl and Na, while groundwater impacted by road salt tends to have an excess of Cl relative to Na, suggesting Na retardation in the subsurface, likely due to cation exchange. A rough estimate of inputs and outputs of Cl in the Chicago region suggests that most of the road salt applied in a year is removed by surface discharge. However, about 14 percent of the road salt is retained in the subsurface, approximately 50,000 metric tons of NaCl annually, representing a long-term source of Cl and Na and other associated ions.

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INTRODUCTION

One of the greatest impacts of urbanization upon the environment is the concentration of numerous contaminant sources in a relatively small area. Chicago is the third largest city in the United States and by far the largest city in Illinois, with about 65 percent of the state's population in its metropolitan area, which is just 6.6 percent of the state's area (U.S. Census Bureau, 2011). In addition to its population, most of Illinois' wastewater treatment facilities (both public and private), landfills, manufacturing facilities, roads and other paved surfaces, and other potential contaminant sources are concentrated in the Chicago region. Thus, surface waters and shallow groundwater are more vulnerable to contamination from these particular sources than in less urbanized areas.

Because of the numerous roadways in highly urbanized areas, deicing salt (primarily halite [NaCl]) is a major pollutant of water resources in northern metropolitan areas of North America and Europe. Halite is extremely soluble and readily enters streams and shallow groundwater. Chloride (Cl) is relatively unreactive at Earth's surface and behaves in a conservative manner in the subsurface. These properties make the Cl ion an excellent indicator and tracer of contamination in the environment. Elevated Cl has been observed in many urban and roadside areas in snowy climates (Huling and Hollocher, 1972; Pilon and Howard, 1987; Amrhein et al., 1992; Howard and Haynes, 1993; Williams et al., 2000; and Bester et al., 2006). Large-scale application of road salt began after World War II and accelerated rapidly from the 1960s (Salt Institute, 2009) (Figure 1). Consequently, Cl concentrations have been increasing in surface waters and groundwater in urban regions of the northern United States and Canada since the 1960s, including Chicago, primarily due to road salt runoff (Howard and Haynes, 1993; Godwin et al., 2003; Kaushal et al., 2005; Kelly, 2008;

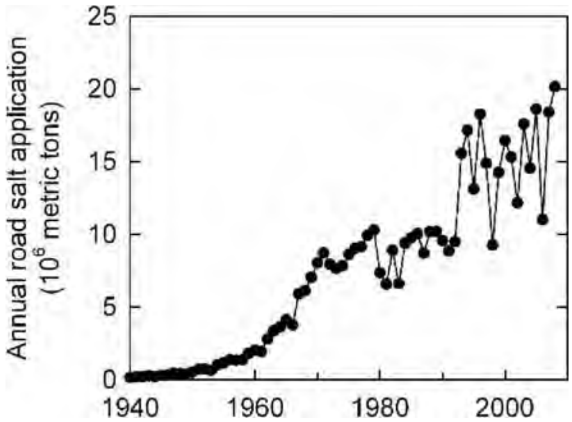

Figure 1. Yearly U.S. highway salt sales. Data are from Salt Institute (2009).

and Novotny et al., 2009). Trends for the other major ions in water (sodium [Na], calcium [Ca], magnesium [Mg], bicarbonate [HCO_3^2; usually determined from alkalinity], and sulfate [SO_4^{22}]), which typically do not behave conservatively, are generally not reported. Because road salt is predominantly NaCl, we would expect to see increases in Na concentrations as well as in Cl^2. Road salt can contain Ca in excess of 1 weight percent and smaller amounts of Mg (Biesboer and Jacobson, 1994), and in Chicago $CaCl_2$ is sprayed on road salt when temperatures fall into the low teens (°F) (City of Chicago, 2011). The introduction of large amounts of Na to the subsurface may also cause increases in Ca and Mg and other cations due to ion exchange (Faure, 1998).

Once in groundwater, Cl^2 and other ions can persist for many years if groundwater travel times are long. Howard et al. (1993) estimated that, even if road salting was stopped immediately in the Toronto area, it would be decades before the Cl^2 concentrations returned to pre-1960 levels in shallow groundwater.

None of the major ions in groundwater and surface water is toxic to humans, although elevated levels of dissolved solids can make water unpotable due to the salty taste, and Na levels greater than 20 mg/L are not recommended for people with hypertension. There is a secondary (non-enforced) drinking water standard in the United States of 250 mg/L for Cl^2 and 500 mg/L for total dissolved solids (TDS). Sulfate also has a secondary standard of 250 mg/L due to its laxative effects, and Na is on the U.S. Environmental Protection Agency's (USEPA) Contaminant Candidate List. Despite their non-toxicity to humans, elevated levels of dissolved ions can have numerous adverse impacts on environmental and human systems. Specifically, dissolved Cl^2 is highly corrosive to steel and may corrode pipes in water treatment and industrial plants. Because of this and the fact that it imparts a salty taste to water, elevated Cl^2 levels in drinking water supplies can lead to increased treatment costs. Chloride from road salt runoff is also a major contributor to corrosion of steel in road beds and bridge decks. Estimates made 20 years ago were that infrastructure repair costs due to the effects of road salt were at least $615 per ton of road salt applied (Vitaliano, 1992); road repair costs in the United States due to road salt application were found to be between $200 and $450 million annually (Transportation Research Board, 1991).

Elevated Cl^2 has also been linked to damage to vegetation on land and in wetlands at concentrations as low as 45 mg/L (Panno et al., 1999), and to aquatic plants and aquatic animals at concentrations as low as 210 mg/L (Wilcox, 1986; Hart et al., 1991; Environment Canada, 2001; Kaushal et al., 2005; and Corsi et al., 2010). The USEPA recommends a chronic criterion for aquatic life of a four-day average Cl^2 concentration of 230 mg/L with an occurrence interval of once every three years (USEPA, 1988). The recommended acute criterion is 860 mg/L, which relates to a one-hour average concentration with a recurrence interval of less than once every three years. The increase in Cl^2 concentrations has killed off native vegetation and allowed invasive salt-tolerant species to thrive in some environments (e.g., Panno et al., 1999). Trees and other land vegetation near roads also can be seriously damaged by salt spray and road salt runoff (Dirr, 1976; Munck et al., 2010).

There are more than 60,000 lane miles (97,000 km) of roads in the Chicago region of Illinois (CMAP, 2010). Because there are hundreds of public and private entities in the Chicago region that apply road deicing chemicals, determining exactly how much is applied is difficult. Using road salt sales as a proxy, Kelly et al. (2010) estimated that, on average, about 471,000 metric tons of road salt were applied annually in Illinois between 2002 and 2005, mostly in the Chicago region. Previous studies have shown elevated concentrations in some surface waters and shallow groundwater in the Chicago region (Kelly and Roadcap, 1994; Kelly, 2008; and Kelly et al., 2010).

The objective of this study was to comprehensively determine long-term trends in the concentrations of Cl^2 and other major ions in surface waters and groundwater in the Chicago region using data collected by federal, state, and municipal agencies. In addition, we used the data to estimate the mass of NaCl (as road salt) applied to the Chicago region, the mass discharging via surface waterways, and the mass being stored in groundwater.

STUDY AREA

For the purposes of this study, the Chicago region consists of six counties (Cook, Lake, DuPage, Kane, McHenry, and Will Counties) (Figure 2). Most of Cook, DuPage, and Lake Counties receive their drinking water from Lake Michigan, while groundwater is the major source of drinking water in the other counties. There are several important rivers in the Chicago region, almost all of which are within the upper Illinois River watershed. From west to east, these include the Fox, DuPage, Des Plaines, and Chicago Rivers. There has been considerable alteration and modification of surface-water flow, primarily in Cook County, including the construction of several large canals, the most important being the Chicago Sanitary & Ship Canal (CSSC) and Cal-Sag Channel (Figure 2). A small sliver of land along Lake Michigan makes up the Lake Michigan watershed in Illinois, and the Chicago River and North Shore Channel receive input from Lake Michigan.

Chloride concentrations have been increasing in shallow groundwater in the Chicago region since the 1960s, when road salt began to be applied in earnest (Kelly, 2008). More than half of shallow public supply wells (<200 ft or 60 m deep) in the region have increasing trends in Cl^2 concentrations, especially in counties west of Chicago. Chloride concentrations are clearly linked to land use in parts of the region. For example, concentrations are relatively low (<15 mg/L) in rural areas of Kane County, but they are much higher in the urban corridor in the eastern part of the county (Kelly, 2005). Increasing Cl^2 concentrations in surface waters in the Chicago region have also been reported. Kelly et al. (2010) reported elevated levels of Cl^2 in the CSSC, Des Plaines River, and Fox River in the Chicago region due to road salt runoff and discharge of treated wastewater. Chloride loads were highest in the winter and early spring as a result of road salt runoff, which increases Cl^2 concentrations by up to several hundred mg/L. The Illinois Environmental Protection Agency (IEPA) identified more than 20 rivers and streams in the Chicago region as being impaired due to excessive Cl^2 in 2010 (IEPA, 2011).

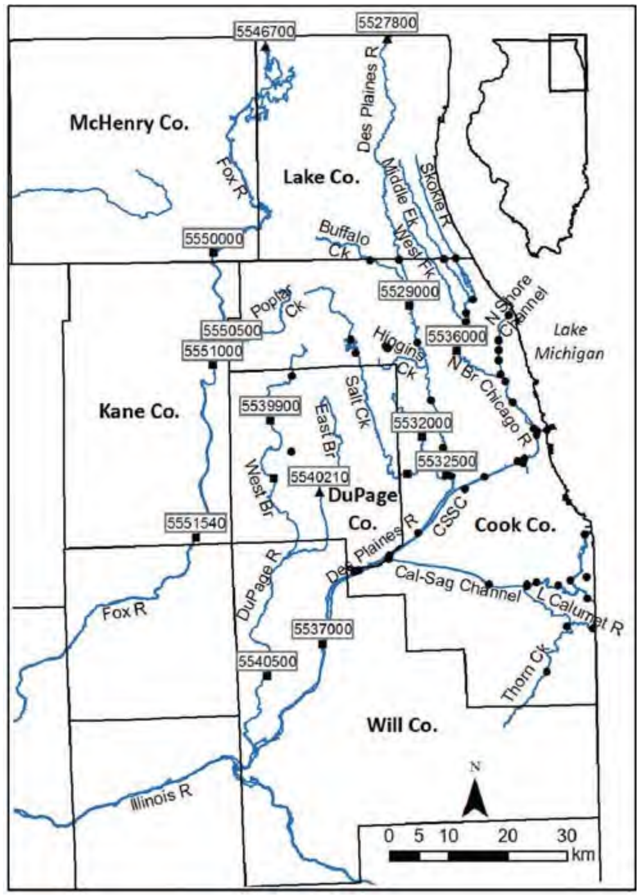

Figure 2. Chicago region. Symbols indicate Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) and U.S. Geological Survey (USGS) station locations. USGS stations are labeled with their station number, and those with triangular symbols have no data past 1997.

METHODS

In this study, data collected by several federal, state, and municipal agencies were acquired and analyzed. There are a large number of entities that are currently collecting or have historically collected surface-water and groundwater samples in the Chicago region and analyzed them for major ions. Federal agencies include the U.S. Geological Survey (USGS) and USEPA. State agencies include the IEPA and Illinois State Water Survey (ISWS). Local entities include the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC), which treats wastewater for more than five million people (primarily in Cook County), and the Lake County Health Department (LCHD).

Water-quality data for lakes were provided by the USEPA and IEPA (Lake Michigan) and the Lake County Health Department (inland lakes). Most of the river data were downloaded from the USGS (2010) and MWRDGC (2010) websites. Data between 1975 and 2008 were obtained from MWRDGC. There are 42 stations that have been monitored regularly (approximately monthly) since 1975, and 17 others with shorter durations (mostly 2001–2008). Most of the stations are in Cook County, with a few in DuPage and Will Counties. Water bodies being monitored by MWRDGC include the Des Plaines River, Little Calumet River, several branches of the Chicago River, the West Branch of the DuPage River, CSSC, and Cal-Sag Channel, among others (Figure 2).

Eighteen USGS stations had samples collected every 4 to 6 weeks, with various starting times depending on the ion but mostly in the mid- to late 1970s. For consistency, we confined our trend analyses starting in 1980 for the USGS sites. Active monitoring by the USGS ended in 1997 for most of their river stations. The IEPA began monitoring at some of these stations in 1999, and we obtained data from IEPA that included samples at 15 USGS stations collected between 1999 and 2005. Most of the USGS/IEPA stations are in rivers and streams monitored by MWRDGC, but there are also four stations in the Fox River Basin in the western part of the Chicago region.

In addition to analyzing entire data sets from MWRDGC, USGS, and IEPA, the data were subdivided for further evaluation. Subdivisions included by river, by sampling month, and different time periods. Median and interquartile (IQR) values were determined for the time periods 1981–1985 and 2001–2005.

There are several limitations and inconsistencies in the data sets. The USGS and IEPA generally report concentrations for both total and dissolved cations (Ca, Mg, Na), while the MWRDGC only reports total Ca and Mg concentrations. MWRDGC did not measure Na, and at some of the USGS stations, alkalinity was not measured. For the MWRDGC data, Na was calculated using the ion balance approach:

$$(Na^{+}) = (HCO_3^{-}) + (Cl^{-}) + (SO_4^{2-}) - (Ca^{2+}) - (Mg^{2+}) \quad (1)$$

with concentrations in milliequivalents per liter (meq/L). Bicarbonate was calculated from alkalinity (= alkalinity/0.82). We used Eq. 1 to calculate Na concentrations for the USGS/IEPA sites and compared the results to measured Na concentrations. Equation 1 tended to slightly overestimate Na concentrations (likely due to not considering potassium concentrations), but the average difference was <5 percent, and the difference was <2 percent for the larger water bodies (CSSC, Des Plaines River). While Eq. 1 is obviously not the most rigorous method for determining accurate Na concentrations, the results using the USGS/IEPA site data suggest that calculated Na concentrations were relatively consistent with respect to the actual concentrations and could be used in trend analysis. For a small number of MWRDGC samples, the calculated Na concentration was <0 mg/L, in which case the data were not used. We attempted to use the same approach to calculate alkalinity (as HCO_3) concentrations for the USGS stations, but those results were much less satisfactory. A much larger number of samples had HCO_3 concentrations <0 mg/L. Because of this, we did not evaluate alkalinity for the USGS stations where it was not reported. For both the surface-water and groundwater data, samples that had a charge balance error in excess of 5 percent were discarded.

For groundwater data, some of the results were reported previously by Kelly and Wilson (2008). A complete methodology is in that report, which we summarize here. Groundwater samples were restricted to shallow wells, arbitrarily defined as less than 200 ft (60 m) deep. Groundwater quality data were obtained primarily from a database maintained by the ISWS, with samples going back to the 1890s. More than 2,100 samples from domestic wells and more than 2,500 samples from approximately 1,000 public supply wells in the six-county area were evaluated.

Groundwater data were divided into five time periods for analysis: prior to 1950, 1950–1969, 1970s, 1980s, and 1990–2005. Wells were subdivided by depth, including less than 100 ft (30 m) and between 100 and 200 ft (30–60 m). These data groupings were then analyzed for statistical differences. In total, 239 public supply wells were identified that had at least four samples over at least a five-year period with the most recent sample in the 1980s or later. These were individually analyzed for trends in major ions. Of these wells, 112 had at least one sample collected between 1990 and 2005; trends in these wells were compared to the entire data set to determine if trends had changed over time.

The presence of trends in concentrations was determined using the non-parametric Mann-Kendall test, a rank-based procedure, at the 95 percent confidence level (Helsel and Hirsch, 2002). Annual rates of change for Cl were estimated by calculating slope coefficients (β_i), using simple linear regression. For the stream and river data, slope coefficients were calculated on five-point running medians in order to damp out some of the variability. Spatial, monthly, and well-depth differences were tested using the analysis of variance (ANOVA) on ranks test. For river data, statistical tests were done for both the entire temporal range (starting in 1975 for MWRDGC stations and 1980 for USGS stations) and more recent ranges (2001–2008 for MWRDGC and 1999–2005 for IEPA) to determine if trends are changing with time.

RESULTS

Lakes

In the early 1900s, the Cl concentration in Lake Michigan was 3.5–4.0 mg/L, and by the early 1960s, it was 6.5–7.1 mg/L (Beeton, 1965; Kenaga, 1978; and Gales and vanderMeulen, 1992). Lake Michigan currently has an average Cl concentration of 12 mg/L, its highest historical level (USEPA, 2011). Concentrations have been slowly increasing since the late 1800s, due to human inputs (Chapra et al., 2009), with an increase of about 3 mg/L since the 1980s. While the increase seems small, it represents an additional annual load of approximately 600,000 metric tons of Cl .

Natural lakes in Illinois are primarily confined to the northern part of the state, especially Lake and McHenry Counties. Many lakes in Lake County have been monitored between April and October for dissolved solids since the late 1980s by LCHD. Chloride concentrations have only been routinely monitored since 2005, but specific conductance, which is highly correlated with Cl concentrations, has been monitored from the beginning. Specific conductance values have been increasing with time in most of these lakes (Figure 3). Between 2005 and 2010, specific conductance and Cl concentrations generally dropped slightly in many of these lakes; this is attributed to dilution during the relatively wet summers during that period (Adams, 2011).

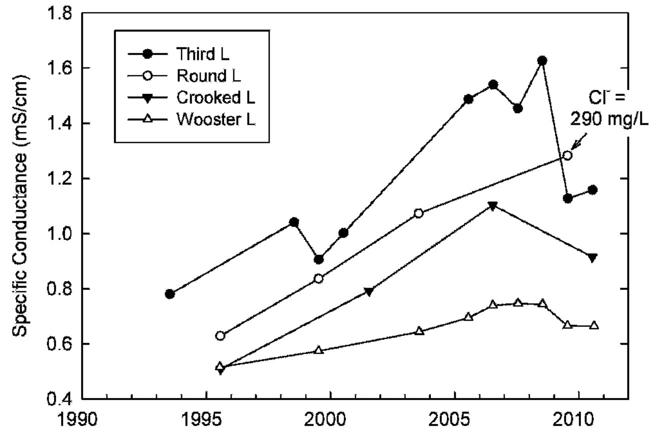

Figure 3. Average yearly specific conductance values in selected lakes in Lake County. The Cl concentration for the most recent sample from Round Lake is reported. Data are from Lake County Health Department.

Rivers and Streams

Spatial Differences

Chloride data are reported for many of the MWRDGC and USGS/IEPA stations in Table 1. Kelly et al. (2010) reported that Cl concentrations in streams in Illinois are highest in the Chicago region. The Illinois River, which drains about 44 percent of Illinois, including almost the entire Chicago region, has significantly higher Cl concentrations than tributaries downstream from Chicago throughout its reach, due to discharge from Chicago. Concentrations in the Illinois River are also significantly higher than in the Mississippi River, into which it discharges, significantly increasing Cl concentrations in the Mississippi River downstream of the confluence (Panno et al., 2006b; Kelly et al., 2010).

The greatest Cl concentrations tend to be in some of the smaller creeks and in the West and Middle Forks of the North Branch of the Chicago River (Table 1 and Figure 2). For the larger rivers, the Des Plaines River tends to have the highest concentrations. The lowest Cl concentrations are in streams receiving input from Lake Michigan (e.g., the Chicago River and North Shore Channel). Chloride concentrations have been increasing with time at the vast majority of the stations (Table 1). There are a few stations where concentrations have decreased or held steady between 1981–1985 and 2001–2005, including Thorn and Salt Creeks, and the DuPage River and its West Branch. These rivers had some of the highest median Cl concentrations for the 1981– 1985 period. Relatively low Cl concentrations are found in the Fox River to the west of Chicago, which has a higher proportion of rural land in its watershed than rivers and streams closer to or within Chicago. However, the greatest increases in median values between 1981–1985 and 2001–2005 were also for the Fox River watershed (Table 1). For example, the median Cl concentration at the USGS station in Poplar Creek, a tributary of the Fox River, increased from 80 to 207 mg/L (more than 150 percent) between those two time periods.

Regardless of location, almost all streams and rivers in the Chicago region have elevated Cl concentrations. In a study of shallow groundwater (<100 m) in northern Illinois, Panno et al. (2006a) determined that Cl concentrations in pristine shallow groundwater do not exceed 15 mg/L, and are probably much lower. Consequently, base-flow concentrations of Cl in streams and rivers in the Chicago region from uncontaminated shallow groundwater should be less than 15 mg/L, assuming insignificant in-stream evaporation. In 2007–2008, the median Cl concentration exceeded 15 mg/L at every MWRDGC station and was >125 mg/L at about 80 percent of the MWRDGC stations. Streams and rivers in Illinois outside the Chicago region almost all have much lower Cl concentrations than these (Kelly et al., in press).

The concentrations of the cations (Na, Ca, Mg) followed similar patterns to Cl (Table 2). A plot of Na versus Cl using median values for the most recent samples (2007–2008) for streams and rivers

Table 1. *Median and 75th percentile Cl^- concentrations (mg/L) for Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) and U.S. Geological Survey (USGS)/Illinois Environmental Protection Agency (IEPA) river stations. For rivers with more than one station, the average values for all stations are given.*

River	1981–1985			2001–2005			% Change	
	Sta.	Med	75th	Sta.	Med	75th	Med	75th
MWRDGC Stations								
Buffalo Creek	1	100	115	1	214	318	114	177
Cal-Sag Channel	3	109	140	3	142	199	30.5	42.3
Calumet R	3	32.0	55.9	2	46.7	86.8	45.9	55.3
Chicago R	0			2	48.9	130		
CSSC	4	70.5	112	6	122	205	73.4	83.4
Des Plaines R	7	120	156	8	181	255	51.4	63.9
Grand Calumet R	0			1	168	195		
Higgins Creek	2	167	229	2	260	421	56.3	84.2
Little Calumet R	4	112	151	4	143	182	28.5	21.0
N Branch Chicago R	4	81.0	115	6	153	252	88.4	118
N Branch Chicago R (M Fk)	1	97.0	128	1	197	286	103	124
N Branch Chicago R (W Fk)	0			1	213	431		
North Shore Channel	2	41.0	54.5	4	69.6	115	69.7	110
Poplar Creek	1	80.0	104	1	187	310	134	199
S Branch Chicago R	1	57.5	87.3	2	105	183	82.7	109
S Branch Chicago R (S Fk)	0			1	98.0	198		
Salt Creek	5	189	240	4	222	334	17.2	39.3
Skokie R	1	102	135	2	179	265	75.8	96.7
Thorn Creek	1	291	370	2	190	224	-34.6	-39.5
W Branch DuPage R	2	179	225	2	137	213	-23.3	-5.36
USGS Stations								
Addison Ck	1	142	176	1	238	383	68.2	118
CSSC	1	82.0	119	1	126	198	53.7	66.0
Des Plaines R	3	87.0	113	2	180	257	107	127
DuPage R	1	174	222	1	145	192	-16.7	-13.7
E Branch DuPage R	1	271	305	0				
Fox R	4	52.5	60.1	3	113	185	116	207
Hickory Ck	1	122	189	0				
N Branch Chicago R	1	122	152	1	226	294	84.8	93.6
Poplar Creek	1	80.0	105	1	207	318	159	204
Salt Creek	1	234	278	1	211	287	-10.0	3.24
W Branch DuPage R	2	176	225	2	191	257	8.82	14.4

monitored by MWRDGC indicates an almost 1:1 ratio between the two (Figure 4). For the rivers with the highest Cl^- concentrations, there appears to be a slight deficiency of Na. For the anions, HCO_3^- is the dominant anion when Cl^- concentrations are relatively low (less than -P80 mg/L), but for the majority of rivers, Cl^- is the dominant anion (Figure 4). Thorn Creek has an unusual composition, with by far the largest concentrations of Na and SO_4^{2-}; the source of these ions is unknown.

Trend Analysis

Of the 42 MWRDGC river stations that were monitored regularly between 1975 and 2008, 36 and 32 had significant increasing trends for Cl^- and Na, respectively. Most of the stations that had significant increasing trends for Cl^- also had significant increasing trends for Na (Table 3). The median increase for Cl^- at the stations with increasing trends was 2.7 mg/L per year. Five stations had increases of greater than 5 mg/L/yr; two of these stations were in the North Branch of the Chicago River. Conversely, 35 and 23 sites had significant decreasing trends for alkalinity and SO_4^{2-}, respectively. Calcium and Mg concentrations were more variable. For Ca, nine sites had significantly increasing concentrations and 13 had significantly decreasing concentrations, while for Mg, there were 17 sites with significantly increasing and 17 with significantly decreasing concentrations. Sites that had increasing trends for Ca and/or Mg (all of the sites with increasing Ca had increasing Mg) tended to be in streams with relatively low Cl^- concentrations, while the decreasing trends were found in streams with relatively high Cl^- concentrations.

Most of the 59 WMRDGC stations that were regularly monitored from 2001 to 2008 had positive Mann-Kendall values for Cl^-, but they were signif-

Table 2. *Median concentrations of major ions for MWRDGC river stations for the period 2007–2008. Values are in mg/L except alkalinity (Alk), which is in mg $CaCO_3$/L.*

River	Sta.	N	Cl	Na	Ca	Mg	Alk	SO_4^{2}
Buffalo Creek	1	20	264	149	79	34	203	86
Cal-Sag Channel	3	66	143	107	65	22	150	105
Calumet R	2	38	45	29	37	12	110	38
Chicago R	2	44	54	31	41	14	118	34
CSSC	6	220	149	105	57	20	136	75
Des Plaines R	8	182	190	119	69	29	184	76
Grand Calumet R	1	20	132	102	96	38	267	161
Higgins Creek	2	34	231	148	69	25	161	83
Little Calumet R	4	83	145	114	70	26	165	115
N Branch Chicago R	6	139	183	112	59	24	154	57
N Branch Chicago R (M Fk)	1	20	270	159	60	26	195	53
N Branch Chicago R (W Fk)	1	36	247	148	69	28	170	60
North Shore Channel	4	89	94	66	51	18	124	45
Poplar Ck	1	22	253	144	74	32	216	57
S Branch Chicago R	2	46	134	94	52	18	131	51
S Branch Chicago R (S Fk)	1	23	158	102	51	18	128	49
Salt Creek	4	112	246	150	64	26	137	78
Skokie R	2	43	213	129	68	27	179	60
Thorn Creek	2	41	160	301	84	31	184	497
W Branch DuPage R	2	69	182	127	66	25	148	65

icant for only four of the stations, three of which were in the North Branch of the Chicago River (Table 4). These stations all had very high Cl concentrations (median values between 201 and 269 mg/L for 2007–2008). There were 11 stations with significant increases in Na concentrations, including the same four sites with significant Cl increases. Other sites with significant Na increases included two additional North Branch Chicago River and three Des Plaines River stations. For the other major parameters, there were no stations with significant increasing trends, but a number of sites had significant decreasing trends (23 for Ca, 45 for Mg, 15 for alkalinity, and 17 for SO_4^{2}). Despite the general lack of significance for trends, calculated rates of change (f3i) for Cl tended to be higher in the more recent data set (2001– 2008) compared to the 1975–2008 data set, in some cases, more than twice as high (Table 5). Figure 5 shows Cl concentrations and regression lines for both the complete data set and the most recent data for a MWRDGC station on the Des Plaines River.

For the USGS/IEPA stations, significant increases in Cl and Na were found at 11 of 15 stations for the period from 1980 to 2005. Kelly et al. (2010) also found increasing trends for Cl in all four USGS Illinois River stations they analyzed. There were significant decreases in Ca and Mg at eight and ten USGS/IEPA stations, respectively, and at all 15 stations for SO_4^{2} . Considering just the most recent data (1999–2005) available for 13 of the stations, four had significant increasing trends for Cl , seven for dissolved Na, and five for total Na. All three Fox River stations had increasing trends in Cl and Na.

Only a few stations (two for dissolved Ca and Mg and three for total Ca and Mg) had significant decreasing trends, but the three Fox River stations had increasing trends for both dissolved and total Mg.

If halite is the predominant source of Cl and Na, we would expect equimolar changes in their concentrations. Many, but not all, of the stations and rivers monitored by MWRDGC had significantly increasing Cl/Na molar ratios. However, the most recent data suggest approximately equimolar concentrations of Cl and Na (Figure 4). For the USGS/IEPA stations, the Cl/Na ratio increased for the smaller streams, but there were no significant trends for the three Fox River stations, two of the three Des Plaines stations, and the CSSC station.

Considering the entire data set, the Ca/Mg ratio increased significantly with time, although some individual rivers had decreasing trends. Rivers with decreasing Ca/Mg trends included the Cal-Sag Canal and CSSC, which receive large volumes of treated wastewater. The Ca/Mg ratio significantly increased at most individual stations, but it significantly decreased at one of the Des Plaines stations and the CSSC station.

Seasonal (Monthly) Differences

There are clear seasonal differences in Cl and Na concentrations. The greatest concentrations tended to occur in the winter and early spring, as would be expected if road salt is the primary cause (Figure 6). Considering the entire MWRDGC data set, the

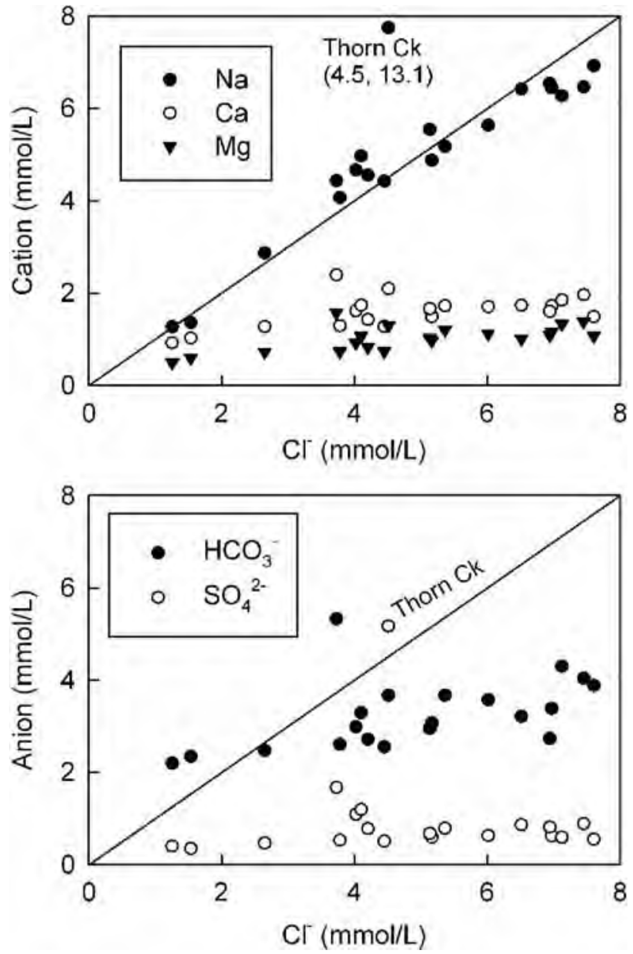

Figure 4. Relationships between median values of Cl and the other major ions for the period 2007–2008 for rivers monitored by MWRDGC (see Table 3). For cation plot (top), Thorn Creek Na data plot off graph (Na = 13.1 mmol/L).

greatest Cl concentrations were in February (median = 222 mg/L), followed by March (median = 211 mg/ L) and January (median = 195 mg/L), which had significantly greater concentrations than any other month. The lowest Cl concentrations were between July and October, with median concentrations between 86 and 97 mg/L in those months, although it should be noted that concentrations were typically greater than 100 mg/L even during these months.

If only the most recent samples (2001–2008) are considered, virtually identical statistically significant differences were observed, but median Cl values were higher (e.g., 294 vs. 222 mg/L in February and 98 vs. 86 mg/L in September).

The other cations, Ca and Mg, had similar patterns, although they were slightly offset temporally, having their greatest concentrations in March and April. Lowest concentrations were in August through October. The greatest alkalinity concentrations were between March and May. Sulfate patterns were slightly different, with greatest concentrations in January and April.

For the complete MWRDGC data set (1975–2008), Cl concentration trends were significantly positive for every month. For the period 2001–2008, however, significant increasing trends for Cl were found for only five months: February, March, May, November, and December. The rates of increase followed the same seasonal pattern as the concentration data, i.e., greatest increases in the winter and smallest in the summer.

The largest Cl/Na values were between January and April, being significantly greater than all other months. The lowest values were between September and November. This was true for the entire data set as well as each river individually, in general. The Ca/Mg values were highest in September and October and lowest between March and June.

Groundwater

Trend Analysis

Shallow aquifers in northeastern Illinois have been heavily impacted by human activities, with the most obvious sign being increasing Cl concentrations. Kelly (2008) showed that Cl concentrations in shallow groundwater in the Chicago region have been increasing since the 1960s. Over half of the shallow (<200 ft; 60 m) public supply wells evaluated (N = 239) had statistically significant increasing trends in Cl concentrations, and there did not appear to be a leveling off of trends for the most recent samples (1990–2005).

Box-and-whisker plots for the major ions for the entire groundwater data set for two ranges of well depth are plotted in Figure 7. Chloride and Na concentrations have been increasing since the 1950s–1960s. The median Cl concentration steadily increased from 6 mg/L prior to 1950 to nearly 20 mg/L in samples from 1990 to 2005, and each time period had significantly greater concentrations than the previous time period, except for the 1990–2005 group compared to the 1980s. The spread in concentrations has also been increasing, indicating spatial variability in sources of Cl contamination. Median Na concentrations have increased from 14 mg/L in the 1950s–1960s to about 31 mg/L in 1990–2005. There have been no obvious changes for Ca, Mg, or alkalinity. Median SO_4^{2} concentrations were highest in the 1950s–1960s, and the 1990–2005 data were significantly lower than all prior data groups.

For individual counties, the greatest temporal changes for Cl were generally found in the western

Table 3. *Mann-Kendall results for MWRDGC river stations with data between 1975 and 2008. Only significant values ($p < 0.1$) are shown.*

River	Sites	Cl^- +	Cl^- –	Alk +	Alk –	SO_4^{2-} +	SO_4^{2-} –	Ca +	Ca –	Mg +	Mg –	Na +	Na –
Buffalo Creek	1	1	0	0	1	0	1	0	0	0	0	1	0
Cal-Sag Canal	3	3	0	0	3	0	1	0	0	1	0	3	0
Calumet R	2	1	0	0	1	1	0	0	0	1	0	1	0
Chicago R													
Main Branch	1	1	0	1	0	1	0	0	0	1	0	1	0
N Branch	4	4	0	0	3	0	3	3	0	4	0	4	0
N Branch–Middle Fork	1	1	0	0	0	0	0	0	0		0	1	0
S Branch	1	1	0	0	1	0	0	1	0	1	0	1	0
CSSC	5	5	0	0	5	0	0	4	0	5	0	5	0
Des Plaines R	7	7	0	0	7	0	7	0	7	0	7	7	0
Higgins Creek	2	2	0	0	2	0	2	0	1	0	2	1	0
Little Calumet R	4	2	0	0	4	2	1	0	0	1	2	1	0
North Shore Channel	2	2	0	1	1	1	1	1	0	2	0	2	0
Salt Creek	5	4	0	0	4	0	5	0	4	0	4	2	2
Skokie R	1	1	0	1	0	0	1	0	0	1	0	1	0
Thorn Creek	1	0	1	0	1	1	0	0	0	0	1	1	0
W Branch DuPage R	2	1	1	0	2	0	1	0	1	0	1	0	1
TOTAL	42	36	2	3	35	6	23	9	13	17	17	32	3

counties, DuPage, Kane, McHenry, and, to a lesser extent, Will County to the south (Kelly, 2008). In DuPage County, the median values of all major ions tended to increase, especially Cl^-, which increased from 4 mg/L prior to 1950 to 101 mg/L in the 1990s and later, an increase of more than 2,500 percent. During the same period, median values of alkalinity increased by 26 mg/L, Ca by 44 mg/L, Mg by 17 mg/L, Na by 41 mg/L, and SO_4^{2-} by 118 mg/L. The same trends were generally also observed in Kane and McHenry Counties for most of the major ions, although the magnitudes of the changes were usually much less. Chloride increased in Will County, but trends were less obvious for the other ions. Chloride in Cook County was highest in the 1990–2005 data group, but there was little change in the previous groups. No significant change occurred in Cl^- concentrations in Lake County during the entire time

Table 4. *Mann-Kendall results for MWRDGC river stations with data between 2001 and 2008. Only significant values ($p < 0.1$) are shown.*

River	Sites	Cl^- +	Cl^- –	Alk +	Alk –	SO_4^{2-} +	SO_4^{2-} –	Ca +	Ca –	Mg +	Mg –	Na +	Na –
Buffalo Creek	1	0	0	0	0	0	0	0	0	0	0	0	0
Cal-Sag Canal	3	0	0	0	0	0	0	0	2	0	3	0	0
Calumet R	2	0	0	0	1	0	0	0	2	0	2	0	0
Chicago R		0	0	0	0	0	0	0	0	0	0	0	0
Main Branch	2	0	0	0	0	0	0	0	2	0	2	0	0
N Branch	6	1	0	0	2	0	1	0	3	0	5	3	0
N Branch–Middle Fork	1	1	0	0	0	0	1	0	1	0	1	1	0
N Branch–W Fork	2	1	0	0	0	0	1	0	2	0	1	1	0
S Branch	3	0	0	0	2	0	0	0	0	0	2	0	0
CSSC	6	0	0	0	0	0	1	0	2	0	4	0	0
Des Plaines R	8	0	0	0	3	0	5	0	4	0	8	3	0
Grand Calumet R	1	0	0	0	1	0	1	0	0	0	1	0	0
Higgins Creek	2	0	0	0	2	0	2	0	1	0	2	0	0
Little Calumet R	4	0	1	0	0	0	0	0	0	0	3	1	0
North Shore Channel	4	0	0	0	1	0	1	0	1	0	2	1	0
Poplar Creek	1	0	0	0	0	0	0	0	0	0	1	0	0
Salt Creek	5	0	0	0	2	0	3	0	1	0	3	0	0
Skokie R	2	1	0	0	1	0	1	0	1	0	2	1	0
Thorn Creek	2	0	1	0	0	0	0	0	1	0	2	0	0
W Branch DuPage R	3	0	0	0	0	0	0	0	0	0	1	0	0
TOTAL	58	4	2	0	15	0	17	0	23	0	45	11	0

Table 5. *Slope coefficients (f3i) offive-point running medians for Cl^- concentrations at MWRDGC stations. For rivers with multiple stations, average f3i values are reported.*

River	1975–2008		2001–2008	
	Sta.	i (mg/L/yr)	Sta.	i (mg/L/yr)
Buffalo Creek	1	6.07	1	12.92
Cal-Sag Canal	3	1.32	3	−1.55
Calumet R	2	0.52	2	0.35
Chicago R	2	0.97	2	0.68
CSSC	5	2.72	5	4.11
Des Plaines R	7	3.75	8	7.60
Grand Calumet R	1	−3.58	1	−8.06
Higgins Creek	2	5.72	2	2.80
Little Calumet R	4	1.00	4	0.09
N Branch Chicago R	4	3.38	6	10.16
N Branch Chicago R (Md Fk)	1	5.70	1	15.48
N Branch Chicago R (W Fk)	0		2	6.36
North Shore Channel	2	0.94	4	4.18
S Branch Chicago R	1	2.66	2	6.96
S Branch Chicago R (S Fk)	0		1	6.90
Salt Creek	5	4.01	6	11.93
Skokie R	1	4.55	2	11.46
Thorn Creek	1	−4.95	2	−3.52
W Branch DuPage R	2	−0.79	2	4.65

span. Sodium decreased in Lake County and stayed relatively constant in Cook County. The decrease in SO_4^{2-} observed for the entire data set appeared to be primarily due to decreases in Cook and, especially, Will Counties.

When data were separated based on well depth, there were differences for many parameters between the shallower (<30 m) and deeper (30–60 m) wells (Figure 7). With the exception of Na and SO_4^{2-}, all the ions had greater concentrations in the shallower

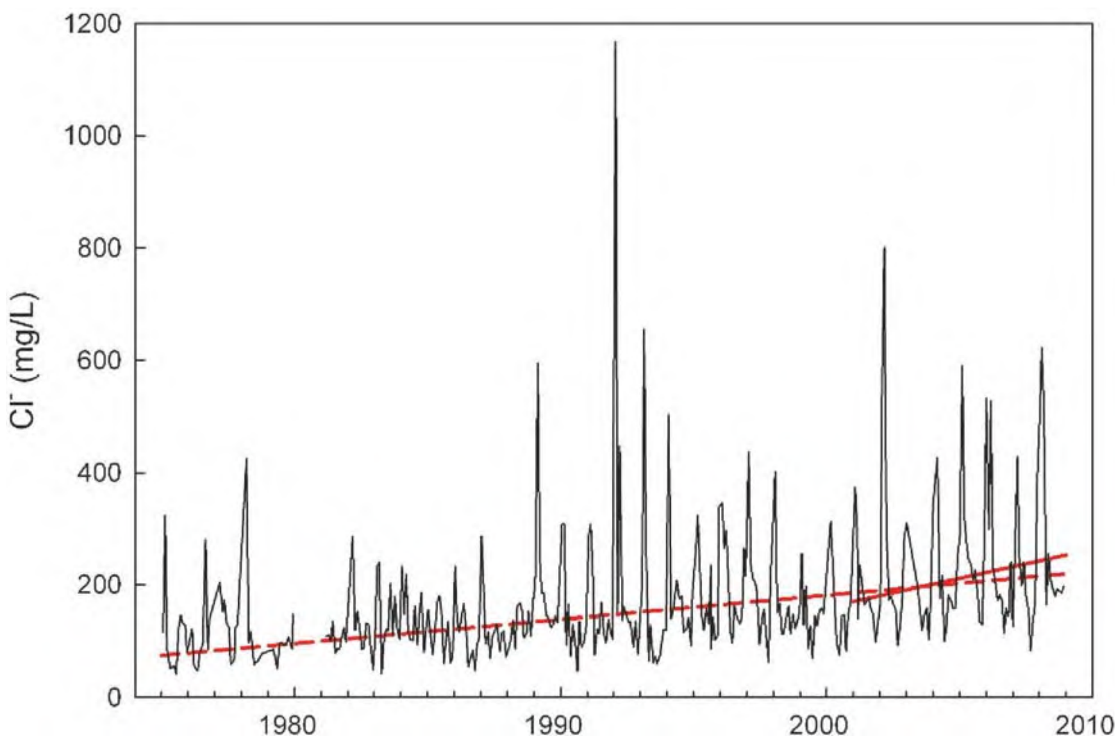

Figure 5. Cl^- concentrations at a MWRDGC station on the Des Plaines River. Dashed red line is regression on a five-point running median for data between 1975 and 2008; solid red line is regression for data between 2001 and 2008.

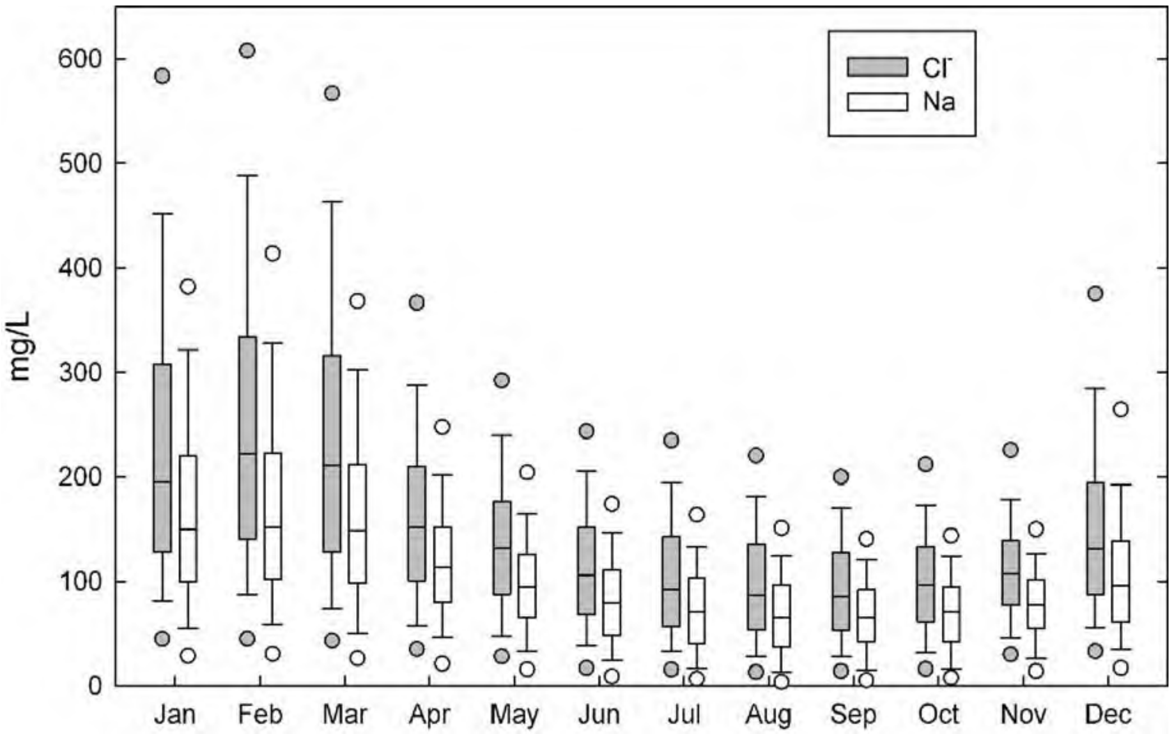

Figure 6. Box plots showing Cl^- and Na concentrations per month for all MWRDGC sites. Data are from 1975 to 2008. Symbols show the 5th and 95th percentiles.

wells than the deeper ones for almost all date groupings. These differences were statistically significant at most time periods for Cl^-, alkalinity, and Ca. Concentration trends were generally the same for both the shallower and deeper wells. There were increasing trends for Cl^- concentrations for both shallower and deeper wells, with the median concentration increasing from 8 to 36 mg/L in the shallower wells and from 5 to 17 mg/L in the deeper wells from prior to 1950s–1960s to 1990–2005. Sodium increased in both the shallower and deeper wells at similar rates since the 1950s–1960s, while the other cations (Ca and Mg) have remained fairly steady in both depth ranges. The increase in alkalinity has been greater in the shallower wells, while SO_4^{2-} has decreased at similar rates in both depth ranges.

Kelly (2008) reported there were significant temporal increases in Cl^- concentrations for the majority of the municipal wells tested (55 percent), and significant positive slope values were calculated for 57 percent of the wells. Chloride trends varied spatially; Lake and Cook Counties had relatively low percentages of wells with increasing Cl^- trends (39 to 45 percent) and slope values, while DuPage, Kane, and McHenry Counties had much higher percentages of wells with positive trends (55 to 71 percent) and slope values.

Almost half (112 of 239) of the individual public supply wells tested had at least one sample collected between 1990 and 2005. The same trends for Cl^- were observed for the wells with the most recent data compared to the entire group of wells, suggesting that there has not been a leveling off in Cl^- concentrations in the 1990s or later (Kelly, 2008).

For the other ions, positive trends for individual wells were most common for Na (33 percent) and least common for alkalinity and SO_4^{2-} (26 percent each). Negative trends were most commonly observed for SO_4^{2-} (11 percent of wells). The same patterns were found for slope coefficients, with 38 percent of wells having significant positive values for Na, and SO_4^{2-} having the smallest percentage (27 percent). Sulfate also had the largest percentage of negative slope values (13 percent).

Cl/Na and Ca/Mg ratios were calculated for all public well samples for the time period 1970 to 2005, as well as for 199 individual wells. There were significant increasing trends for Cl/Na for the entire data set in all counties except Lake County, and there were significant increasing trends for Ca/Mg for all counties except Lake County (which had a significant negative trend) and McHenry County. About 30 percent of the individual wells had significant increasing trends in Cl/Na. There were more significant increasing trends in counties to the west and south (DuPage, Kane, McHenry, Will) and fewer in Cook and Lake Counties. For the 90 wells with the most recent samples (1990–2005), there were higher

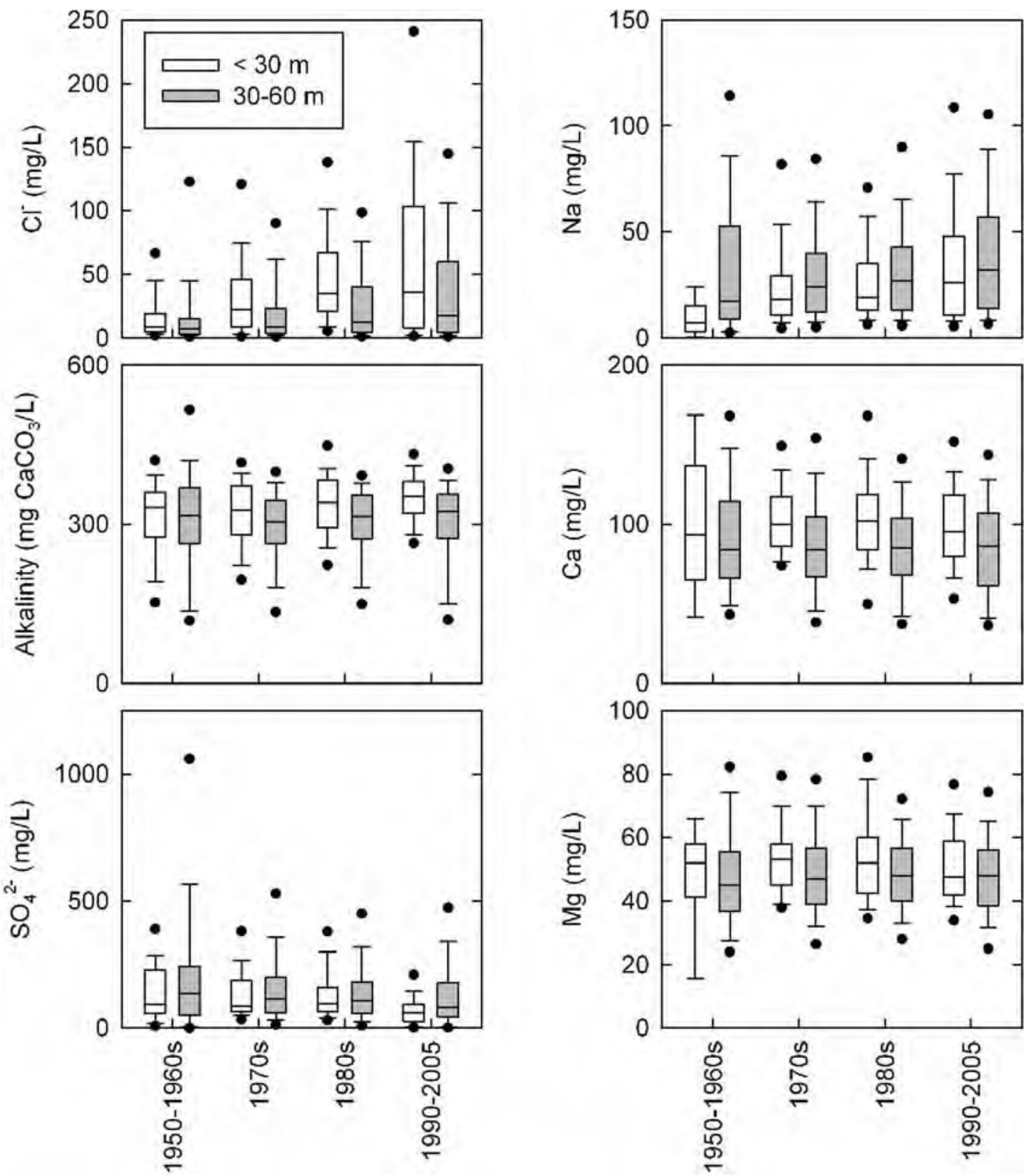

Figure 7. Box-and-whisker plots for major ions for the entire groundwater data set, separated by well depth. Symbols show the 5th and 95th percentile values.

percentages of significant increasing trends. This was especially true in Kane and McHenry Counties, the two most rural but fastest-growing counties. A plot of some of the Kane County wells shows the depletion of Na relative to Cl² as Cl² concentrations increase (Figure 8).

Chloride Mass Balance

In order to estimate the magnitude of NaCl entering shallow groundwater via road salt runoff in the Chicago region, we performed a simple mass balance calculation on Cl². Kelly et al. (2010) estimated the amount of Cl² from road salt in the Chicago region to be at least 214,000 metric tons annually (calculated for 2002–2005). In the absence of sufficient application data from the many entities responsible for deicing, Kelly et al. (2010) used national road salt sales as a proxy for application amounts, as well as county road mileage, snowfall, and population data, to make their estimate. For the Cl² mass balance, we assumed that all of the road salt applied in a year entered the hydrologic cycle.

The other main source of Cl² to waters in the Chicago region is treated wastewater. Kelly et al. (2010) estimated the mass of Cl² from the

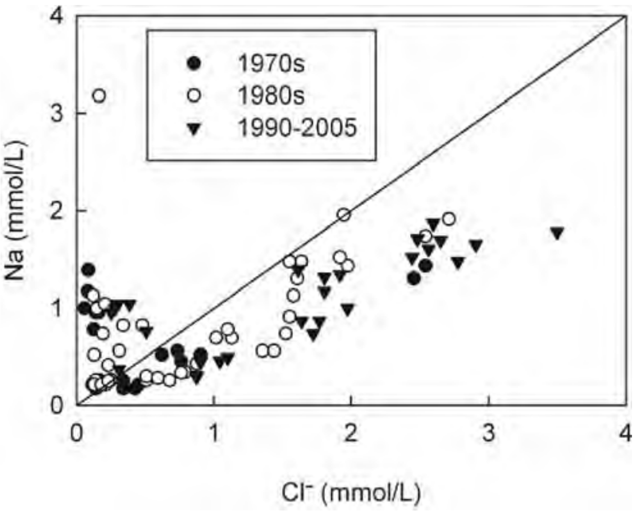

Figure 8. Na versus Cl^- concentrations for 13 public supply wells in Kane County.

MWRDGC wastewater treatment plants to be approximately 175,000 metric tons per year. Other potentially important sources of Cl^- include water-conditioning salt, fertilizer (KCl), livestock, and groundwater withdrawals (Lake Michigan withdraw-als should mainly end up in treated wastewater). Using estimates made by Kelly et al. (in press), the other sources account for about 100,000 metric tons of Cl^- annually, for a total of 489,000 metric tons of Cl^- per year being added to the hydrologic cycle in the Chicago region by human activities. Using load calculations made by Kelly et al. (2010) and Kelly et al. (in press), there is on the order of 500,000 metric tons of Cl^- discharging annually from the Chicago region via the CSSC, Des Plaines River, and Fox River. In order to determine how much anthropo-genic Cl^- is flowing out from Chicago, groundwater discharge of naturally occurring Cl^- to rivers and streams must be factored out. Using a natural background concentration of 8 mg/L Cl^- for shallow groundwater (Panno et al., 2006a) and base-flow estimations, we estimate that approximately 55,000 metric tons of Cl^- per year are discharged to streams from natural sources. Almost all of the treated wastewater (175,000 metric tons of Cl^-) is removed via surface water. Subtracting Cl^- from natural and treated wastewater sources leaves 270,000 metric tons of the 314,000 metric tons (approximately 86 percent) from anthropogenic sources of Cl^- other than wastewater being removed annually from the Chicago region via the Illinois River. The remaining 44,000 metric tons of Cl^- per year are presumably being stored in subsurface domains of the hydrologic cycle (soil, unsaturated zone, and groundwater). Thus, approximately 14 percent of the road salt applied in a year (ʻ30,000 metric tons Cl^-) enters the subsurface for relatively long-term storage.

Because road salt application rates have been increasing, the amount of Cl^- from road salt entering groundwater has also been increasing. Assuming that the amount of road salt applied in the Chicago region mirrors national trends (Figure 1), we can make a rough estimate about the amount of Cl^- that has historically been added to groundwater in the region. Assuming that 14 percent of road salt recharges groundwater each year, a total of about 15 million metric tons of salt (8.8 million metric tons Cl^-) from deicing activities has entered groundwater since 1960.

There are obviously uncertainties in the values used in making this estimate. The calculation of Cl^- from wastewater treatment plants is fairly straightforward and known with confidence, while the other source term values were calculated using indirect measures (sales, population) and/or average Cl^- concentrations. Despite these uncertainties, we believe this is a credible estimate of the amount of Cl^- being retained in the subsurface; increasing Cl^- concentrations in shallow aquifers are undeniable evidence that not all of the anthropogenic Cl^- released in a year is being flushed down the Illinois River.

DISCUSSION

It is clear from both surface-water and groundwater data that Cl^- concentrations have been increasing and continue to increase in almost all water bodies in the Chicago region. Chloride concentrations have been increasing in surface water since the earliest samples available (mid- to late 1970s for rivers, early 1990s for Lake County lakes) and in groundwater since the 1960s (Kelly, 2008). Kelly (2008) reported that Cl^- trends have continued to increase in groundwater in the Chicago region with no sign of abating. In rivers and streams, on the other hand, there are conflicting results regarding recent trends. The fact that there are fewer stations with significant increasing trends in recent years suggests that the increase in Cl^- concentrations has slowed down in the last decade and may be approaching a steady state. For example, approximately 86 percent of the MWRDGC stations had significant increasing trends in Cl^- concentrations for the period 1975–2008, while only about 7 percent had significant increasing trends for the period 2001–2008. Most of the stations did have a positive value from the Mann-Kendall test for the period 2001–2008, so Cl^- concentrations may still be increasing, but in a manner that cannot be picked up by the Mann-Kendall test. The slope coefficient data ((3i) suggest that rates of increase in Cl^-

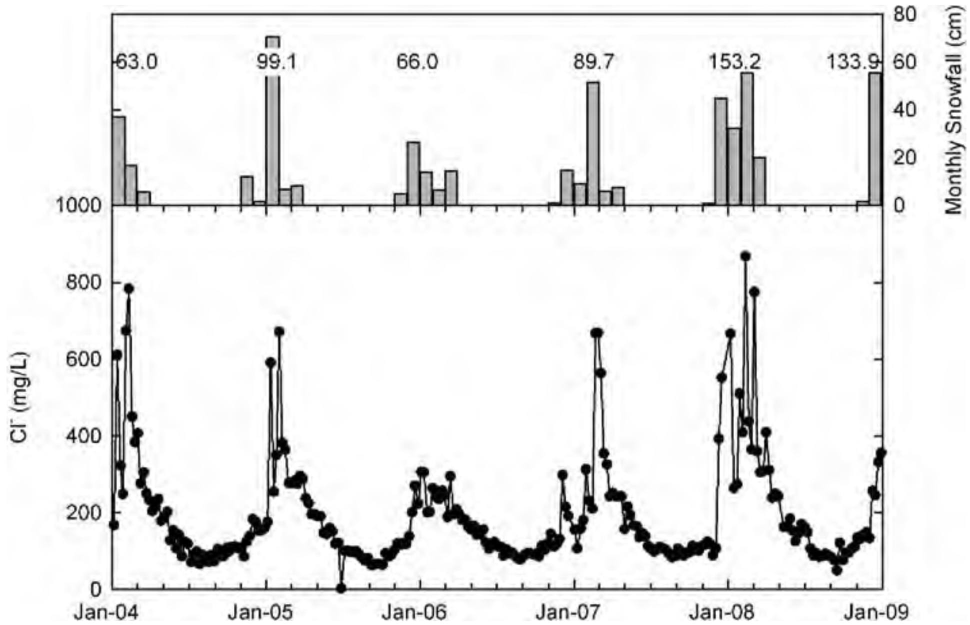

Figure 9. Chloride concentrations at a MWRDGC station on the CSSC at Lockport, IL, and monthly snowfall totals in Chicago (winter totals shown above bar). Snowfall data are from NOAA (2010).

concentrations are not slowing down, and in fact are increasing at many stations.

We are unaware of any systematic studies of the effects of elevated levels of Cl^2 on aquatic biota in the Chicago area, but it seems certain that there would be negative effects. Corsi et al. (2010) reported that seven of 13 streams in the Milwaukee, WI, area exhibited toxicity to water fleas (*Ceriodaphnia dubia*) and fathead minnows (*Pimephales promelas*) due to road salt runoff. They measured very high Cl^2 concentrations in some of the streams (commonly $>$1,000 mg/L and up to 7,730 mg/L). While these are higher than typically found in stations monitored in Chicago, some of the smaller streams occasionally had Cl^2 concentrations $>$1,000 mg/L, and smaller streams that are unmonitored undoubtedly experience even higher concentrations.

The greater range and variability in Cl^2 concentrations in smaller streams, relative to the variability seen in larger streams, reflect the flashier nature of the smaller streams. They are more vulnerable to large Cl^2 increases during snowmelt events because there is less water available to dilute a sudden influx of road salt–laden runoff.

Chicago and many of its suburbs have combined sewer systems, with storm-water runoff being collected and treated at wastewater treatment plants. A large percentage of road salt runoff in the most urban parts of the Chicago region thus does not enter shallow groundwater but is diverted to surface streams and rivers in discharge from wastewater treatment plants. The rapid transfer of saline snowmelt to streams and rivers in Chicago produces very high Cl^2 and Na concentrations in the winter (Figure 6). In snowy winters, large applications of NaCl produce Cl^2 and Na concentrations and loads in streams and rivers considerably higher than in winters with low snowfalls (Figure 9).

Obviously, some road salt runoff ends up in the soil zone and shallow groundwater, and this could represent a relatively long-term source of Cl^2 and other ions to surface water. Kelly and Roadcap (1994) measured Cl^2 concentrations in excess of 1,000 mg/L in several shallow ($<$25 ft; 7.6 m) monitoring wells installed along the uncurbed Interstate 94 in south Chicago, including two exceeding 3,500 mg/L. We did not attempt to determine base-flow Cl^2 concentrations in this study, but if we assume that the largest contribution of Cl^2 from groundwater would be during the months of July through October, we can make a rough estimate. The median Cl^2 concentration at all MWRDGC stations during those months in 2007 and 2008 was about 110 mg/L. Kelly et al. (2010) reported that Cl^2 concentrations were negatively correlated with discharge in the Illinois River Basin, as higher flows tend to cause dilution. Therefore, Cl^2 concentrations in groundwater discharge to streams and rivers in the Chicago region are likely to be significantly greater than the median value, probably closer to the 90th percentile value of about 200 mg/L.

The largest increases in Cl^2 concentrations in surface water over the time period analyzed were in the Fox River watershed, similar to evidence Kelly (2008) reported for increasing Cl^2 concentrations in groundwater in Kane and McHenry Counties, both of which are primarily in the Fox River watershed. The average increase in median Cl values for the four USGS stations in the Fox River between 1981– 1985 and 2001–2005 was 116 percent, and 147 percent for two stations (one MWRDGC and one USGS) on Poplar Creek. The Fox River watershed is primarily rural, but there has been increased urbanization in the watershed, primarily in Kane and McHenry Counties, in recent years. As urban and residential infrastructure increases in this region, the increasing impact of road salt runoff is becoming apparent. Kelly (2008) suggested that a larger percentage of road salt runoff reaches aquifers in Kane and McHenry Counties compared to Cook and Lake Counties due to thinner overlying tills, less road curbing, and less control of storm-water runoff. This suggests increasing ground-water loads of Cl and other ions in the shallow groundwater resources that can discharge to surface water in the Fox River watershed.

In both surface water and groundwater, trends for Na tended to mirror Cl trends; if halite (NaCl) is the predominant source of both Na and Cl to water resources, this is what we would expect. The fact that Na appears historically to be retarded relative to Cl in streams and rivers is likely due to reactions in soils and groundwater systems. Cl/Na ratios were more likely to increase than decrease, indicating chloride's more rapid transport compared to Na. This is more obvious in the groundwater data, where Na is clearly retarded relative to Cl (Figure 8). Ion exchange is the likely mechanism removing some Na from solution, being replaced by Ca or Mg, and it is also possible that the influx of Na and increasing ionic strength of water in the subsurface are promoting desorption of toxic metals (Srivastava et al., 2005). For the most recent surface-water data (2001–2008), there are more significant increasing trends for Na than Cl , which may reflect the relatively slower transport of Na through the subsurface. This, and the fact that the Na/Cl molar ratio is close to one for most rivers and streams in data from 2007–2008 (Figure 4), suggests that the soils and shallow groundwater systems with short residence times may have become saturated with respect to Na. For deeper aquifers, this is clearly not the case (Figure 8), suggesting that the flux of ions in discharge from aquifers to streams and rivers in the Chicago region is currently small compared to surface runoff and wastewater treatment plant discharge. Ca/Mg ratio trends were somewhat ambiguous, although they increased more than they decreased. From an ion radius perspective, Mg is less strongly bound to solids than Ca, and thus the increase in Ca relative to Mg would suggest a generally greater amount of Ca available to be exchanged in the soils and aquifer materials of the Chicago region (Faure, 1998). The fact that road salt has a greater amount of Ca compared to Mg (almost 100 times more by weight as reported by Biesboer and Jacobson, 1994), as well as the occasional use of $CaCl_2$ as a deicing component in Chicago (City of Chicago, 2011), might also account for the greater increases in Ca relative to Mg.

Salt is being added in large amounts in the Chicago region. Because of its extremely high solubility, once introduced it invariably ends up in the water resources. All parts of the hydrologic cycle are seeing increases in Cl , Na, and TDS concentrations: lakes, streams and rivers, groundwater, and undoubtedly soil water as well. Natural background levels of Cl and Na have been far surpassed in surface waters of the Chicago region, to the point that natural background is a relatively meaningless concept in this region. As long as road salt continues to be applied in large amounts (and salt is used for water softening and industrial processing), Cl and Na will remain elevated.

There is interplay between natural hydrogeologic and hydrologic conditions and human activities affecting the water quality in the Chicago region. Shallow aquifers in rural areas of the Chicago region tend to have good quality (Kelly, 2005), but land-use changes that involve additional roadways and increased road salt are beginning to degrade ground-water quality. Because most roadways in Cook and Lake Counties are curbed, saline runoff is being channeled to storm-water retention and not recharging aquifers; thus shallow aquifer quality is relatively good in these counties, despite their intense road infrastructure (Kelly, 2008). Results from Kelly and Roadcap (1994) indicate that where curbing is absent in the city of Chicago, Cl concentrations in shallow groundwater can reach extremely high levels (>3,500 mg/L).

CONCLUSIONS

Levels of Cl and Na in water resources of the Chicago region have been increasing since the 1960s due to road salt runoff. In the past decade, the most rapid degradation of water quality due to road salt runoff has occurred in areas of rapid suburbanization west of Chicago. Although most of the road salt applied in a year is removed by surface discharge, we estimate that about 14 percent salt is retained in the subsurface, which amounts to approximately 50,000 metric tons of NaCl annually, representing a long-term source of Cl and Na and other associated ions.

High salt contents in the water resources of the Chicago region could be linked to a host of negative impacts. While Cl is non-toxic to humans, public water supplies must treat water with levels >250 mg/L for public consumption. Increasing Na levels in drinking water are a concern for people with hypertension. Elevated salt contents are likely damaging aquatic ecosystems in the region, and the effects may be both chronic and acute. Chloride's corrosive nature makes it a threat to infrastructure such as road beds, bridges, water and wastewater treatment plants, and thermoelectric plants, as well as industrial operations. Road salt runoff has the potential to have large costs, both environmentally and economically.

There are no easy solutions to the problems of road salt runoff. Many public officials are aware of the issues and have taken steps to reduce application rates, but there is still a strong societal desire to keep roads clear following snow events. This, and the fact that road salt is much more inexpensive than alternative deicing agents, means that large amounts of road salt will continue to be applied in the future. Its high solubility means that it will continue to find its way into water resources, complicating effective water resource management. A growing consensus among water resource managers in the Chicago area is that storm-water infiltration should be promoted as opposed to allowing rapid/direct runoff to surface streams and wastewater treatment plants. Consequently, surface-water quality would improve, but at the expense of groundwater quality, only postponing the inevitable groundwater discharge of NaCl to surface streams.

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ATTACHMENT 4
Reduction in Nonfatal Injury Crashes After Implementation of Anti-Icing Technology
Mahoney, et. al.

Reduction in Nonfatal Injury Crashes After Implementation of Anti-Icing Technology

James Mahoney, Donald A. Larsen, and Eric Jackson

Several published papers and studies have shown that adverse weather conditions contribute to motor vehicle crashes and have an overall negative effect on highway safety. No publications were found to demonstrate the positive effects of winter maintenance anti-icing policies on safety for an entire network, such as a state highway system. Following a decision in the 2005–2006 season, the Connecticut Department of Transportation (DOT) converted from deicing to anti-icing policies. In this paper, aggregated motor vehicle crashes with nonfatal injuries are analyzed graphically to determine if winter weather safety was affected by the Connecticut DOT's switch from deicing with a sand–salt mix to anti-icing procedures that included switching to salt only. A survey of the states surrounding Connecticut provided evidence that the Connecticut DOT had applied winter deicing chemical types and quantities in a similar manner to its neighboring states. This Connecticut study concluded that crashes with nonfatal injuries during winter seasons, in all kinds of weather and road conditions, declined by 19.2% between seven winters (1999–2000 through 2005–2006) in which a sand–salt (7:2) mix was used and seven winters (2006–2007 through 2012–2013) in which only salt was used and that the same types of crashes that occurred when roads were snow, slush, or ice covered declined by 33.5%. Also, there was an immediate additional reduction in nonfatal crashes with injuries after the Connecticut DOT converted to anti-icing in the 2006–2007 winter. Even considering the increase in safety technology employed by modern vehicles, it appears that anti-icing likely reduces the amount of time that roads are slippery and therefore reduces serious crashes.

FHWA estimates that, in the United States, "each year, 24% of weather-related vehicle crashes occur on snowy, slushy or icy pavement and 15% happen during snowfall or sleet. Over 1,300 people are killed and more than 116,800 people are injured in vehicle crashes on snowy, slushy or icy pavement annually" (*1*). Winter maintenance policies for roadways have the potential to significantly influence these crash statistics, particularly in the Snow Belt states.

Connecticut is one of several northeastern states that has been working to make winter weather driving safer through the adoption of anti-icing policies and strategies. From 2006 to the time of writing, the Connecticut Department of Transportation (DOT) has been proactive in transitioning from roadway deicing to a strategy of anti-icing (*2*), which includes

- Eliminating the use of sand,
- Pretreating with sodium chloride brine solution,
- Prewetting solids (salt) with a solution of calcium chloride or magnesium chloride,
- Planning to increase the number of road weather information systems, and
- Experimenting and conducting pilot trials with salt slurry generators (*3*).

As a result of Connecticut's winter maintenance policy transition, there is evidence of a reduction in winter weather nonfatal injury crashes on state-maintained roadways. This research paper presents the data and information that led to this conclusion. The paper provides an example of the impact of proactive government actions on safety.

The following section provides a brief review of the literature on the effects of adverse weather on traffic volumes, traffic speeds, and crashes and injuries. The next section describes the method followed in the construction and analysis of the crash data set from the Connecticut Crash Data Repository (CTCDR). That section is followed by a summary of findings on the use of deicers in Connecticut in comparison with surrounding northeastern states. Next is a graphical analysis of motor vehicle crashes with nonfatal injuries that occurred during winter. The final sections of the paper provide a summary of the findings and conclusions about motor vehicle crashes on Connecticut DOT–maintained roads during winter weather.

LITERATURE REVIEW

Studies that evaluated the relationship between adverse winter weather and traffic volumes or speeds were found (*4*–*6*). There is documented evidence that during major winter weather events, there is a reduction in travel; this reduction can have a negative effect on the economy, yet reduces the severity of crashes because of the lower levels of traffic and the slower travel speeds. However, even with reduced traffic and travel speeds, the reduced traction associated with slippery surface conditions, coupled with lower visibility, typically produces a significant increase in the vehicle crash rate.

In Alberta, Canada, Datla and Sharma studied highway traffic volumes versus cold temperatures, snowfall amount, and a combination of both factors, as well as the time during the winter season when snowfalls occur (*4*). Datla and Sharma concluded that there was a 1% to 5% reduction in traffic volume per centimeter of snow, depending on the temperature at the time of the snowfall. Datla and Sharma also found that the largest impact on traffic occurred during the snowfalls earlier in the season. Knapp and Smithson looked at traffic volumes on Iowa Interstate highways for 64 winter storms of at least 4-h duration and with snowfall rates of 0.20 in./h and higher (*6*).

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The average traffic volume reduction was 29%, varying from 16% to 47% depending on the total snowfall and the wind gust levels. Maze et al. performed a literature-based review and summary of the impact of weather on traffic demand (deferring or eliminating trips), traffic flow (volume, speed, and density) and traffic safety (crash rate per mile) (*5*). A reduction in traffic volumes attributable to snow was found to be highly variable and ranged from 7% to 80%, depending on the type of traffic (commercial, commuter, or long distance) and weather severity. In the area of safety, it was reported in Maze et al. that "the increased risk of a crash while traveling during severe winter weather is greater than the risk brought by behaviors that state governments already have placed sanctions against, such as drunk driving or speeding" (*5,* p. 175).

A study by Qiu and Nixon found that all types of crashes [fatal, nonfatal injury, and property damage only (PDO)] exhibit some level of increase in crash rate during rain or snowfall (*7*). The average percentage change in the overall crash rate during snow is reported to be 84%. Hierarchy meta-analyses were conducted to assess the extent of changes in motor vehicle crash patterns between 1950 and 2005. The percentage change of crash rates during snowfall indicates a decreasing tendency over the decades. One possible explanation given in Qiu and Nixon for this finding is that winter maintenance methods and technologies have improved, particularly with the introduction of anti-icing (*7*). A second study by Qiu and Nixon produced the probability of crashes in certain adverse weather conditions (primarily, snow, wind, low visibility, and low temperature) and the effects of winter maintenance (plowing, sanding, and salting) in mitigating crashes in Iowa. The results of the 4-year study, which used data from road weather information systems, DOT crash records, automated traffic recorders, and automated weather systems, were that "plowing activities indirectly reduce injury probability by 24.2% and PDO probability by 23% through improving road surface conditions for interstate or primary highways. Similarly, chemical application reduces injury by 33.3% and PDO by 17.8%." The use of sand and abrasives alone reportedly did not produce similar results (*8*).

In 2005, Ye et al. used an artificial neural network to investigate and evaluate the effects of winter maintenance chemicals on road safety and applied the model to two highways in Idaho (*9*). A benefit–cost analysis produced a positive benefit–cost ratio of 5.5–7.0 based on estimates that the nonapplication of winter chemicals would result in 200 additional crashes at the study sites. Another study by Eisenberg and Warner used crash data from the Fatality Analysis Reporting System (a nationwide census) and the NHTSA's State Data System for a subsample of 17 states during the 1990s to estimate the effects of snowfall on PDO crashes, crashes with injuries, and fatal crashes (*10*). A total of 1.4 million fatal crashes, 13.5 million nonfatal injury crashes, and 22.9 million PDO crashes were available for the 17 states. However, Eisenberg and Warner did not account for or consider the level or variability of highway winter maintenance provided in the various states, presumably on the assumption that similar efforts were applied everywhere to mitigate the effects of snowfall on travel (*10*). During the period of the data set (1975 to 2000), many states were using deicers and abrasives alone, but a few were in various stages of conversion to anti-icing. Since 2005 it has become widely recognized that anti-icing produces a greater impact on travel than deicing alone. In fact, a survey of 26 states and Canadian provinces in April 2014 performed by Cui and Shi indicated that many states had converted to and found many benefits in anti-icing that had not been recognized in a similar survey of 15 states and provinces performed by the same organization in 2005 (*11*). The anti-icing benefits include achieving bare pavement quickly and making snowplowing much easier (*11,* p. 12).

The safety benefits of anti-icing strategies have been reported in several states. According to an online brochure published by the Pacific Northwest Snowfighters Association, "Snow and ice control methods have had a major, positive impact on traveler safety. . . . During a twelve-year study involving anti-icing strategies on the interstate system in the Denver metro area, Colorado saw an average decrease of 14% in snow and ice related crashes" (*12,* pp. 1–2).

With the exception of one study in Idaho (*13*), in which the costs of the Idaho Transportation Department's road weather information system stations were compared with the benefits of reduced crashes, no studies were found in which it was established that an agency's winter maintenance policy had directly affected a change in safety, with a resultant reduction in vehicle crashes on a statewide network of roads. This Connecticut study shows that such a reduction in statewide crashes did occur in Connecticut after a decision in 2005 to 2006 to eliminate the use of sand and abrasives and implement anti-icing practices, including pretreating roadways, prewetting deicers, and upgrading to state-of-the-art winter maintenance equipment.

BACKGROUND

This paper illustrates the effect that advances in winter weather maintenance practices and policies have had on road safety in Connecticut. Aggregated motor vehicle crash data for the state-maintained roadway network were used, and the results can assist in justifying state DOT expenditures for policies that include greater emphasis on state-of-the-art technology, such as anti-icing, road weather information systems, and modern plow and spreading equipment. The research presented in this paper is based on the graphical analyses of 117,890 motor vehicle crashes with nonfatal injuries that occurred on Connecticut state-maintained roadways from 1999 to 2013. The crash information presented in this paper was part of a larger study conducted in 2015 in partnership with the Connecticut Academy of Science and Engineering at the invitation of the Connecticut DOT in response to legislation enacted by the Connecticut General Assembly (*3*).

METHODOLOGY

Data Sources

The CTCDR, funded by the Connecticut DOT and maintained by the Connecticut Transportation Institute at the University of Connecticut, was used to perform the crash analyses in this study. The CTCDR contains data from all the motor vehicle crashes that occurred in Connecticut on the 3,734 centerline miles of state-maintained and 17,339 centerline miles of municipal-maintained roadways (*14*). The crashes recorded in the CTCDR involve property damage and personal injuries or fatalities and have been reported and investigated by a local or state law enforcement agency. Information on approximately 1.6 million motor vehicle crashes for the years 1995 through 2014 currently resides in the CTCDR. The CTCDR crash data can be retrieved, sorted, and summarized by any number of attributes, such as location (route, town, and region), collision type, date, time, weather condition, road surface condition, and light condition (*15*).

The FHWA Road Weather Management Program defines weather-related crashes as "those that occur in the presence of adverse weather (including rain, sleet, snow, fog, rain/fog, and sleet/fog) and/or slick pavement (wet, snowy/slushy, and icy)" (*1*). Paul Pisano of FHWA reported that "slick pavement conditions are very dangerous, even when there is no precipitation or fog. Over one-third of weather related crashes occur on slick pavement in the absence of adverse weather" (*16*, p. 3). In the FHWA study, wet pavement (representing 73% of adverse weather crashes) is included in the reported slick pavement category. This Connecticut study, however, only analyzes motor vehicle crashes that reportedly occurred on pavement with conditions of snow, slush, or ice. Crashes in wet (or dry) pavement conditions are excluded from this analysis, with the exception that the long-term trends of total crashes (which include those that occurred in wet and dry conditions) are discussed briefly. The ambient weather conditions, however, were not restricted, so a crash that occurred under any reported weather condition—clear, snow, rain, fog, and so on—was included in the analysis, as long as the pavement conditions were recorded by the investigating law enforcement officer as snow, slush, or ice. Therefore, many of the crashes occurred during winter weather events, but others occurred after the event and before the road returned to bare pavement. Crashes that resulted from a refreeze or from frost are also included in the analysis if the surface was reported to be snow, slush, or ice.

This study uses only crashes that occurred on the state highway system, which includes Interstates, U.S. routes, and Connecticut state routes. The exclusion of municipal roads eliminates the consideration of the different winter maintenance policies and procedures deployed within Connecticut's 169 cities and towns. The winter maintenance policies applied to state roadways are fairly consistent throughout Connecticut, with the primary variables being traffic levels and local climatic conditions. Finally, to ensure there are sufficient crash data for analysis, the retrieved aggregated crashes are analyzed statewide rather than by geographic region or by Connecticut DOT maintenance district.

The weather data for this study (the number of winter weather events and the average annual snowfall) were obtained from the Connecticut DOT, which monitors and records snowfall at 26 locations throughout Connecticut for every winter weather event. The Connecticut DOT categorizes a winter weather event as either a storm or an activity. Activities typically last less than 6 h and involve less than 50% of the workforce. Storms are of longer duration and involve more than 50% of the snow and ice control workforce being activated.

Vehicle miles traveled data are not included or analyzed in this study. Such data are estimated by the Connecticut DOT as daily and annual averages for the network. However, these data are not available in relation to weather conditions. As reported in the literature, the vehicle miles traveled likely vary between periods with storm events and non–storm events. Also, as mentioned in the literature review, other studies have documented traffic volume reductions during snow events, particularly during major storms. Without the vehicle miles traveled, the crash frequency (the actual number of crashes), rather than the crash rate, is presented for the winter weather event crashes. The number of crashes during comparable periods with dry pavement is not included in this analysis. Therefore, the only information that can be gleaned from the presented data sets is the variation of crashes occurring during winter seasons under snow, slush, and ice surface conditions during the 14-year period. Since it has been reported by others that winter weather crashes have been declining over the long term (*7*), it is possible that some of the decline in crashes seen in the data set is attributable to other factors, such as improvements in vehicle technology, law enforcement, and better-trained drivers.

An obvious benefit of anti-icing (as opposed to sanding and deicing alone) is the reduction in snowy, slushy, and icy surface conditions. That is, the amount of time when snow, slush, or ice occurs on the pavement during each weather event, as well as the total over the entire year, should be significantly reduced by anti-icing efforts, and this reduction could be the single biggest factor in the reduction of crashes found in this study. The Connecticut DOT's current anti-icing strategy leads to less snow or ice bonding to the road surface and the easier removal of snow by plowing (*2*). In addition, the chemicals applied before or in the early stages of a winter weather event make ice formation below the snow layer less likely. The reduction in ice formation provides more traction (less-slippery road conditions) and, in theory, should lead to fewer motor vehicle crashes.

Amount of Salt Usage

All deicing chemicals have potential negative issues associated with them, such as adverse environmental impacts, high costs, or the potential for the corrosion of certain materials used in infrastructure and motor vehicles. A survey of surrounding northeastern states performed during 2015 provides a comparison benchmark for deicer use in Connecticut (*3*). State transportation agencies in Connecticut, Maine, Massachusetts, Rhode Island, New York, New Jersey, New Hampshire, and Vermont were surveyed. Connecticut fared well among the seven nearby states as far as chloride (salt) use was concerned. In comparison with the surveyed northeastern states, in which the average annual total tons of chlorides applied ranged from 12.5 to 31.1 tons per lane mile for the 2009–2010 to 2013–2014 winter seasons, the Connecticut DOT's 14.2 total chloride tons placed per lane mile ranked on the low end for salt application. Only the Maine DOT and the Vermont Agency of Transportation had lower application rates for total chlorides per lane mile. However, because the Connecticut DOT proactively prewets nearly all solid sodium chloride to keep it from bouncing off the road and to initiate faster melting, the 87 gal per lane mile per season of liquid magnesium chloride solution (and, previously, liquid calcium chloride solution) applied by the Connecticut DOT places Connecticut on the higher end of liquid treatment applications relative to the surrounding states, just below the usage on a per lane mile basis of the New Jersey DOT. The surveyed states used various blends of liquid and solid chemicals, which made direct comparison between the states somewhat difficult. In addition, the climate between and within each state varied significantly. The winter maintenance policy and level of service provided in each state also differed and resulted in variations in winter maintenance procedures.

EFFECT OF SALT USAGE ON VEHICLE CRASHES

It was determined that motor vehicle crashes involving nonfatal injuries would be the best metric to gauge the effect of Connecticut DOT winter maintenance operations on highway safety. When driving is compromised by snow, slush, or ice conditions, the number of crashes involving fatalities is typically very small. Because of the small sample size, fatal crashes are not included in the analysis. PDO crashes are also excluded from the analysis. During winter

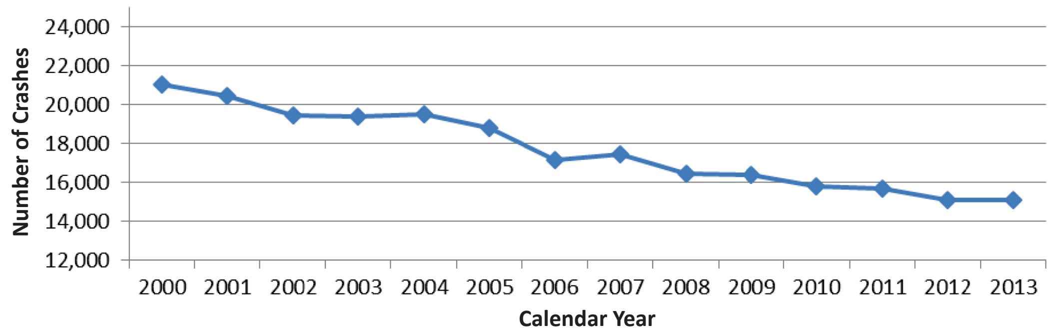

FIGURE 1 Yearly number of motor vehicle crashes involving nonfatal injuries on Connecticut state-maintained roads (2000–2013).

weather events that arrive abruptly, law enforcement personnel are forced to prioritize their response among the many crashes that can occur in a relatively short period of time. Crashes involving injuries typically receive the most attention. Thus, even though PDO-type crashes are much more prevalent than crashes with injuries, it is believed that the information recorded about winter weather PDO crashes would be less reliable, particularly during those periods when hundreds of crashes occur in a short time frame.

For general reference, a plot of all motor vehicle crashes involving only nonfatal injuries on Connecticut state-maintained roadways (247,988 crashes) over the 14 calendar years from 2000 to 2013 shows that there was a steady decline in crashes nearly every year (Figure 1). The crashes plotted in Figure 1 occurred under all possible pavement surface conditions (dry, wet, snow, slush, ice, sand, mud, dirt or oil, other, or unknown). The crashes included in these data also occurred under all weather conditions (Figure 1).

A similar plot of motor vehicle crashes involving only nonfatal injuries and occurring only during the winter season, defined in this study as November 1 through April 30, also shows a significant decline over time, but with a notable step downward after the implementation of anti-icing strategies during the 2006–2007 winter season (Figure 2). The 117,890 winter season crashes plotted in Figure 2 are for the 14 winters of 1999–2000 to 2012–2013; the following attributes were used when extracting these crashes from the CTCDR:

- Months: November, December, January, February, March, or April.
- Roads: state routes, Interstate routes, or U.S. routes (no local roads).
- Crashes: injury crashes only (no PDO or fatal injury crashes).
- Weather conditions: any.

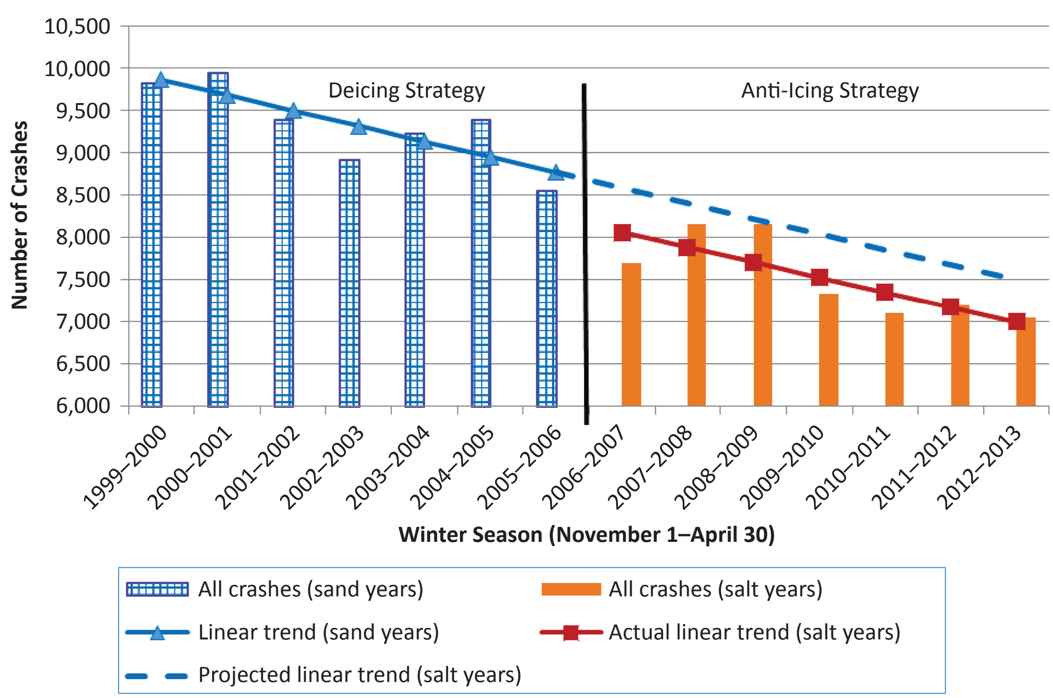

FIGURE 2 Winter season motor vehicle crashes involving nonfatal injuries (1999–2000 to 2012–2013).

- Surface conditions: any (wet, dry, snow or slush, ice, sand, mud, dirt or oil, other, or unknown).
- Other attributes, such as contributing factors, collision types, or light conditions: any.

Linear trend lines for both the deicing strategy years when sand and salt were used in a 7:2 ratio (seasons 1999–2000 to 2005–2006) and the anti-icing strategy years when only salt (little or no sand) was used (seasons 2006–2007 to 2012–2013) are included in Figure 2.

A third plot was developed for winter season motor vehicle crashes with only nonfatal injuries that occurred when the road surface was reported to be snow, slush, or ice covered (Figure 3). This graph shows significant year-to-year variability of crashes with injuries. The data indicate that the number of vehicle crashes involving injuries in surface conditions of snow, slush, or ice for the period is 12,199, with roughly 200 to 1,400 crashes per winter season. A linear trend line for the deicing strategy period is superimposed onto the graph in Figure 3, as well as projected forward through the anti-icing years. A second linear trend line is placed over the salt-only years (the anti-icing period).

A single-factor analysis of variance was performed on the data plotted in Figures 2 and 3. The analysis of variance showed that there was likely a statistically significant difference between anti-icing crashes and deicing crashes (i.e., between 1999 to 2005 and 2006 to 2013). The null hypothesis, that the means of the two data sets were equal, was rejected, and the F-test value (F) was greater than the F-critical value (F_{crit}). In both cases, at the 95% confidence level, F_{crit} is 4.747225 for both Figures 2 and 3. The calculated F for Figure 2 is 47.51264, and for Figure 3 is 4.953074.

Much like the crash rate during surface conditions of snow, slush, or ice, Connecticut's average snowfall (the midpoint of the range of snowfall measured by the Connecticut DOT at 26 locations) for winter seasons 2000–2001 to 2012–2013 demonstrates great year-to-year variability (Figure 4). A linear trend line that is overlaid onto Figure 4 shows that even though the average snowfall varies significantly from year to year, the long-term trend has been rather flat. The average annual snowfall for six of the winter seasons when deicing was used (2000–2001 to 2005–2006) is 51 in., and for the later seven years of anti-icing (2006–2007 to 2012–2013) is 42 in.

Last, a plot of the average snowfall superimposed onto the average number of crashes indicates that a direct relationship exists between the average seasonal snowfall and the number of vehicle crashes with nonfatal injuries when the surface is snow, slush, or ice covered (Figure 5).

DISCUSSION OF RESULTS

The causes of motor vehicle crashes are numerous and diverse. A graphical representation of crashes involving nonfatal injuries shows that fewer crashes occurred in the most recent anti-icing winter seasons than in the deicing years before 2006 to 2007. Yet it would be irresponsible to conclude that anti-icing alone accounted for the reduction in vehicle crashes.

All Crashes Involving Nonfatal Injuries

Figure 1, which is a plot of all motor vehicle crashes involving injuries (no fatalities) on Connecticut state-maintained roadways (247,988 crashes) that occurred over 14 years from 2000 to 2013, shows that there was a steady decline in annual vehicle crashes nearly every year. This finding corroborates information cited above at the national level (*7*). Much of the decline in total year-round injury crashes is likely the result of improved vehicle safety technology (e.g., antilock brakes, air bag restraints, tire tread design, stability

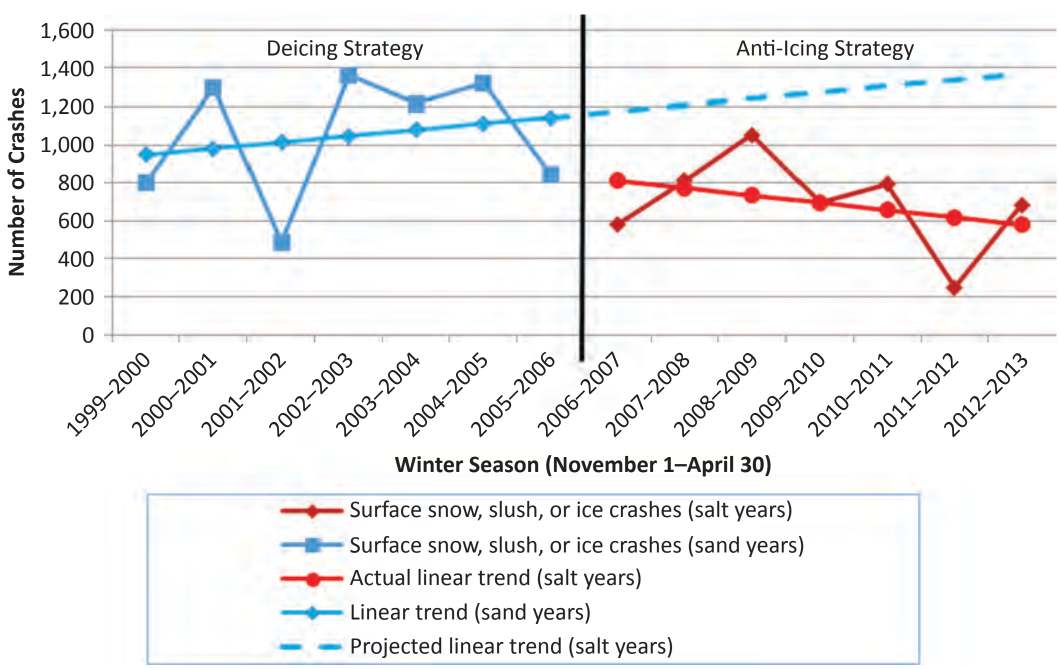

FIGURE 3 Motor vehicle crashes involving nonfatal injuries in snow-, slush-, or ice-covered pavement surface conditions.

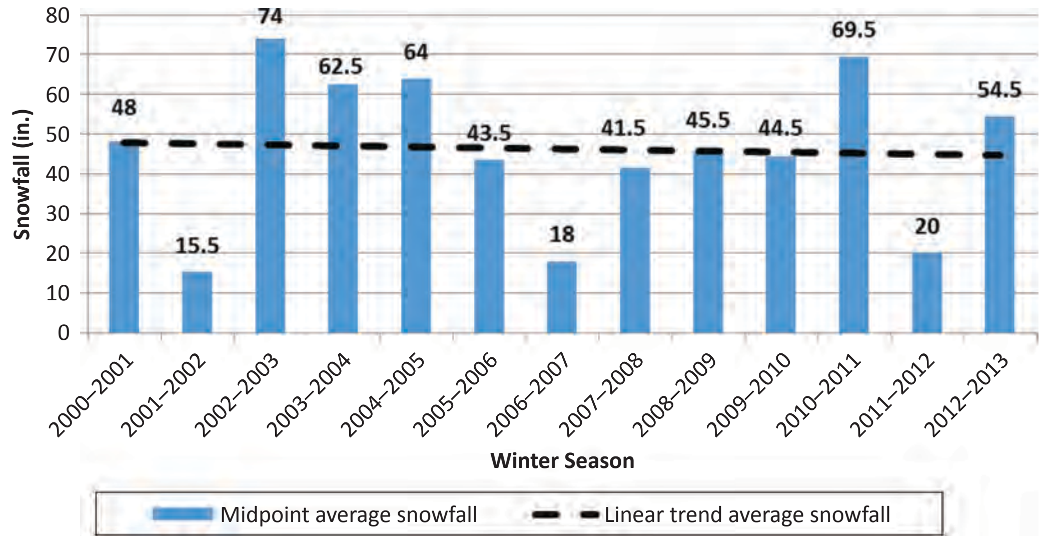

FIGURE 4 Connecticut's statewide average seasonal snowfall (2).

control, traction control, and all-wheel drive) and possibly increased seat belt usage, law enforcement action, driver education, and safety awareness, as well as an increase over time in the number of vehicles equipped with state-of-the-art safety technology.

Winter Season Crashes Involving Nonfatal Injuries

Figure 2 shows a significant decline in winter season crashes over time, but with a notable step downward after the implementation of anti-icing strategies. As shown in Figure 2, the deicing strategy trend line, when projected forward, is nearly parallel to the actual trend line for the anti-icing strategy years. However, the actual trend for the anti-icing strategy years is approximately 500 crashes lower than the projected trend. It can be inferred from the trend of the 117,890 vehicle crashes with nonfatal injuries (on state roads only) plotted in Figure 2 that the anti-icing strategy implemented by the Connecticut DOT may be responsible for an additional decline in the number of winter weather crashes beginning in the winter season of 2006 to 2007.

Crashes Involving Nonfatal Injuries When Pavement Surface Is Snow Covered, Slush Covered, or Ice Covered

Much of the year-to-year variability in vehicle crashes seen in Figure 3 is related to the number of winter weather events. For example,

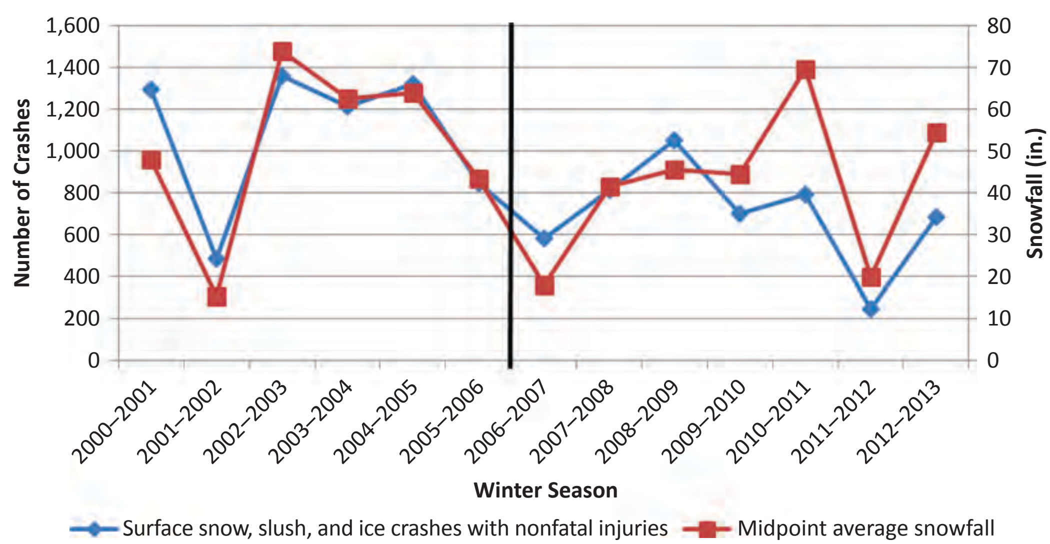

FIGURE 5 Average snowfall and motor vehicle crashes involving nonfatal injuries in snow-, slush-, or ice-covered pavement surface conditions.

TABLE 1 Difference in Average Number of Motor Vehicle Crashes with Nonfatal Injuries on Connecticut State-Maintained Roadways for Deicing and Anti-Icing Time Periods

	Average Number of Crashes			
Type of Crash	Deicing Years (A)[a]	Anti-Icing Years (B)[b]	A – B[c]	(A – B)/A[d]
All crashes with nonfatal injuries	9,314	7,527	1,787	–19.2%
Crashes with nonfatal injuries when road surface contained snow, slush, or ice	1,046	696	350	–33.5%

[a]Sand-and-salt years: 1999–2000 through 2005–2006 (seven seasons).
[b]Salt-only years: 2006–2007 through 2012–2013 (seven seasons).
[c]Change in average number of crashes between deicing and anti-icing years.
[d]Percent change in average number of crashes from deicing to anti-icing years.

the small number of crashes during 2001 to 2002 and 2011 to 2012 is directly related to the smaller number of winter weather events that occurred during those two seasons in Connecticut and the resultant lower total snowfall. It can also be seen in Figure 3 that motor vehicle crashes with nonfatal injuries during surface conditions of snow, slush, or ice have trended downward since the implementation of the anti-icing strategy. During the deicing years of 1999–2000 to 2005–2006, the plot of crashes had trended upward. The average number of winter season crashes with injuries in Connecticut for the 7 years after anti-icing was implemented is 33.5% lower than for the 7 years prior, when sand and salt were used.

In Figure 5, in which snowfall has been plotted along with crashes, the later four winter seasons (2009–2010 to 2012–2013) show greater variance between snowfall amounts and vehicle crashes and have fewer crashes relative to the snowfall amount than in the earlier years. Freezing rain events are not included in the weather data plotted in Figures 4 and 5. Admittedly, without this additional information, the relationship between frozen precipitation and crashes is not completely defined in this analysis. However, because of Connecticut DOT diligence, it is a rare occasion when Connecticut roads are ice covered as a result of freezing rain.

Summary Comparison of Deicing Years and Anti-Icing Years

Summary information on the average reduction in crashes extracted from Figures 2 and 3 is presented in Table 1. As previously indicated, these values are based on only nonfatal injury crashes. There was a 19.2% reduction between the average number of winter weather crashes during the deicing and the anti-icing periods for all nonfatal injury crashes plotted in Figure 2, but an even greater reduction of 33.5% for the crashes when the surface road condition was listed as snow, slush, or ice covered (Figure 3). Thus, the reduction in crashes with surface conditions of snow, slush, or ice is significantly greater than the general reduction in winter motor vehicle crashes that occurred between these two time periods.

CONCLUSION

A decline in total vehicle crashes with injuries on Connecticut state-maintained roads over a 14-calendar-year period (1999 to 2013) mirrors trends found elsewhere in the United States and is likely the result of improved vehicle safety technology (e.g., antilock brakes, air bag restraints, tire tread design, stability control, traction control, and all-wheel drive), as well as an increase over time in the number of vehicles on the road with improved safety technology. Other factors contributing to the decline may be increased seat belt usage, better law enforcement, and improved driver education and safety awareness. When Connecticut winter season crashes with nonfatal injuries are analyzed, with the switch to an anti-icing (all-salt) policy used as a dividing point, there is a notable difference between the 7 years of deicing with the sand–salt mix and the 7 years of the salt-only applications. For winter season injury crashes occurring on snow-, slush-, or ice-covered roads, the salt-only period (2006–2007 to 2012–2013) shows a distinct decrease in the trends for injury crashes compared with the trends during the previous 7 years of the sand–salt mix (1999–2000 to 2005–2006). Although it is not possible to conclude that the switch to all salt and the implementation of the latest technology in winter maintenance by the Connecticut DOT were solely responsible for the change in the data trends, it is difficult to ignore the obvious, significant trends in nonfatal injury crashes occurring on snow-, slush-, or ice-covered roadways. The reduction of 33.5% in injury crashes on snow-, slush-, or ice-covered surfaces was significantly greater than just the reduction in overall injury crashes of 19.2% that occurred between these two time periods.

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The Standing Committee on Winter Maintenance peer-reviewed this paper.

ATTACHMENT 5
Benefit-Cost of Various Winter Maintenance Strategies
Western Transportation Institute, 2015

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Benefit-Cost of Various Winter Maintenance Strategies

Western Transportation Institute

CLEAR ROADS

research for winter highway maintenance

Project 99006/CR13-03
September 2015

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15. Supplementary Notes: * Principal Investigator (Email: laura.fay@coe.montana.edu)		

16. Various costs and benefits are incurred while performing winter maintenance operations. However, a summary of these costs and benefits for different maintenance scenarios has not been compiled to date. This report summarizes past work that documented the quantified and non-quantified costs and benefits of three different winter maintenance strategies of interest; use of abrasives, salts and other chemicals in solid and liquid forms, and snow plows. Basic strategies were defined as plowing and use of abrasives, intermediate strategies were defined as the use of rock salt and salt brine (NaCl), and advanced strategies were defined as the use of corrosion inhibitors, inhibited salt brine, magnesium chloride, calcium chloride, and blended products. These approaches employ different components, both in terms of equipment as well as materials. Some components of the various strategies have better cost and benefit information available than others. This is particularly true of sanding/abrasives and salting. Other, more recently developed and employed approaches and materials have more limited cost and benefit information published. There are also a number of different environmental impacts associated with different components of each maintenance strategy. Using information gained from the literature review, surveys, and interviews summary benefit-cost matrices were developed for various winter maintenance strategies. Information and data gap analysis has aided in identification of areas for recommended research. This document is intended for use by transportation agencies, such as by maintenance supervisors, to aid in the decision making process in terms of the selection of winter maintenance strategies used to achieve a prescribed LOS.

17. Key Words	Distribution Statement
Costs, Benefits, Winter Maintenance, Winter Maintenance Practices, Winter Maintenance Equipment, Winter Maintenance Operations, Snow Plows, Road Salt, Abrasives	No restriction. This document is available to the public through the Clear Roads Organization and the Minnesota Department of Transportation 395 John Ireland Boulevard St. Paul, Minnesota 55155-1800

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Benefit-Cost of Various Winter Maintenance Strategies

Final Report

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Executive Summary

Various costs and benefits are incurred while performing winter maintenance operations. However, a summary of these costs and benefits for different maintenance scenarios has not been compiled to date. This summary report provides all levels of decision-makers with information on which to base sound decisions. In doing so, agencies could better maximize the roadway level of service relative to the maintenance strategy's costs and have a mechanism to explain the available options, their costs, benefits, and consequences to various stakeholders, including DOT personnel, legislators, and the general public.

In order to facilitate that summary, it was necessary to identify past work that identified the quantified and non-quantified costs and benefits of three different winter maintenance strategies of interest to this project. The first strategy was basic and consisted of actions performed to maintain traveler mobility and safety, including plowing and the use of abrasives (sanding). A second, intermediate strategy reflected an improvement over the basic approach; it consists of plowing and the use of some abrasives in spot locations, but also relies on salt in solid or liquid forms for anti-icing and deicing. The third strategy uses magnesium chloride, calcium chloride, and blended products such as corrosion-inhibiting liquids and/ or treated or chemically enhanced solid chemicals in anti-icing and deicing to address the corrosion risks associated with untreated materials. This strategy allows for the selection of specific chemicals that will work best in a specific climatic region or temperature range, avoiding the overuse of salt or salt brine at colder temperatures as may be the case in the second strategy. Collectively, these three approaches employ various equipment and materials. Such components include materials such as abrasives, salts and other chemicals in solid and liquid forms, and snow plows. Literature related to these various components was identified and summarized during the course of a literature review, the results of which are presented in this document.

Some components of the various strategies of interest have better cost and benefit information available than others. This is particularly true of sanding/abrasives and use of road salt (sodium chloride). This may stem from the historical use over time, and because this has been the most common treatment used by maintenance agencies. Historically, salting approaches have provided benefits that generally exceed the quantified costs associated with them, not factoring in environmental impacts. For example, they have been shown to reduce crashes and improve or maintain mobility (travel time and speeds). The costs and benefits of snow plows, which represent the other common approach historically employed by agencies, have not been as well defined. It is possible that agencies have difficult separating the contribution of plowing versus material usage.

Other approaches developed and employed in the past two to three decades (e.g. prewetting and materials such as magnesium chloride and calcium chloride) have more limited cost and benefit information published. While the cost of the equipment and materials are available from agency records (although it did not appear in literature), benefit information is generally lacking outside of generalized terms. Such information gaps were addressed through an agency survey conducted by this project.

As one would expect, there are a number of different environmental impacts associated with different components of each maintenance strategy. This is particularly true of materials, each of which had negative impacts on the environment. In some cases, equipment, alternative materials

or practices can be employed to reduce this impact. For example, the use of prewetting can facilitate adhesion and enhance melting action of granular chemicals, such as salt and magnesium chlorides. Similarly, wetting abrasives with hot water can enhance adhesion to ice and snow covered pavements, reducing bounce and scatter into the roadside environment. Research has shown prewetting of sand to provide up to 25 percent material savings, and prewetting rock salt to provide 20 to 33 percent material savings. Additionally, one researcher found $CaCl_2$ to be 9.5 to 71.4 percent more effective as a prewetting agent and outperformed $MgCl_2$.

The results of the survey and interviews have been incorporated into the benefit-cost matrices. In general, the survey and interviews identified Basic and Intermediate Activities as the most commonly used winter maintenance strategies. This includes plowing, use of abrasives, use of solid and liquid salt (sodium chloride) for deicing and anti-icing. Less commonly reported was the use of the Advanced Activities including the use of corrosion inhibitors, inhibited salt brine, magnesium chloride, calcium chloride, or blended products. This may be indicative of these winter maintenance strategies being less commonly employed, a result of who responded to the survey and interviews, or the result of survey fatigue. Gathering information on costs associated with the various winter maintenance strategies from the individuals surveyed and interviewed was a challenge. This may be due to a lack of available data, a lack of ability to access the data, or a lack of available time for interviewees to spend gathering the data. This highlights the need for easy to use cost-tracking tools for use by winter maintenance professionals.

The information gathered in the literature review, surveys, and interviews was used to populate the developed benefit-cost matrix. The matrix is presented as three sub-matrices Basic Activities, Intermediate Activities, and Advanced Activities. Within each sub-matrix information is reported on the cost, benefits, effectiveness in achieving LOS, positive and negative impacts, pros and cons, respective performance, environmental impacts, and the calculated benefit-cost ratio where possible. Benefit-cost ratios were calculated for all winter maintenance strategies with the exception of the use of corrosion inhibitors because not enough information was available to successfully calculate a ratio as shown in Table 1.

Table 1. Summary of winter maintenance strategies and the calculated benefit-cost ratios.

Activities	Winter Maintenance Strategy	Benefit/Cost Ratio
Basic	Plowing	5.3
	Abrasives	0.2
Intermediate	Rock salt (solid NaCl)	2.4
	Salt brine (liquid NaCl)	3.8
Advanced	Corrosion inhibitors	8.0-13.2*
	Inhibited salt brine	3.8
	Magnesium Chloride ($MgCl_2$)	3.6
	Calcium Chloride ($CaCl_2$)	3.8
	Blended products	3.8 - 4.0

*The B/C ratios represent the use of proactive maintenance and corrosion prevention. Calculated by Shi et al., 2013a; Honarvarnazari et al., 2015.

Knowledge gaps and future research recommendations include the need to support winter maintenance agencies in keeping detailed cost data. Specifically, a cost analysis of corrosion inhibitors and agriculturally derived products is needed.

Chapter 1
Introduction

Highway agencies such as Departments of Transportation (DOTs) are tasked with numerous responsibilities, including winter maintenance operations. When completing winter maintenance, agencies employ a suite of approaches customized to their local snow and ice control needs and funding, staffing, and equipment constraints.

This can include, but is not limited to the following options depending on the road weather scenarios, resources available, and local rules of practice:

- Anti-icing, deicing, and sanding
- Mechanical removal (e.g., snowplowing)
- Snow fencing

On average, state DOTs expend roughly 20% of their budgets on such activities, with a direct cost of $2.3 billion and an indirect (infrastructure and environmental) cost of $5 billion annually (FHWA, 2014).

Typically, the strategies employed by agencies come with many tradeoffs. The costs include resources expended by the agency, corrosion and abrasive wear, and potential environmental impacts. Benefits can include economic impacts to society and increased safety and mobility for travelers. In light of these costs and benefits, it is necessary to assess and communicate how different strategies can produce the most cost-effective winter maintenance approach.

A helpful analogy is to think of winter maintenance as a staircase. The ***initial step*** consists of the most basic activities that can be performed in order to maintain traveler mobility and safety. The first step consists of activities such as plowing and the use of abrasives (sanding). These activities can have some effectiveness in terms of maintaining mobility and safety. Vehicles are provided with traction, but travel speeds are greatly reduced, and snow and ice are still likely to build up on the roadway surface. Additionally, this strategy can result in the need for more operator time to maintain a reasonable level of service (LOS), potential damage to vehicles (e.g., windshield), and cleanup of the abrasives between storms or at the end of the season.

As a result of the limitations produced by this first strategy, agencies typically ***move upward another step,*** to a strategy of plowing and the use of some abrasives in spot locations, which largely incorporates and relies on salt in solid or liquid forms. This approach may also incorporate some anti-icing materials applied in advance of a storm event. Salt brine can be used in this strategy for anti-icing and pre-wetting, whereas the solid salt is typically used for deicing practices. The use of these materials either prevents or weakens the bond of snow and ice to the pavement surface under ideal temperature ranges. While this strategy permits greater mobility and safety through the provision of bare or wet pavement, it has drawbacks. Namely, salt and salt brine do not incorporate corrosion inhibitors (as inhibitors are typically much more costly than salt brine), which can result in significant corrosion to infrastructure and vehicles. In addition, these products only work effectively above a certain temperature range (e.g., 15°F), below which the road can refreeze or a higher application rate would be required. In other words, if a temperature is colder than the effective range of a product, more of that product may be needed in order to facilitate the mechanical removal of snow and ice from the pavement, or an alternative product or treatment strategy should be considered. In summary, this strategy produces bare or wet pavement and facilitates mobility and safety, but at the cost of potential corrosion to critical infrastructure and with some environmental risk associated with the use of chemicals.

In order to maintain or enhance the mobility and safety benefits produced by treatment materials from this second strategy, many agencies move on to the ***third step*** of the staircase, the use of magnesium chloride, calcium chloride, and blended products such as corrosion-inhibited liquids and/ or treated or chemically enhanced solid chemicals. This approach uses inhibitors to address the corrosion risks associated with the untreated materials. The use of inhibitors and other additives can extend beyond direct liquid and solid products that incorporate inhibitors to the treatment or enhancement of solid chemicals. The prewetting of non-inhibited solid chemical with inhibited liquid chemical may partially reduce the corrosiveness of the latter. The strategy allows for the selection of specific chemicals that will work best in a specific climatic region or temperature range, avoiding the overuse of salt or salt brine at colder temperatures as was the case in the second strategy. Consequently, this final strategy sits atop the staircase of winter maintenance approaches by addressing corrosion impacts of chemicals while reducing the amounts of materials being used, resulting in prospective savings to an agency. In the course of meeting these goals, a high LOS is met, maintaining mobility and safety for the public.

As the discussions of these strategies indicate, various costs and benefits are incurred while performing winter maintenance operations. However, the absence of guidance regarding these costs and benefits of different maintenance scenarios is a significant void for the winter maintenance community. Therefore, efforts are necessary to address this gap and develop initial guidance for different scenarios in order to provide all levels of decision-makers with information on which sound decisions can be based. In doing so, agencies can better maximize the LOS they achieve for the costs of a strategy employed. Furthermore, winter maintenance professionals will be provided with another tool in their toolbox that can be used to explain the available options, their costs, benefits, and consequences to various stakeholders, including DOT personnel, legislators, and the general public. This would include: agency costs in achieving a specific LOS; economic impacts of different maintenance strategies; corrosion and abrasive impacts on highway users, equipment and infrastructure; safety benefits achieved through different strategies; and environmental impacts resulting from different strategies.

Consequently, the overall objective of this project is to identify the costs and benefits previously cited in literature, to identify and address any gaps in the cost and benefit information previously documented through a survey of practitioners, and to analyze and organize the available information into a format ready to be communicated to stakeholders. To this end, the information presented within this document identifies and summarizes the costs and benefits of winter maintenance previously discussed in literature. Prior to moving on to an examination of that information, it is first necessary to define what is meant by the costs and benefits of winter maintenance.

Defining Winter Maintenance Costs and Benefits

The winter maintenance community has recognized the need to better establish and understand the various costs and benefits of different aspects of their operations. This ranges from understanding the collective costs and benefits of winter maintenance (Kuemmel and Hanbali, 1992; Hanbali, 1994; Qiu and Nixon, 2009; Ye et al., 2012) as well as understanding specific costs and benefits of different equipment, materials, and operations (Veneziano, et al., 2010a; Veneziano, et al., 2013). These efforts have shed light on the costs and benefits of winter maintenance, but they do not necessarily consider general scenarios that employ different combinations of strategies, such as those outlined in the previous paragraphs. Consequently, there remains a need to develop an understanding of the different costs and benefits collectively associated with such scenarios and develop a mechanism to present that information not only to winter maintenance professionals, but also the many stakeholders that are involved in, or impacted by, these operations.

The costs and benefits of winter maintenance may be quantifiable or qualitative. Quantifiable benefits are those that a specific value can be assigned to. In some cases, the quantified value can take the form of a percentage; in other cases, it may take on a dollar value or other numerical form. Qualitative benefits are those which are numerically non-quantifiable, but still produce some tangible benefit. For example, the use of a specific technology in maintenance operations such as Automatic Vehicle Location (AVL) can reduce material use (agency benefit), but it may be difficult to assign a value (percent reduction, dollars, etc.) that this specific tool contributes when used in combination with other maintenance operations (e.g., plowing or anti-icing). This must be kept in mind when reviewing the information provided by the following text.

Winter Maintenance Costs

In addition to the need for safety, there is also a large economic benefit associated with good winter maintenance. In 1999 it was estimated that approximated $1.4 billion dollars would be lost in wages alone if all of the snowbelt states were immobilized for just one day due to a winter weather event. Since then that number has climbed closer to $2.6 billion according to IHS Global Insight (Booz Allen Hamilton, 1999; IHS Global Insight, 2014; while the one day loss of retail sales was found to be $870 million (IHS Global Insight, 2014). When looking into the number of dollars lost as a full economic impact at a federal, state, local and individual level the numbers are even more staggering at around $3.9 billion[1] (Booz Allen Hamilton, 1999). A study of economic forecasts for Kansas estimated that for an average February weekday, the Interstate and State highway system caries $175 million in goods and accounts for $30 million in daily wages (Kansas DOT, 2013).

Costs per storm are determined on a routine basis. Below are a few examples of states' calculated cost per storm:

- New Hampshire cost for 8-hour storm is $587,227 including two salt applications (includes state equipment, hired equipment, labor, fuel, salt and sand). New Hampshire spends $40 million per year on snow and ice removal (Wickham, 2012).
- Virginia: The average cost for a major statewide snow or ice storm affecting all nine VDOT districts and requiring a full mobilization is approximately $11 million per day (Virginia DOT, 2014).

[1] Based on impacts to the following snowbelt states if they were shut down due to winter weather: Illinois, Iowa, Indiana, Kentucky, Maryland, Michigan, Massachusetts, Minnesota, Missouri, New Jersey, Ohio, Pennsylvania, Virginia, Utah, and Wisconsin The greatest impact per day would be New York with $700.17 million, and the least would be Iowa at $70.4 million.

The economic impact of snow-related road closures far exceeds the cost of timely snow removal. Although states and localities may be hesitant to expend significant upfront resources in the short-term, the long-term payoff more than justifies the expense (Roadway Safety Foundation, Undated). Among all economic classes, snow- related shutdowns harm hourly workers the most, accounting for almost two- thirds of direct economic losses.

Costs of maintaining roadways vary greatly by state and region; these metrics rely greatly on the number of lane miles that the DOT maintains as well as the amount of snow received each season. Winter maintenance budgets for the Clear Roads member states range from $50 to $90 million dollars for one winter season. Staffing for the winter season is similarly location dependent and was found to be between approximately 650 to 3,300 employees. Due to the various reporting by each of the DOTs these numbers typically include the snow plow operators, dispatch personnel, mechanics, and all other winter maintenance staffing. The overall winter maintenance budget typically also funds the training operations held by each DOT normally performed during the off season. At a minimum, all facilities have new driver training, annual refresher courses and safety training. Examples of off-season training include Minnesota’s and California’s programs that include yearly summer training camps, as well as Iowa’s program which features a travelling plow training simulator.

Environmental Costs Assessment

There is very limited information in the published domain on the environmental costs of winter maintenance practices. This is in part because it is difficult to assign a dollar value to a tree, fish, or stream, for example. Some attempts to assign values to trees have used damaged fruit trees because it was easy to assess the loss of fruit and the financial loss to the farmer (Bacchus, 1986). Another study conducted in a state park surveyed visitors to determine how viewing trees and other damage by winter maintenance practices impacted their experience in nature and determined the total loss of revenue based on the survey responses (Vitaliano, 1992). These two methods are good approaches to quantifying the environmental impacts of winter maintenance practices, but this area of research needs more attention.

To determine the cost or benefit of using a product, such as salt brine, it is necessary to quantify what the financial impacts are once the product leaves the roadway and enters the environment. To understand the full cost of a product, you need to consider how much you are paying to buy and ship the product, apply the product, clean-up or manage the product in the environment, and costs of direct impacts to the environment. The environmental impacts of road salts are difficult to quantify in monetary terms, as they are site-specific and depend on a wide range of factors unique to each formulation and spatial and temporal factors of the location, further complicating the issue. Despite the potential damaging effects of road salts, their use can reduce the need for applying abrasives, and pose less threat to the surrounding vegetation, water bodies, aquatic biota, air quality, and wildlife (Fay and Shi, 2012).

Information on the environmental costs and benefits of winter maintenance products and practices can be found in Environmental Costs and Benefits.

<u>Winter Maintenance Benefits</u>

While overall travel times (3 percent to 16 percent reduction) and lane capacity (3 percent to 30 percent reduction) decrease during and shortly after a snow event, the overall preparedness and efficiency of a DOT can ensure that the removal process goes as quickly and effectively as possible to minimize delay and get travelers safely to their destination. The Federal Highway Administration (FHWA) has determined that winter weather conditions are responsible for approximately 31 percent of weather related crashes over a ten year period, a metric that would be much higher if winter maintenance was not performed according to the Roadway Safety Foundation.

The FHWA has published the following 10-year average (2002-2012) weather-related crash statistics for road weather conditions (Table 2). For example, over the ten year period 211,188 crashes occurred, for which 4%, or 847, occurred during conditions classified as snow/sleet. Of 211,188 crashes which occurred during snow/sleet conditions 17%, or 35,902, were weather related.

Table 2 Weather-related crash statistics by road weather conditions (FHWA 2014).

Road Weather Condition	10 -Year Annual Average (2002-2012)	10 Year Percentage	
Snow/Sleet	211,188 crashes	4% of vehicle crashes	17% of weather-related crashes
	58,011 persons injured	3% of crash injuries	13% of weather-related injuries
	769 persons killed	2% of crash fatalities	13% of weather-related fatalities
Snow/Slushy Pavement	175,233 crashes	3% of vehicle crashes	14% of weather-related crashes
	43,503 persons injured	2% of crash injuries	10% of weather-related injuries
	572 persons killed	2% of crash fatalities	10% of weather-related fatalities

Winter weather has been shown to negatively affect winter driving. Reduced visibility and traction from snowfall can lead to reduced driving speeds, an increase in headway, and reduced acceleration. These in turn increase delay and crash frequency, while decreasing the effectiveness of traffic signal plans and roadway capacity. Average speed reductions on freeways have been determined for varying winter weather conditions (Table 3) (FHWA 2014).

Table 3 Traffic flow reduction on freeways caused by winter weather conditions (FHWA 2014).

Weather Conditions	Freeway Traffic Flow Reductions			
	Average Speed	Free Flow Speed	Volume	Capacity
Light Rain/ Snow	3%-13%	2%-13%	5%-10%	4%-11%
Heavy Snow	3%-16%	6%-17%	14%	10%-30%
Low Visibility	10%-12%	N/A	N/A	12%

Every winter, over 115,000 people are injured and over 1,000 are killed on America's highways due to snowy, slushy, or icy pavement (Roadway Safety Foundation, Undated). The common winter maintenance practice of deicing has been shown to reduce crash frequency by 88.3 percent, and to decrease the average cost of each crash by 10 percent.

Beyond the monetary value associated with the lack of closures and reduced number of crashes, these benefits can be hard to quantify. Many states employ a snow level of service (LOS) metric, which they strive to maintain throughout the winter season and use as a performance measure evaluation tool to improve the next season's maintenance planning.

Research Goals and Approach

The objectives of this research were to identify winter maintenance strategies which are sustainable in terms of cost, safety, and mobility; and assess and communicate the costs and benefits of commonly used winter maintenance strategies to better understand the safest and most cost-effective approaches based on desired level of service. To accomplish the objectives a comprehensive literature review was conducted to identify sustainable and commonly used winter maintenance strategies, associated benefit-cost, safety, and level-of-service data associated with each winter maintenance strategy, and to identify data gaps. A survey and follow-up interviews were used to capture additional data. Information gained in the literature review, survey, and interviews was used to create a summary matrix of winter maintenance strategies, associated level of service, costs, pros and cons, and a benefit-cost ratio for each winter maintenance strategy. The methodology used for each task is presented in Chapter 2 Methodology, and findings from each task are presented in this document.

Report Organization

This document is organized into four chapters. The first chapter has outlined the general problem examined by the project and provides background information on the different winter maintenance strategies of interest. Chapter 2 reviews the methodology used in each task of the research to develop the content of this report. Chapter 3 presents the information identified during a comprehensive literature review of the costs and benefits, both quantified and non-quantified, which are associated with the different components of each maintenance strategy of interest, as well as an overview of data and information gaps associated with each of the maintenance strategies being examined. Chapter 4 presents the developed matrix of information on the various winter maintenance strategies and the calculated benefit-cost ratios associated with each. Chapter 5 provides conclusions based on the work presented in this document and discusses information gaps and research needs to improve upon this work.

Chapter 2
Methodology

Literature Review

A comprehensive literature review was completed which focused on the use of the winter maintenance strategies and the related agency costs in achieving a level of service; economic impacts to users and society of winter maintenance; corrosion impacts to highway equipment, users, and infrastructure; abrasive wear impacts to highway equipment, users and infrastructure; safety impacts of strategies; and environmental impacts of strategies. The information on these different aspects of each strategy, including specific costs and benefits, have been summarized in a manner that documents financial values and other numerical metrics (e.g., percent reductions in crashes) and qualitative metrics (e.g., reduced cleanup following a storm) where possible for inclusion in the benefit-cost matrix. Information gained from the literature search was incorporated into all aspects of this report and was also employed in the development of the survey questionnaire.

Information was gathered from a review of several databases including: Transportation Research International Database (TRID), Google Scholar, ISI Web of Science, and the Montana State University library. Research conducted domestically and internationally was used whenever available, including work completed by DOTs, Clear Roads, Pacific Northwest Snowfighters (PNS) Association, University Transportation Centers (UTCs), Strategic Highway Research Program (SHRP), FHWA, National Cooperative Highway Research Program (NCHRP), Airport Cooperative Research Program (ACRP), American Public Works Association (APWA), and AASHTO. Ongoing research efforts that were complimentary or that produced information of interest to the project were incorporated into the report greatest extent possible.

Survey

A survey was developed to seek additional information on various winter maintenance strategies and fill in data gaps identified in the literature review. The developed survey was submitted to the project panel for review, was revised and posted using an online survey tool. A link to the online survey was sent out to Clear Roads member states, and posted on the Snow and Ice ListServ, and on the Winter Maintenance & Effects LinkedIn page. The audience for the survey was winter maintenance professionals from the United States and other international agencies. The initial survey received minimal complete responses, likely due to survey fatigue. A follow-up request for information was sent out to Clear Roads member states, and again posted on the Snow and Ice ListServ, and on the Winter Maintenance & Effects LinkedIn page. Respondents to the follow-up survey who indicated they were willing to be contacted for follow-up information were sent an online survey focused on the Advanced Activities. Limited responses were received from the follow-up survey.

Phone interviews were conducted as a follow up to the surveys, specifically targeting survey respondents who did not provide detailed information regarding winter maintenance practices and products used. A total of 19 winter maintenance practitioners from 12 states with varying climates were interviewed. The interview questionnaire aimed at collecting information regarding winter maintenance practices, materials, and associated costs and benefits particularly for product categories that received little feedback from the survey. Based on the interviewee's responses to the survey, specific questions were used for different types of products and corresponding costs and performance. Information gained from the surveys and follow-up interviews was used to populate the benefit-cost matrix. The survey interview questionnaires can be found in Appendix A, and the survey and follow-up survey results can be found in Appendix B.

Benefit-cost Matrix

Information gained from the literature, survey, and interviews was used to populate the summary matrix. The matrix presents information on the following winter maintenance activities: plowing and use of abrasives (Basic Activities), use of solid and liquid salt (sodium chloride) for anti-icing and deicing (Intermediate Activities), and use of corrosion inhibitors, inhibited salt brine, magnesium chloride, calcium chloride, or blended products (Advanced Activities). For each activity information is reported on the cost, benefits, effectiveness in achieving LOS, positive and negative impacts, pros and cons, respective performance, environmental impacts, and the calculated benefit-cost ratio where possible. The benefit-cost matrices can be found in Chapter 4 along with a description of how the benefit-cost ratios were calculated.

Chapter 3
Literature Review

Costs and Benefits of Common Winter Maintenance Practices

Roughly 20% of the budgets of state DOTs are expended on winter maintenance activities, with a direct cost of $2.3 billion and an indirect (infrastructure and environmental) cost of $5 billion annually (FHWA, 2014). Typically, the strategies employed by agencies come with many tradeoffs, including costs to the agency, economic impacts to society, corrosion and abrasive wear, and potential environmental impacts, as well as the safety and mobility benefits to travelers. In light of these costs and benefits that result from winter maintenance, it is necessary to assess and communicate how different strategies can produce cost-effective approaches to providing the traveling public with safety and mobility.

Due to the tradeoffs associated with winter maintenance strategies, it is necessary to establish a better understanding of the respective costs and benefits associated with the materials and operations employed in the scenarios. This understanding will both identify the quantitative values associated with the various costs and benefits of these strategies, and identify those for which a value has not been quantified. Collectively, this information can serve as a starting point to identify and address any gaps in cost and benefit information and to support the analysis and organization of this information into a format to communicate to stakeholders.

Plowing

The types of plows generally used by DOTs are front plows, tow plows, underbelly (under body) plows, wing plows, and rotary plows. Front plows are typically the most common piece of equipment used for snow removal. DOTs reported having anywhere from 450 to 950 front end plows on the roads each season. Underbelly plows are equipped with a blade underneath the vehicle that assists in scraping the hard pack snow from the roadway. Underbody plows can be stand alone or be an additional plow blade added to a vehicle with a traditional front end plow. The wing plow is similar to the tow plow in many respects. Essentially, it is a 6 to 8 foot 'wing' that is attached to the side of the front end plow to clear a larger path than the traditional front plow alone. By using the wing plow, agencies can deploy fewer pieces of equipment and facilitate snow removal from areas such as roadway shoulders.

Tow plows are relatively new and add the capability to plow an additional 26 foot wide area as the plow is pulled behind the traditional plow allowing the one piece of equipment to clear two lanes of traffic in one pass. Tow plows cost between $70,000 and $93,000 and approximately 200 tow plows are being used nationwide. Rotary plows are much like today's snow blowers but on a much larger scale.

Tandem or gang plowing is not a type of plow but rather a plowing technique. Tandem plowing uses two or more plows driving in a staggered formation to clear an entire multi-lane roadway in one pass. DOTs use front end loaders and motor graders in the winter months for snow removal in places with heavy snow fall, such as the Donner Pass area of California.

Costs of Plowing

It is difficult to quantify the specific costs of plowing operations within a DOT's budget. Winter maintenance vehicles are used for year-round activities such as roadway maintenance, as well as other winter activities such as roadway salt and sand distribution. However, some DOTs have an hourly billing rate for equipment they can apply to winter operations. If they also have a plow up/plow down sensor, then an exact value for plowing operations can be derived. However, such information has not been available in literature to date. A few examples of state plowing costs follow.

In Maine, the DOT operates approximately 450 front end snow plow trucks. The cutting edge blades are used to clear 10,000 linear feet per season with a cost per linear foot of $48.32 (Maine DOT 2009).

For Michigan DOT, the cost of a new Tow Plow was $93,000 (Michigan DOT 2014). The cost of Tow Plows in New Hampshire ranged from $70,000 – $80,000 (Blechl 2012). In Iowa, the Tow Plow costs $70,000, which is about half the cost for a standard plow truck.

Benefits of Plowing and Plow Types

Front Plows

Front plows are the most common type of equipment in use; however, specific data on the costs and benefits of their use have not been discussed in literature. Rather, the literature related to front plows has in general focused on blade types and plow blade configurations. This information is summarized in the following subsections.

Plow Blade Inserts

Plow blade inserts are installed onto the plows to extend the life of the plow edge. Carbide flexible blade inserts have been found to be the most cost effective and longest lasting blade inserts available at $668.43 per inch or $0.71 per mile, although steel, rubber, or ceramic blade inserts can be used as well (Table 4) (Iowa DOT, 2010). Carbide is a metal alloy of tungsten, and these blades are tougher and more resistant to wear than steel (Maine DOT, 2004). However, the carbide can be more brittle than steel. The severe shock loads experienced by plows hitting rough broken pavement, rocks, curbs, or other objects can crack and break the carbide edges, leading to rapid wear on the edge. Maintenance crews say that once the carbide has worn away the blade must be replaced immediately because the remaining steel will not last for even one more storm, and it will damage the plow, resulting in costly repairs. Cracks can develop in the carbide, which spread to adjacent sections leading to increased breakage (Maine DOT, 2004). Additionally, an evaluation of carbide blades found that the chemical constituents of blades are very important, and that poor manufacturing processes result in inserts with voids and cracks that lead to more rapid wear (Braun Intertec Corp., 2010).

The JOMA 6000 plow blades are a combination of rubber, steel, and carbide blade inserts. These lightweight blades are flexible and adjust to the roadway. The blades lasted three times longer than the traditional carbide blades. In addition, after prices for carbide increased, the extra costs associated with the JOMA blades were deemed to be a cost effective investment with a cost per mile of less than half of a standard carbide blade (Iowa DOT, 2010). A re-testing/trial period in 2008 determined that the JOMA blades reduced noise and vibration in the cab, and were found to have three to four times longer wear, and "cleaned the roadway better than traditional blades" (Iowa DOT, 2009).

Table 4 Blade type, wearing rate, and cost (Iowa DOT, 2010).

Blade Type	Inches of Carbide Blade	Miles per Inch of Carbide	Cost of 11' Blade Set	Cost per inch of Carbide	Cost per Mile
JOMA 6000	1	4161.7	$1,226.89	$1,226.89	$0.35
Polar Flex	3/4	5911.9	$2,785.20	$3,713.60	$0.69
Std. Carbide	5/8	1295.95	$417.77	$668.43	$0.71
Milo FlexEdge (Iowa DOT design)	5/8	Not tested for wear			

North Dakota performed an evaluation of JOMA and Polar Flex blades compared to a traditional carbide blade and stacked (multiple) carbide blade (North Dakota DOT, 2011). The stacked blade was found to have no advantage and was discontinued. The carbide cost was $525.20 per complete plow setup, while the stacked blade was double this cost. The Joma blade cost was $1875.84 per complete plow setup, and the Polar Flex cost $2,310 per complete plow setup. The JOMA and Polar Flex blades lasted on average three to four times longer than the traditional carbide blades.

Extensive testing has been done with carbide blades as state DOTs spend between $500,000 to $1 million on carbide blade inserts annually, with many DOTs using more than 10,000 linear feet of plow cutting edges each season (Maine DOT, 2009; Braun Intertec Corp., 2010). Carbide blades have been found to be the most cost effective option to date (Iowa DOT, 2009). Both rubber encased steel blades and full rubber blades have been used by DOTs, but have not been deemed to be comparable alternatives based on poor performance and higher unit costs (Iowa DOT, 2009). Ceramic blade inserts showed promising results in a 2009 study as a viable alternative based on performance, and could be an option in the future if the costs decreased.

Iowa DOT conducted testing of ceramic blade inserts and other blade types because of the high cost of ceramic blades (Iowa DOT, 2009). These blades were reviewed in 2008-2009 and again in 2009-2010 as an alternative to the traditional carbide blade. The ceramic blades were determined to perform at a level comparable to the traditional carbide blades based on level of hardness, weight, and cutting edge wear. Ceramic blades prices may decrease in the future and a benefit-cost analysis should be considered if this occurs.

Plow Blade Configuration

The configuration of the plow blades can lead to more effective snow removal (Ohio DOT, 2011). Common blade configurations are stacked, articulated, multi-blade, and special in-house configurations. Stacked blades are not commonly used and were found to be ineffective. However multi-blade configurations commonly have two to three blades that all perform different functions in snow removal. The multi-blade system has separate blades to remove slush and scarify the snow/ice, as well as a more typical cutting edge blade which is used for snow removal (Figure 1). The benefit of this multi blade system is that road segments with variable snow and ice conditions can be treated in a single pass. Prototype testing of a multi blade configuration was shown to remove 20 percent to 25 percent more material than traditional blades and it was determined that the multi blade plows "may be an effective tool for improved snow removal operations and potentially could reduce deicing chemical use" (Ohio DOT, 2011).

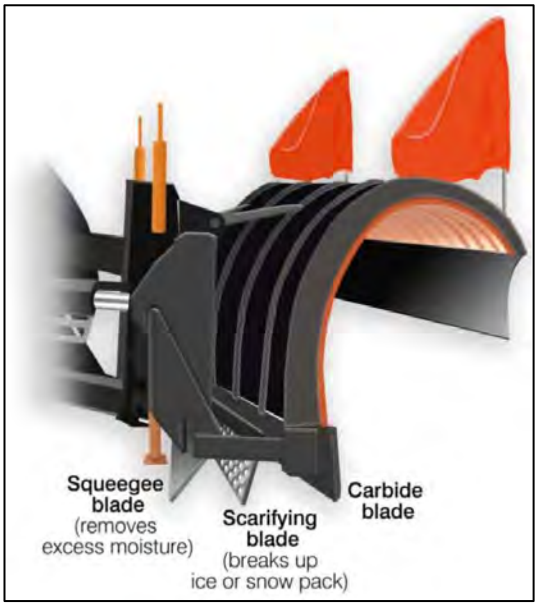

Figure 1 A picture of the multi-blade configuration (Iowa DOT 2010)

A two blade system, incorporating a snow blade in front and slush blade in the back, was tested in Northern Illinois. The trial was such a success, Illinois DOT now specifies that all new trucks have the two blade system (WTIC, 2012).

In-house blade modifications are typically unique to each DOT, but the results, if successful, may be shared within an organization. Maine DOT recently tested using a carbide blade on the under body plow instead of the traditional steel plow blade and found that the carbide underbody blade lasted much longer (Table 5) (Maine DOT, 2009). Additional testing was conducted the following season with the new blade configuration.

Table 5 Field testing of alternative carbide edge snow plow blades (Maine DOT 2009).

Snow Plow Blade Tests												
	Isolated Carbide Insert Blades (Test)						Regular Carbide Insert Blades (Control)					
		Miles	Hours	Ave. MPH	Ave. Cost (per lane-mile)	Ave. Cost (per hour)		Miles	Hours	Ave. MPH	Ave. Cost (per lane-mile)	Ave. Cost (per hour)
Amity		775.0	32.5	23.8	$0.38	$9.14		1014.0	53.8	18.9	$0.19	$3.63
Ellsworth		1161.0	63.5	18.3	$0.26	$4.68		1070.0	82.5	13.0	$0.18	$2.37
Baileyville		1036.0	95.0	10.9	$0.29	$3.13		1255.0	113.0	11.1	$0.16	$1.73
Richmond		1140.0	57.0	20.0	$0.26	$5.21						
South Paris		1280.0	63.7	20.1	$0.23	$4.66		1280.0	63.7	20.1	$0.15	$3.07
	Ave.	990.7	62.3	18.6	$0.28	$5.36	Ave.	1154.8	78.2	15.8	$0.17	$2.70
	Regular Carbide Insert Blades (Test, Alternative Brand)						Regular Carbide Insert Blade (Control, Stock Brand)					
		Miles	Hours	Ave. MPH	Ave. Cost (per lane-mile)	Ave. Cost (per hour)		Miles	Hours	Ave. MPH	Ave. Cost (per lane-mile)	Ave. Cost (per hour)
Gouldsboro		811.4	45.9	17.7	$0.37	$6.47		1786.0	62.8	28.5	$0.11	$3.11
Richmond		1360.0	68.0	20.0	$0.22	$4.37						
	Ave.	1085.7	57.0	18.8	$0.29	$5.42		1786.0	62.8	28.5	$0.11	$3.11

Assumptions:		
Costs (per foot)	Isolated Carbide Blades	$27.00
	Regular Carbide Blades (Alternative)	$17.76
	Regular Carbide Blades (Stock)	$17.76

Maine DOT conducted a 4 year evaluation of the Kuper-Tuca SX36, to determine if it would be comparable to the carbide blades the DOT was using (Maine DOT, 2004). The Tuca SX36 plow blade had a wear life of approximately 3,500 to 4,500 miles while the standard carbide blade lasted 1,500 to 2,000 miles. However, after comparing the $352.99 per set of carbide blades to the $1,782.00 cost for Tuca blades, the Maine DOT did not find the Tuca blades to be a cost effective investment for Maine DOT.

A synthesis on plow blades made the following conclusions:

- Rubber-encased steel blades, which have been more expensive than steel in the past, may be worthy of consideration as costs be have decreased. A benefit-cost analysis is recommended if an agency is considering this blade type.
- Solid rubber blades did not receive favorable results as compared to conventional blades.
- Alternative carbide edge snow plow blades did not receive favorable results as compared to conventional blades.

New products are continuously available but have not been evaluated; one of the recommendations called for working with vendors to test these products (EVS, 2011).

Plow Blades and Infrastructure Damage

Much of the past and current research on snow plow blades has focused on snow and ice removal performance and blade wear and has addressed the effects of hard cutting edges on various pavement types only in passing. With the advent and placement of thin overlays for pavement repair by many maintenance agencies, it is expected that hard cutting edges may adversely affect these thin overlays (EVS, 2011). A 2012 brainstorming session by Nebraska DOT highlighted the need for research to determine the best plow blade to roadway material configuration in an effort to extend the life of the roadway and reduce plow maintenance costs (Nebraska DOT, 2012). Finally, plow blades can damage pavement markings, leading to reduced retroreflectivity and lane guidance (Agent and Pigman, 2014).

Tow Plows

The Tow Plow has an expected service life of 30 years, while the average service life for a standard plow is 10-years (Michigan DOT, 2014). The cost of tow plows in Iowa, was $70,000 per plow vehicle which is about half the cost of a standard plow truck (Iowa DOT, 2014). The tow plow is 26-ft-wide, allowing two interstate travel lanes to be cleared and treated in a single pass (ITD, 2010; Ohio DOT, 2011). Because of the wider clearing path, Maine DOT was able to “free-up” or replace trucks to enable the department to improve its LOS (Maine DOT, 2009). The original design for the Tow Plow was the brainchild of a Missouri DOT (MoDOT) employee who applied his knowledge of farm equipment to snowplows. MoDOT worked with a snowplow contractor to design and build the version in use today. According to one vendor, the TowPlow can maintain speeds of 55 - 60 mph during the plowing process. According to MassDOT the TowPlow can take the place of three pieces of equipment, reduces emissions, and decreases manpower needs (MassDOT, 2012).

Underbody Plows

Iowa DOT conducted an investigation into using flame hardened under body plow blades ($170 per 8 foot blade) versus the typical baked steel under body blade ($94.13 per 8 foot blade) in the winter season of 2012-2013 (Rehbein, 2013). They found that on average the flame hardened blades lasted for 335 miles at a cost of $0.51/mile, while the standard blade lasted 273 miles at a cost of $0.34/mile. Despite the increased mileage from the flame hardened blade, the lack of cost savings did not facilitate procurement of the hardened blade for DOT use.

In 2006 Iowa DOT investigated the use of automation for underbody plows (Nixon, et al, 2006). Many variables influence the effectiveness of underbody plow: proper downward pressure where too little pressure can cause ineffective snow removal; too much pressure can result in damage to the plow blade and possible gouging to the road surface; and proper cutting edge angle. The automated underbelly plow system was designed to use a set of if-then system rules to determine the angle, and downward force needed to effectively remove snow from the road surface. The automated system was created and tested in a simulator, but has not yet been implemented on a plow due to funding constraints. However, this project did determine that a computer automated underbody plow would be a feasible option to improve plowing procedures and increase the life of the plow blades.

Wing Plows

Wing plow blades can clear an area up to 22-ft-wide (Caltrans, 1999). MassDOT found that using wing plows clears snow from a wider portion of the roadway than a traditional front end plow, which reduces the total pieces of equipment and personnel needed (MassDOT, 2011). Many of Iowa DOT's plows also have the 6-8 foot wing plow attached to the trucks in addition to the standard front plow. Due to decreased visibility of wing plows, a GL3000C guidance laser was mounted to the cab of the plow, projecting a beam indicating where the truck and wing plow projected clearing path lies (Iowa DOT, 2009). This addition to trucks using wing plows will reduce the number of collisions with mailboxes, bridges, and other roadside structures.

Rotary Plows

Caltrans uses rotary plows and have found it costs about $120/hour to operate them (Caltrans, 1999).

Tandem and Gang Plowing

Tandem and gang plowing operations involve multiple trucks plowing in a pattern in order to clear multiple lanes on a roadway during one pass. Some entities also utilize other vehicles, such as garbage trucks, to perform winter maintenance during the course of their primary activity. The city of Chicago has quick hitch plows for their garbage trucks that they use in tandem with snow plows that have salt spreading capabilities. The partnership allows for heavy equipment and labor to be available from other municipal departments for snow removal operations during and after storms.

New Hampshire has found that tandem plowing makes it possible to clear roads and shoulders with increased productivity (New Hampshire DOT, undated). They have also found that roads where tandem plowing was used require less anti-icing, and buildup of snow and ice is prevented. Tandem plowing allows them to avoid leaving windrows which can be dangerous to the driving public, avoids throwing snow on already cleared pavement, removes snow from narrow medians, and allows trucks to separate and clear blocked ramps, while also preventing unsafe driving maneuvers, including vehicles passing plows.

Motorgrader Use

Caltrans has about 44 motorgraders in one district alone, costing about $60/hour to operate in the late 1990s (Caltrans, 1999).

Sanding

Blackburn, et al. discussed various winter maintenance operations, including the use of sand/abrasives (Blackburn et al., 2004). These materials are not ice control chemicals nor do they support the objectives of anti-icing or deicing. In particular, when applied before a storm, sand can be blown off the pavement by passing traffic, rendering the application useless. Sand and other abrasives are typically used at pavement temperatures below 12° F and on roads with lower traffic and lower LOS (Blackburn et al., 2004). Sanding may also be used when an agency has run out of chemicals to use for treatment. When used individually (or in combination with plowing), this approach cannot be expected to produce a high LOS (although an estimated LOS is not provided by the authors). The benefit of abrasives is that they can provide traction when temperatures have fallen to the point that chemicals are rendered ineffective. Effective application rates for these materials range from 500 to 1,500 pounds per lane mile, which can be extrapolated to a general material cost for sand based on local costs for the material. However, aside from the general discussions of effectiveness, no specific values of costs or benefits were cited.

Recent surveys of state highway agencies (Fay, et al., 2008; CTC & Associates, 2011) indicated that abrasives are recognized to have their place at low temperatures, despite concerns. During heavy snowfall, sand and grit are often used to provide traction. Fay, et al. completed a survey of agencies in which 17 indicated the use of abrasives in their winter maintenance operations (Fay, et al., 2008). While responses indicated that sand had a moderate advantage compared to other materials such as chlorides, acetates/formates, and ag-based treatments in terms of a low cost per lane mile, it was viewed as the easiest material to apply. It was also found to have the lowest performance compared to these other materials, however, having essentially no ice melting capacity. Abrasives were indicated as creating a hazard when applied prior to a storm since they reduce skid resistance in dry conditions. Respondents indicated that abrasives do have a low impact in terms of corrosion and pavement/structure damage, but high impacts on water quality and the general environment. Aside from survey responses, however, no specific values were assigned to the costs or benefits of abrasives by this work.

A more recent (2011) review of agency practice by CTC & Associates found that sand was either applied dry or prewetted with calcium chloride, magnesium chloride agricultural by-products or salt brines (CTC & Associates, 2011). Sand use was being minimized by many agencies because of concerns with effectiveness and environmental impacts. Innovations such as hot water sand spreaders offered the potential to more effectively apply abrasives by facilitating the freezing of sand to the snow, ice or pavement of the road surface. This reduces the bounce and scatter of materials as they are applied to the pavement. The document also reported on observations from the Maine DOT during a 2011 storm using different materials on an interstate route. A delayed application of sand was found to be the most cost effective approach (although no numbers were reported), with the sand applied when pavement temperatures were 6 to 7° F and the road surface had begun to glaze over. The use of salting early in the storm followed by sanding as temperatures rose was ineffective, primarily because the salt component was ineffective. Sand was still observed to be effective in providing traction in this case. The summary did not provide any specific figures related to the costs or benefits of sanding.

An FHWA report determined the total costs of using abrasives per lane mile in different states. In California, this cost, which included labor, equipment and materials, was $37.93 (1995 dollars). Calculated to a present cost, this value becomes $58.43. Similar values were obtained for Nevada, including $13.21 per lane mile without clean up and $57.64 with clean up. In 2014 dollars, these values are $20.35 and $88.80, respectively. Consequently, it is evident that cleanup costs have considerable impact on the economics of sand use.

A literature review for the Wisconsin DOT highlighted the limited effectiveness on abrasives on roads with higher vehicle speeds (CTC & Associates, 2008). It also noted that the use of sand had decreased over time as the result of several factors, including overall effectiveness, environmental impacts, safety implications, and cost. Limitations to the effectiveness of sand included the propensity for it to blow off the road and disperse with passing traffic, the need to keep salt from freezing so it remains workable, lower friction values compared to bare and wet pavement, and the reduced capacity for salt to melt ice when mixed with sand. Among the environmental impacts cited was the tendency for 50 to 90 percent of sand to remain in the environment after clean up, the entry of sand into waterways and drains, the potential for fine particles to enter the air, and for salt leeching from storage piles. Finally, windshield damages were 365 percent higher in areas where abrasives were used compared to alternatives.

An early evaluation of the impacts of sanding came from work performed by Kuemmel and Hanbali (1992). On roads where sand and salt mixtures were applied, it was found that crash rates for all accident types (per million vehicle miles travelled) fell by 87 percent, while the average cost per crash fell by 10 percent. Travel time costs were reduced from $0.22 to $0.16 cents per vehicle mile travelled on routes using sand-salt mixtures. Finally, the direct road user benefits of using sand and salt mixes were $6.50 for every $1.00 spent on direct maintenance costs of operations.

In a follow-up to their previous work, Kuemmel and Bari (1996) evaluated the cost effectiveness of abrasives in winter maintenance. The authors found that the benefit-cost ratio associated with the use of abrasives was 0.8:1 on two lane roads and 2.8:1 on freeways. The costs taken into account were direct costs associated with maintenance operations for the routes, while the benefits included travel time savings, fuel savings, and crash reduction savings. As the results indicate, potential benefits for sanding appear to exist for higher-volume roads.

Nixon (2001), as part of a review of the use of abrasives for the Iowa DOT, developed a set of recommended practices for the use of the material. Recommended applications included rural gravel roads (low speed sections), rural intersection approaches, and low speed urban roads and urban intersection approaches when snow pack persists. The benefit cited for these locations was that traction would be provided while sand dispersion by vehicles would be minimized.

Parker (1997) compared the Oregon DOT's plow and sand strategies to chemical-based strategies (calcium magnesium acetate and magnesium chloride). The motivation for the comparison stemmed from concerns over airborne particulates and silting from the use of sanding and other abrasives in the state. Figures at the time (1997) indicated the cost of sanding was between $15 and $65 per lane mile ($21.94 - $95.08 in 2014). These figures included labor, material, equipment, and clean-up costs. Even after clean up, it was found that 50 percent to 90 percent of abrasives remained in the environment. Clean-up costs alone ranged from $2 to $20 per cubic yard ($2.93 - $29.26 in 2014) and varied depending on the type of roadway shoulder present at a site. Other costs associated with sanding included cracked windshields, with claims against the DOT totaling approximately $50,000 per year ($73,140 in 2014).

Fischel (2001) documented that sand and other abrasives can pose negative impacts to water quality and aquatic species, air quality, vegetation, and soil, and incur hidden costs such as cleanup. Specific to air quality, the use of sands in winter maintenance can contribute at least 45 percent of the small particulates present in the air. However, the low cost of abrasives makes their use economical. In Colorado, the cost of sand and other abrasives ranged from $6 to $16 per ton in 2001 ($7.95 - $21.21 in 2014).

Schlup and Ruess (2001) provided a balanced perspective on the use of abrasives and salt, based on their impact on security, economy, and the environment. Based on an analysis of test segments of roads in Switzerland, they found that the cost of applying abrasives was six times higher than those of salt during a normal winter. During a severe winter, the cost of using abrasives was ten times higher. Additionally, abrasives had only a short term effect on friction when applied.

Leppänen (1996), in examining the socioeconomic effects of winter maintenance and studded tires in Finland, discussed the results of tests using sand instead of salt on low volume roads (<6,000 vehicles per day). The work found that the use of sanding increased costs by an average of 20 percent over salting, and sanded roads were free of snow and ice only 59 to 68 percent of the time. However, the observed increase in costs was not attributed to a specific aspect of sanding, although one could conclude that clean-up costs were the most likely explanation.

Chang, et al. (2002) discussed the costs associated with the sanding operations of the Colorado DOT. The costs identified by the work included materials, labor (mechanical and manual sweeping, snow removal/sanding and ice control), and equipment. In general, it was observed that the cost of abrasive materials was low compared to alternatives such as rock salt. Costs for labor by district ranged from $1.35 to $2.50 per mile (2000 dollars, or $1.84 - $3.41 in 2014). Equipment costs for sanding ranged from $1.00 to $3.00 per mile ($1.36 - $4.09 in 2014).

Mokwa and Foster (2013), in discussing the potential for the Montana Department of Transportation (MDT) to recycle recovered sanding materials in subsequent winters, performed a cost analysis to determine if such a practice was economically viable. The total estimated cost per ton for using different mixes of recycled and virgin materials ranged from $10.50 to $21.00 (2013 dollars). Depending on the material mix, estimated cost savings from using recycled abrasives could range from $0.70 to $1.52 compared to the alternative of using virgin materials. In some cases however, negative savings were estimated, indicating that the cost of using recycled materials would exceed the use of virgin materials.

Chang, et al. investigated then-current (1994) practices for environmentally sensitive sanding practices for the Colorado DOT (Chang, et al., 1994). While specific values were not documented, the report did highlight the positives and negatives of sand and abrasive use in winter maintenance. Positive aspects included the ability to increase the coefficient of friction on snow and ice covered roads, the ease of application, and the generally low cost of materials. Negative aspects cited in the report included the need for post storm/season clean up, the addition of particulates into the air, and the potential to decrease the coefficient of friction on dry roads.

Fu, et al. (2006) evaluated the effects of winter maintenance treatments, including sanding, on highway safety in Ontario, Canada. Based on statistical modeling that considered crash frequency, weather, and maintenance operations, the authors determined that a 1 percent increase in sanding operations (in total kilometers treated) would reduce crashes by 0.245 percent.

O'Keefe and Shi (2005) synthesized information on anti-icing and prewetting operations for the Pacific Northwest Snowfighters (PNS) Association. The work touched upon sanding and abrasives, particularly their drawbacks. These included the need to apply up to seven times more material than alternatives to treat a segment of road, impacts on water quality, and the addition of particulates into the air. This figure of seven times more material being required came from www.saltinstitute.org.

Gertler, et al. (2006) examined the impacts of street sweeping of winter maintenance sand on dust entrainment. The use of street sweeping was found to increase dust emission rates, specifically PM10 emissions. Consequently, while cleaning sand at the end of the season reduces its overall environmental impacts in some respects, it increases air quality issues in doing so.

The Handbook of Road Safety Measures provided guidance, primarily obtained from studies in Europe, of the effectiveness of different winter maintenance measures on safety (Elvik, et al., 2009). The use of sanding within 24 hours of a storm event could reduce crashes (unspecified types) by as much as 85 percent.

Shi et al. (2014) evaluated different snow and ice control materials for comparison purposes, including sand. The work developed a composite index for this comparison, which considered the cost of the material per lane mile, its average performance in addressing snow and ice conditions, its impacts to vehicles and infrastructure, and its environmental impacts. Based on testing results, the composite index for sand was lowest among all materials, highlighting its poor performance aside from providing friction and its high environmental impacts.

A collaboration between Colorado DOT and the Colorado auto insurance industry provided data on windshield damage costs and the use of sand as a winter traction material (Chang et al., 2002). The total windshield damage cost includes both repair and replacement. For Colorado, the statewide industry total windshield damage costs were $6.19 million annually in 2002. Colorado DOT, specifically in the Denver Metro area, now limits its use of sand as a winter traction material because of air quality issues.

Prewetting

Prewetting is a winter maintenance practice that employs the addition of a liquid chemical to an abrasive or solid chemical before it is applied to the road. The pre-wetting of these solids is performed either at the stockpile or at the spreader. O'Keefe and Shi (2005) synthesized information obtained from a literature review and agency surveys on the advantages and disadvantages of pre-wetting for winter highway maintenance relative to traditional methods for snow and ice control. They found that pre-wetting led to decreased applications of chemical products, reduced use of abrasives, decreased maintenance costs, improved roadway friction, and lowered accident rates. Pre-wetting has been shown to increase the performance of solid chemicals or abrasives and their longevity on the roadway surface, thereby reducing the amount of materials required. Overall, maintenance agencies are confident that pre-wetting strategies significantly improve material retention and speed up the melting process. Pre-wet abrasives refreeze quickly to the road surface and create a sandpaper-type surface, which can cut abrasive use by 50 percent in cold temperatures (Williams, 2003). If warm, chemicals can accelerate break-up of snow pack while providing increased traction for the public (Williams, 2003).

For the City of Kamloops, British Columbia, switching to anti-icing and pre-wetting reduced the use of abrasives and resulted in an estimated cost savings of $11,933 per year just from costs associated with roadside cleanup of abrasives (McCormick Rankin Corp and Ecoplans Limited, 2004).

Prewet Sand

A review of agency practice by CTC & Associates found that sand was either applied dry or prewetted with calcium chloride, magnesium chloride, agricultural by-products, or salt brines (CTC & Associates, 2011). When pavement temperatures reached 10° F, prewetted salt (using a 70/30 blend of salt brine and magnesium chloride) was applied at a rate of 400 pounds per lane mile. Specific costs and benefits associated with prewetting were not cited.

Hot water-wetted sand or prewetting abrasives with liquid deicers or hot water can greatly reduce bounce and scatter and contribute to improved friction even with vehicular traffic (Dahlen and Vaa, 2001; Perchanok, 2008). Initial tests in Ontario by the Ministry of Transportation (MTO) indicated that the use of hot water sanding equipment could reduce sand use by traditional dry applications by 25 percent. Additionally, it was estimated that the traditional mixture of salt with the sand to keep it from freezing could be eliminated, producing cost savings for salt as well (a reduction of 74 tons was cited by the author) (Perchanok, 2008). Dahlen and Vaa discussed the results of work in Finland testing the application of wetted sand using water heated to between 90 - 95° C (Dahlen and Vaa, 2001). It was found that even after 2,000 vehicles had passed, friction levels were maintained above the existing standard of using dry sand for snow covered conditions. Additionally, it was concluded that hot water-wetted sand was likely to remain on the road surface 10 to 20 times as long as dry sand with the same traffic volume.

In a recent report, the Iowa DOT provided an estimate on cost savings when using salt brine as a prewetting chemical (Iowa DOT, 2014b) as shown in Table 6. The study considered using brine as a prewetting agent for two scenarios such as 50/50 salt/sand mix applied at 300 pounds per lane-mile on a 40-lane-mile route and straight salt applied at 200 pounds per lane-mile on a 40-lane-mile route. Further, Iowa assumed a reduction in 25 percent of dry materials usage due to prewetting. It can be noted from Table 6 that a total cost savings of $32.88 and $40.95 for 50/50 salt/sand mix and straight salt respectively can be achieved from prewetting on a 40 mile lane route. In addition, Iowa also estimated the cost savings to be more significant when prewetting is used for larger operations.

Table 6: Expected Cost savings by using brine as prewetting agent (Iowa DOT, 2014b)

Assumptions		
Salt	$45 per ton	
50/50 salt/sand mix	$26 per ton	
Brine	$0.09 per gallon	
Prewet at 15 gallons per ton of dry material		
50/50 salt/sand mix applied at 300 pounds per lane-mile on a 40-lane-mile route		
Without prewetting		
6 tons of material at $26/ton		$156
With prewetting assuming application rate is reduced by 25 percent (225 pounds per lane-mile)		
4.5 tons of dry material at $26 per ton		$117.00
68 gallons of brine at $0.05 per gallon		$6.12
Total costs		$88.90
Total savings		$32.88
Straight salt applied at 200 pounds per lane-mile on a 40-lane-mile route		
Without prewetting		
4 tons of material used at $45 per ton		$180
With prewetting assuming application rate is reduced by 25 percent (150 pounds per lane-mile)		
3 tons of dry material at $45 per ton		$135.00
45 gallons of brine at $0.09 per gallon		$4.05
Total costs		$139.05
Total savings		$40.95

Prewet Salt

Prewetting can accelerate the dissolution of solid chemicals and enhance its melting action (TAC, 2013). The benefit of prewetting salt is that particle bounce can be minimized, however, care must be taken when applying prewetting agent from a vehicle to minimize the amount that is directly applied to the pavement. Prewetting can reduce salt usage (no figures cited) but can also require more complex equipment, storage tanks and brine making equipment.

In general, DOTs recommend using prewet salt for their winter maintenance operations. A New Hampshire report strongly recommended using 23 percent sodium chloride, 32 percent calcium chloride, Magic Minus Zero TM and other patented products as prewetting chemicals for winter maintenance activities. The report estimates a cost savings of up to one third over dry salt (NH Best Management practices, 2014). In addition, another report prepared by Cripps and Leeds (2013) to the town of Milton recommended prewetting dry salt with 23 percent salt brine for winter maintenance operations. In order to implement this prewetting technology, the study recommended conversion of the city's eleven winter plow trucks to accommodate salt brine dispensing equipment. The cost of truck conversion was estimated at about $106,205 with the expected payback period to be less than two years due to reduction in salt usage (Cripps and Leeds, 2013). Sooklall et al. (2006) evaluated the use of calcium chloride as a prewetting agent for rock salt in a study using highways in Ontario, Canada. It was found that prewetted salt outperformed dry salt, reducing snow cover on the roadway between 14.8 and 37.9 percent at a prewetting ratio of 7 percent by mass of dry salt.

Burtwell discussed the results of the use of prewetted salt on roads in England (Burtwell, 2004). Prewetting agents in use included sodium chloride, calcium chloride, and water. The work found that prewetted salt was retained on roads better with less waste through targeted spreading. Evidence suggested that a 25 to 33 percent savings in salt was possible through the use of prewetting. However, spreading equipment must be calibrated for the specific salt grade in use, and prewetting may not be applicable for all weather conditions.

A University of Wisconsin Transportation Bulletin indicated that prewetting could reduce salt loss on road surfaces by 30 percent while providing faster melting and penetration of snow and ice pack (University of Wisconsin, undated). Salt should be prewetted with 8 to 12 gallons of liquid per ton. Salt use could be reduced by 20 percent through the use of prewetting, although the exact source of this figure was not stated.

Perchanok (2001) examined the feasibility of applying salt at higher travel speeds in Ontario by using ground speed controllers and prewetting using magnesium chloride. The work found that at lower speeds (35 km/h) prewetting did not improve material placement over dry salting. However, at a higher speed (60 km/h), prewetting improved material placement. This improvement would translate into reduced loss of materials on the roadside that would impact the environment and improve maintenance operation efficiency by allowing them to be conducted at higher speeds.

Luker et al. (2004) examined the melting performance of rock salt with the use of prewetting agents in a laboratory environment. Different prewetting agents were tested, including distilled water, calcium chloride, IceBan, liquid corn salt, Caliber, and Mineral Melt Elite. Results from friction recovery times showed that prewetting salt slightly decreased its performance at temperatures of -1° C and -5° C, but was effective at -10° C. Melting was improved by increasing the ratio of liquid to rock salt. Overall, it was concluded that melting performance of salt improved by prewetting at colder temperatures. Benefits stemming from prewetting were cited as improved retention of particles on the roadway, improved melting capacity at certain temperatures, and a reduction in the amount of dry salt that would need to be applied. However, the work did not discuss the relative costs associated with the different prewetting agents tested.

Comparison of Prewetting with Liquid Sodium Chloride, Magnesium Chloride, or Calcium Chloride

Prewetting can be accomplished by brine or other liquid chemicals such as NaCl, $MgCl_2$ and $CaCl_2$. A recent report was published about the cost-effectiveness of prewetting chemicals (Salt Institute, Undated). The study demonstrated the cost savings due to the use of $CaCl_2$ as a prewetting chemical with dry salt. The study estimated about 30 percent reduction in salt usage and approximate net savings of $5,950 (per 1000 tons of dry salt) due to the use of $CaCl_2$ as a prewetting chemical. The cost savings was calculated based on the difference between dollars saved from reduced salt usage and dollars spent on $CaCl_2$ (prewetting chemical). Experiments conducted in 1993 and 1994 by the British Columbia Ministry of Transportation and highways found a significant reduction in salt usage due to prewetting salt with $MgCl_2$ and $CaCl_2$ (as much as 53 percent in one instance) (Bodnarchuck and Gooding, 1994). In the 1970s the Michigan DOT conducted a study that confirmed the effectiveness of pre-wetting in winter maintenance activities (Lemon, 1975). Over three winter seasons, the study found a reduction in salt usage due to more salt staying on the road. In particular, the salt usage was reduced by 12 percent in the 1974-1975 winter season compared to the 1973-1974 winter season even though snow accumulation and number of storms were higher for 1974-1975 winter season. The study used 30 percent $CaCl_2$ brine as a pre-wetting chemical with dry salt (10 gallons for every ton of dry salt). A cost analysis shows an annual savings in excess of $100,000 due to the reduction in application rates (reduced from 500 to 400 lbs. per mile) (Lemon, 1975).

Fu et al. performed a statistical analysis on observational data to identify the quantitative effects of weather and maintenance operations on snow melting trend (Fu, et al., 2006b). Chemicals included near-saturation solutions of NaCl (sodium chloride brine), $CaCl_2$ (calcium chloride brine with corrosion inhibiting additives), and $MgCl_2$ (magnesium chloride brine with corrosion inhibiting additives). $CaCl_2$ was found to be more effective as a pre-wetting agent and outperformed $MgCl_2$ by 9.5 percent to 71.4 percent, and was also more effective than salt brine (NaCl).

Prewetting Techniques

Prewetting can occur in the pile or at the spreader. Prewetting at the pile involves applying a quantity of prewetting agent to a granular storage pile in the yard before loading it on a truck. Prewetting at the spreader involves applying the prewetting agent as the solid material is about to be applied to the roadway by the spreader. Additionally the creation of material slurries by prewetting is a newer approach. Each approach offers advantages and disadvantages, as the following sections highlight.

At the Spinner

A more direct approach to prewetting is to perform the task at the material spreader on the plow vehicle. Prewetting at the spreader coats the deicer with liquid as it comes from the hopper via the conveyor/auger onto the spinner. The benefit of this approach is that liquid is only applied to the material when it is used.

Information from New Hampshire provided general information on prewetting best practices (Local Technical Assistance Center, undated). This included guidance on the use of 8 to 10 gallons of prewetting liquid per ton of deicer. The information provided indicated that the use of prewetting in general could reduce material application rates by 15 percent to 20 percent, producing material and cost savings for an agency. Similarly, NCHRP Project 20-07 (Task 117) provided guidance on liquid use in prewetting at the spreader, indicating 8 to 12 gallons per ton of material should be applied, with a solids application rate of 200 pounds per lane mile (Boselly, 2001).

Information from the Salt Institute indicated that prewetting could reduce salt application rates by 26 percent to 30 percent due to more material being retained on the roadway (Salt Institute, undated a). In a case where an agency used 1,000 tons of salt per winter, this could translate into thousands of dollars of savings, even when factoring in the cost of the prewetting brine (ex. $CaCl_2$).

Burtwell (2004) discussed the performance of prewetted salt spreading from trials in the United Kingdom. Prewetted salt that was wet at the spreader was found to be preferable to dry salt because most small salt grains dissolved before being blown off the pavement. It was reported that salt use reductions of 25 to 33 percent were possible using prewetting. However, it was noted that care must be taken when calculating prewetting cost savings because different salt types can be used for the base salt and wetting agent, as well as different proportions of dry salt to wetting agent, having direct impacts on the calculation of costs and benefits. Additionally, the life of prewetted salt vehicles is generally shorter than those vehicles applying dry salt.

Nixon (2009), as part of a field test study of abrasive delivery systems, discussed some of the advantages of prewetting. While prewetting at the different spreader systems were not part of the tests conducted, the advantages of such systems were cited from work completed by Lemon in Michigan (Lemon, 1975) and included material savings, as well as the potential to extend the patrol range of the snow plow itself. In the case of extending the plow range, this was the result of reduced material usage requiring fewer stops to reload, resulting in both time savings as well as increased maintenance coverage of the roadway system.

The Federal Highway Administration touches on general aspects of prewetting, including prewetting at the spreader, as part of a larger discussion on effective anti-icing programs (Ketcham, et al., 1996). Such systems were cited as reducing solid material quantities being used by 30 percent at speeds as high as 40 mph. Prewetting systems at the spreader were also cited as being relatively inexpensive, using electric or hydraulic pumps, in cab controls, nozzles, hoses, tanks and general fittings. However, no cost figures were provided by the report to quantify what was considered inexpensive at the time.

Perchanok (2001) examined the use of prewetting at the spreader in conjunction with high-speed salt spreading in Ontario. The work found that at lower speeds (35 km/h) prewetting at the spreader did not improve over traditional application approaches but worked equally as well. At a higher speed (60 km/h), prewetting at the spreader improved material placement, translating to reduced environmental impacts and more efficient salting operations.

In the Pile

Prewetting in the pile is another approach to prewetting. Since it does not require specialized equipment (ex. prewetting spreaders), it offers an initial, basic approach to prewetting. The common approach to this practice involves spreading the salt (or other granular material) on a flat, impermeable surface. Next, the prewetting agent is sprayed in the salt, with the salt being moved around to allow for adequate and consistent coverage. Once the salt has been covered, it is placed back into a pile for storage and later use. Alternatively, injections of the prewetting agent may be made into the upper section of the stockpile itself. Ketcham, et al. (1996) indicated that approximately 8 gallons of liquid prewetting agent should be applied per ton of granular material. Frequent reworking of the pile may be needed to keep the material manageable.

Most likely because of its basic nature, the costs and benefits of this approach to prewetting have not been discussed in literature. Despite the lack of documented information, the benefit of this approach can be identified as allowing for prewetting to be conducted without the purchase of extensive support equipment (ex. prewetting spreaders). This approach allows an entity to develop experience with prewetting and to make a determination of whether it is an approach worth implementing on a larger scale without making an extensive investment. The costs associated with this approach are primarily for prewetting agents from the manufacturer, although an entity could purchase brine making equipment and storage tanks in support of a longer-term commitment to prewetting at the pile. There is a potential for liquid runoff to occur at the bottom of the pile, particularly as temperatures rise above 70° F, which can present environmental issues as well (Ketcham, et al., 1996).

Slurries

Schnieder et al. (2013) discussed the results of an evaluation of the Epoke slurry spreader in Ohio, which was performed to determine its feasibility in wider use. The evaluation examined the impact of the spreader on level of service, material usage and equipment versatility. When compared to standard salting trucks, the use of the slurry spreader reduced salt use by 12 percent while treating the same segment of roadway. Level of service remained the same between slurry and salt applications, with the slurry spreader requiring 17 treatment passes versus 26 treatment passes for the salt spreader (all storms compared collectively). Using a slurry spreader and based on a 12 percent salt use reduction, the slurry spreader investment cost was estimated to be recovered within eight years.

An application of an unspecified model of Epoke unit in West Des Moines, Iowa was summarized in 2009. The unit prewets salt at rates of up to 90 gallons per mile, while reducing salt gradation to achieve faster melting action (Barbaccia, 2009). An informal evaluation found that a prewetting rate of 60 gallons per ton of salt was effective when using a liquid comprised of 80 percent salt brine, 10 percent Fusion or GeoMelt and 10 percent calcium chloride. The unit allowed for a 25 to 30 percent reduction in granular applications, lowering the amount of chloride entering the environment.

The Maine DOT evaluated a Monroe slurry maker that crushed salt to a smaller particle size and then combined it with salt brine at a rate of 50 gallons or more to produce slurry (Colson, 2009). The equipment required two days to install at a cost of $1,000. The evaluation, which was conducted over 10 storm events in 2008-2009, found that the unit did well in crushing salt to a more desirable size and applying it as a slurry. However, hydraulic issues with the salt crusher were encountered when the vehicle was operating its plow and wing. The key findings from the evaluation were that a larger crushed particle size (3/8 inch) was required for temperatures below 20°F to prevent refreezing, while a smaller particle size (1/4 inch) was acceptable during warmer temperatures.

The Epoke and Monroe units are very different. The Epoke unit requires a finer gradation of salt which may be more costly or require specialized crushing equipment, but the Epoke unit can spread salt in up to three lanes in a single pass, potentially offsetting these costs by saving time and money.

Deicing (with Rock Salt)

Kuemmel and Hanbali performed a simple before and after analysis on the effectiveness of salting on safety in New York, Minnesota and Wisconsin (Kuemmel and Hanbali, 1992; Hanbali, 1994). The researchers found a significant reduction in crashes following salting operations, with an 87 percent reduction observed on two-lane undivided highways and a 78 percent reduction on freeways. This approach employed estimated traffic volumes based on historical data rather than observed counts. Weather-related factors, as well as the use of other winter maintenance operations (ex. plowing), were not considered by this work either, which calls into question the true contribution of salting to the observed crash reductions. In computing user mobility benefits/savings, it was assumed that speed reductions of 10 mph on both two-lane highways and freeways resulted from weather. The researchers found that total direct operating costs for motorists fell from $0.073 cents to $0.061 cents per vehicle mile traveled on two-lane highways and $0.53 cents to $0.23 cents per vehicle mile traveled on freeways following maintenance activities. During the first two hours following maintenance, the direct road user benefits amounted to $6.50 for every dollar spent on two-lane highways and $3.50 for every dollar spent on freeways for maintenance. The direct costs of maintenance were offset once 71 vehicles and 280 vehicles had driven over a two-lane highway and freeway, respectively, with maintenance costs being paid for after approximately 35 minutes.

Usman et al. (2012) developed disaggregate models for quantifying the safety effects of winter maintenance activities at an operational level. The models examined the link between winter road crashes and weather, road surface conditions, traffic exposure, temporal trends and site-specific effects. Hourly data from 31 highway routes in Ontario, Canada, were used in the analysis. The work also allowed for a quantification of the benefits of maintenance operations and service standards in terms of expected crashes. This included identifying the safety benefits of combined plowing and salting versus a no maintenance condition and the timing of those operations (ex. 2 hours into event, 4 hours, etc.), and the time to bare pavement. For plowing and salting operations, the mean number of accidents expected following that operation were quite low, steadily rising back to the expected mean had no maintenance been performed over a period of hours following the maintenance. An examination of the expected reduction in accidents from the models versus time to bare pavement indicated that, as one would expect, the sooner maintenance activities produce bare pavement, the greater the reduction in the percent of crashes.

Baroga (2004) evaluated different aspects of salt use with and without the use of corrosion inhibitors in Washington state. This work included cost comparisons, differences in road conditions following applications, corrosion impacts, and environmental impacts. The reported cost per lane mile for salting operations, including labor, equipment, and materials ranged from $113.98 to $683.10 (2004 dollars), depending on the region of the state. The cost of salting with the use of corrosion inhibitors ranged from $695.55 to $1652.93 for the same winter season. Road surface conditions with and without the use of corrosion inhibitors were found to be largely the same. Corrosion inhibitors reduced metal corrosion by 53 percent in the field (when measured using metal coupons on maintenance vehicles). However, steel coupons mounted on roadside guardrails experienced 17 percent more corrosion on routes where corrosion inhibitors were used. No differences in environmental impacts were found between the use of salt with and without corrosion inhibitors.

Fu et al. (2006b) performed a statistical analysis on observational data to identify the quantitative effects of weather and maintenance operations on snow melting trends. Chemicals included rock salt with and without pre-wetting liquid. The test site was a 50 kilometer route on Highway 21 in southwest Ontario, Canada. The primary findings of this work were that pre-wetted salt outperformed dry salt by a reduction in snow cover from 17.9 percent to 40.0 percent.

Norem (2009) discussed the selection of winter maintenance strategies based on climatic parameters in Sweden. Of interest was the discussion of the performance of salting activities on safety. In the southern region of the country, it was determined that salted roads had a 28 percent reduction in accidents over unsalted roads. Data from the northern region indicated that there were no more accidents on unsalted roads than on salted ones. The overall work concluded that salt should not be used when temperatures fall below -8°C.

Environment Canada (2006) summarized the different costs and benefits associated with road salt use in Canada. Among the benefits cited was a reduction in accidents of up to 88 percent, a figure obtained from the Salt Institute (Salt Institute, Undated b). Other specific benefits cited included:

- Fuel savings – 33 percent reduction, translating into savings of $1.88 (2006 Canadian dollars) per 62 miles traveled (100 kilometers traveled)[2]
- Travel time savings - $11.00 per hour for car, $9.73 per hour for bus
- Avoided fatalities, injuries and property damage- savings of $1,594,412 per fatality, $28,618 per injury and $5,724 per property damage crash eliminated

Indirect benefits included:

- Reduction in tort liability claims
- Maintained economic activity – estimated at $27.00 per hour per employee
- Maintained access to social activities

Qiu and Nixon (2008) examined performance measurements for winter maintenance operations. As part of this work, the effects of maintenance operations, including the use of sand-salt on vehicle speeds and volumes were investigated. In general, the winter maintenance operations (chemical treatment) examined had positive effects on the speeds observed (i.e. speeds were higher where maintenance was employed at a higher priority level compared to a lower level). Chemical treatment had a small effect (below 1 mph higher speeds the following hour after treatment).

Miedema and Wright (1995) identified several direct and indirect benefits to winter maintenance when examining the impacts that different weather information sources might have on response

[2] This is approximately equivalent to $1.65 in 2015 US dollars per 62 miles traveled, or $2.18 in 2015 Canadian dollars per 100 km traveled.

times (call outs) to storms. Direct benefits included decreased materials usage (salt), equipment costs, and labor costs. Indirect benefits identified included decreased accidents, travel time, and fuel consumption. While direct benefits varied by location (in this case, sub-districts), general values for indirect benefits were developed. The benefit of reduced accidents was valued as $0.0748 per vehicle kilometer of travel on two lane roads and $0.0357 for four lane roads. The benefit of improved weather information on travel time was $0.0383 per vehicle kilometer of travel on two lane roads and $0.0162 on four lane roads. Finally, the benefit of reduced fuel consumption was determined to be $0.0007 per vehicle kilometer of travel on two lane roads and $0.0003 for four lane roads. Note that the savings listed here are not entirely attributable to salt, but also include the overall benefits accrued by maintenance operations incorporating the use of salt.

Ye, et al. (2012) developed methods for estimating the benefits of winter maintenance operations using statewide data from Minnesota. The analysis included consideration of materials (primarily salt) to establish safety, operational (travel time) benefits, and fuel savings benefits from maintenance operations. It was determined that by performing winter maintenance, crashes were reduced by 4,600 over the do nothing alternative between 2001 and 2006. A travel time savings of $10,915,690 was produced by facilitating higher travel speeds and a fuel savings of $41,057,063 resulted from more efficient travel. When the value of all benefits was compared to the total costs over the 5 year time period, a benefit-cost ratio of 6.0 was computed.

Fortin Consulting (2014) estimated damages to infrastructure, automobiles, vegetation, human health and the environment from the use of road salt and provided a cost range from $803 - $3,341 per ton of salt used.

The Handbook of Road Safety Measures provided guidance, primarily obtained from studies in Europe, of the effectiveness of different winter maintenance measures on safety (Elvik, et al., 2009). The use of salting throughout a winter season was estimated to reduce injury crashes by 7 percent and 22 percent and property damage crashes by 19 percent and 39 percent.

Shi, et al. (2013a) discussed the use of chloride-based salts in winter maintenance, specifically the benefits they produce and their negative impacts. Specific benefits of salt include reduced crashes, improved mobility, and reduced travel costs. Crash reductions cited from previous literature ranged from 78 percent on freeways to 87 percent on two lane roads. Improvements to mobility cited from prior work are presented in Table 7. Finally, cost savings provided by salt cited from previous work ranged from $0.06 to $0.53 cents per mile on two lane roads and freeways. Negative aspects of salts included vehicle and infrastructure corrosion as well as impacts to water and soils.

Table 7 Mobility improvements achieved by salt use (Shi, et al., 2013a).

Volume to capacity ratio	Improvement observed
Low snowfall event	
0.35 - 0.60	6 - 7%
0.70 - 0.75	26 - 27%
0.90 - 1.0	10 - 11%
Heavy snowfall event	
0.35 - 0.60	11%
0.70 - 0.75	29 - 36%
0.90 - 1.0	5 - 12%

Rubin, et al. (2010) examined the use of salt on Maine roads, including its impacts on the environment and its costs. It was found that the use of salt on all roads in the state totaled 750 pounds per resident annually. Climatic conditions, methods of use, and application rates all contributed in influencing the extent of corrosion caused by salt use in winter maintenance. Environmentally, salts entered water and soil along roads in the state, with long-term impacts found along some routes (ex. well contamination). Recovery from the use of salt in the state was estimated to require years and possibly decades should salt use be stopped.

Fitch, et al. (2013) conducted an environmental life cycle assessment of winter maintenance treatments, including salt, using data from Virginia. Based on calculations of the costs associated with the energy used to produce the materials, greenhouse gas emissions, water use, chloride emissions, and biochemical oxygen demand, the environmental burden of salt on a per storm basis was calculated to be $3,149. This value was associated with a 100 lane mile segment of roadway.

Fu and Usman (2014) analyzed crash data between 2000 and 2006 from Ontario, Canada to determine the relationship between safety and the use of salt. The work found that a 10 percent improvement in road surface conditions from conducting some form of winter maintenance could produce a 20 percent reduction in the average number of crashes that occurred. The use of salt in winter maintenance reduced the average number of crashes over the study period by 20 to 85 percent and reduced crash rates by 51 percent.

The environmental impacts of road salts have been a subject of research since their usage became widespread during the 1960s for highway maintenance (Hawkins, 1971; Roth and Wall, 1976; Paschka, et al., 1999; Ramakrishna and Viraraghavan, 2005). The environmental costs of salt were estimated to be an average of $469 per ton of material used (in 2005 dollars) (Shi, 2005). Evidence demonstrates that chloride salts accumulate in aquatic systems (Mason, et al., 1999; Kaushall et. al, 2005), cause damage to terrestrial vegetation (Public Sector Consultants. 1993; Bryson and Barker, 2002), and alter the composition of plant communities (Miklovic and Galatowitsch, 2005). Environment Canada (2001) reported that many woody plant species sensitive to salt had vanished from Canadian roadsides. The environmental impacts of road salts are difficult to quantify in monetary terms, as they are site-specific and depend on a wide range of factors unique to each formulation and spatial and temporal factors of the location. Despite the potential damaging effects of road salts, their use can reduce the need for applying abrasives, and pose less threat to the surrounding vegetation, water bodies, aquatic biota, air quality, and wildlife (Fay and Shi, 2012).

Anti-icing

Anti-icing is defined as "the snow and ice control practice of preventing the formation or development of bonded snow and ice by timely applications of a chemical freezing-point depressant" (Ketcham et al., 1996). Anti-icing has proven to be a successful method of proactively maintaining roadways during the winter season.

In comparison with traditional deicing methods, anti-icing operations reduce the cost significantly for snow and ice control operations (Illinois Technology Transfer Center, 1998). Washington DOT conducted three case studies to determine the benefit-costs of anti-icing strategies compared to traditional deicing methods. The first case study was conducted on a 20 mile lane with average distance travelled (ADT) of 2,500 vehicles covered with heavy frost and ice. Repeated treatments of sand and chemicals were used for deicing, and liquid $MgCl_2$ at 30 gallons per lane mile were used for anti-icing operations. Overall, both methods were effective for snow and ice control operations. However, on cost comparison, the anti-icing cost was about $383 and the traditional deicing method was about $4,400 (11.5 times greater). In the second case study, calcium magnesium acetate (CMA) was used for an anti-icing operation on a 23 mile segment of interstate highway consisting of four travel lanes (including bridges and underpasses, ADT of 42,000 vehicles). Similarly, the cost of anti-icing was significantly less than the traditional deicing, estimated at $1360 for anti-icing and $4,179 for deicing (sand and granular chemicals). In the third case study, several bridges were used (ADT of 2,200 vehicles) to study the cost effectiveness of deicing and anti-icing (liquid $MgCl_2$) methods on controlling ice formation. Similar to the previous two case studies, the cost of anti-icing ($22 per bridge) was very less compared to traditional deicing ($257 per bridge). Further, the cost of deicing would go up by $302 by including sweeping charges resulting from sand usage (Illinois Technology Transfer Center, 1998).

In another report, Minnesota field trials show a savings of about 10 percent in costs due to the use of anti-icing methods. The cost reduction is further increased if the snow falls on a weekend, due to the increased labor cost during weekends. In addition to cost savings, the time required to treat the lane also significantly reduces (MnDOT, 2009).

Colorado evaluated the cost of sanding applications in terms of labor, equipment and materials. This helped the Colorado DOT evaluate best practices for winter maintenance and implement changes where necessary. In the last decade or so, Colorado has had one of the highest population growths in U.S. history, resulting in increased traffic, insurance claims, and insurance costs. The number of windshield replacement claims is cyclical with peaks occurring in the late spring and early summer. Yet, with the increase of liquid chemicals for anti-icing, the number of claims has been following a downward trend, resulting in cost savings to the public (Chang et al., 2002). While implementing anti-icing practices has allowed Colorado to meet air quality standards and reduce windshield replacement and repair claims, total costs for winter maintenance are still increasing due to the increasing population. Equipment and labor costs have remained relatively constant with the addition of anti-icing; however, the cost of chemical product per lane mile has increased nearly 400 percent (Chang et al., 2002).

Kahl (2002) completed work for the Michigan DOT investigating the use of agricultural by-products (Ice Beeter, Caliber M-1000, Ice Ban and First Down) for anti-icing and deicing in southwest Michigan. As part of this work, the impact of anti-icing was determined on one route (I-94, 123 miles). It was estimated that anti-icing activities reduced the number of expected crashes along the study route by 401 crashes during the winter of 2000-2001. However, caution is strongly recommended in interpreting this result, as linear regression was employed to estimate the expected number of crashes; this approach has historically been shown to be inappropriate for modeling crashes. Based on the overall findings of the project, it was recommended that agricultural by-products should be used for anti-icing and the prewetting of rock salt, but not for deicing.

In one study of the cost savings of anti-icing, Colorado, Kansas, Oregon, Washington and the Insurance Corporation of British Columbia (ICBC) were asked to state any cost savings from anti-icing. Specifically, Colorado saw an overall cost savings of 52 percent while Oregon saw a cost savings of 75 percent for freezing rain events. It was concluded that anti-icing could provide a 10 percent to 20 percent cost savings in snow and ice control budgets, and possibly result in a 50 percent reduction in cost per lane mile (Boselly, 2001).

On a highway in Idaho, implementing anti-icing reduced accidents by 83 percent and labor costs by 62 percent (Breen, 2001). Reducing accidents also translates into an economic savings to the traveling public in terms of vehicle repair, insurance costs, and injuries or fatalities, as well as litigation costs. A reduction of accidents by 8 percent in Canada resulted in savings of over $240,000 (McCormick Rankin Corp and Ecoplans Limited, 2004).

In a large study on the economic benefits of anti-icing, it was found that savings could range “from $1,266 to $30,152 per typical maintenance snowplow truck route per year,” while user cost savings in terms of reduced accidents could be as high as $107,312 for 900 storm hours. Total cost savings were estimated to be $1.7 billion (Epps and Ardila-Coulson, 1997).

In Montana, the 4-year average (1997-2000) centerline mile cost (labor, equipment, materials) for winter maintenance was examined for two sections using different practices to achieve the same level-of-service. Anti-icing the Plains section of State Route 200 resulted in a 37 percent reduction in costs per lane mile compared with the Thompson Falls section where pre-wetting is used (Goodwin, 2003).

Brine

Brine Making and Storage

Benefits associated with brine-making equipment are accrued from the use of brine itself, which is discussed elsewhere in this document. However, there are costs associated with brine making that have been documented. Veneziano, et al. (2010b) discussed the use of a benefit-cost toolkit for winter maintenance operations, equipment, and materials. As part of this work, the costs associated with brine-making were identified. If an agency made brine itself, a cost for labor (per hour, per employee) as well as material inputs (ex. granular material such as salt) would be incurred. In addition, brine-making equipment would also need to be purchased. In 2010, the cost of such equipment varied widely, ranging from $1,940 to $21,500.

Using Recycled Water

Water from cleaning snow and ice control equipment may have a wide range of contaminants, including oil and other hydrocarbons, metals, detergents, road salts, and grit. It is important to collect, reuse, and properly manage vehicle wash water and salt-impacted site drainage to comply with local water quality regulations and protect surface and groundwater resources (Transportation Association of Canada, 2013).

Many state DOTs have implemented systems where water used to wash vehicles is recycled and then used to make brine on site. Reusing salt-laden truck wash water allows for material cost savings in making the brine solutions and conserves water use, while reducing the amount of runoff into the environment (Allenman, et al., 2004; Fay, et al., 2013). The city of Toronto recycles salt-laden runoff from its wash bays by collecting the water, removing the oil and grit using separators and settling, and then placing in holding tanks for brine making (Fay, et al., 2013).

Virginia DOT (VDOT) conducted a research project to look into the option of using recycled runoff for its onsite brine making operations, including a benefit-cost analysis comparing only the costs of using recycled runoff with the alternative of hauling away the runoff (Craver, et al., 2008). They determined that recycling was feasible, and that all capital costs would be recovered in 2 to 4 years depending on the severity of winters and the average amount of salt used. Based on these findings, VDOT is working to recycle all collectable runoff, an estimated 60 million gallons of water (Salt Institute, 2010). In an average year, the collected runoff should be sufficient to supply all water needed for brine production.

Indiana DOT (INDOT) conducted a field investigation of a proof-of-concept brine production system using recycled wash bay water (Alleman, et al., 2004). The cost estimate for the "do-it-yourself" system was $3,055, but they had a lot of necessary equipment already on hand. In 2000 to 2001, approximately 3,600 gallons of salt brine were produced from recycled wash water. By 2004, six of the 33 INDOT brine-making facilities were set up to use truck wash water to make brine.

Initial investment costs for a commercial vehicle washing facility were estimated to be $80,000 (1991 dollars), with an additional investment of $1,600 every 10 years and maintenance costs of about $4,000 per year (Kovac and Kocis, undated). The estimated investment recovery period was 1.3 years, while achieving an 80 percent recycling of runoff.

Magnesium Chloride

Little information specific to the costs and benefits of magnesium chloride ($MgCl_2$) has been documented to date. The work done with this material has largely focused on its effects on corrosion from a chemistry standpoint, as well as the performance of corrosion inhibitors. Corrosion is clearly one of the costs of the material itself.

Parker (1997) compared the use of alternative deicers, including $MgCl_2$, to sand use in Oregon. Results of a cost comparison found that $MgCl_2$ produced benefit-cost ratios ranging from 3.93 to 15.0 over sanding, depending on the specific type of storm event being addressed.

Lewis (1999) examined the environmental effects of $MgCl_2$ in Colorado in the late 1990s. The advantages of this material that were cited by the author included allowing a reduction in the use of sand and salt mixtures, as well as an improvement in road surface conditions versus these alternatives. Toxicity tests found that aquatic organisms differed in their sensitivity to $MgCl_2$. It was concluded that the use of $MgCl_2$ was unlikely to contribute to environmental damage at a distance greater than 20 yards from a roadway.

Fischel (2001) evaluated several deicer materials, including $MgCl_2$, based on information in existing literature. Reported cost information at the time (2001) showed $MgCl_2$ with corrosion inhibitors cost $0.25 to $0.78 per gallon or $46.00 to $124.00 per ton. This translated into a cost per lane mile for the material of $8.00 to $28.00, depending on application rates.

Shi, et al. (2009) evaluated alternative anti-icing and deicing compounds for the Colorado DOT. The reported costs of $MgCl_2$ ranged from $0.53 to $0.84 per gallon, including delivery, with a usage rate of 20 to 100 gallons per lane mile. The authors confirmed the negative effects of solid salt as well as liquid NaCl and $MgCl_2$, especially those on the durability of metals and Portland cement concrete. However, it was recommended to continue the use of chloride brines until better alternatives became available.

Shi, et al. (2014) evaluated the performance of different materials used in snow and ice control, including $MgCl_2$ (with corrosion inhibitors). The work developed a composite index for this comparison, which considered the cost of the material per lane mile, its average performance in addressing snow and ice conditions, its impacts to vehicles and infrastructure, and its environmental impacts. Based on testing results, the composite index for $MgCl_2$ was high (a rating of 59 out of 100) compared to other materials, indicating that the material should be considered a best practice when road conditions warrant its use. In particular, the authors recommended that $MgCl_2$ brine would be a better choice to use for cold pavements compared to other materials.

Calcium Chloride

Calcium chloride ($CaCl_2$) is a deicer that can also be employed in anti-icing operations when in a liquid form. Similar to magnesium chloride, the focus of published information for $CaCl_2$ has been on the testing of the material in lab settings, as opposed to quantifying its costs and benefits. Still, some quantified and non-quantified costs and benefits have been reported over time.

Fischel (2001) evaluated several deicer materials, including $CaCl_2$, based on information in existing literature. One benefit of $CaCl_2$ was that it does not attract animals to the roadside like other materials due to its lack of sodium. Inhibited $CaCl_2$ could deposit trace metals into the environment, with possible impacts to human health. The material could also increase soil and water salinity. Reported cost information at the time (2001) showed $CaCl_2$ with corrosion inhibitors cost $0.50 per gallon or $91.00 per ton. This translated into a cost per lane mile of $10.00 and $25.00.

Vestola, et al. (2006) examined the side-effects of $CaCl_2$ in Finland. Side effects were compared to those of sodium chloride, which was also being used in winter maintenance operations, including differences in extent and severity. $CaCl_2$ was found to contribute to vehicle corrosion, bridge and equipment corrosion, and impacts to asphalt pavements (reducing the sealing performance of bentonite layers). Vehicle and bridge corrosion were found to be more severe than that caused by NaCl. Additionally, $CaCl_2$ was found to reduce friction between vehicle brake discs and pads, impacting stopping performance. $CaCl_2$ was also harmful to vegetation and groundwater, although the impact was dependent on the quantity applied to the roadway.

Tuan and Gerbino-Bevins (2012) discussed findings from an investigation of different winter maintenance materials, including $CaCl_2$. Results from friction tests found $CaCl_2$ would not cause slippery roads when applied. $CaCl_2$ also showed longer refreeze times than other materials in a lab setting, translating to a benefit in achieving bare pavement during winter maintenance operations. However, the material was found to be corrosive to stainless steel through anecdotal observations during lab tests. Interestingly, the finding of longer refreeze times contradicts that of Nixon and Wei (2003), who found during lab tests that refreeze generally occurred quickly (within 30 minutes) of the initial application. This difference may be the result of the form of material tested; Nixon and Wei tested solid $CaCl_2$ samples as opposed to liquids.

Agriculturally Based Products

There is very limited information on agriculturally based (ag-based) products in the published domain. Information found on ag-based products includes the qualitative assessment that ag-based products remain on the road longer than chlorides, with limited lab and field data available to support this finding. Lab data from the ongoing Clear Roads project *Understanding the Effectiveness of Non-Chloride Liquid Agricultural By-Products and Solid Complex Chloride/Mineral Products Used in Snow and Ice Control* suggests that manufacturer developed chloride and ag-based blended products work at colder temperatures and can be applied at lower application rates to achieve the same or better LOS when compared to salt brine. All products tested with an ag-based component were found to reduce the bond strength between snow/ice and the pavement allowing for easier plowing. Additionally the ag-based products spread more evenly on the pavement surface and remained on the pavement longer than salt brine.by up to 250 to 750 vehicle passes varying by product type.

In another project, field testing showed that after 4 days 20 percent, 30 percent, and 50 percent of applied products (CCB, NaCl + GLT, and Freezeguard; respectively) remained on the road surface (Shi et al., 2011).

Corrosion and Corrosion Inhibitors

With the increased use of road salts, there is genuine concern from the general public, trucking industry, and DOTs about the corrosion damage that snow and ice control operations may cause to motor vehicles and transportation infrastructure (steel bridges, large span supported structures, parking garages, pavements, etc.), which can have significant safety and economic implications (Johnson, 2002; Shi, et al., 2009, Honarvarnazari et al., 2015). Chlorides are generally considered the most corrosive winter maintenance chemicals (Shi, et al., 2009). Often, commercially available, corrosion-inhibited versions of these chemicals are used to reduce their deleterious impacts on vehicles and infrastructure. It should be cautioned that deicer products noncorrosive to one metal might be corrosive to other metals (Fay, et al., 2008) and additives used to inhibit certain metallic corrosion may have little to no inhibition effect on other metals (Levelton Consultants, 2007).

Chloride based deicers sales topped 20.2 million tons in 2008 and continue to grow because they are the least expensive materials to use for deicing and anti-icing to date (www.saltinstitute.org). The upfront cost of purchasing products is an easy way to justify using specific products, but the secondary costs, or indirect costs, such as corrosion and environmental impacts, are often not considered in the initial purchase cost. DOTs and the trucking industry have observed directly the effects of corrosion to vehicles and infrastructure (Buckler and Granato, 1999; Koch et al., 2002, Johnson, 2002). Average costs of about $32 per vehicle was the estimate for corrosion to vehicles from deicers, with higher corrosion costs of about $140 per vehicle in seasonally cold maritime climates, such as Boston, Massachusetts and Bangor, Maine (Johnson, 2002).

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Theoretically, a region could estimate the number of cars and estimate corrosion costs to vehicles and include this in the purchase cost of various products. This does not include corrosion impacts to infrastructure, such as reinforced or pre-stressed concrete structures and steel bridges (Koch et al., 2002). In fact, NCHRP 577 identified deicer corrosion to steel rebar as the primary concern, followed by impacts to vehicles, concrete in general, structural steel, and then roadside structures (Levelton Consults, 2007). The estimated cost to install corrosion protection on new bridges and repair old bridges in snowbelt states is between $250 million and $650 million annually (TRB, 1991). Indirect costs including corrosion to parking garages, pavements, roadside hardware, and non-highway objects are estimated be greater than ten times the cost of corrosion maintenance, repair, and rehabilitation (Yunovich et al., 2002).

Costs of Corrosion

Several studies have examined the costs of corrosion. Some of the findings from this work include:

- In 1978, Battelle estimated the cost of corrosion to the US at $70 billion, ~4.2% GNP (Battelle, 1978)
- Michigan DOT reported costs due to vehicle corrosion ranging from $715 - $8,558 per vehicle (Michigan DOT, undated).
- In 2002, NACE, FHWA, CC Technologies Laboratories, Inc., estimated the cost of corrosion using two methods, 1. Cost of corrosion control methods and services, and 2. Corrosion costs of specific industry sectors (explained below) (Koch, et al., 2002).
  1. Corrosion Control Methods and Services – this includes protective coatings ($108.6 billion), corrosion-resistant alloys ($7.7 billion), corrosion inhibitors ($1.1 billion), polymers ($1.8 billion), anodes and cathodic protection ($2.22 billion), and corrosion control and monitoring equipment ($1.2 billion). Other contributions to total annual direct cost considered include: contract services, corrosion research and development ($20 million), and education and training ($8 million) (Koch et al., 2002). Total cost of corrosion = $121 billion, ~ 1.4percent gross domestic product (GDP).
  2. Corrosion costs of specific industry sectors – Infrastructure, Utilities, Transportation, Production and Manufacturing, and Government Figure 2 shows corrosion costs for each category (Koch et al., 2002). Total cost of corrosion = $137.9 billion, ~1.6percent GDP.

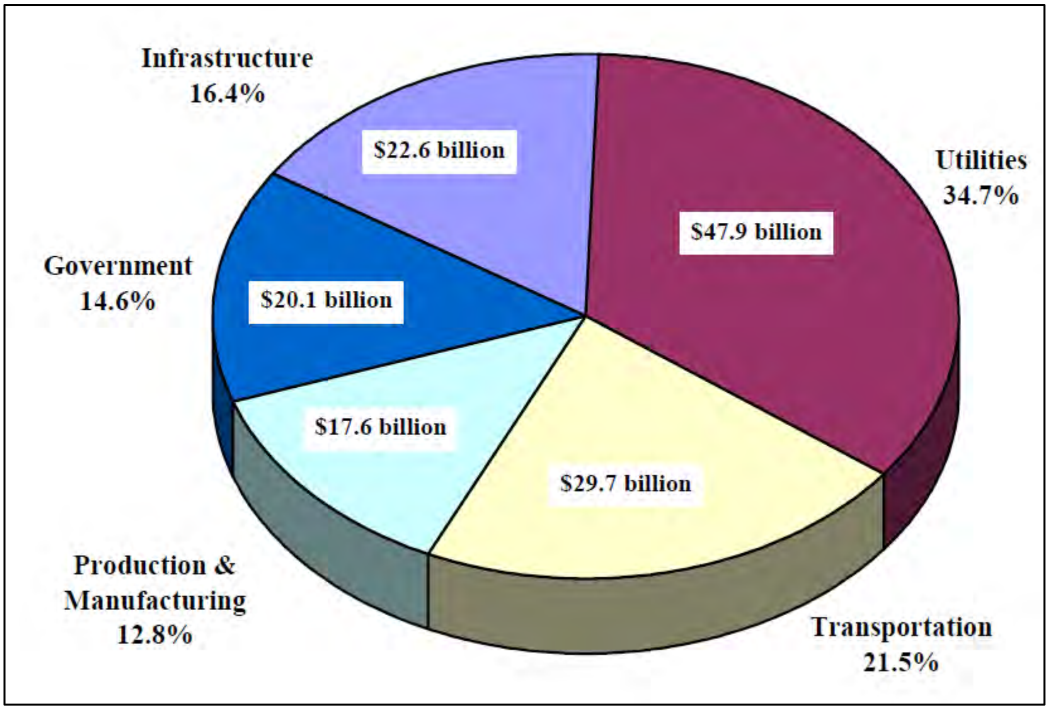

Figure 2 Cost of corrosion in sector categories analyzed by Koch, et al. based on total cost of corrosion at $137.9 billion per year (Koch, et al., 2002).

The costs of corrosion to the transportation sector was broken down into the following smaller categories - motor vehicles, ships, aircraft, rail cars, and hazardous materials transport (Koch, et al., 2002). Relevant to this project is the motor vehicles category, which considered increased manufacturing costs for corrosion engineering and resistant materials, corrosion related repairs and maintenance, and corrosion related depreciation of vehicles; for a total cost of corrosion estimated to be $23.4 billion. Motor vehicles were considered to have the greatest corrosion cost, accounting for approximately ~80percent of the transportation category.

A total cost of corrosion for all sectors of the US economy, including those not considered in the second benefit-cost approach by Koch, et al. (2002), was estimated to be $276 billion, ~3percent GDP, and indirect costs (lost productivity due to outages, delays, failures, and litigation; taxes and overhead on the cost of the corrosion portion of good and services; and indirect costs of non-owner/operator activities) of corrosion were estimated to be $552 billion, ~6percent GDP (Koch, et al., 2002).

It was estimated that 25 – 30percent of corrosion costs could be saved if optimum corrosion management practices were used. This document also stated the current per capita direct cost of corrosion for each US resident (as of 2001) is about $970 per year, and if indirect user costs are included this number would double (Koch, et al., 2002).

As part of a comprehensive study of the impacts of deicers in Michigan, estimates of the direct costs of corrosion to vehicles and bridge decks for various deicers were developed and are presented below (Public Sector Consulting, 1993).

- Road Salt – vehicle corrosion $119 - $265.5 million and bridge deck corrosion $11.2 – $25.5 million.

- Salt/Sand – vehicle corrosion $79.6 - $177 million and bridge deck corrosion $7.5 - $17 million.
- CMA – vehicle corrosion $8.6 – $32 million and bridge deck corrosion $1.3 – $3.1 million.
- CG-90 Surface Saver – vehicle corrosion $54.8 - $122 million and bridge deck corrosion $11.2 - $45.2 million.
- Calcium Chloride – vehicle corrosion $76.4 - $170 million and bridge deck corrosion $7.2 - $16.3 million.

Jones and Jeffery (1992) estimated annual vehicle corrosion cost associated with road salting at $11.7 billion nationwide. Kelting and Laxon (2010) estimated salt induced corrosion cost of $2.1 - $4.2 billion per year, based on TRB (1991) estimates of corrosion protection costs per vehicle of $125 - $250 multiplied by the 10.7 million cars sold in 2009. Kelting and Laxon (2010) pointed out that "it is difficult to estimate the specific cost associated with corrosion protection of vehicles. The value of even the most detailed calculation is questionable, and must be used with caution."

A study of deicer impacts in Anchorage, Alaska estimated that corrosion damage to vehicles was $5.1 million per year, and repair costs for corrosion damage to bridge decks was estimated at $68,000 per year (Nottingham, et al., 1983). The goal of the study was to determine the actual costs of using salt in winter maintenance, not just the purchase cost, as a possible means of justifying using alternative products that may cost more than salt initially. The corrosion damage to vehicles was estimated to cost $3,000 to restore a 5-6 year old vehicle to near-new condition, and value loss to the vehicle was estimated to be 50 percent of repair costs. This study estimated that if Alaska DOT continued to use the same winter maintenance practices, by 1990 vehicle value loss would be $6.5 million per year, and by 2000 $8 million per year.

The corrosion damage of road salts to the transportation infrastructure (steel bridges, large span supported structures, parking garages, pavements, etc.) has enormous safety and economic implications (Shi, et al., 2009). Over five billion dollars are spent each year by state and local agencies to repair infrastructure damage caused by snow and ice control operations (FHWA, 2014), which translates into $333 per ton of road salts. As of 1999, there were 583,000 bridges in the United States, with approximately 15 percent of all bridges structurally deficient and an annual corrosion cost of $8.3 billion. It is estimated that installing corrosion protection measures in new bridges and repairing old bridges could cost Snowbelt states between $250 million and $650 million per year (TRB, 1991). Parking garages, pavements, roadside hardware, and non-highway objects near salt-treated roads are also exposed to the corrosive effects of road salts. Indirect costs to the user in traffic delays and lost productivity are estimated at more than ten times the direct cost of corrosion maintenance, repair, and rehabilitation (Yunovich, et al., 2002).

A recent publication by Shi et al. (2013a) determined total repair costs for Washington State DOT (WSDOT) equipment for 2008 through 2011. The relevant values are presented in Table 8.

Table 8 Total and Plow-related Corrosion Repair Costs in Washington (Shi, et al. 2013a).

Year	All corrosion related maintenance	Snowplows maintenance only
2008	$457,956	$327,529
2009	$712,969	$355,514
2010	$558,516	$268,816
2011	$736,362	$299,578

Figure 3 provides a visual description of corrosion costs seen on WSDOT vehicles, with the majority of corrosion costs resulting from damage to chassis, axles, brakes, frame, steering, suspension, and tire and wheels, accounting for 32 percent of corrosion costs.

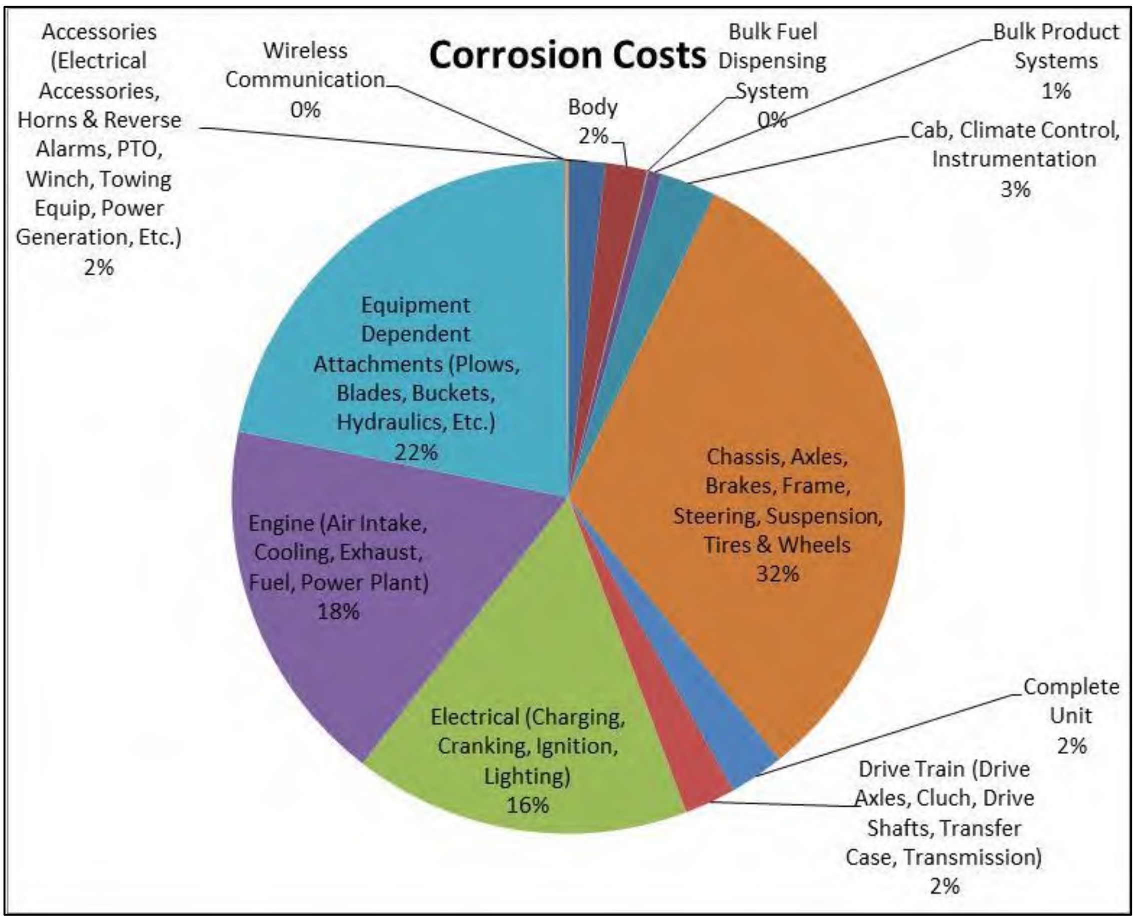

Figure 3 Allocation of corrosion-related repair costs among WSDOT equipment (Shi, et al., 2013a).

Based on the information gathered on equipment, and corrosion damage and repair costs, it was determined that corrosion related damage from deicers could be reduced by 20 percent if WSDOT increased its investment in proactive maintenance and corrosion prevention (Shi et al., 2013a). A benefit-cost ratio of 8.0 was calculated for proactive maintenance and corrosion prevention, which was found to be a conservative value because indirect costs of equipment corrosion (estimated to be at least 20 percent) were not taken into account. Estimated corrosion costs to DOT equipment fleet related to deicer exposure is $14,050,368 per year (Shi et al., 2013a), with the benefit-cost of 13.2 calculated by Honarvarnazari et al. (2015) for corrosion prevention and mitigation by DOTs.

Corrosion Inhibitors and Prevention

Shi et al. (2009) suggested that the most effective way to address concrete durability is at the design and material selection phase. It is important to maintain adequate concrete cover and to use high-quality concrete. Additionally, increasing the concrete thickness over steel rebar to act as a barrier to chloride migration improves durability (Newton and Sykes, 1987). Other options to mitigate the corrosive impacts of chlorides on concrete are the addition of corrosion-inhibiting admixtures to fresh concrete, surface treatment of steel rebar, or using alternative reinforcement materials (Shi, et al., 2009). Other options include a hydrophobic surface treatment of concrete to reduce the ingress of chloride, cathodic protection (CP), electrochemical extraction (ECE), injecting beneficial species into concrete or migrating corrosion inhibitors (MCIs), or electrochemical injection of corrosion inhibitors (EICI). While cost values were not provided for any of these techniques, Shi et al. (2009) suggested that EICI has not taken off as a treatment method due to high costs. Another option to reduce corrosion is to seek out non-corrosive deicer alternatives and optimize application rates using all available technology.

Work by Glass and Buenfield (2000) estimated that replacing all rebar with epoxy coated rebar in transportation infrastructure would cost over $5 billion. Vitaliano (1992) estimated the cost to repair or rehabilitate interstate and arterial bridges in 14 snow-belt states at $2.5 billion per year. Another estimate for rehabilitation of bridge decks damaged by salt estimated it would cost $50 to $200 million per year for 10 years (TRB, 1991).

Work by Monty et al. (2014) found that salt neutralizers used to wash vehicles to reduce corrosion from chloride based deicer products can cost from $567 - $1,810 for a 350 gallon wash per truck. Using salt neutralizers was estimated to increase service life by 6 months to 1 year for vehicles, when washed five to 18 times per year (varies based on facility and vehicle replacement lifecycle). Monty et al. (2014) found the least expensive salt neutralizer to be cost-effective. Potential additional savings may appear as more data becomes available, such as reduced maintenance of wiring.

Environmental Costs and Benefits

There is very limited information in the published domain on the environmental costs of winter maintenance practices. This is in part because it is very difficult to assign dollar values to natural items such as trees, fish, or streams. To further complicate this issue, questions arise about who assigns these values and how this is done. For example, if a stream has an endangered species in it is it worth more than a stream without an endangered species? If only trees in the right-of-way are impacted are they worth less than if trees were impacted that are beyond the right-of-way?

To determine the cost or benefit of using a product, like salt brine, it is necessary to quantify what the financial impacts are once the product leaves the roadway and enters the environment. To understand the full cost of a product, it is necessary to consider the cost of the product,

product transportation costs, application costs, clean-up costs, costs to manage the product in the environment, and costs of direct impacts to the environment.

There is substantial research that shows that application of sanding materials, and deicing and anti-icing products like salt, salt brine, and magnesium chloride and calcium chloride (liquid and solid) can impact soil, plants, waterways, and animals (Fay et al., 2014). Salt use has been shown to disrupt the natural ecological balance in specific areas. Assigning a dollar value to these losses is challenging, but several methods have been used to quantify the environmental costs associated with winter maintenance practices.

Murray and Ernst (1976) used available data to determine the costs of highway deicing and snow removal practices to water supplies (lakes and rivers), trees and other vegetation, bridges, vehicles, underground power transmission lines, and on public health. Estimated minimum annual cost associated with salt use in snowbelt states was $2.9 billion. The environmental costs were further broken down as:

- Surface and groundwater supplies with the potential for irreversible public health damage to the hypertension-sensitive segment of the population = $150 million
- Vegetation = $50 million
- Highways and Bridges = $500 million
- Vehicles = $2000 million
- Underground power transmission lines = $10 million
- Salt purchase and application = $200 million

Murray and Ernst (1976) found that the damage associated with road salt use cost almost 15 times the annual national purchasing budget, and almost six times as much as the annual national budget for snow and ice removal. Applying these values to recalculate the environmental costs of road salt based on more recent salt volumes used and current snow and ice budgets, environmental costs associated with road salt use can be estimated as follows:

- 15 x (annual national budget for salt purchases) = 15 x (20.2 million tons[3] x $70 per ton[4]) = $21.2 billion (2013 dollars)
- 6 x (annual national snow and ice removal budget) = 6 x $2.3 billion[5]= $13.8 billion (2013 dollars)

Work by Bacchus (1986) utilized an expert panel to investigate financial implications of switching from salt to CMA throughout Ontario, Canada. The expert panel identified the following costs – material costs, storage and spreading costs, vehicle corrosion costs, bridge deterioration costs, parking garage deterioration costs, groundwater contamination costs, and damage to vegetation and other private property. Indirect costs associated with impacts to groundwater contamination and damage to vegetation and other private property due to salt

[3] Salt Institute, amount of salt purchased for winter maintenance in 2007.
[4] Average cost of salt per ton delivered based on the 2012-2013 DOT salt price comparison and 5 year average completed for the National Peer Exchange, n=43 states.
[5] FHWA, Road Weather Management Program, http://ops.fhwa.dot.gov/weather/weather_events/snow_ice.htm, last modified July 2, 2013.

damage were not included. The costs that were considered were based on damage observed to fruit trees and nursery shrubs (see Figure 4).

Bacchus (1986) concluded that the relatively high costs of CMA as compared to salt were too high to offset the costs of damages to the identified parameters. For CMA to break-even, costs need to be around $343 to $481 per ton. The calculated saving from vehicle corrosion if they switched to CMA was $650 million per year, a savings of $135 per car per year. At the time this document was written, costs of CMA were still above the breakeven range of $343 - $481 per ton suggested by Bacchus (1986).

Acetates are known to cause elevated biological oxygen demand (BOD) in water bodies, and have been shown to have much higher environmental footprint than chlorides when you consider the process used to make CMA (Fitch et al., 2013). While the degree of impacts to the environment for varying products may be debatable, it is important to remember that all available deicing products have impacts and it is important to be aware of them.

Claims Against MTO

Fruit	Highway(1) Frontage km	Affected(2) Area km^2	Full (3) Value $/$km^2$/yr (000)	% Damage(4)	$ Loss/Yr (000)
Apple	119	3.57	357	30%	382
Peach	17	0.51	513	60%	157
Mixed (apple and other or peach and other)	49	1.47	369 For want of precise proportions a simple arithmetic average is taken	45%	244
Nursery (shrubs)	3	0.09	?	45%	---
Other (grapes or plums or pears)	17	0.51	325 (av. - 349) (257) (and 370)	60%	99
TOTAL					882

NOTE: It is realized that damage occurs, in a salt world, to lawns, gardens, aluminum siding, boats, etc., but data on these items are not readily available.

Present Value of these savings, in 1985 dollars
Discounted at 5% over 20 years = $11 x 10^6
Discounted at 10% over 20 years = $ 8 x 10^6

Claims Against Municipalities

Applying ratio of 1:2.225 (see Section on Groundwater), we get:
Present Value of Savings, in 1985 Dollars
Discounted at 5% over 20 years = $24 x 10^6
Discounted at 10% over 20 years = $17 x 10^6

Figure 4: Damage to vegetation and other private property from Bacchus (1986).

Work by Vitaliano (1992) also looked at the economic feasibility of using CMA as a deicing alternative to salt. This feasibility assessment was based on an estimate of salt damage values to bridges and for bridge repairs and highway maintenance which totaled $615 per ton of salt used This estimate included accelerated vehicle corrosion costs of $113 per ton of salt used, and salt damage to trees described as lost aesthetic value in Adirondack Park at $75 per ton of salt used. In 1992 the estimated cost of CMA was $615 per ton, which seemed high compared to the estimated cost of rock salt at $50 per ton, but based on the completed economic analysis, CMA was shown to be a potentially cost-effective option.

Damage to Trees

To assign a value to the damage to trees reported as the environmental cost of salt by Vitaliano (1992), a Hotelling-Clawson travel cost model and loss of consumer surplus from degraded recreational experience were calculated based on visits to Adirondack campsites. This method estimates a low value for the social cost of damage to the environment from using road salt on campers in the Adirondacks, a limited set of individuals, but ones that may be highly sensitive to this issue. A $1.55 per capita cost was determined, and when multiplied by the 2 million non-winter visits total damage costs of $3.1 million were related to tree damage from road salt. Based on local salting practices and an average of 43,000 tons of salt estimated to be used in the area of the study, the damage per ton was calculated by dividing $3.1 million by 43,000 tons of salt, yielding an aesthetic damage cost of $73 per ton (which was rounded up to $75 per ton).

Estimated damage to trees and shrubs estimated by MTO totaled $882,000 per year (Bacchus, 1986).

Road salt can contribute sodium cations to drinking water sources. For this reason Vitaliano (1992) investigated the potential link between road salting practices, excess sodium cations in drinking water, and deaths from hypertension. A cross-sectional regression of hypertensive deaths from 106 communities in New York State was completed. A positive but statistically insignificant relationship between sodium levels in public drinking water supplies and hypertensive related deaths was found. This study reinforces the finding that road salting contributes sodium cations to drinking water supplies, such that for every one-ton increase in lane mile salting, the sodium levels in drinking water supplies increase by 6.4 percent. Based on these numbers, there is potential for road salting to increase sodium cations in drinking water beyond the 20 mg/L threshold for human health effects.

Newbery (1987) looked at the costs of transportation on British roads. Environmental costs were defined as noise and exhaust emissions pollution, and assigned a cost of 4 percent to 6 percent for trucks in urban areas (not considering other vehicles and non-urban areas). Newbery (1987) looked at road damage costs, congestion costs, the value of time (commute), capital and recurrent costs of the road network, costs of accidents, the value of life, and accident external factors.

Shi et al. (2014) assessed the relative risk of deicers used by the Idaho Transportation Department (ITD) on the environment and considered the following parameters: average aquatic toxicity (as average lethal concentration (ALC), chemical oxygen demand (COD), biological oxygen demand (BOD), risk to air quality (as average aggregate emissions), and chloride anion emission (ClE). Shi et al. (2014) utilized data from multiple disciplines and published work. The data shown in Table 9 is an overall risk assessment of deicers commonly used by ITD. The higher the *ALC*, the less likely the deicer would pose toxicological effects to aquatic species. The lower the *COD* and *BOD*, the less likely the deicer would lead to a significant reduction in the concentration of dissolved oxygen in the surrounding environment such as receiving soil and water bodies. Finally, the *EF* (air quality emission factor) and *ClE* (chloride emissions) indicate the air quality risk and the amount of chloride emission into the environment, respectively, and lower values are desirable. Among the ITD deicers examined, salt brines featured the lowest *COD*, *BOD*, *EF* and *ClE* values as well as the highest *ALC* values.

Table 9. Risk of ITD deicers and sand on the natural environment (from Shi, et al. 2014).

	ALC (g/L)	COD (mg/L)	BOD (mg/L)	Air Quality (Emission Factor (EF), mg/km)	Cl^- emissions (ClE) (Kg, per lane mile)
All Salts, including IceSlicer	3.04	6209	1085	26.4	204
All 23% Salt Brines	13.22	3725	651	6.1	130
30% $MgCl_2$ Boise	2.58	27800	4860	7.9	208

Shi et al. (2014) performed an analysis of the data, normalizing the results based on four dimensions and a composite indices of factors identified as important by ITD district and maintenance sheds winter maintenance practitioners, including economics, performance (safety and mobility), infrastructure preservation, and environmental stewardship. The analysis design is flexible and allows for varying factors to be used to run "what if" scenarios to compare for impacts for varying products and factors. Based on this analysis, AF salt, a solar salt, featured the highest composite index of 65 and thus should be considered a best practice where the road weather scenario allows its effective use. Some salt brines also featured relatively high composite indices. The inhibited $MgCl_2$ liquid deicer featured the lowest composite index of 41 among the investigated chemicals. One caveat is that in the absence of sensitivity analysis, it is unclear how the error in the raw data would propagate through the calculation of composite index. In other words, it is uncertain whether the differences in rankings are statistically significant or not.

While there has been some effort to assign a cost value to environmental impacts from deicers, another approach to consider is ranking the products based on their relative impacts compared to one another. Work completed by Fitch et al. (2013) and Pilgrim (2013) can be used to assign a relative value based on product type, so that products other than just rock salt can be considered.

Figure 5 shows the relative ranking of corrosion inhibited deicer toxicity, or the Deicer Toxicity and Impact Scale based on work by Fitch et al. (2013) and Pilgrim (2013).

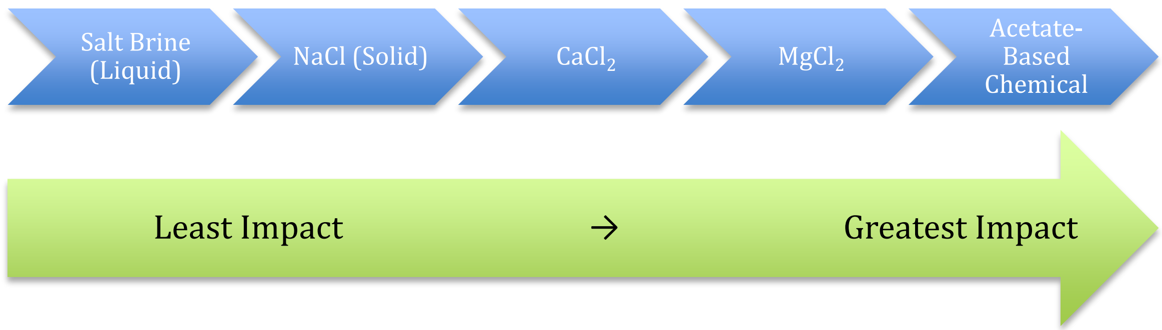

Figure 5. Relative ranking of toxicity of corrosion inhibited products used during snow and ice control operations.

Fitch et al. (2013) also identified the following DOT-controlled steps as having the greatest potential for improvement: reducing energy consumed for the salt application process and implementing practices that reduce total storm water runoff to reduce chloride loading.

Chapter 4
Benefit-cost Matrix

The summary benefit-cost matrix was developed using information gained from the literature review, surveys, and interviews. The matrix is broken down into three sub-matrices;

- Basic Activities which include plowing and the use of abrasives,
- Intermediate Activities which include the use of solid and liquid salt (NaCl) for anti-icing and deicing,
- Advanced Activities which include the use of corrosion inhibitors, inhibited salt brine, magnesium chloride, calcium chloride, or blended products.

Within each sub-matrix, information is reported on the cost, benefits, effectiveness in achieving LOS, positive and negative impacts, pros and cons, respective performance, environmental impacts, and the calculated benefit-cost ratio where possible. The effectiveness in achieving LOS used the following LOS definitions:

- A - Bare pavement - wet, extensive chemical use and plowing to achieve this condition and maintain normal travel speeds.
- B – Bare wheel paths - some slush, plowing, and chemical applications being made, maintenance performed to maintain roadway being open to near-normal travel.
- C – Fair condition – Wheel paths may or may not be visible, some snowpack remaining, chemical use and plowing performed but travel ability is reduced.
- D – Poor condition – Maintenance is being performed, but snowpack across the roadway. Travel ability is diminished or reaching the point where it is not advisable.

The process of calculating the benefit-cost values reported in the matrices is presented below. Note that the benefit-cost values were calculated based on available data and may vary in the costs and benefits for winter maintenance strategy based on local conditions and pricing.

<u>Benefit-Cost Calculations</u>

When a financial value can be assigned to most of the costs and benefits of a piece of equipment, a practice, or an operation, a benefit-cost ratio can be calculated. Benefit-cost ratios greater than 1.0 are generally desired. In some cases, winter maintenance items can entail long lives such as Road Weather Information Systems (RWIS) that incorporate present and future (e.g., recurring maintenance) costs and benefits. In such cases there is a need to bring the values of all future costs and benefits accrued to a present value. A discount rate is employed to normalize costs to a present value where necessary (non 2014-2015 data). In cases where older values were used (such as values reported in past research), these were brought up to a present (2015) value by using applying the Consumer Price Index (CPI, 2015).

Benefit-cost values were calculated by dividing present value benefits by present value costs, each which had been reported or provided by survey participants on a per lane mile basis. Total costs and benefits include those accrued by the agency (e.g. material costs, labor costs, etc.) and the benefits accrued by the agency and road users (e.g. reduced material application savings, improved safety, etc.). The benefit-cost figures were developed using information from the matrices, specifically reported and estimated values that were reported on a per lane mile basis. For example, using the cases of abrasive and salt applications, the specific cost data employed in the calculation were $3,173 and $4,784, as shown in the Basic and Intermediate matrices. The respective benefits of abrasive and salt use were $696 and $11,357, respectively. Dividing these figures (in some cases updated to 2015 dollar values when necessary) produced the respective benefit-cost ratios. Using the example figures provided, the ratio for abrasives was calculated as 696/3,173 = 0.20. Similarly, the figure for salt was calculated as 11,357/4,784 = 2.37. For the remaining ratios presented, the same approach was applied.

The majority of materials and plowing produce positive benefit-cost ratios. Abrasives did not produce a benefit-cost ratio exceeding 1.0, due in large part to the clean-up costs associated with the material combined with spot applications that do not produce as significant of safety benefits compared to other materials applied on a wider scale. These ratios are based primarily on the values reported in literature and by survey respondents. Some values, specifically benefits such as the value of reduced corrosion are not readily available, as they have often not been quantified in any manner. Still, the ratios presented in the matrix provide a general indication of the cost effectiveness of each material and a baseline with which different materials can be compared to one another.

Maintenance operation	Basic Activities	
	Plowing	**Abrasives**
Value of Costs	**Annual average cost / lane mile - $1,335** ● State DOTs - $1,353 ● Counties - $882* ● Municipalities - $251*	**Average cost / ton of abrasives** - $9.32 (range - $4.00 - $16.00) **Average cost / ton of abrasive-salt mixtures** - $20.86 (range - $15.00 to $35.00) **Average clean up cost/mile** - $85.66 (range - $62.95 - $120.00)
Value of Benefits	**From research (Hanbali and (Kuemmel, 1993) direct road user benefits amounted to $6.50 for every $1.00 spent on maintenance for two-lane highways and $3.50 for every $1.00 spent on freeways. Determined for salt use but could be extrapolated to plowing.** *Ye, et. al 2012 found lane mile benefit of plowing and combined salt/abrasive use to be $6960*	**Reduced/targeted abrasive use** - produce savings of $185 to $277 per lane mile **Estimated abrasive annual cost/lane mile** - $3,173 *Ye, et. al 2012 found lane mile benefit of plowing and abrasive use to be **$696***
Effectiveness in Achieving LOS‡	**LOS of C or D** produced using this approach alone or combined with abrasives	**LOS of C or D** produced using this approach alone or combined with plowing
Positive Impacts	● Directly remove snow and ice from road surface ● Provides for mobility ● Helps reduce treatment material usage	● More effective than chemicals at low temperatures and for spot traction - hills, curves, intersections, shaded areas ● Provides for mobility ● Useful alternative in environmental sensitive locations (no salt roads)
Negative Impacts	● Degraded LOS versus targeted levels when used alone or in combination with only abrasives ● Reduced mobility, slower traffic speeds when used alone	● Degraded LOS versus targeted levels when used alone or in combination with only plowing ● Recovery from storms slower when used alone or in combination with only plowing ● More passes and applications required than if chemicals used ● Does not ensure safety and the mobility as well as alternative materials
Pros and Cons	**Pros** ● Improved safety (less crashes) ● Combination blades provide reduced noise, vibration, driver fatigue and longer life **Cons** ● Recovery from storms slower when used alone or in combination with only abrasives	**Pros** ● Ability to provide traction ● Improved safety (less crashes) ● Materials from clean up can be reused or employed elsewhere (ex. shoulders) **Cons** ● Cannot achieve deicing ● Not recommended for use on high traffic volume or high speed roads. ● Impacts on PM10 attainment ● Damage to vehicles and increased claims ● Require clean up after winter season ● Recovery from storms slower when used alone or in combination with only plowing
Respective Performance	**Blade life - miles** ● Carbide blades -809 to 3,600+ *(Iowa DOT, 2010)* ● Steel blades - 1,200 to 1,500 ● Combination blades - 300 to 4,430+ *(Iowa DOT, 2010)* ● Ceramic blades - ● Rubber blades - **Labor hours to complete replacement** ● Avg - 1 - 2 hrs ● Carbide blades - 1 - 2 hrs ● Steel blades - 1/2 - 2 hrs ● Combination blades - 4 - 5 hrs ● Ceramic blades - 1 - 2 hrs ● Rubber blades - 1 - 2 hrs	● Application rates per lane mile - 500 - 1500 lbs *(from survey response)* (Typical 400 - 1000 lbs/l-m) ● Abrasive-salt mix ratio range - 7% salt - 93% abrasive to 50% salt - 50% abrasive ● Gradations/sizes - 3/8 in. most common, range 1/4 - 1/2 in.
Environmental Impacts	● Minimal, only clear the roadway surface and at most move materials (abrasives, chemicals) to the roadside	● Abrasives can enter the water ways and clog streams and clog drains, can impact water quality and aquatic species. Can impact air quality. ● Can be left on gravel roads without clean up after season ● Straight abrasive use does not pose corrosion issues, but abrasive-salt mixes can
B/C ratio	5.32	0.22

Maintenance operation	Intermediate Activities: Solid salt (NaCl) for anti-icing and deicing	Intermediate Activities: Salt Brine for anti-icing and deicing
Value of Costs	**Average cost/ton** - $71.04 (range - $48.63 - $120.00) **Average cost of anti-icing / lane mile** - $68.41 (range - $39.47 - $100.00)	**Average cost of brine (per gallon)** - $0.16 (range $0.05 - $0.35) **Average costs of brine production and application / lane mile** - $37.92 (range - $5.91 - $78.94) **Average cost of anti-icing / lane mile - $68.41** (range - $39.47 - $100.00) **Average brine-making equipment cost** - $89,273 (range - $7,000 - $250,000)
Value of Benefits	**1/3 reduction in material applications versus abrasives** **Estimated granular salt annual cost/lane mile** - $4,784 **Estimated granular salt annual benefit/lane mile** - $11,357	**Estimated salt brine annual cost/lane mile** - $2,964 **Estimated salt brine annual benefit/lane mile** - $11,290 **Brine use reduces granular salt use by up to 30%**
Effectiveness in Achieving LOS‡	**LOS of B** produced using this approach combined with plowing	**LOS of B** produced using this approach combined with plowing
Positive Impacts	● Increased LOS over Basic practices ● Improved public safety and mobility ● Prevent snow and ice from bonding to pavement ● Improved melting capacity	● Increased LOS over Basic practices ● 28% - 83% crash reduction versus untreated roads ● Prevents snow and ice from bonding to pavement (anti-icing) ● Improved melting capacity ● 62% labor cost reduction (anti-icing) ● Reduced granular scatter (prewetting)
Negative Impacts	● Corrosion ● Impacts on roadside and waterways ● Potential animal attractant ● Pavement deterioration	● Corrosion ● Impacts on roadside and waterways ● Potential animal attractant ● Difficulty in handling and application ● Pavement deterioration
Pros and Cons	**Pros** ● Faster recovery time ● Improved safety versus Basic practices ● Melting capacity ● Low cost of material ● Ease of application **Cons** ● Environmental impacts ● Corrosion ● Public feedback	**Pros** ● Low cost of material ● Improved safety and mobility ● Reduced pavement marking wear **Cons** ● Corrosion ● Environmental impacts ● Special storage and handling may be needed if storing over summer or if longer storage is required
Respective Performance	● Application rates -25 - 600 pounds/lane mile *(from survey response)* (Typical 100 - 800 lbs/l-m)	● Application rates (on road) -11 - 100 gallons/lane mile (from survey response) (Typical 10 - 40 gal/l-m) ● Application rates (prewet solids) - 5 - 17.8 gals/ton (or 10% to 23%) (from survey response) (Typical 8 - 20 gal/l-m) ● Up to 10% - 20% cost savings in total winter maintenance budget (anti-icing) ● 400% increase in chemical cost /lane mile (anti-icing) ● Cost savings of $1,266 to $30,152 / typical maintenance snowplow truck route / year (anti-icing)
Environmental Impacts	● Entry into waterways ● Impact to roadside soil, vegetation ● Corrosion to vehicles and infrastructure	● Entry into waterways ● Impact to roadside soil, vegetation ● Corrosion to vehicles and infrastructure
B/C ratio	2.37	3.8

‡ Level of service (LOS) defined as:
A – Bare pavement: wet, extensive chemical use and plowing to achieve this condition and maintain normal travel speeds.
B – Bare wheel paths: some slush, plowing and chemical applications being made, maintenance performed to maintain roadway being open to near normal travel.
C – Fair condition: wheel paths may or may not be visible, some snowpack remaining, chemical use and plowing performed but travel ability is reduced.
D – Poor condition: maintenance is being performed, but snowpack across the roadway. Travel ability is diminished or reaching the point where it is not advisable.

Maintenance operation	Advanced Activities		
	Corrosion inhibitors	Inhibited salt brine	Magnesium Chloride
Value of Costs	**Average cost per gallon** - $1.18 (range $0.78 to $1.50) **Cost per ton** - $650.00 **Cost per lane mile** - $695.55 to $1652.93 **Liquid storage (tank, pump, hose and nozzle) setup for stockpile prewetting** - $3,000.00	**Average cost per gallon** - $0.31 (range - $0.12 - $0.50)	**Inhibited solid cost / ton** - $150.00 **Inhibited liquid cost / gallon** - $1.00 - $1.50 **Uninhibited liquid cost / gallon** - $1.20
Value of Benefits	**See specific materials below**	**50% and 70% less corrosive than salt brine**	**Estimated Magnesium Chloride annual cost/lane mile** - $3,408 **Estimated Magnesium Chloride annual benefit/lane mile** - $12,165 **Corrosion inhibited Magnesium Chloride at least 75% less corrosive than granular salt**
Effectiveness in Achieving LOS‡	**Dependent on the specific treatment material being used**	**LOS of B** produced using this approach combined with plowing	**Comparable LOS to salt and salt brine at 1/2 the application rate**
Positive Impacts	● Better cold temperature performance ● Improved safety and mobility ● Prevents snow and ice from bonding to pavement ● Public vehicle protection ● Increased service life of agency vehicles	● Reduced salt and abrasive use ● Better cold temperature performance ● Improved safety ● Cost savings	● Prevents snow and ice from bonding to pavement (anti-icing) ● Reduced salt and abrasive use ● Better cold temperature performance ● Improved safety and mobility ● Reduced amount of product used ● Cost savings ● Reduced corrosion (inhibited materials) ● Reduced number of application vehicles needed
Negative Impacts	● High cost of products	● Impacts on roadside and waterways ● Material cost ● Difficulty in handling and application ● Pavement deterioration	● Pavement deterioration ● Increased corrosion (uninhibited materials) ● Environmental impacts ● Difficulty in handling and application ● Material cost
Pros and Cons	**Pros** ● Improved LOS at lower temperatures ● Reduced corrosion to vehicles and infrastructure ● More rapid melt ● Improved roadway condition in less time **Cons** ● Cost of materials ● Politics of using inhibitors	**Pros** ● Improved LOS at lower temperatures ● Better performance **Cons** ● Cost of materials ● Requires more frequent applications (2x more than MgCl) ● Special storage and handling may be needed if storing over summer or if longer storage is required	**Pros** ● Persists on the road surface, aiding in longer black ice prevention ● Reduced applications needed ● Reduced scatter with solid materials (prewet) ● Achieve LOS faster than with other products **Cons** ● Can cause slick conditions when anti-icing if over applied in certain conditions ● Cost of materials ● Special storage and handling may be needed if storing over summer or if longer storage is required
Respective Performance	● Inhibited salt (NaCl) brine 50% and 70% less corrosive than salt brine ● Corrosion inhibited Magnesium Chloride at least 75% less corrosive than granular salt (NaCl)	● Average application rate gals/lane mile - 36 (or 20 - 100 gals/lane mile)	Application rates: ● Inhibited solid - 180 - 220 lbs/lane mile ● Uninhibited solid - 100 - 300 lbs/lane mile, up to 500 lbs/l-m ● Inhibited liquid - 15 - 150 gals/lane mile or 6-10 gals/ton ● Uninhibited liquid - 5 -15 gals/lane mile (typical 10 - 40 gal/l-m) ● Used when temperatures were below 22°F ● Blended with salt brine for temperatures below 20°F ● Mixed with stockpiles to prevent freezing
Environmental Impacts	● Potential impact to waterways ● Potential impact to roadside	● Less public complaints about vehicle corrosion after switching from corrosion inhibited magnesium chloride ● Entry into waterways ● Impact to roadside	● More public complaints with vehicle corrosion versus inhibited salt brine ● Entry into waterways ● Impact to roadside ● Impact to bridge infrastructure ● Leaching/run-off from stockpiles ● Products are not animal attractants
B/C ratio	Not able to be calculated at this time	3.8	3.57

Maintenance operation	Advanced Activities	
	Calcium Chloride	Blended products
Value of Costs	**Inhibited liquid cost / gallon** - $1.00 - $2.80 **Uninhibited liquid cost / gallon** - $0.40 - $1.09 **Uninhibited solid cost / ton** - $340.00-$450.00 **Inhibited solid cost / ton** - $963.50	**Inhibited liquid cost / gallon** - $0.50 - $2.80
Value of Benefits	**Estimated Calcium Chloride annual cost/lane mile** - $3,048 **Estimated Calcium Chloride annual benefit/lane mile** - $11,672	**Estimated ag by-product annual cost/lane mile** - $3,241 - $3,328 **Estimated ag by-product annual benefit/lane mile** - $12,675 - $12,921
Effectiveness in Achieving LOS‡	**Comparable LOS to salt and salt brine at 1/2 the application rate**	**Comparable LOS to salt and salt brine at 1/2 the application rate**
Positive Impacts	● Prevent snow and ice from bonding to pavement (anti-icing) ● Better cold temperature performance ● Improved safety and mobility ● Cost savings ● Reduced amount of product used ● Reduced salt and abrasive use ● Reduced number of application vehicles needed	● Better cold temperature performance ● Reduced need for salt and abrasives ● Improved safety and mobility ● Cost savings ● Reduced amount of product used ● Longer lasting applications
Negative Impacts	● Pavement deterioration ● Increased corrosion ● Environmental impacts ● Material cost ● Difficulty in handling and application	● Environmental impacts ● Material cost ● Pavement deterioration ● Increased corrosion ● Difficulty in handling and application
Pros and Cons	**Pros** ● Reduced product used ● Better performance at low temperatures ● Public feedback ● Liquids easier to handle than solids ● Mixes well with salt brine **Cons** ● Cost of materials ● Special storage and handling may be needed if storing over summer or if longer storage is required	**Pros** ● Reduced product used ● Longer lasting applications ● More effective than salt and abrasives **Cons** ● Cost of materials ● A high level of accuracy required for mixing correct ratio ● Special storage and handling may be needed if storing over summer or if longer storage is required
Respective Performance	Application rates ● Inhibited liquid - 8-30 gals/lane mile to pretreat, 1.5-5 gals/ton for "hot loads" ● Inhibited solid - 300-500 lbs/lane mil ● Uninhibited liquid - 6-8 gals/ton to pre-wet, 13 gals/lane mile ● Uninhibited solid - spot treatment ● Mixed with salt for temperatures below 25°F ● Mixed with salt brine and beet juice for temperatures below 25°F ● Used when temperatures were below 10°F ● Mixed with stockpiles to prevent freezing	Application rates ● Inhibited liquid - 9-150 gals/lane mile, 2.5-35 gals/ton for pre-wetting ● High ice melting capacity ● Low effective temperature ● Mixed with salt brine
Environmental Impacts	● Entry into waterways ● Impact to roadside ● Products are not animal attractants	● Entry into waterways ● Impact to roadside ● Products are not animal attractants ● Leaching/run-off from stockpiles ● Complaints from mechanics about aluminum corrosion
B/C ratio	3.83	3.81 - 3.99

Chapter 5
Conclusions and Recommendations

Various costs and benefits are incurred while performing winter maintenance operations. However, a summary of these costs and benefits for different maintenance scenarios has not been compiled to date. The information contained in this report provides all levels of decision-makers with information on which to base sound decisions. In doing so, agencies could better maximize the LOS relative to the maintenance strategy's cost and have a mechanism to explain the available options, their costs, benefits, and consequences to various stakeholders, including DOT personnel, legislators, and the general public.

In order to facilitate the summary of cost and benefit information, it was first necessary to identify past work that identified the quantified and non-quantified costs and benefits of the three different winter maintenance strategies of interest to this project. The first strategy included was basic and consisted of actions performed to maintain traveler mobility and safety, including plowing and the use of abrasives (sanding). A second, intermediate strategy reflected an improvement over the basic approach. It consisted of plowing and the use of some abrasives in spot locations, but also relied on salt in solid or liquid forms for anti-icing and deicing. The third strategy uses magnesium chloride, calcium chloride, and blended products such as corrosion-inhibiting liquids and/ or treated or chemically enhanced solid chemicals in anti-icing and deicing to address the corrosion risks associated with untreated materials. This strategy allows for the selection of specific chemicals that will work best in a specific climatic region or temperature range, avoiding the overuse of salt or salt brine at colder temperatures as may be the case in the second strategy. Collectively, these three approaches employ various equipment and materials. Literature related to these various components was identified and summarized during the course of a literature review, the results of which have been presented in this document.

Some components of the various strategies of interest have better cost and benefit information available than others. This is particularly true of sanding/abrasives and use of road salt (sodium chloride). This may stem from their historical use over time, because they have been the most common treatments used by maintenance agencies. Historically, salting approaches have been recorded to provide benefits that generally exceed the costs associated with them. For example, they have been shown to reduce crashes and improve or maintain mobility (travel time and speeds).

The costs and benefits of snow plows, which represent the other common approach employed historically by agencies, have not been as well defined. It is possible that agencies have difficulty separating the contribution of plowing versus material usage. As more automated recording technologies are employed by agencies in winter maintenance, comparing the contributions of various activities occurring simultaneously or individually should become more feasible. For example, sensors recording information such as plow status (up versus down) and material applications on the same vehicle can address this shortcoming.

Other, more recently developed and employed approaches and materials (e.g. prewetting and materials such as magnesium chloride and calcium chloride), have more limited cost and benefit information published. While the cost of the equipment and materials are available from agency records (although it did not appear in literature), benefit information is generally lacking outside of generalized terms. Such information gaps were determined through an agency survey conducted for this project. The intent of such a survey is to develop a reasonable value range for costs and benefits that do not have quantified values available in literature. The survey would also seek to obtain any quantified information that an agency may have that has not appeared in literature.

As one would expect, there are a number of different environmental impacts associated with different components of each maintenance strategy. This is particularly true of materials, each of which had positive and negative impacts on the environment. In some cases, equipment or practices can be employed to reduce this impact. For example, the use of prewetting can facilitate adhesion and enhance melting action of granular chemicals, such as salt and magnesium chlorides. Similarly, wetting abrasives with hot water can enhance adhesion to ice and snow covered pavements, reducing bounce and scatter into the roadside environment. Research has shown prewetting of sand to provide up to 25 percent material savings, and prewetting rock salt to provide 20 to 33 percent material savings. Additionally, one researcher found $CaCl_2$ to be 9.5 to 71.4 percent more effective as a prewetting agent and outperformed $MgCl_2$.

The results of the survey and interviews have been incorporated into the benefit-cost matrices. In general, the survey and interviews identified Basic and Intermediate Activities as the most commonly used winter maintenance strategies. This includes plowing, use of abrasives, use of solid and liquid salt (sodium chloride) for deicing and anti-icing. Less commonly reported was the use of the Advanced Activities including the use of corrosion inhibitors, inhibited salt brine, magnesium chloride, calcium chloride, or blended products. This may be indicative of these winter maintenance strategies being less commonly employed, a result of who responded to the survey and interviews, or the result of survey fatigue. Gathering information on costs associated with the various winter maintenance strategies from the individuals surveyed and interviewed was a challenge. This highlights the need for easy to use cost-tracking tools for use by winter maintenance professionals.

The information gathered in the literature review, surveys, and interviews was used to populate the developed benefit-cost matrix. The matrix is presented as three sub-matrices Basic Activities, Intermediate Activities, and Advanced Activities. Within each sub-matrix information is reported on the cost, benefits, effectiveness in achieving LOS, positive and negative impacts, pros and cons, respective performance, environmental impacts, and the calculated benefit-cost ratio where possible.

Table 10 Summary of winter maintenance strategies and the calculated benefit-cost ratios.

Activities	Winter Maintenance Strategy	Benefit/Cost Ratio
Basic	Plowing	5.3
	Abrasives	0.2
Intermediate	Rock salt (solid NaCl)	2.4
	Salt brine (liquid NaCl)	3.8
Advanced	Corrosion inhibitors	8.0-13.2*
	Inhibited salt brine	3.8
	Magnesium Chloride ($MgCl_2$)	3.6
	Calcium Chloride ($CaCl_2$)	3.8
	Blended products	3.8 - 4.0

*The B/C ratios represent the use of proactive maintenance and corrosion prevention. Calculated by Shi et al., 2013a; Honarvarnazari et al., 2015.

The benefit-cost ratio was calculated based on cost data per lane mile. Benefit-cost ratios were able to be calculated for all winter maintenance strategies with the exception of the use of corrosion inhibitors, where not enough information was available to successfully calculate a benefit-cost ratio. Table 10 shows the calculated benefit-cost ratio for the various winter maintenance strategies.

Knowledge Gaps and Recommendations

Based on the literature review presented in this document, survey and follow-up interviews specific knowledge gaps associated with the components for each maintenance strategy of interest could be identified. In reviewing the information presented in this report, it is clear that some components of the different maintenance strategies have better defined information than others. This is particularly true of sanding and salt use. It stands to reason that these aspects have more detailed information available, because they represent the approaches that have been in use for decades at agencies. Newer materials and equipment often lack detailed information on costs and benefits. In some cases, cost information can vary significantly due to the quantities being purchased by an agency, the location of the agency versus the procurement source, and so forth. As a result, such information does not necessarily get discussed in existing literature. This highlights the need for detailed cost data in general, but specifically a cost analysis of corrosion inhibitors and agriculturally derived products. This could be aided by the development of an easy to use cost tracking tool.

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Appendix A
Survey Questionnaire

Overview

This survey is being undertaken by the Western Transportation Institute, Montana State University, and is sponsored by the Clear Roads Pooled Fund, to obtain information about the costs and benefits associated with different winter maintenance operations and materials. The specific operations and materials of interest to this work consist of three tiers:

I. Basic activities including plowing and the use of abrasives.

II. Intermediate activities including plowing, spot abrasive use, and the use of salt and/or salt brine (NaCl) for anti-icing and deicing.

III. Advanced activities including the selection and use of alternative chemicals, corrosion-inhibited liquids and/ or treated or chemically enhanced solid chemicals to match performance with environmental conditions for anti-icing and deicing, with plowing and possible spot use of abrasives.

The objective of this survey is to better understand the dollar values that may be associated with the components of these different tiers based on practical experience and to identify the Level of Service (LOS) achieved by each. Note that certain practices may not yield the LOS that an agency is looking for, and this may require the use of different practices in combination or on specific routes, and the participant should bear this in mind when completing the survey. In addition, this survey also seeks any other information you may have regarding the winter maintenance operations and materials that may be of interest to this work. In terms of dollar values, estimated values based on professional experience are sufficient; it is understood that the time required to look up records of specific values is prohibitive for a participant, but greatly appreciated.

If you would like to participate in this survey, please begin by answering the questions that follow. The survey may take up to 60 minutes of your time, depending on the approaches used by your agency and their complexity. You may provide this survey to others in your agency / organization as well. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

Important: To save your answers and finish later, **click "Next" to save what you've entered on the current page**, even if you're not finished with that page. When you reopen the survey **on the same computer**, the survey will open to the last page you were working on. Use the "Prev" and "Next" buttons to navigate to unfinished pages. If you're unable to retrieve your responses, please contact David Veneziano at 406-994-6320 or david.veneziano@coe.montana.edu.

Your contact information will only be used by the researchers for the purposes of this study. The researchers will not contact you for any other reason and your contact information will not be released or shared for any other reason. For questions about the research project, contact David Veneziano at 406-994-6320 or david.veneziano@coe.montana.edu. For questions regarding your rights as a human subject, contact Mark Quinn, IRB Chair, 406-994-4707 or mquinn@montana.edu.

Background Information

Important: To save your answers and finish later, **click "Next" to save what you've entered on the current page**, even if you're not finished with that page. When you reopen the survey **on the same computer**, the survey will open to the last page you were working on. Use the "Prev" and "Next" buttons to navigate to unfinished pages. If you're unable to retrieve your responses, please contact David Veneziano at 406-994-6320 or david.veneziano@coe.montana.edu.

1. Contact Information

Name:

Agency (Region)/Title:

Mailing Address:

City:

State:

Zip Code:

Email address:

Phone Number:

2. Please provide some basic background on your agency and operations:

Number of plow vehicles

Number of winter maintenance practitioners/employees (incl. full and part time winter maintenance employees)

Number of lane miles maintained

Number of winter storm events per season

Average annual accumulative snow depth (inches)

*3. Does your agency employ basic activities for winter maintenance, including plowing and/or the use of abrasives?

◯ Yes

◯ No

Basic Practices

Basic Practices – includes plowing and/or the use of abrasives.

4. What is your agency's Level of Service using mainly the practices already in place and what would it be using only plowing and/or abrasives (please describe)?

5. What has the impact of this practice been on the mobility of the public (please describe)?

6. Has your agency observed a reduction in crashes using these practices compared to other winter maintenance practices? Reports or figures may be submitted via this upload link.

7. Do you have any information on the number of passes or applications needed to achieve an LOS for a given condition for this approach versus another practice?

Basic Practices

***8. Does your agency use plowing as part of its maintenance operations?**

- ◯ Yes
- ◯ No

Basic Practices

9. What types of plows does your agency employ? (Select all that apply)

- ☐ Front plows
- ☐ Tow Plows
- ☐ Underbody Plows
- ☐ Wing Plows
- ☐ Rotary Plows or snowblowers
- ☐ Tandem/Gang Plowing
- ☐ Motor Graders

Other (please explain)

10. Please provide an estimate of the annual average cost per lane mile of responsibility to plow at your agency.

11. How important are the following plowing capabilities to you? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Removes snow and ice from the road	◯	◯	◯
Reduced number of vehicle passes	◯	◯	◯
Reduced treatment material usage	◯	◯	◯
Reduced personnel hours	◯	◯	◯

Other (please specify)

12. What type of blade inserts do you use? (Select all that apply)

- ☐ Standard steel
- ☐ Carbide steel
- ☐ Combination blades (rubber, steel and carbide, such as JOMA 6000)
- ☐ Full rubber or rubber encased steel
- ☐ Ceramic

Other (please specify)

13. How many plow miles does your agency achieve per blade set?

14. Approximately how many man hours are required to replace blade inserts for one truck?

15. What is the average hourly loaded labor rate for your personnel?

16. Please list or discuss any specific costs or benefits (ex. effective for snow and ice removal, expensive to replace inserts, etc.) you would like to share regarding plowing, plow types, and blade inserts.

Abrasives

***17. Does your agency use abrasives as part of its maintenance operations?**

- ◯ Yes
- ◯ No

Abrasives

18. When/how are they used?

- ☐ System-wide (all routes)
- ☐ Intersection approaches
- ☐ Curves
- ☐ Bridges
- ☐ Hills
- ☐ Shaded areas
- ☐ Windblown areas
- ☐ Low temperature events

Other (please specify)

19. What abrasive materials are used? (Select all that apply)

- ☐ Abrasives
- ☐ Abrasive-salt mix (Please indicate what percent mix is used in the "Other" text box.)

Other (please specify)

20. What abrasive gradation(s) are used by your agency? Note, if you have gradation information in a table, please submit it via this upload link. Otherwise, provide gradation examples that most closely represent those your agency uses.

21. What is the approximate cost per ton of each specific abrasive material being used?

22. How many tons of abrasives (straight and/or salt-mixed) are applied annually by your agency?

23. How important are the following benefits of using abrasives? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Low cost of material	◯	◯	◯
Ease of application	◯	◯	◯
Provide traction	◯	◯	◯

Other (please specify)

24. Do you have any specific values or information on any of these benefits (please list)?

***25. Does your agency have an abrasive clean-up program in place?**

◯ Yes

◯ No

Abrasive clean-up

26. Is cleanup performed by (select all that apply):

☐ Agency personnel

☐ Contracted out

27. What is the approximate cost to clean up abrasives per mile?

28. What is the approximate cost to dispose of spent abrasives?

29. Does your agency recycle abrasives? (If yes please explain)

Abrasives

30. How important are the following negative aspects of using abrasives? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Entry of abrasives into waterways	☐	☐	☐
Increased dust/air pollution	☐	☐	☐
Vehicle damage (ex. chipped windshields)	☐	☐	☐
Does not provide deicing capacity	☐	☐	☐

Other (please specify)

31. Do you have any specific cost information for any of the negative aspects of abrasives mentioned above (please list)?

Intermediate Practices

***32. Does your agency employ Intermediate activities, such as the use of solid salt (NaCl) or salt brine for anti-icing and deicing (in addition to Basic activities such as plowing and spot abrasive use)?**

◯ Yes

◯ No

Intermediate Practices

Intermediate activities include the use of salt and/or salt brine (NaCl) for anti-icing and deicing (with possible use of plowing and spot abrasive use).

33. What is your agency's Level of Service using mainly the practices already in place and what would it be using only Intermediate practices (please describe)?

34. What has the impact of Intermediate practices been on the mobility of the public (please describe)?

35. Has your agency observed a reduction in crashes using these Intermediate practices compared to other winter maintenance practices? Reports or figures may be submitted via this upload link.

36. Do you have any information on the number of applications needed to achieve an LOS for a given condition using Intermediate versus another practice?

***37. Does your agency use solid salt?**

- Yes
- No

Solid Salt

38. Approximately how many tons per year are used?

39. What is the approximate cost per ton delivered?

40. Please provide your table of application rates, either in the text box provided or via this upload link.

41. How important are the following aspects associated with the use of salt? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost of material itself	◯	◯	◯
More difficult to handle and/or apply	◯	◯	◯
Environmental impacts to the roadside	◯	◯	◯
Increased corrosion	◯	◯	◯
Pavement deterioration	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

42. How important are the following benefits associated with the use of salt? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Melting capacity	◯	◯	◯
Clear roads of snow and ice	◯	◯	◯
Ease of use/application	◯	◯	◯
Low cost of material	◯	◯	◯

Other (please specify)

Salt-abrasive mix

*43. Does your agency use a salt-abrasive mix?

◯ Yes

◯ No

Salt-abrasive mix

44. What ratio of solid salt to abrasive material is used?

45. Please provide your table of application rates, either in the text box provided or via this upload link.

Salt Brine

***46. Does your agency use salt brine?**

- ◯ Yes
- ◯ No

Salt Brine

47. Approximately how many gallons per year are used?

48. Do you manufacture your salt brine or purchase it? (Select all that apply)

- ☐ Manufacture
- ☐ Purchase

49. What is the approximate cost per gallon delivered?

50. Please provide your table of application rates, either in the text box provided or via this upload link.

51. How important are the following aspects associated with the use of salt brine? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost of material itself	◯	◯	◯
More difficult to handle and/or apply	◯	◯	◯
Environmental impacts to the roadside	◯	◯	◯
Increased corrosion	◯	◯	◯
Pavement deterioration	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

52. How important are the following benefits associated with the use of salt brine? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Melting capacity	◯	◯	◯
Clear roads of snow and ice	◯	◯	◯
Ease of use/application	◯	◯	◯
Low cost of material	◯	◯	◯

Other (please specify)

Prewetting

***53. Does your agency prewet or pretreat (before material is loaded) with salt brine?**

◯ Yes

◯ No

Prewetting

54. What does your agency prewet? (Select all that apply)

☐ Abrasives

☐ Solid Salt

Other (please specify)

55. How does your agency perform prewetting? (Select all that apply)

- [ ] At the pile
- [ ] At the spreader
- [ ] Use of slurry spreading
- [ ] Shower wetting of a truckload

Other (please specify)

56. What percentage of brine is used for prewetting solid material?

57. If your agency is using a slurry spreader, has it been able to reduce application rates, and if so by how much?

58. What percentage of brine is used for direct application?

59. Please provide an estimate of the annual cost associated with producing and applying salt brine at your agency (equipment, materials, labor, etc.).

60. How important are the following benefits of prewetting and/or pre-treating? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Reduced granular product used	○	○	○
Reduce the amount of product lost into the environment (bounce and scatter)	○	○	○
Achieve faster melt	○	○	○
Increased range of maintenance vehicles between reloads	○	○	○
Reduced vehicle patrol hours	○	○	○
Reduced personnel hours	○	○	○

Other (please specify)

Anti-icing with salt or salt brine

***61. Do you perform anti-icing using salt or salt brine?**

- ◯ Yes
- ◯ No

Anti-icing with salt or salt brine

62. What equipment do you use to apply anti-icers?

63. Please provide an estimate of the annual cost associated salt/salt brine anti-icing operations at your agency (equipment, materials, labor, etc.).

64. How important are the following benefits of salt/salt brine anti-icing? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Reduced amount of product used	◯	◯	◯
Reduced number of application vehicles needed	◯	◯	◯
Cost savings	◯	◯	◯
Improved safety	◯	◯	◯
Reduced impacts to the environment	◯	◯	◯
Reduced impacts to vehicles and infrastructure	◯	◯	◯

Other (please specify)

Brine making

***65. Does your agency make salt brine?**

- ◯ Yes
- ◯ No

Brine Making

66. What are the approximate annual costs ($) associated with the following:

Equipment	
Transport (if product shipped to other locations)	
Input materials	
Fuel cost	
Transport truck maintenance	
Labor	
Other costs? (please specify)	

67. How important are the following benefits of brine making? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Can make as needed	☐	☐	☐
Quality Control	☐	☐	☐
Can control amount produced	☐	☐	☐
Cost savings (please provide an approximate estimate in the "Other" text box)	☐	☐	☐

Other (please specify)

Advanced Practices

*68. Does your agency use Advanced Practices? These include the selection and use of alternative chemicals, corrosion-inhibited liquids and/or treated or chemically enhanced solid chemicals to match performance with environmental conditions for anti-icing and deicing (in addition to Basic and Intermediate activities such as plowing and use of salt, salt brine and/or abrasives).

- ◯ Yes
- ◯ No

Advanced Practices

Advanced Practices include the selection and use of alternative chemicals, corrosion-inhibited liquids and/or treated or chemically enhanced solid chemicals to match performance with environmental conditions for anti-icing and deicing (in addition to possible use of Basic and Intermediate activities such as plowing and use of salt, salt brine and/or abrasives).

69. How much did advanced practices impact your organization's Level of Service? (please describe)?

70. What has the impact of Advanced practices been on the mobility of the public (please describe)?

71. Has your agency observed a reduction in crashes using Advanced practices compared to other winter maintenance practices? Reports or figures may be submitted via this upload link.

***72. Does your agency use corrosion inhibitors with your winter maintenance products?**

- ◯ Yes
- ◯ Yes, in some areas
- ◯ No

Corrosion Inhibitors - Materials come in different forms or fashions includ...

73. What corrosion inhibiting product(s) does your agency use? (Name/Brand)

74. What is the approximate cost of the material used? (per gallon or per ton)

75. Please provide and describe any additional costs associated with the use of the corrosion inhibitor(s) not included in the purchase price (storage, handling, etc.):

76. How important are the following benefits of the corrosion inhibitor(s)? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Public vehicle protection	◯	◯	◯
Increased service life of agency's vehicles	◯	◯	◯
Reduced corrosion to equipment (if so please explain below)	◯	◯	◯
Reduced corrosion to infrastructure (if so please explain below)	◯	◯	◯

Other (please specify)

Inhibited Salt Brine

***77. Does your agency use inhibited salt brine?**

◯ Yes

◯ Yes, in some areas

◯ No

Inhibited Salt Brine

78. What application rate is used when applying this material? (per lane mile)

79. How much do you pay for this material (per gallon or ton)?

80. What equipment do you use to apply this material?

81. How do you use your inhibited salt brine and where do you use it?

82. Have you applied this material in combination with other products (like pre-wetting) ?

◯ Yes

◯ No

83. Do you have any information on the number of applications needed to achieve an LOS for a given condition versus another product?

84. Please provide an estimate of the annual cost associated inhibited salt brine operations at your agency (equipment, materials, labor, etc.):

85. How important are the following aspects associated with using inhibited salt brine? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost of material itself	◯	◯	◯
More difficult to handle and/or apply	◯	◯	◯
Environmental impacts to the roadside	◯	◯	◯
Increased corrosion	◯	◯	◯
Pavement deterioration	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

86. How important are the following benefits you have observed or experienced from using inhibited salt brine? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost savings	◯	◯	◯
Improved safety	◯	◯	◯
Reduced amount of product used	◯	◯	◯
Reduced number of application vehicles needed	◯	◯	◯
Better performance at cold temperatures	◯	◯	◯
Reduces need for salt and/or sand	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

Magnesium Chloride

***87. Does your agency use Magnesium chloride?**

- ◯ Yes
- ◯ No

Magnesium Chloride

88. In what form do you use magnesium chloride? (Select all that apply)

- ☐ Inhibited Liquid
- ☐ Uninhibited Liquid
- ☐ Inhibited Solid
- ☐ Uninhibited Solid

Other (please specify)

89. What application rate is used when applying this material? (per lane mile)

90. How much do you pay for this material (per gallon or ton)?

91. What equipment do you use to apply this material?

92. How do you use magnesium chloride and where do you use it?

93. Have you applied this material in combination with other products (like pre-wetting) ?

- ◯ Yes
- ◯ No

94. Do you have any information on the number of applications needed to achieve an LOS for a given condition versus another product?

95. Please provide an estimate of the annual cost associated magnesium chloride operations at your agency (equipment, materials, labor, etc.):

96. How important are the following aspects associated with using magnesium chloride? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost of material itself	◯	◯	◯
More difficult to handle and/or apply	◯	◯	◯
Environmental impacts to the roadside	◯	◯	◯
Increased corrosion	◯	◯	◯
Pavement deterioration	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

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97. How important are the following benefits you have observed or experienced from using magnesium chloride? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost savings	◯	◯	◯
Improved safety	◯	◯	◯
Reduced amount of product used	◯	◯	◯
Reduced number of application vehicles needed	◯	◯	◯
Better performance at cold temperatures	◯	◯	◯
Not an animal attractant	◯	◯	◯
Reduces need for salt and/or sand	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

98. Using a magnesium chloride, do you see a savings versus a straight salt brine of:

- ☐ Reduction in vehicle refresh rates
- ☐ Reduction in applications
- ☐ Longer timeframe for black ice prevention

Other (please specify)

Calcium Chloride

***99. Does your agency use calcium chloride?**

- ◯ Yes
- ◯ No

Calcium Chloride

100. In what form do you use calcium chloride? (Select all that apply)

- [ ] Inhibited Liquid
- [ ] Uninhibited Liquid
- [ ] Inhibited Solid
- [ ] Uninhibited Solid

Other (please specify)

101. What application rate is used when applying this material? (per lane mile)

102. How much do you pay for this material (per gallon or ton)?

103. What equipment do you use to apply this material?

104. How do you use calcium chloride and where do you use it?

105. Have you applied this material in combination with other products (like pre-wetting) ?

- ( ) Yes
- ( ) No

106. Do you have any information on the number of applications needed to achieve an LOS for a given condition versus another product?

107. How important are the following aspects associated with using calcium chloride? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost of material itself	◯	◯	◯
More difficult to handle and/or apply	◯	◯	◯
Environmental impacts to the roadside	◯	◯	◯
Increased corrosion	◯	◯	◯
Pavement deterioration	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

108. How important are the following benefits you have observed or experienced from using calcium chloride? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost savings	☐	☐	☐
Improved safety	☐	☐	☐
Reduced amount of product used	☐	☐	☐
Reduced number of application vehicles needed	☐	☐	☐
Better performance at cold temperatures	☐	☐	☐
Not an animal attractant	☐	☐	☐
Reduces need for salt and/or sand	☐	☐	☐
Public feedback	☐	☐	☐

Other (please specify)

Blended Products - agricultural byproducts blended with de-icing and anti-i...

*** 109. Does your agency use blended products?**

◯ Yes

◯ No

Blended Products

Blended Products - agricultural byproducts blended with de-icing and anti-icing chemicals.

110. What type(s) of blended product do you use?

111. Is the product inhibited or uninhibited?

- [ ] Inhibited
- [ ] Uninhibited

112. What application rate is used when applying this material? (per lane mile)

113. How much do you pay for this material (per gallon or ton)?

114. What equipment do you use to apply this material?

115. How do you use blended products and where do you use them?

116. Have you applied this material in combination with other products (like pre-wetting) ?

- ◯ Yes
- ◯ No

117. Do you have any information on the number of applications needed to achieve an LOS for a given condition versus another product?

118. Please provide an estimate of the annual cost associated blended product operations at your agency (equipment, materials, labor, etc.):

119. How important are the following aspects associated with using blended products? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost of material itself	◯	◯	◯
More difficult to handle and/or apply	◯	◯	◯
Environmental impacts to the roadside	◯	◯	◯
Increased corrosion	◯	◯	◯
Pavement deterioration	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

120. How important are the following benefits you have observed or experienced from using blended products? (Select all that apply)

	Very Important	Somewhat Important	Not Important
Cost savings	◯	◯	◯
Improved safety	◯	◯	◯
Reduced amount of product used	◯	◯	◯
Longer lasting applications	◯	◯	◯
Reduced number of application vehicles needed	◯	◯	◯
Better performance at cold temperatures	◯	◯	◯
Not an animal attractant	◯	◯	◯
Reduces need for salt and/or sand	◯	◯	◯
Public feedback	◯	◯	◯

Other (please specify)

Chemical Selection to Achieve LOS

Chemical selection to achieve LOS using deicing/anti-icing agents such as salt, brine or alternative chemicals.

121. What factors aid in the decision of what snow and ice control products are used? (Select all that apply)

- [ ] Cost
- [ ] Ease of use
- [ ] Effectiveness
- [ ] Availability
- [ ] Reduced impacts (environment, corrosion, etc.)
- [ ] Meets Level of Service objective
- [ ] Public feedback

Other (please specify)

122. Has your agency modified its snow and ice control products selection to better meet the prescribed level of service?

- ○ Yes
- ○ No

123. Please explain what products were used, what product you switched to, why, and if the switch has proven to be more effective.

124. Has your agency received any feedback (positive, negative, constructive) on any of the products used (e.g., rock salt, brine, mag, calcium, blended products, pre-wet/pre-treated, or corrosion inhibited)?

Conclusion

If your organization has conducted any in-house research on the costs, benefits, or cost-benefit studies of any of the winter maintenance operations or materials discussed in this survey and has not published this work in the public domain but is willing to share this information, please upload it **here** or send to this study's Principal Investigator David Veneziano (406-994-6320, david.veneziano@coe.montana.edu) and we will follow-up with you.

Thank you for your time and participation in this survey!

Advanced Materials Survey Questionnaire

Interview Questionnaires

Corrosion Inhibitors

Contact Information

- Name:
- Agency (Region)/Title:
- Phone Number:

Please provide some basic background on your agency and operations:

- Number of plow vehicles
- Number of winter maintenance practitioners/employees (incl. full and part time winter maintenance employees)
- Number of lane miles maintained
- Number of winter storm events per season
- Average annual accumulative snow depth (inches)

What corrosion inhibiting product(s) does your agency use? (Name/Brand)

What is the approximate cost of each product used? (per gallon or per ton)

Please provide and describe any additional costs associated with the use of the corrosion inhibitor(s) not included in the purchase price (storage, handling, etc.):

What Level of Service is achieved by products using corrosion inhibitors in your operations? (please describe)?

Has your agency observed a reduction in crashes while using products with inhibitors? Do you have any reports or figures that document this?

How important are the following benefits of the corrosion inhibitor(s)? (Very, somewhat or not important)

- Public vehicle protection
- Increased service life of agency's vehicles
- Reduced corrosion to equipment (if so please explain)
- Reduced corrosion to infrastructure (if so please explain)
- Other (please specify)

What factors aid in the decision of what snow and ice control products are used? (Select all that apply)

- Cost
- Ease of use
- Effectiveness
- Availability
- Reduced impacts (environment, corrosion, etc.)
- Meets Level of Service objective

- Public feedback
- Other (please specify)

Has your agency modified its snow and ice control products selection to better meet the prescribed level of service?

Please explain what products were used, what product you switched to, why, and if the switch has proven to be more effective.

Has your agency received any feedback (positive, negative, constructive) on any of the products used (e.g., salt brine, mag, calcium, blended products, prewet/ pretreated, or corrosion inhibited)?

If this is the only material that information is being sought for from the contact, be sure to thank them for their time and assistance.

Corrosion Inhibited Salt Brine

Contact Information

- Name:
- Agency (Region)/Title:
- Phone Number:

Please provide some basic background on your agency and operations:

- Number of plow vehicles
- Number of winter maintenance practitioners/employees (incl. full and part time winter maintenance employees)
- Number of lane miles maintained
- Number of winter storm events per season
- Average annual accumulative snow depth (inches)

What corrosion inhibiting product(s) does your agency use? (Name/Brand)

What application rate is used when applying corrosion inhibited salt brine? (per lane mile)

How much do you pay for corrosion inhibited salt brine (total cost per gallon)?

What equipment do you use to apply this material?

How do you use your corrosion inhibited salt brine and where do you use it?

Have you applied corrosion inhibited salt brine in combination with other products (like prewetting)?

What Level of Service is achieved by corrosion inhibited salt brine in your operations? (please describe)?

Please provide an estimate of the annual cost associated with corrosion inhibited salt brine operations at your agency (equipment, materials, labor, etc.):

How important are the following aspects associated with using inhibited salt brine? (very, somewhat or not important)

- Cost of material itself

- More difficult to handle and/or apply
- Environmental impacts to the roadside
- Pavement deterioration
- Public feedback
- Other (please specify)

How important are the following benefits you have observed or experienced from using inhibited salt brine? (very, somewhat or not important)

- Cost savings
- Improved safety
- Reduced amount of product used
- Reduced number of application vehicles needed
- Better performance at cold temperatures
- Reduces need for salt and/or sand
- Public feedback
- Other (please specify)

Do you have any additional information or thoughts on corrosion inhibited salt brine that you would like to share?

What factors aid in the decision of what snow and ice control products are used? (Select all that apply)

- Cost
- Ease of use
- Effectiveness
- Availability
- Reduced impacts (environment, corrosion, etc.)
- Meets Level of Service objective
- Public feedback
- Other (please specify)

Has your agency modified its snow and ice control products selection to better meet the prescribed level of service?

Please explain what products were used, what product you switched to, why, and if the switch has proven to be more effective.

Has your agency received any feedback (positive, negative, constructive) on any of the products used (e.g., salt brine, mag, calcium, blended products, prewet/ pretreated, or corrosion inhibited)?

If this is the only material that information is being sought for from the contact, be sure to thank them for their time and assistance.

<u>Magnesium Chloride</u>

Contact Information

- Name:

- Agency (Region)/Title:
- Phone Number:

Please provide some basic background on your agency and operations:

- Number of plow vehicles
- Number of winter maintenance practitioners/employees (incl. full and part time winter maintenance employees)
- Number of lane miles maintained
- Number of winter storm events per season
- Average annual accumulative snow depth (inches)

Which of the following Magnesium Chloride forms do you use?

- Magnesium Chloride Solid
- Magnesium Chloride Liquid
- Magnesium Chloride Corrosion Inhibited Solid
- Magnesium Chloride Corrosion Inhibited Liquid

What application rate is used when applying Magnesium Chlorides (per lane mile)? Please specify application rates for all forms of Magnesium Chloride used (ex. solids, inhibited liquids, etc.).

How much do you pay for the form(s) of Magnesium Chloride used (total cost per gallon or ton)? Please specify costs for all forms of Magnesium Chloride used (ex. solids, inhibited liquids, etc.).

What equipment do you use to apply the form(s) of Magnesium Chloride being used? Please specify the specific equipment for all forms of Magnesium Chloride used (ex. solids, inhibited liquids, etc.).

How do you use Magnesium Chloride and where do you use it? Please specify the uses for all forms of Magnesium Chloride being employed (ex. solids, inhibited liquids, etc.).

Have you applied Magnesium Chloride in combination with other products (like prewetting)? Please consider the different applications for all forms of Magnesium Chloride used (ex. solids, inhibited liquids, etc.).

What Level of Service is achieved by the form(s) of Magnesium Chloride being used in your operations? (please describe)? Please specify the LOS achieved for all forms of Magnesium Chloride used separately (ex. solids, inhibited liquids, etc.).

Do you have any information on the number of applications needed for the form(s) of Magnesium Chloride used to achieve an LOS for a given condition versus another product?

Please provide an estimate of the annual cost associated with Magnesium Chloride operations at your agency (equipment, materials, labor, etc.):

Which of the following aspects associated with using Magnesium Chloride present concerns? (very, somewhat or not important)

- Cost of material itself

- More difficult to handle and/or apply
- Environmental impacts to the roadside
- Pavement deterioration
- Public feedback
- Corrosion (uninhibited materials only)
- Other (please specify)

Which of the following benefits you have observed or experienced from using Magnesium Chloride? (very, somewhat or not important)

- Cost savings
- Improved safety
- Reduced amount of product used
- Reduced corrosion (inhibited materials only)
- Reduced number of application vehicles needed
- Better performance at cold temperatures
- Not an animal attractant
- Reduces need for salt and/or sand
- Public feedback
- Other (please specify)

Do you have any additional information, cost or benefit values or thoughts on Magnesium Chloride that you would like to share?

What factors aid in the decision of what snow and ice control products are used? (Select all that apply)

- Cost
- Ease of use
- Effectiveness
- Availability
- Reduced impacts (environment, corrosion, etc.)
- Meets Level of Service objective
- Public feedback
- Other (please specify)

Has your agency modified its snow and ice control products selection to better meet the prescribed level of service?

Please explain what products were used, what product you switched to, why, and if the switch has proven to be more effective.

Has your agency received any feedback (positive, negative, constructive) on any of the products used (e.g., salt brine, mag, calcium, blended products, prewet/ pretreated, or corrosion inhibited)?

If this is the only material that information is being sought for from the contact, be sure to thank them for their time and assistance.

<u>Calcium Chloride</u>

Contact Information

- Name:
- Agency (Region)/Title:
- Phone Number:

Please provide some basic background on your agency and operations:

- Number of plow vehicles
- Number of winter maintenance practitioners/employees (incl. full and part time winter maintenance employees)
- Number of lane miles maintained
- Number of winter storm events per season
- Average annual accumulative snow depth (inches)

Which of the following Calcium Chloride forms do you use?

- Calcium Chloride Solid
- Calcium Chloride Liquid
- Calcium Chloride Corrosion Inhibited Solid
- Calcium Chloride Corrosion Inhibited Liquid

What application rate is used when applying Calcium Chlorides (per lane mile)? Please specify application rates for all forms of Calcium Chloride used (ex. solids, inhibited liquids, etc.).

How much do you pay for the form(s) of Calcium Chloride used (total cost per gallon or ton)? Please specify costs for all forms of Calcium Chloride used (ex. solids, inhibited liquids, etc.).

What equipment do you use to apply the form(s) of Calcium Chloride being used? Please specify the specific equipment for all forms of Calcium Chloride used (ex. solids, inhibited liquids, etc.).

How do you use Calcium Chloride and where do you use it? Please specify the uses for all forms of Calcium Chloride being employed (ex. solids, inhibited liquids, etc.).

Have you applied Calcium Chloride in combination with other products (like prewetting)? Please consider the different applications for all forms of Calcium Chloride used (ex. solids, inhibited liquids, etc.).

What Level of Service is achieved by the form(s) of Calcium Chloride being used in your operations? (please describe)? Please specify the LOS achieved for all forms of Calcium Chloride used separately (ex. solids, inhibited liquids, etc.).

Do you have any information on the number of applications needed for the form(s) of Calcium Chloride used to achieve an LOS for a given condition versus another product?

Please provide an estimate of the annual cost associated with Calcium Chloride operations at your agency (equipment, materials, labor, etc.):

Which of the following aspects associated with using Calcium Chloride present concerns? (very, somewhat or not important)

- Cost of material itself
- More difficult to handle and/or apply
- Environmental impacts to the roadside
- Pavement deterioration
- Public feedback
- Corrosion (uninhibited materials only)
- Other (please specify)

Which of the following benefits you have observed or experienced from using Calcium Chloride? (very, somewhat or not important)

- Cost savings
- Improved safety
- Reduced amount of product used
- Reduced corrosion (inhibited materials only)
- Reduced number of application vehicles needed
- Better performance at cold temperatures
- Not an animal attractant
- Reduces need for salt and/or sand
- Public feedback
- Other (please specify)

Do you have any additional information, cost or benefit values or thoughts on Calcium Chloride that you would like to share?

What factors aid in the decision of what snow and ice control products are used? (Select all that apply)

- Cost
- Ease of use
- Effectiveness
- Availability
- Reduced impacts (environment, corrosion, etc.)
- Meets Level of Service objective
- Public feedback
- Other (please specify)

Has your agency modified its snow and ice control products selection to better meet the prescribed level of service?

Please explain what products were used, what product you switched to, why, and if the switch has proven to be more effective.

Has your agency received any feedback (positive, negative, constructive) on any of the products used (e.g., salt brine, mag, calcium, blended products, prewet/ pretreated, or corrosion inhibited)?

If this is the only material that information is being sought for from the contact, be sure to thank them for their time and assistance.

Blended Products

Contact Information

- Name:
- Agency (Region)/Title:
- Phone Number:

Please provide some basic background on your agency and operations:

- Number of plow vehicles
- Number of winter maintenance practitioners/employees (incl. full and part time winter maintenance employees)
- Number of lane miles maintained
- Number of winter storm events per season
- Average annual accumulative snow depth (inches)

What types of blended products (in any form) do you use in your operations?

Are the blended products you use uninhibited or inhibited?

What application rate(s) is used when applying blended products (per lane mile)? Please list rates for each product used separately.

How much do you pay for the blended product(s) being used (per gallon or ton)? Please list the price of each product used separately.

What equipment do you use to apply blended products? Please list the equipment used for each product separately.

How do you use blended products and where do you use them? Please list the uses of different products separately.

Have you applied blended products in combination with other products (like prewetting)? Please consider the different applications for all forms of blended products used.

What Level of Service is achieved by the form(s) of blended product being used in your operations? (please describe)? Please specify the LOS achieved for all forms of blended product used separately.

Do you have any information on the number of applications needed for the form(s) of blended products used to achieve an LOS for a given condition versus another product?

Please provide an estimate of the annual cost associated blended product operations at your agency (equipment, materials, labor, etc.):

Which of the following aspects associated with using blended products are of concern? (very, somewhat or not important)

- Cost of material itself
- More difficult to handle and/or apply
- Environmental impacts to the roadside
- Pavement deterioration

- Public feedback
- Increased corrosion
- Other (please specify)

Which of the following benefits have you observed or experienced from using blended products? (very, somewhat or not important)

- Cost savings
- Improved safety
- Reduced amount of product used
- Longer lasting applications
- Reduced number of application vehicles needed
- Better performance at cold temperatures
- Not an animal attractant
- Reduces need for salt and/or sand
- Public feedback
- Other (please specify)

Do you have any additional information, cost or benefit values or thoughts on blended products that you would like to share?

What factors aid in the decision of what snow and ice control products are used? (Select all that apply)

- Cost
- Ease of use
- Effectiveness
- Availability
- Reduced impacts (environment, corrosion, etc.)
- Meets Level of Service objective
- Public feedback
- Other (please specify)

Has your agency modified its snow and ice control products selection to better meet the prescribed level of service?

Please explain what products were used, what product you switched to, why, and if the switch has proven to be more effective.

Has your agency received any feedback (positive, negative, constructive) on any of the products used (e.g., salt brine, mag, calcium, blended products, prewet/ pretreated, or corrosion inhibited)?

If this is the only material that information is being sought for from the contact, be sure to thank them for their time and assistance.

Appendix B
Survey and Follow-up Survey Results

Preliminary Survey Results

A total of 34 responses were obtained from various agencies throughout the United States. This included 18 state agencies (DOTs, some providing multiple responses), 7 counties and 3 towns/cities/public works entities. State DOTs responding to the survey included Colorado (1 response), Idaho (2 responses), Illinois (1 response), Iowa (1 response), Kansas (1 response), Kentucky (1 response), Missouri (1 response), Montana (1 response), Nebraska (1 response), New Hampshire (1 response), New York (1 response), North Dakota (2 responses), Ohio (1 response), Oregon (1 response), Vermont (2 responses), Virginia (1 response), Washington (3 responses) and Wyoming (2 responses). All of these states, with the exception of Kentucky, are Clear Roads member states, representing 59 percent participation from the overall group. All 7 of the respondent counties were from Wisconsin and included Fond du Lac, Green, Iowa, Oconto, Oneida, Ozaukee and Waukesha counties. Finally, municipalities responding to the survey included the Town of Heath, Massachusetts/Massachusetts Local Technical Assistance Program (LTAP), the City of West Des Moines, Iowa and the City of Cedar Rapids, Iowa.

Agency Background

The initial information provided by respondents pertained to the background of their agency's winter maintenance operation. General information including number of plow vehicles, number of employees, lane miles maintained, average number of storms per winter and average snow depth per winter were obtained. The number of plow vehicles operated varied by entity and ranged between 6 (Town of Heath, Massachusetts) and 11,993 (Virginia DOT). In one case (New Hampshire DOT), the number of vehicles reported included contractors. All responses taken together produced an average of 821 plows in use per entity. On average, state DOTs employed 1,162 plow vehicles, although this number was influenced by the overall responses coming in some cases from the statewide level and in other cases, the district or garage/shed/depot level. Vehicle numbers reported by county-level respondents were more consistent, with an average of 35 plows employed. Finally, respondents from municipalities reported an average of 40 plow vehicles in use, although this number was heavily influenced by the 95 plows in use by the City of Cedar Rapids, Iowa versus the 6 in use in Heath, Massachusetts.

Respondents were also asked for information on the number of personnel assigned to winter maintenance operations, including both full and part time employees. The number of personnel assigned to winter maintenance operations varied, depending on the size of the entity. Personnel ranged from 6 (Town of Heath, Massachusetts) to 15,000 (Virginia DOT). The average number of state DOT personnel reported was 1,965, while the county average was 43 and the city/municipal average 53. In the case of the New Hampshire DOT, the figure reported also included contractor/hired drivers, and these were not broken out separately.

The amount of lane miles maintained by an entity plays a significant role in the extent and costs of winter maintenance. In light of this, information was sought from respondents regarding the lane miles maintained by their entity. At the state level, the total lane miles maintained ranged from 730 to 76,000. Bear in mind that these figures reflect the position of the respondent, which in some cases was the statewide level and in other cases, the district or garage/shed/depot level. The average lane miles maintained by state DOTs was 22,432. As one would expect, the average lane miles for counties and cities/ municipalities was lower, being 1,334 and 501 miles, respectively.

Another items of interest to the work was the average number of storm events per winter season (i.e. October through March) faced by each responding agency. A total of 21 agencies provided feedback on the number of storms that occurred, with remaining agencies not providing any information and others indicating they had not tracked this data element. On average, all responding agencies experienced an average of approximately 31 storms per season. State DOTs indicated an average of 32 storms per season, while counties reported 31 storms and cities/municipalities reported 30 storms.

In line with information on the number of storms that occurred, the average total depth of snowfall for an entire winter season was also of interest. As one would expect, the range of values for snow depth varied, ranging from 10 to 12 inches up to 300 inches (on mountain passes). A total of 26 agencies provided feedback on snow depth, with remaining agencies not providing any information. State DOT's reported an average snowfall depth of 56 inches, while counties reported an average of 71 inches and cities/municipalities reported 46 inches.

Basic Practices

Basic winter maintenance practices were those that centered on the use of plowing and abrasives to address storm events. In developing the survey, it was expected that all responding agencies would incorporate these practices to some extent, and this was confirmed by the responses received. A total of 33 respondents indicated that their agency used plowing and/or abrasives in winter maintenance operations, while 1 respondent indicated that their agency did not use plowing or abrasives (incidentally no further survey responses were provided by this particular agency).

Given that plowing and abrasive use are basic procedures, the Level of Service (LOS) achieved through their use was of interest. To this end, respondents were asked what their agency's LOS was using practices already in place (which may include chemical use) versus what it would be if only plowing and/or abrasives were used. Summaries of the relevant information provided that was pertinent to answering this questions included:

- High level, moderate at best without chemical treatment.
- Plowing and abrasives only would not permit us to recover roads as quickly.
- Our LOS is dependent on AADT. If we were to only utilize plowing and abrasive treatments our LOS would be reduced.
- Abrasives are almost exclusively used at low temperature.
- Level of service varies by roadway type, however the only roads that currently are only plowed and treated with abrasives are type 5 roads that are no salt roads and is restricted to roads with less than 1,000 vehicles daily, with concurrence of the local public officials.
- Current LOS: A. Sand & Plow LOS: C.
- It is expected to have certain roads bare pavement after a storm in a certain time frame, the use of abrasives only would make that impossible. If we went strictly to abrasives it would be difficult and costly to still deliver this LOS.

- The Transportation Commission has demanded LOS B for the past several years. Using only plowing and abrasives, we would not be able to attain this LOS. Our LOS would be in the D area, snow-packed, icy in spots.
- Only plowing and/or abrasives would not ensure the safety and the mobility of the public as well.
- Would not be able to achieve our LOS using only plowing or abrasives.
- Current level of service for snow and ice control is to maintain reasonably safe and passible highways, preventing hard pack and keeping snow plowable. Using abrasives tends to promote hard pack conditions. Therefore LOS would not be maintained to our standards.
- Our level of service would degrade significantly, particularly on the continuous operations routes, if we employed only plowing and abrasive use.

As these responses indicate, the use of only plowing and abrasives in winter maintenance operations would lead to a deteriorated LOS compared to the established guidelines of agencies. In two cases, respondents indicated that LOS would be C or D (Washington State and Colorado, respectively) if only plowing and abrasives were used. Still, one respondent indicated that abrasives are almost exclusively used at low temperatures, while another certain “no salt roads” those with less than 1,000 vehicles per day. In light of this, the use of plowing and abrasives does occur, but LOS should be expected to be low and other considerations, such as low traffic volumes and/or environmental concerns can lead to the use of these approaches separate from chemicals.

Next, respondents were asked what the impact of using plowing and abrasives has been on the mobility of the public. Summaries of the relevant information provided that was pertinent to answering this questions included:

- Slower.
- Decreased LOS negatively impacts traveler mobility during and after winter storm events.
- If we are only using abrasives and not using chlorides, mobility would be impacted.
- Drive slower on pack.
- Lowered.
- Using abrasives tends to promote hard pack conditions that need to be avoided. This negatively impacts mobility. However during extremely cold weather, abrasives can be a benefit when salt is ineffective, by providing some traction on problem areas such as hills and intersections.
- If we used only plowing and abrasives there would a much longer time to meet this objective, resulting in reduced mobility.

As these responses indicate, the impacts on public mobility would be significant based on the experience or assumptions of the respondents. Vehicles would be expected to travel slower, and bare pavement would not be achieved. Instead, snow pack would persist and it would take longer to achieve a higher LOS than if chemicals were employed. However, one respondent did point out that abrasives have a benefit over salt in extremely cold weather, providing traction in problem areas such as hills and intersections. Consequently, there is some acknowledgement that abrasives (used with plowing) have their place in winter maintenance, but that use should be limited to spot treatments or extremely low temperatures.

With respect to plowing and abrasives, respondents were next asked whether their agency had observed a reduction in crashes using these practices compared to other winter maintenance practices. Those who responded to this question (19 agencies) were unsure whether plowing and abrasives had an impact on reducing crashes or indicated that they made some difference, but not as much as chemicals do. A common indication from respondents was that crashes during winter weather were not tracked, and so the impacts of different approaches were not immediately clear.

Next, respondents were asked whether they had any information to share regarding the number of passes or applications needed to achieve an LOS for a given condition using plowing and abrasives versus another practice. Most respondents indicated that they did not have such information available. However, those that did provide feedback indicated that more passes and applications would be required when using plowing and abrasives than if salt or other chemicals were used.

Plowing

With background on the operation itself provided, respondents were asked for information specific to plow and abrasive use. First, respondents were asked if their agency employed plowing in their winter maintenance operations. All agencies responding to the survey indicated that plowing was in use. Next, respondents were asked what types of plows were used by their agency. As the results of Figure 6 illustrate, front plows, wing plows and motor graders were the most commonly used pieces of plowing equipment. Underbody and tow plows saw lower use, but were still employed by a fair number of agencies. Items listed as “Other” included front end loaders, snow cats, tractors with plows, and sidewalk plows.

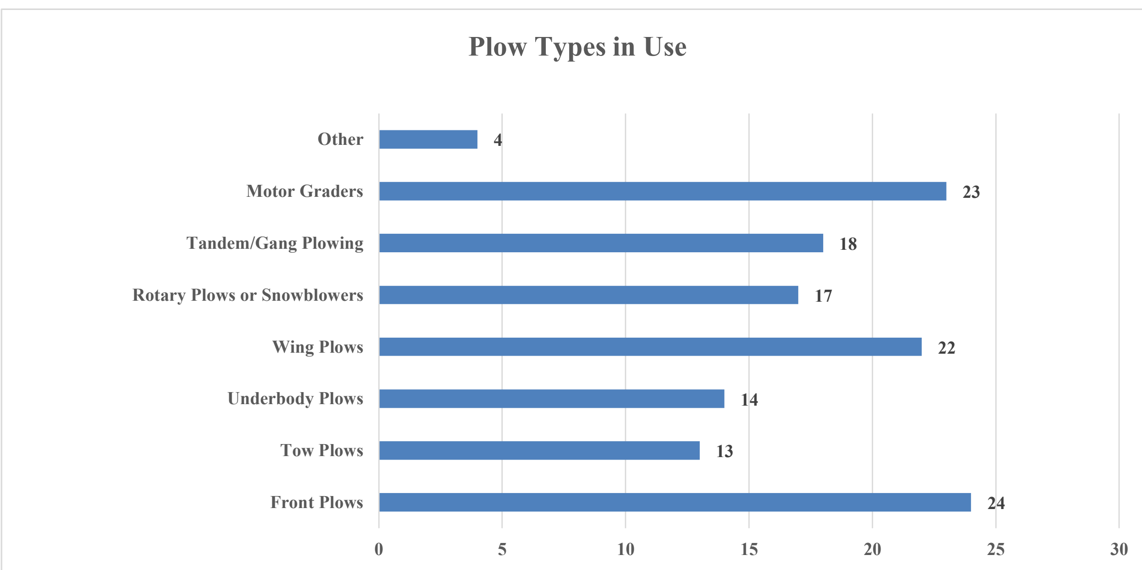

Figure 6: Types of plows in use by agencies

The costs associated with plowing were also of interest. Respondents were asked to provide an estimate of the annual average cost per lane mile of responsibility to plow at their agency. A total of 11 agencies provided feedback on this cost, with the annual average cost per lane mile for plowing being $1,335. For state DOTs, the average was $1,353 (8 agencies), while counties had an average of cost of $882 (2 agencies) and cities and average of $251 (1 agency). It is believed that the higher response rate from state DOTs is the result of better data collection and recording procedures being in place compared to smaller municipal entities. Still, the feedback to this question provides a useful element in better understanding the costs of plowing.

The importance of different aspects of plowing were next rated by respondents. The ability to remove snow and ice from the road was very important to 22 respondents and somewhat important to 1 respondent. The ability of plowing to reduce the number of vehicle passes was very important to 17 respondents and somewhat important to 7 respondents. The ability of plowing to reduce treatment material usage was very important to 19 respondents and somewhat important to 4 respondents. The ability of plowing to reduce personnel hours was very important to 17 respondents and somewhat important to 6 respondents. Finally, supplemental comments from one respondent indicated that the ability of plowing to reduce operator fatigue was important.

Next, the type of plow blade inserts being used was asked of respondents (Figure 7). In many cases, respondents indicated more than one blade type was in use. The most common blade in use was carbide steel, used by 22 agencies. This was followed by combination blades, which used multiple materials together, such as rubber steel and carbide, which were used by 15 agencies. A fair number of agencies reported using standard steel blades, while only a limited number used full rubber, rubber encased steel or ceramic blades. Finally, one respondent used a multi-sectional articulating blade type (JOMA and PolarFLEX).

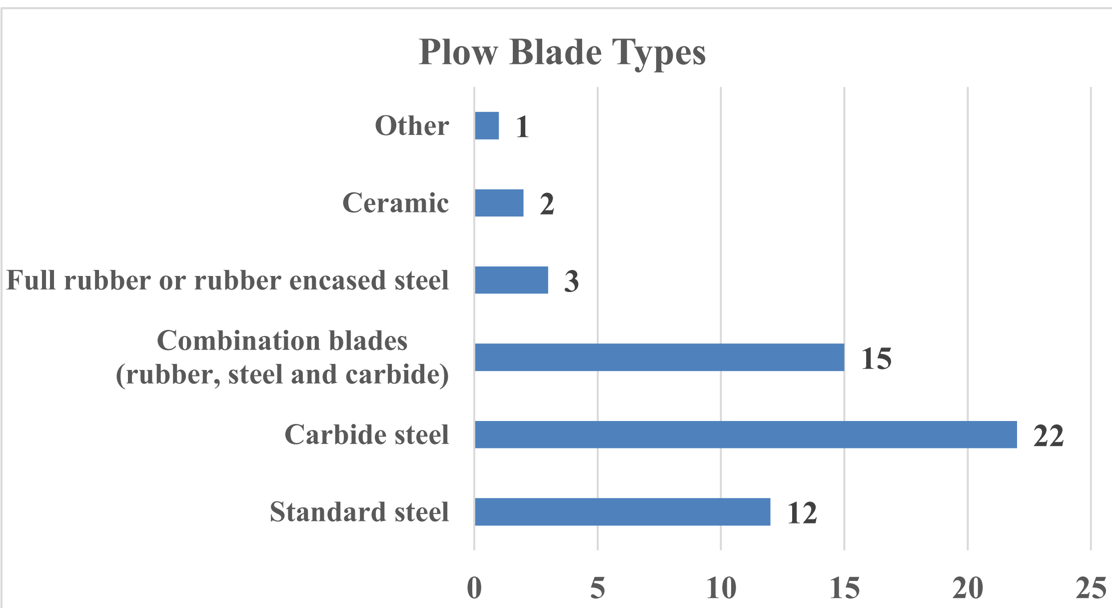

Figure 7: Plow blade types in use by agencies

The lifespan of each blade type expressed in miles was the next piece of information sought from respondents. Specifically, respondents were asked how many plow miles their agency achieved per blade set. Most respondents did not provide a specific mileage; rather, they indicated that blade life "varies". Summaries of the relevant information provided that was pertinent to answering this question (with blade type in parentheses) included:

- Without cover blades and with plow saver valve we can push 3600 miles with a set (carbide steel).
- In an average winter, we will go through 1 set of blades (combination blades).
- 4000-5000 (carbide steel, combination blades).
- Unsure for miles, normally 40 to 50 hours on state roads (standard steel blades) [equates to 1200 to 1500 miles].
- 300+ depends on surface conditions (combination blades).
- It varies widely, high performance blades such as the JOMA 6000 can last multiple seasons. Rubber blades may only make a few passes. (carbide, rubber blades).
- Varies by type of blade. JOMA's last 4-8 times as long as standard carbide. (carbide, combination blades).
- Depends on storm - 32 [units not specified, may be hours].
- 5000 [type not specified in earlier responses].

As these results indicate, the life of specific blade types can vary greatly. Carbide blades were indicated to last 3,600+ miles, steel blades from 1,200 to 1,500 miles and combination blades (specific material not indicated) 300 miles. The life of full rubber and ceramic blades was not provided by any respondent.

The time required to change a blade factors into the cost of plowing. In light of this, respondents were asked approximately how many man hours were required to replace blade inserts for one truck. Responses to this question were straightforward, with the average reported time for blade changes being 1 to 2 hours. Standard steel blades were reported to require ½ to 2 hours to change, carbide steel blades 1 to 2 hours, combination blades 4 to 5 hours, full rubber blades 1 to 2 hours and ceramic blades 1 to 2 hours. Aside from the time required for combination blade changes, the 1 to 2 hour threshold appears to be fairly standard across blade types. The hourly loaded labor rate for the staff charged with changing blades averaged $31.21 ranged from $19.00 to $40.00.

Finally, respondents were asked for any additional feedback they might have on the specific costs or benefits (ex. effective for snow and ice removal, expensive to replace inserts, etc.) regarding plowing, plow types, and blade inserts. This was an open-ended question, and the responses received included:

- We studied the use of cover blades and without cover blades, also use of front plow hydraulic control valve or not, if properly utilized and enforced, we can triple blade life without cover blades and with plow saver valve versus cover blade without valve, or no valve with cover blade.
- From 2013 reports WYDOT average 3 12 foot blades sets per truck.
- Will only use Joma Blades. Cleaning of roadway is best and longevity of blade life has led us to this determination.
- The winter guard and Joma Black cats are good for their noise reduction and vibration reduction on the plows also reduce operator fatigue.
- Operator training and buy in is curtail to efficient/effective operations.
- The high performance blades Joma 6000 and Polar Flex clear pavement better. They reduce operator fatigue because of reduced noise, shock and vibration. They also last much long than other blades. Our standard carbide blades are the dowel type from Kennametal.

- The longer a blade lasts the less injuries your employees suffer replacing blades.
- Plow set up is critical to the effectiveness of a plowing strategy.
- Multi sectional blades, to be specific JOMA has reduced our down time and increased safety due to more snow and ice being removed. We also now use less salt because of this.

As these responses indicate, combination blades are viewed to provide the benefits of reduced noise, vibration and driver fatigue while also having a longer life. One other benefit from the use of a longer lasting blade was identified as a reduction in employee injuries during the course of changing blades (less changes equals less opportunity for injury).

Abrasives

Abrasive use formed the second component of the basic winter maintenance activities considered by the survey. In light of this, respondents were asked whether their agency employed abrasives as part of their maintenance activities. A total of 23 respondents indicated that their agency uses abrasives in their winter maintenance operations, while 1 agency indicated it did not. For those agencies that indicated abrasives were used, it was of interest the location(s) or situations where such materials were employed. Figure 8 presents the locations where agencies indicated they were applying abrasives. Abrasives were most commonly cited as being used on hills, followed by low temperature events, shaded areas intersection approaches and curves. Only a limited number of respondents indicated system-wide use of abrasives as opposed to spot treatments. However, use during low temperature events the use of abrasives could move to system-wide, although respondents were not asked to give an indication of whether this could be the case. "Other" locations where abrasives were indicated as being used included locations affected on a case by case basis by temperatures and blowing, under the direction of the deputy director, low salt areas, low volume roads, locations outside of PM 10 (particulate matter) attainment areas and on gravel roads.

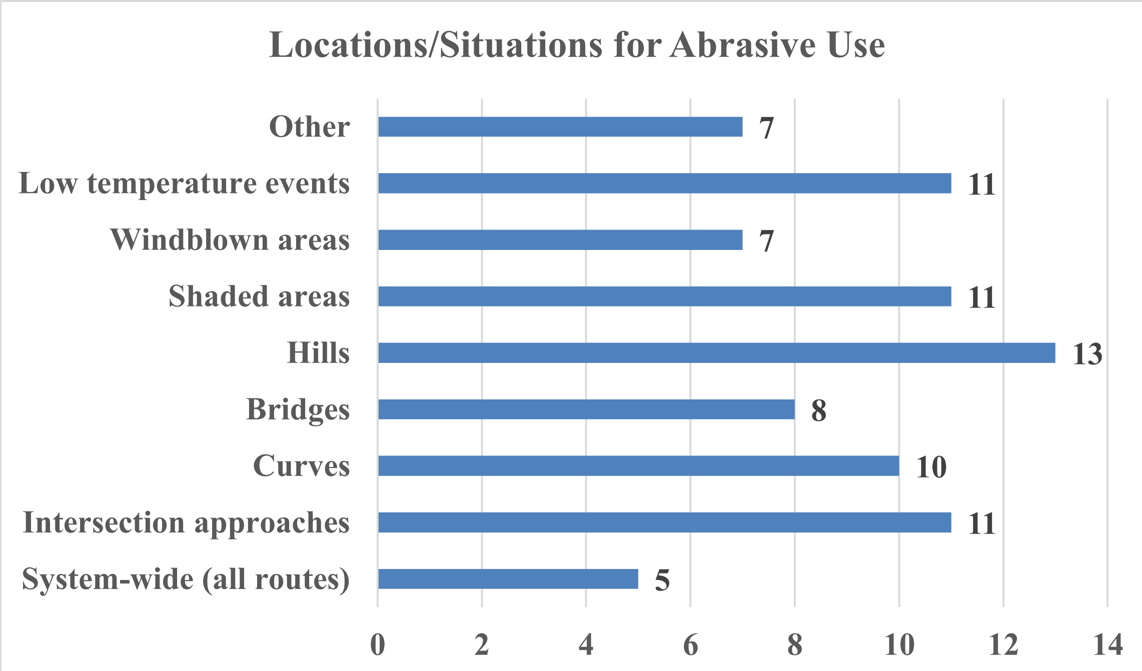

Figure 8: Locations where abrasives are used

Next, respondents were asked what abrasive materials their agency used. Nine respondents indicated that their agency used abrasives without a salt mix, while 19 agencies used an abrasive-salt mix. When abrasive-salt mixes were used, the average of salt versus abrasives used was 21 percent. The range of mixtures was 7 percent salt to 93 percent abrasive to 50 percent salt to 50 percent abrasive. Abrasive gradations/sizes ranged from 1/4 inch to 1/2 inch, with the most common size being 3/8 inch. Minus 4 gradation, #9 stone and #20 sieve were also cited as abrasive sizes, but these were limited.

The cost of abrasives is of particular interest given that they are a low-cost treatment option. In light of this, respondents were asked to provide information on the average cost per ton of abrasives and abrasive-salt mixtures used by their agency. Abrasive costs per ton were an average of $9.32, with reported prices ranging from $4.00 to $16.00 per ton. Abrasive-salt mixes had an average cost of $20.86 per ton, with reported prices ranging from $15.00 to $35.00 per ton.

The quantity of abrasives used each year were of interest to this work. Consequently, respondents were asked how many tons of abrasives (straight and/or salt-mixed) were applied annually by their agency. Respondents indicated that their agency used anywhere from 50 tons up to 358,371 tons of abrasives and abrasive-salt mixes total, with an average tonnage of 59,521.

The use of abrasives may be done to achieve different benefits. In light of this, respondents were asked how important different benefits of using abrasives were from their perspective. A large number of respondents indicated that the ability to provide traction was a very or somewhat important benefit of abrasives. Figure 9 illustrates the responses to this question. Most respondents indicated that ease of application was an important benefit of abrasives, although some did not consider it a benefit. The low cost of the material was viewed by an equal number of respondents as being a very or somewhat important benefit of abrasives as well. Other comments provided respondents indicated that low temperature performance, visibility to the public (shows that an application was made), absorbance of solar radiation to aid in melting and being a material that can remain on gravel roads after winter were also considered to be benefits of abrasives.

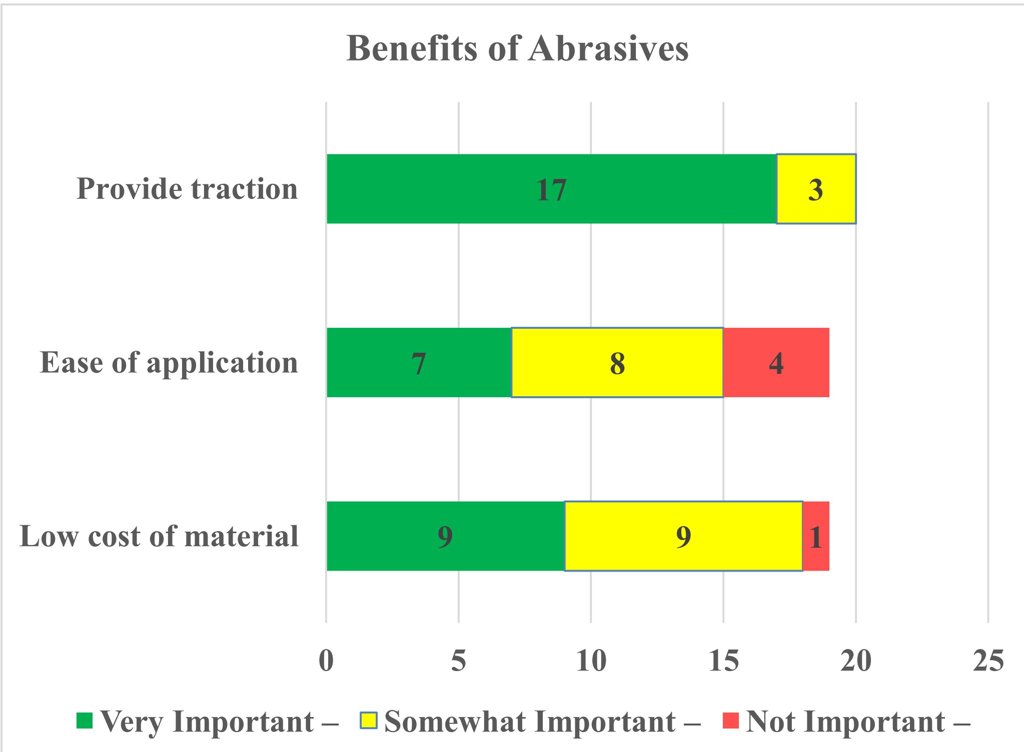

Figure 9: Benefits of abrasives

Abrasives are a material that remains after the winter season, and it was also of interest to see if agencies performed any abrasive clean-up activities in the spring. A nearly even split among respondents was made to this question, with 11 indicating their agency had a clean-up program in place while 10 agencies did not. A total of 11 respondents indicated agency staff performed these operations, while three respondents indicated that their agency contracted out clean-up activities to private firms. The average clean-up cost per mile was $85.66, with reported costs ranging from $62.95 to $120.00 per mile. Disposal costs were indicated as being factored into these figures, although some respondents indicated that the cost was $0.00 and that abrasives were reused to maintain shoulders. When asked if the abrasives were recycled, 4 respondents indicated that they were, while 3 indicated they were not. Only one respondent commented that the abrasives were reused with new stockpiles during the following winter season. Other respondents indicated that abrasives were recycled for use as shoulder material, construction of berms and as fill.

Respondents were also asked for feedback on the importance of the negative aspects of using abrasives. Figure 10 illustrates the feedback received regarding this question. As the figure illustrates, the entry of abrasives into waterways was very or somewhat important to the highest number of respondents. The inability of abrasives to provide deicing capacity was very or somewhat important to most respondents. Similarly, increases to dust/air pollution were a concern. Finally, windshield damage was acknowledged by most respondents, although it was generally not viewed by most as being a very important negative of abrasives. Finally, one respondent provided the comment that the costs of clean-up and the potential to clog drainage systems were also negative aspects of abrasives.

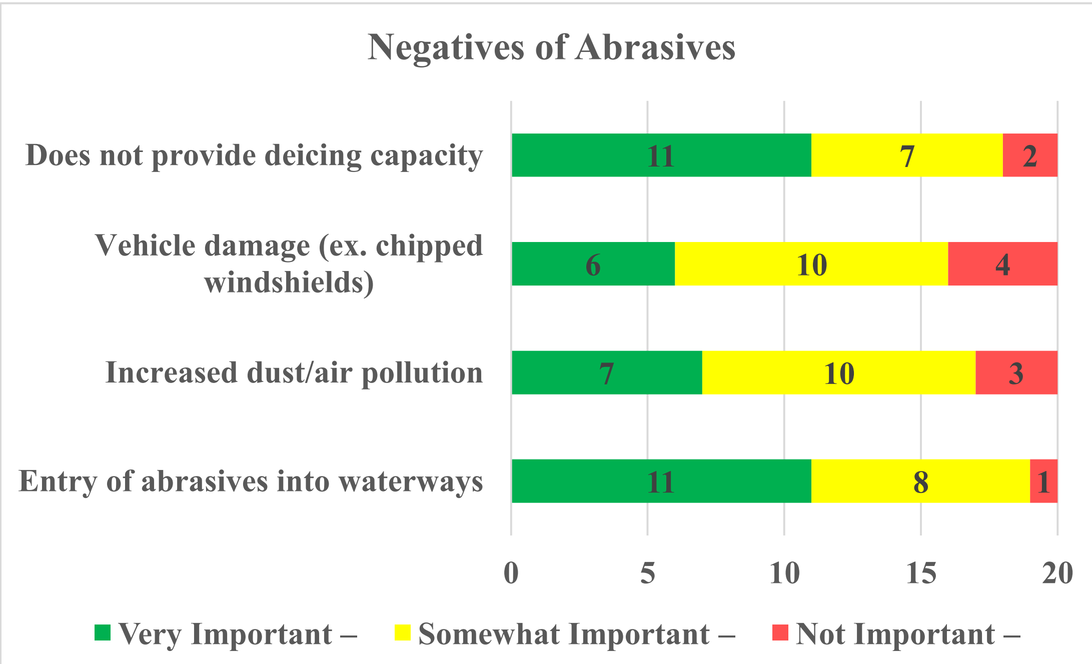

Figure 10: Negative aspects of abrasives

Finally, respondents were asked if they had any more information or values for the benefits or costs of abrasive use. One respondent indicated that broken windshield claims from abrasive use were $5,000 annually. Another respondent indicated that their agency was able to save $20,000 to $30,000 annually by removing all abrasives from use on black top roads and using them only on gravel roads. This was on a system of 108 lane miles, so the savings from eliminating abrasive use would be $185 to $277 per lane mile.

Intermediate Practices

Intermediate winter maintenance practices were those that employed the use of solid salt (NaCl) or salt brine for anti-icing and deicing (in addition to basic activities such as plowing and spot abrasive use). A total of 23 respondents indicated their agency used intermediate practices, while zero respondents indicated that their agency did not use such practices. Those who indicated their agency used Intermediate practices were asked what their agency's LOS using current practices was and what would it be using only Intermediate practices. Summaries of the relevant information provided that was pertinent to answering this questions included:

- No change.
- If we used more of the intermediate practices we would be able to recover roads quicker.

- MDT currently uses multiple strategies. If we were to employ only intermediate practices as defined in this survey our LOS would decrease. It's necessary to use the right tool at the right time and place to achieve the best results.
- Main application in NH is salt. Abrasives are the exception. Those roads that are type 1-A to type 4 use virtually only salt unless temperatures are too low in which a sand/salt mix is applied to allow traction.
- LOS B as before.
- Our level of service would be decreased some using these intermediate practices, however using the anti-icing and deicing capabilities of salt or salt brine can achieve a decent level of service.
- This District went all road salt or brine usage in 2009, level of service has increased during this period.

As these responses indicate, there was not a clear picture provided regarding the impacts of using salt/salt brine versus other approaches (ex. abrasives, advanced chemicals). One respondent indicated that LOS B would be achieved using intermediate practices, which is generally what would be expected using deicing agent in addition to plowing to maintain a roadway surface. This was further confirmed by supplemental reports and documents provided by respondents. Other respondents indicated that the use of intermediate practices would produce an acceptable LOS, which indicates that the use of salt in lieu of or in addition to abrasives produces a better LOS than plowing and abrasives alone would.

Next, respondents were asked to describe what the impact of Intermediate practices been on the mobility of the public. Summaries of the relevant information provided that was pertinent to answering this questions included:

- Increased LOS over basic practice.
- Maintain bare roads after a storm versus season long pack.
- Seems to work very well.
- The mobility of the travelling public has improved.
- Within 12 hours full mobility.
- Increased mobility and safety.
- Positive impact; salt works well to maintain desired LOS.
- Mobility has been greatly improved with the use of these intermediate practices. We can in most cases prevent the bonding of snow to the pavement and can melt accumulated snow and ice through the use of salt and salt brine.
- Winter mobility measured in Idaho as percent of time water is on the roadway below 32 degrees, mobility in District 5 has been 2010-2011 - 51%, 2011-2012 - 60%, 2012-2013 - 68% and 2013-2014 -78%.

As these responses indicate, the use of Intermediate practices has improved public mobility compared to basic practices. As one would expect, the capacity of salt/salt brine to facilitate melting and produce bare pavement has a significant impact when used with other approaches (ex. plowing) to assure public mobility in a reasonable time period following a storm event.

It was also of interest to better understand the safety impacts (i.e. crash occurrence) of Intermediate versus other practices. In light of this, the next question asked respondents if their agency observed a reduction in crashes using Intermediate practices compared to other winter maintenance practices. Summaries of the relevant information provided that was pertinent to answering this questions included:

- No change.
- Yes.
- Yes.
- We have not quantified this. As the LOS improves so does the traffic count and travel speed which could account for more accidents.
- Yes, compared to abrasives and plowing only intermediate practices are an improvement.
- Yes.
- Yes.
- This is the only practice we use. No observed impact on crash records.
- Yes.
- Yes, reports submitted.

As the responses received indicate, the use of Intermediate practices was viewed as being more beneficial to safety than other practices. However, caution should be taken in interpreting these responses, as respondents may have been thinking of basic practices in this comparison as it was the only alternative presented by the survey questions at this point in the survey. Still, the responses are logical, as the use of salt/salt brine produces a better road surface compared to the use of abrasives and plowing alone. Consequently, a better road surface should result in fewer crashes compared to a snow packed surface.

Respondents were next asked if they had any information on the number of applications needed to achieve an LOS for a given condition using Intermediate versus another practice. Nearly all respondents indicated that they did not have such information available. Some of these respondents further indicated that the number of applications needed was dependent on the type of storm, length of storm, temperatures, wind, precipitation type and so forth. Still, one respondent did indicate that the use of salt had reduced the number of applications by 2 to 3 over abrasives.

Solid Salt

The use of solid salt versus salt brine was the next focus of the survey questions. A total of 20 respondents indicated that their agency used solid salt, while two indicated solid salt was not used. The average quantity of salt used by agencies was 183,500 tons, with a range of 500 tons (county) to 800,000 tons (state DOT) reported. The approximate cost of salt per ton (delivered) averaged $71.04, with the range of reported costs being $48.63 to $90.00. Application rates varied widely by agency, ranging from 25 pounds per lane mile up to 600 pounds per lane mile. These rates vary based on the nature of the storm being addressed, which explains the wide range of values reported by respondents.

The next item that feedback was sought on regarded the views of respondents on the importance of different aspects associated with the use of salt. The results of this question are presented in Figure 11. In most cases, the aspects cited were very or somewhat important to the respondent and their agency. The exception was the difficulty in applying or handling salt, which was largely rated as not important to respondents. In addition to the different aspects cited, additional feedback from respondents included indication that the public expected salt to be used, do not over apply salt for environmental or corrosion concerns, and that the use of spinners had been discontinued on 90 percent of the vehicles since they threw material onto the shoulder and foreslopes rather than the road itself.

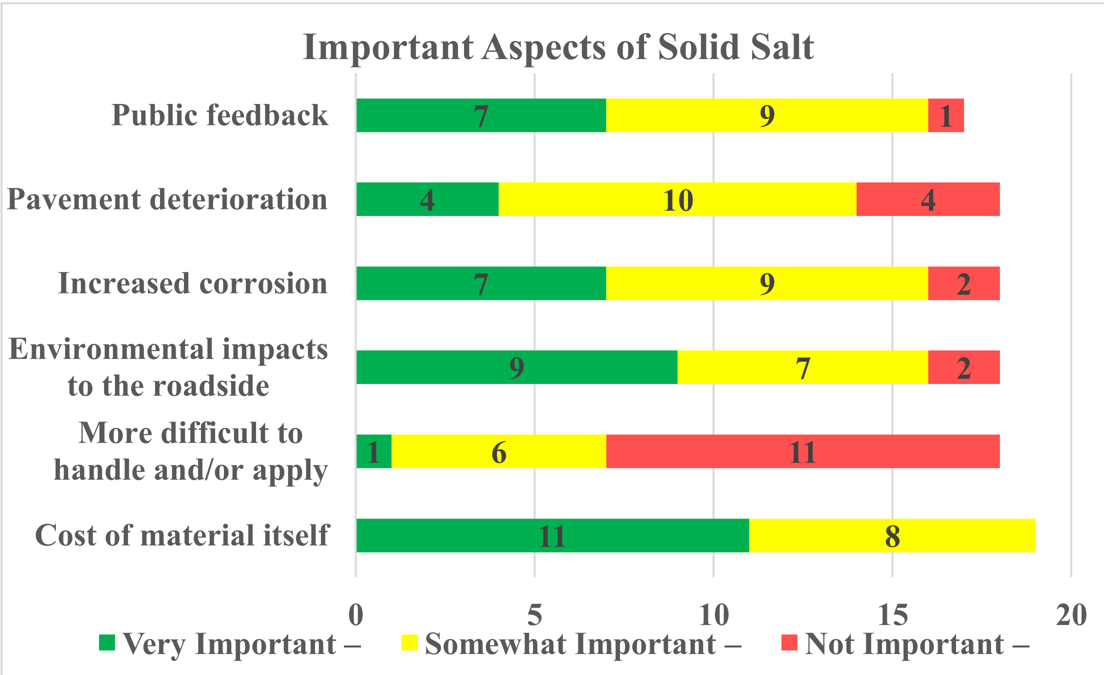

Figure 11: Importance of various aspects of solid salt

Next, respondents provided feedback on the benefits associated with the use of salt. The results of this question are presented in Figure 12. As the figure illustrates, respondents indicated that cost, ease of use, snow and ice clearance and melting capacity were all very or somewhat important. In the case of melting capacity and snow and ice clearance, respondents were unanimous regarding the importance of solid salt. An additional benefit provided by one respondent was that solid salt has a lower purchase cost than other deicing materials.

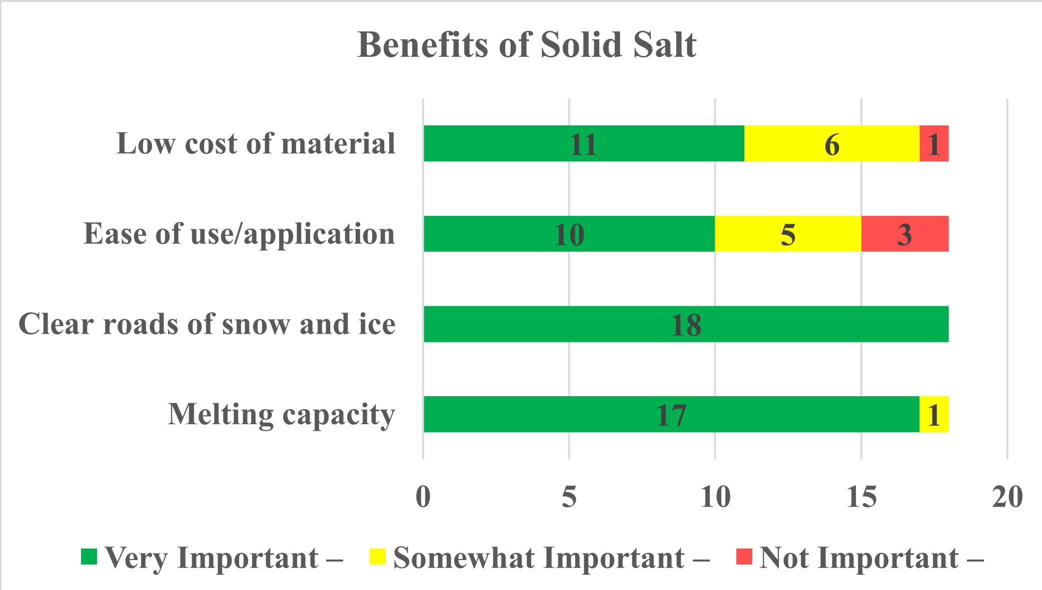

Figure 12: Benefits of solid salt

<u>Salt/Abrasive Mixes</u>

Next, respondents were asked if their agency used a salt/abrasive mix. A total of 19 respondents indicated that their agency did use such a mix, while 2 respondents indicated their agency did not. The average percentage of solid salt in the mixture was 26 percent, with the range being between 4.5 percent and 50 percent. Application rates varied widely by agency, ranging from 100 pounds per lane mile up to 1,200 pounds per lane mile. On average though, the rates cited by respondents were in the 200 to 400 pound per lane mile range. Again, these rates vary based on the nature of the storm being addressed, which explains the wide range of values reported by respondents.

<u>Salt Brine</u>

The use of salt brine by agencies was of interest to the work, and the next portion of the survey sought feedback regarding this aspect of Intermediate practices. A total of 20 respondents indicated that their agency used salt brine, while 2 respondents indicated their agency did not. On average, respondents indicated their agency used 2,371,480 gallons of brine per year, with a range of 15,000 to 15,893,383 gallons reported. Seventeen respondents indicated their agency manufactured its own brine, while 2 indicated that brine was purchased. In the 2 cases where brine was purchased, the respondent indicated that the agency also manufactured brine. The average cost of brine, including delivery was $0.16, with a range of $0.05 to $0.35 reported.

Most respondents provided feedback regarding the application of salt brine in gallons per lane mile, while a few others provided brine application rates per ton of salt (prewetting). An average application of 43 gallons per lane mile was reported by respondents, with reported rates ranging from 11 to 100 gallons per lane mile. An average of 7 gallons of brine used to prewet 1 ton of salt was cited by respondents, with a range of 6 to 10 gallons per ton.

Next, respondents were asked for feedback regarding their views toward different aspects associated with the use of salt brine. The results of this question are presented in Figure 13. As the figure illustrates, most of the aspects of salt brine were cited as being somewhat important to respondents. One exception was the difficulty in handling and applying the material, which was rated as not being an important factor by half of respondents. Additionally, a majority of respondents indicated that the cost of salt brine was a very important aspect. Additional feedback provided to this question included mention that salt brine is used because the respondent's agency wanted no complaints from the public about closed roads. Other feedback included mention that the brine being used by a particular agency was corrosion inhibited (discussed later in this text), while another indicated that their agency did not over apply due brine to environmental and corrosion concerns.

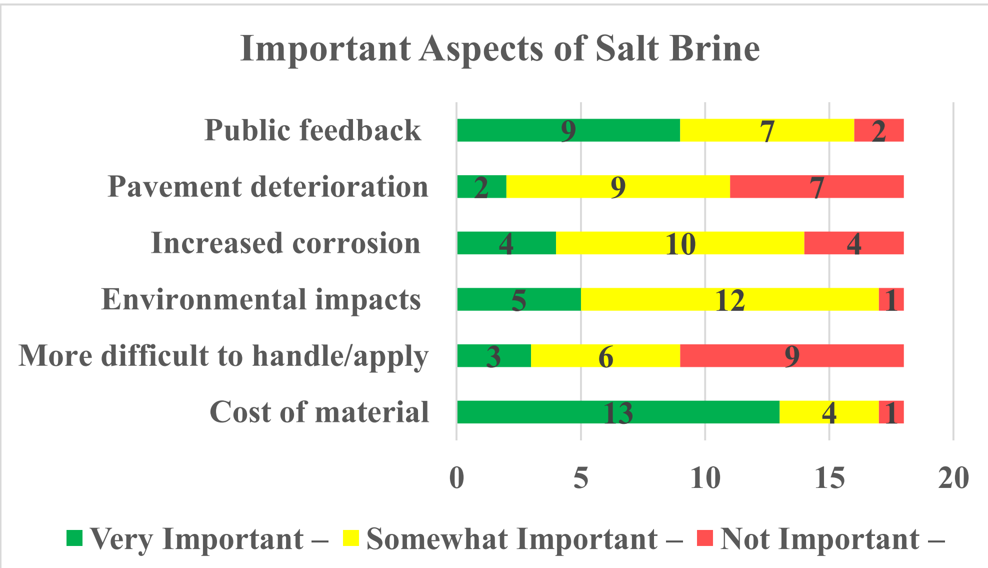

Figure 13: Importance of various aspects of solid salt

Respondents were also asked for feedback on the benefits of salt brine. The results of this question are presented in Figure 14. As the figure indicates, a majority of respondents specified that each of the aspects listed was very important. None of the respondents to the question indicated that the listed aspects were not important. Additional comments provided to this question included that brine was useful in frost prevention on bridges and roadway striping wear is reduced compared to abrasive and anti-skid usage. Further, manpower savings for roadway sweeping were produced through brine usage, and reportable accidents and slide off accidents were reduced.

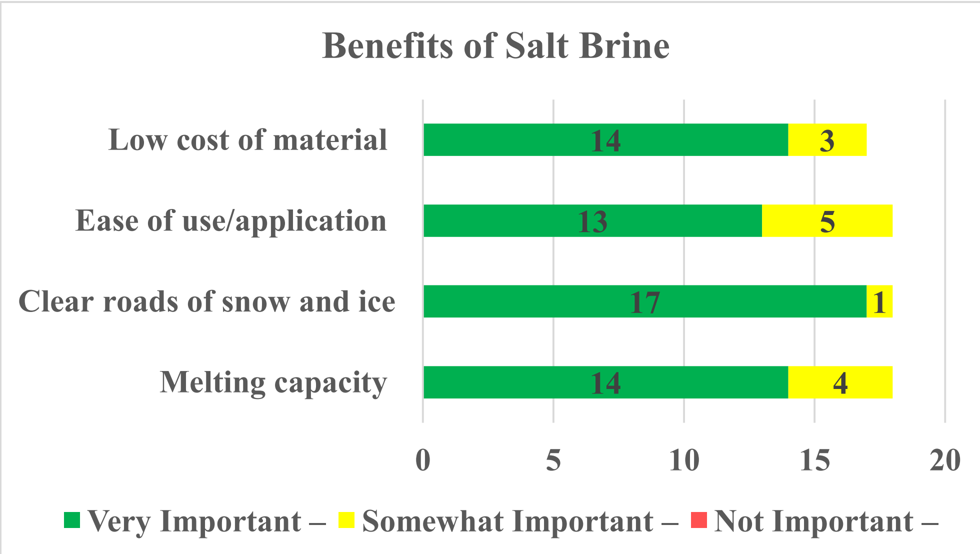

Figure 14: Benefits of salt brine

Salt brine can be used in a prewetting and pretreating capacity, so the next series of questions focused on this aspect of use. A total of 16 respondents indicated that their agency used salt brine in prewetting or pretreating operations, while 5 indicated their agency did not. Eleven respondents indicated that abrasives were prewet, 10 respondents indicated solid salt was prewet, and one respondent each indicated that Ice Slicer and an abrasive/solid salt mix were prewet. Prewetting operations were conducted at the pile by 6 agencies, at the spinner by 12 agencies, by a slurry spreader at 6 agencies and by shower wetting a truckload at 6 agencies. The brine applications made to solids were reported as gallons per ton by some respondents and as percentages by others. The average application by those who reported gallons per ton was 8.9 gallons per ton, with a range of 5 to 17.8 gallons. For those who reported use as a percentage, an average of 20 percent brine was used for prewetting solids, with a range of 10 to 23 percent. Respondents using slurry spreaders were asked if it has been able to reduce application rates, and if so by how much. Two respondents provided information for this question, with one indicating usage had decreased by 20 to 40 percent, while the other reported a decrease of 30 percent. The percentage of brine being used for direct application (i.e. pretreating roadways) was an average of 25 percent of salt brine was used in this manner, with a range of 15 to 90 percent.

Of interest to this work were the costs associated with the use of salt brine. To this end, the next survey question asked respondents to provide an estimate of the annual cost associated with producing and applying salt brine at their agency (equipment, materials, labor, etc.). Only limited information was available related to this aspect of brine use. Three respondents provided values for this question which included $326,849.50, $100,834 and $4,000,000 to $6,000,000. The lane miles maintained by each of these agencies were 23,000, 17,049 and 76,000 respectively. Based on these, general values for estimated costs associated with brine production and application on a per lane mile basis would be $14.21, $5.91 and $52.63 to $78.94, respectively. However, care must be taken to remember that these figures are on a per lane mile basis, and if the number of storms were factored in, they would likely drop significantly.

Respondents were asked for their views regarding the benefits of prewetting. The results of this question are presented in Figure 15. As the figure indicates, the primary benefits of prewetting were viewed to be achieving a faster melt on the pavement surface and reducing the amount of granular product lost to the environment because of bounce and scatter. Reductions in personnel and patrol hours were viewed to be benefits by most respondents, although both of these were listed as benefits that were not important to one respondent. Finally, reductions in the use of granular material were cited by all respondents as being very or somewhat important benefits of prewetting.

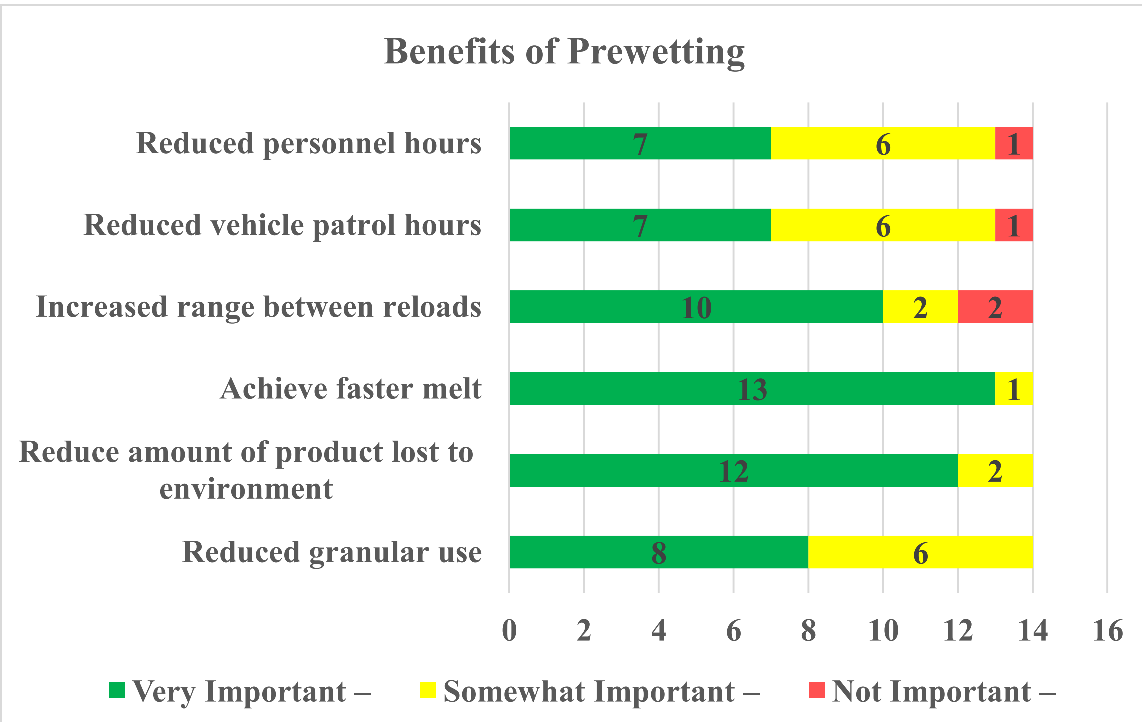

Figure 15: Benefits of prewetting

<u>Anti-icing</u>

The conduct of anti-icing operations using salt or salt brine was the next focus of the survey. A total of 15 respondents indicated that their agency conducted anti-icing using salt or salt brine, while 3 respondents indicated that their agency did not. The equipment used to apply anti-icers varied by agency and included tank trucks and spreader bars (7 agencies), dump trucks with tanks (9 agencies) and standard plow trucks (1 agency). Only limited information was provided by two respondents on the estimated annual costs associated salt/salt brine anti-icing operations (including equipment, materials, labor, etc.). The average cost for these operations was $68.41 per lane mile, with a range of $39.47 to $100.00 per lane mile reported.

When asked about the benefits associated with anti-icing with salt and/or salt brine, respondents replied predominantly in a positive manner. The results of the benefits associated with anti-icing are presented in Figure 16. As the figure illustrates, improved safety was universally viewed by respondents as a very important benefit of anti-icing. All other benefits were also rated as very or somewhat important by the majority of respondents, with the exception of one agency indicating that reducing the number of application vehicles needed for operations was not an important aspect of anti-icing. Additional comments provided to this question indicated that anti-icing applications on bridge decks reduce the occurrence of frost and that anti-icing applications also decrease amount of time for the salt to become active as it is already in solution and does not need to melt into a brine.

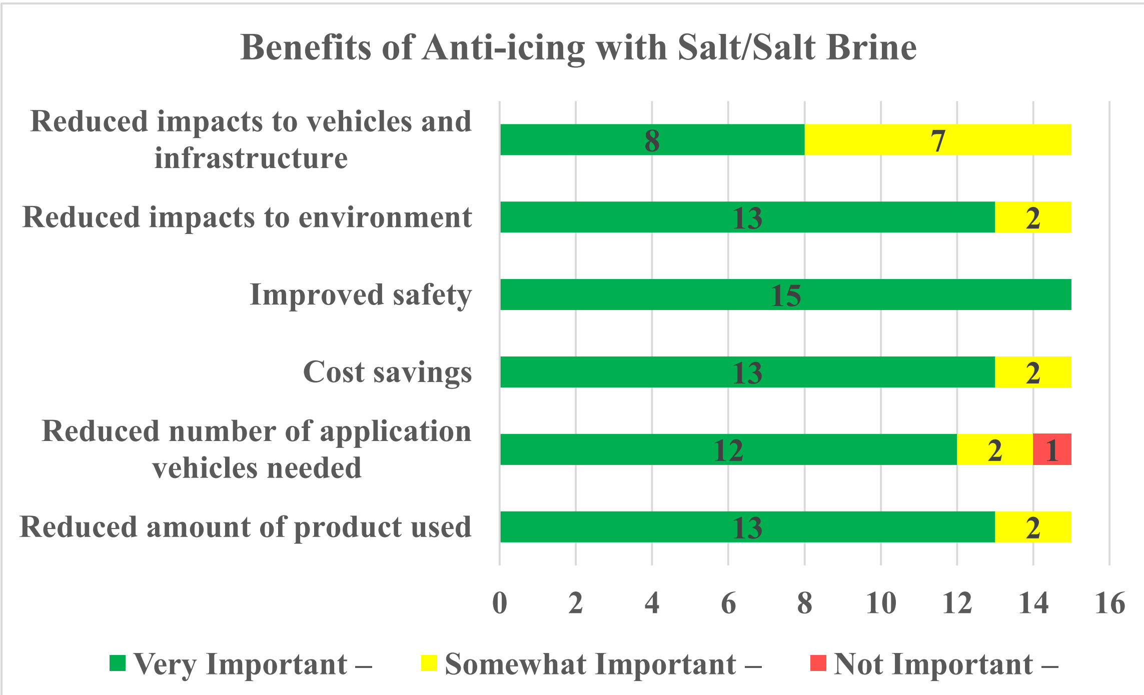

Figure 16: Benefits of anti-icing with salt / salt brine

A total of 18 respondents indicated that their agency produced its own salt brine. In line with this, the different costs associated with the production of brine were of interest. Therefore, follow-up questions were posed that sought information on the costs of brine-making such as the cost of equipment, transport, materials, maintenance, labor, etc. Unfortunately, only a limited number of respondents provided feedback to these questions, and in most cases, responses indicated that the information being sought was not available or tracked. In light of this, the following information that is presented should be considered as a supplemental point of reference and may or may not represent the true costs associated with a particular aspect of brine-making.

The average cost of brine-making equipment was $89,273, with reported costs ranging from $7,000 to $250,000. Only one response was provided regarding the cost to transport brine from a production location to another site. The respondent indicated that the cost of transport was "16-31% of haul cost (Haul cost is labor to haul, brine production cost and the cost of the transport to haul)". Input materials used in making the brine were reported by one respondent as "51-56% of haul cost" and a second respondent as $1,563,901. Fuel costs associated with the transport of brine were indicated as being included in the equipment cost by two respondents, while a third indicated a cost of $0.035 per gallon. Similarly, two respondents indicated that transport truck maintenance was included under equipment costs, while a third indicated a cost of $80.00. Finally, labor costs were cited as $50.00 (units such as per hour or season not specified), $256,245 (units not specified, but assumed to be the annual cost for all production in the respective state) and "13-18% of haul cost". As these collective values indicate, there appear to be different approaches to tracking and reporting the costs of brine-making, when values themselves are tracked. In light of these responses, it is difficult to assign a specific cost to the production of brine.

The final question sought feedback on the benefits of brine-making. The results of this question are presented in Figure 17. As the figure indicates, all aspects of brine making were rated by respondents as being very or somewhat important. The ability to make brine on an as-needed basis was the benefit most widely indicated as important by respondents. Information provided by one respondent indicated that the cost of brine per gallon was $0.10 when produced by the agency and $0.30 when purchased from a vendor. Another respondent indicated that their agency had reduced the use of salt by 30 percent when using brine.

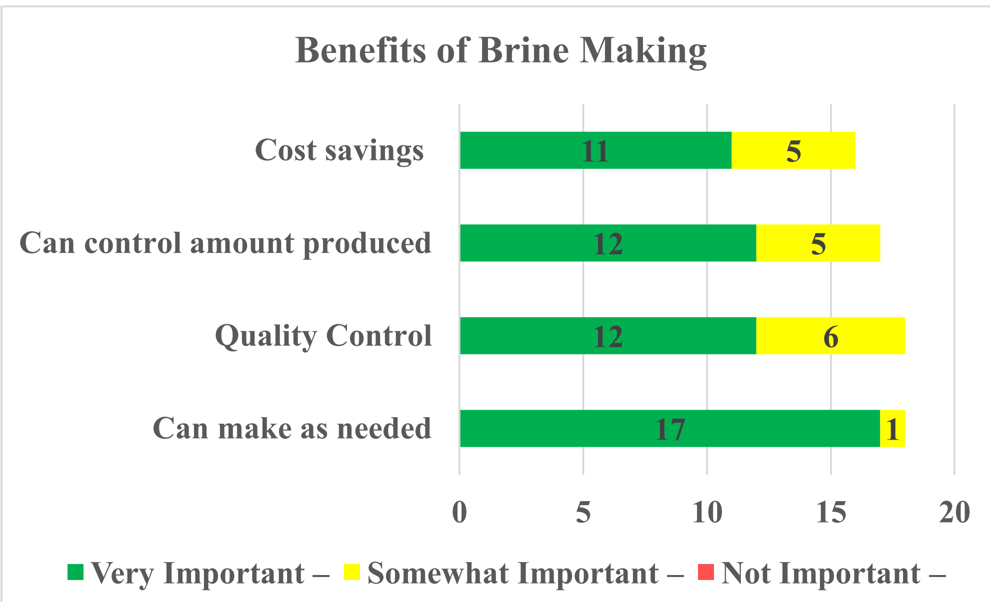

Figure 17: Benefits of brine-making

Advanced Practices

Advanced winter maintenance practices were those that employed the selection and use of alternative chemicals, corrosion-inhibited liquids and/or treated or chemically enhanced solid chemicals to match performance with environmental conditions for anti-icing and deicing (in addition to Basic and Intermediate activities such as plowing and use of salt, salt brine and/or abrasives). A total of 14 respondents indicated their agency used Advanced practices, while 7 respondents indicated that their agency did not use such practices. Those who indicated their agency used Advanced practices were asked to describe how much these practices impacted their organization's LOS.

- Ability to improve LOS in colder temps. Save on corrosion related to vehicle and infrastructure. Air and water impact reduction.

- Our use has been experimental. Where advanced practices have been tried the feedback has been positive.
- Utilizing advanced practices have allowed us to maintain a very high LOS regardless the intensity of the storm.
- We have had a dramatic reduction in corrosion to our equipment. Faster melt down of the roadways. Elimination of hard pack and the elimination of all street sweeping.
- Major impact in a positive way. Reduced crashes, more rapid melt down, no bond of frozen precipitation.
- Improves LOS at colder temperatures
- We only use beet juice as an enhancer. It has helped us in cold temperatures and also with bounce and scatter. It has had a positive impact on our level of service, but it is not quantified.

As these responses indicate, the use of Advanced practices has led to improved LOS, particularly when storm events involve colder temperatures. A specific LOS level achieved through their use was not specified by any user however. As a follow-up question, respondents were asked what the impacts of Advanced practices have been on public mobility. Once again this was an open-ended question that received written responses. Summaries of the relevant information provided included:

- Increased LOS sooner due to higher performing materials and application strategies when temperatures are below 10°F.
- Roads generally clear faster.
- Good.
- Safer roads. Fewer vehicle crashes.
- Increased mobility. Safer roads in less time.
- Improves LOS at colder temperatures.
- Allows us to provide better mobility in cold temperatures and also keep more salt on the road leading to better melting and improved mobility.

Again, these responses are indicative that Advanced practices have enhanced public mobility, particularly during colder temperature events, by producing safer roadway surfaces. Finally, respondents were asked whether any change in crashes had been observed from the use of Advanced practices. Only limited responses were provided to this question, with 4 respondents indicating that crashes had changed, 1 respondent indicating there had been no change and 2 respondents indicating that changes were unknown. In the cases where changes were indicated, no figures were provided to illustrate the extent of these perceived changes.

Corrosion Inhibitors

Next, the survey sought information related to specific aspects of Advanced practices, beginning with corrosion inhibitors. Corrosion is a significant impact of winter maintenance operations, affecting the equipment and infrastructure of the agency itself as well as the vehicles of the general public. To address the issue of corrosion, agencies have begun to employ corrosion inhibitors in their winter maintenance operations. To understand the extent that corrosion inhibitors were employed, respondents were first asked if their agency used corrosion inhibitors with its winter maintenance products. A total of 6 respondents indicated their agency used inhibitors, 4 indicated they were used in some locations and 4 indicated inhibitors were not used.

Next, respondents were asked what corrosion inhibiting product(s) their agency used. Responses included the following:

- Ice Ban, Apex [Envirotech].
- Frezgaurd, Headwaters.
- Ice B Gone liquid.
- Safe Melt, Triethanolamine.
- Provided by supplier within the material. Not applied or purchased separately.
- We use beet juice.

As these responses indicate, a number of different products (mostly proprietary from vendors) are employed as corrosion inhibitors.

Respondents were also asked to provide the approximate cost of the material used (per gallon or per ton). Information provided indicated the following costs for each respective product:

- Ice Ban - $0.78 per gallon.
- Headwaters [brand] - $650.00 per ton.
- Ice B Gone - $1.50 per gallon.
- Safe Melt - $1.21 per gallon.
- Beet juice - $1.25 per gallon.

Additional information related to costs provided by one respondent indicated that a tank, pump, hose and nozzle setup cost approximately $3,000.00 to facilitate stock pile treating.

The benefits of using corrosion inhibitors were the next area of focus for the survey. Respondents were asked to rate the importance of different benefits of corrosion inhibitor(s). The results for this question are presented in Figure 18. As the figure indicates, feedback from respondents indicated that all of the listed benefits of inhibitors were very or somewhat important. Reduced corrosion to the agency vehicle and equipment received a slightly more positive rating than reducing corrosion to the public's vehicles or infrastructure.

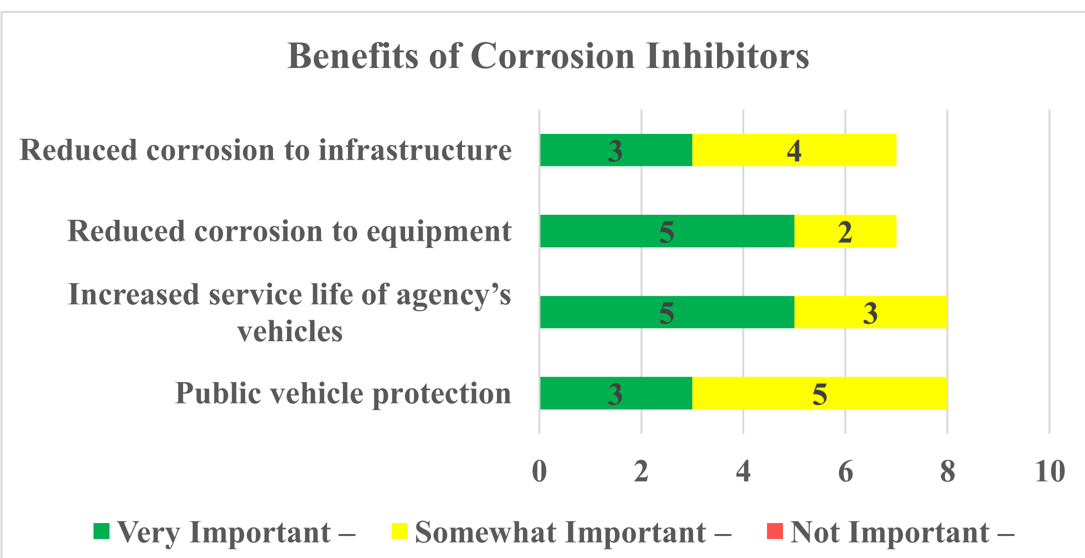

Figure 18: Benefits of corrosion inhibitors

Inhibited Salt Brine

The next portion of questions focused specifically on inhibited salt brine use. A total of 2 respondents indicated their agency used inhibited salt brine, 3 indicated it was used in some locations and 8 indicated inhibited salt brine was not used. Reported application rates averaged 36 gallons per lane mile, with a range of 25 to 60 gallons per lane mile cited. The cost of inhibited salt brine was $0.12 to $0.50 per gallon. The equipment used to apply inhibited salt brine included direct liquid application units, pre-wet solid spreaders, brine tank trucks and saddle tanks with spinners. Responses when asked when and where inhibited salt brine was used included for prewetting, anti-icing and deicing, on interstate corridors prior to a storm, and on every road. Three respondents indicated that their agency had used inhibited salt brine in a prewetting operation. No respondents had information on the number of applications needed to achieve an LOS for a given condition versus another product. Responses when asked to provide an estimate of the annual cost associated inhibited salt brine operations at an agency (equipment, materials, labor, etc.) indicated that this information was not tracked or available.

Next, respondents were asked to rate the importance of different aspects related to using inhibited salt brine. The results for this question are presented in Figure 19. Given the limited number of respondents that indicated the use of inhibited salt brine, the feedback provided to this and follow-up questions was low. As the figure indicates, environmental impacts of the material to the roadside were important to respondents, as was increased corrosion. Difficulty in handling and application was not as big of a concern to respondents. Aside from these items, remaining aspects were rated variably among respondents in terms of importance.

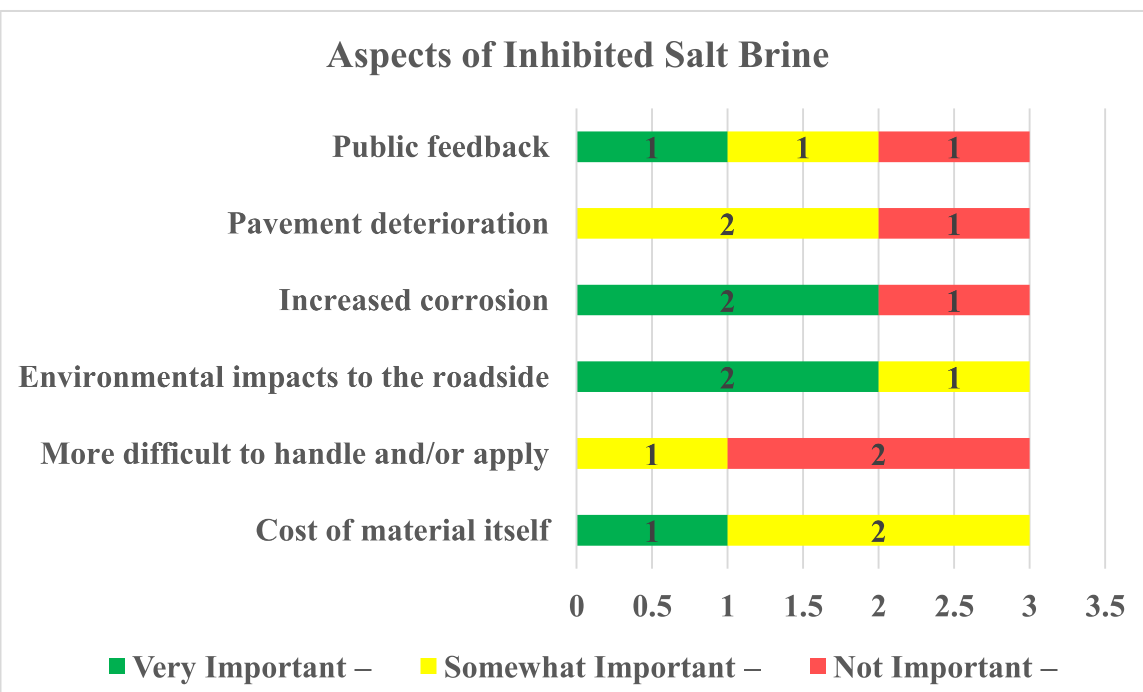

Figure 19: Importance of aspects for inhibited salt brine

A follow-up question sought feedback on the importance of the benefits related to inhibited salt brine. The feedback received to this question is presented in Figure 20. As the figure illustrates, improved safety was cited as a very important benefit by all respondents. Reduction of salt/sand use, better low temperature performance and cost savings were all rated as very or somewhat important by respondents. Reductions in the number of application vehicles was not viewed as important by 2 or the 3 respondents.

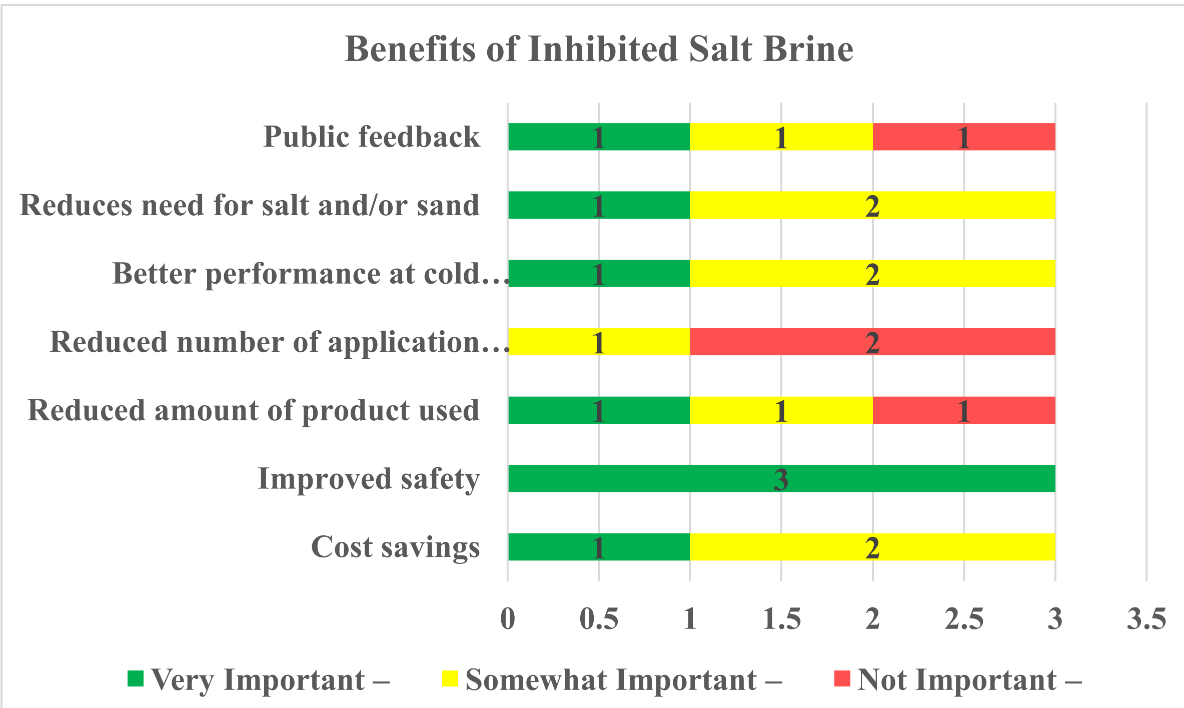

Figure 20: Benefits of inhibited salt brine

<u>Magnesium Chloride</u>

The next portion of the survey sought feedback on the use of Magnesium Chloride ($MgCl_2$) by agencies. A total of 10 respondents indicated that their agency used $MgCl_2$, while 3 agencies did not. Magnesium Chloride can be used in different forms, and 7 respondents indicated that their agency used an inhibited liquid, 2 indicated an uninhibited liquid was used, and 1 indicated an inhibited solid was used. No agency indicated the use of an uninhibited solid form of $MgCl_2$. Reported application rates for inhibited solids ranged from 180 to 220 pounds per lane mile (1 respondent), application rates for inhibited liquids ranged from 20 to 50 gallons per lane mile or 8 to 10 gallons per ton of solids (4 respondents), and application rates for uninhibited liquids were cited as being ½ gallon per lane mile (1 respondent). Reported costs for each material were $150 per ton for inhibited solids, $1.00 to $1.50 per gallon for inhibited liquids and $1.20 per gallon for uninhibited liquids.

The different materials were applied using standard equipment, including dump trucks and spreaders for solid materials and direct liquid application units or tanks with sprayer bars for liquid applications. Use of $MgCl_2$ included when temperatures dropped below 5 degrees Fahrenheit in trouble areas (intersections), in deicing operations at higher elevations, for prewetting/pretreating and anti-icing operations (including as a stock pile treatment), and within salt brine mixtures. Seven respondents indicated that their agency had applied $MgCl_2$ in combination with other products (like pre-wetting), while 2 respondents indicated this was not done. Most respondents indicated that their agency did not have any information on the number of $MgCl_2$ applications needed to achieve an LOS for a given condition versus other products. However, one respondent did indicate that the material in use (inhibited solid) extended the same LOS achieved by salt applications down to about -5°F to - 8°F below zero, with LOS being about the same as utilizing a sand-salt mixture at these same temperatures but for a fraction of the cost.

Only limited information was provided by respondents on the annual costs associated $MgCl_2$ operations at their agency (such as equipment, materials, labor, etc.). One respondent indicated that their agency ordered "roughly 100 ton or less [inhibited solid], so a minimal cost and operations". A second respondent (municipality) indicated their agency costs were $6,000. Aside from this information, remaining respondents indicated that this information was not tracked or broken out separately.

Next, feedback was sought regarding the importance of different aspects related to $MgCl_2$ use. Feedback to this question is presented in Figure 21. As the figure illustrates, corrosion, environmental impacts and material cost were most highly cited as being very or somewhat important concerns to respondents. In other cases, such as public feedback and pavement deterioration, most indicated that these were somewhat of a concern. The application of $MgCl_2$ presented mixed feedback regarding importance, with some respondents indicating it was an important factor while others did not.

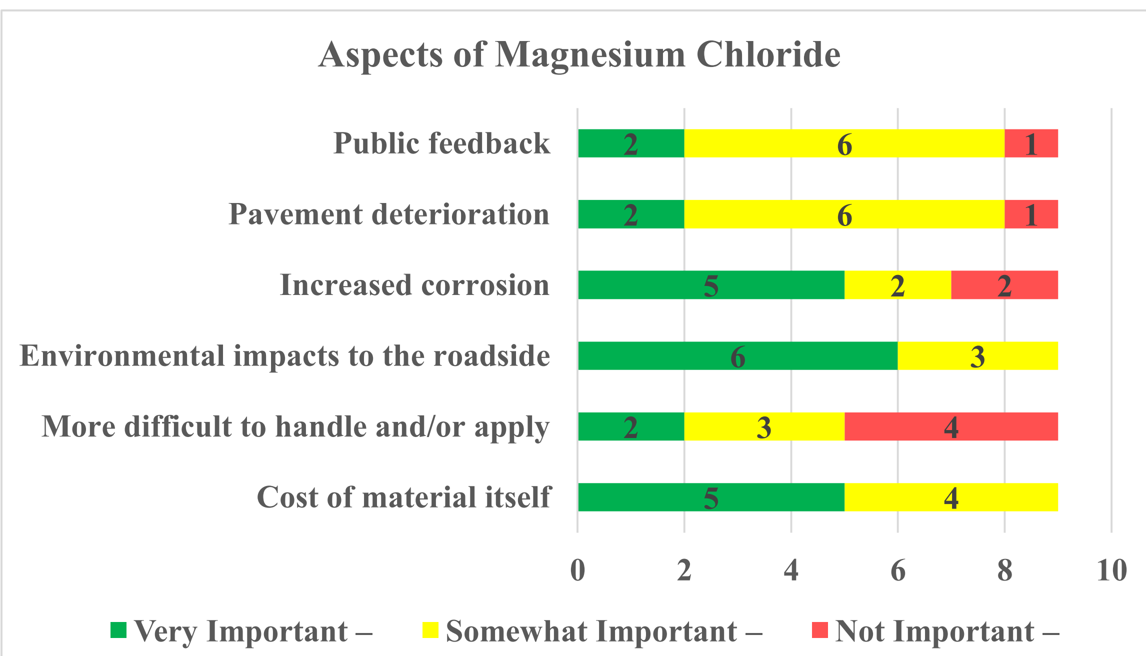

Figure 21: Importance of aspects for Magnesium Chloride

A follow-up question asked respondents to indicate the importance of various benefits associated with $MgCl_2$. The results of this feedback are presented in Figure 22. The most important benefit of $MgCl_2$ was its better performance in cold temperatures. Other benefits were mostly rated as being very or somewhat important to respondents. The only benefit that was not highly rated in terms of importance was $MgCl_2$ not being an animal attractant.

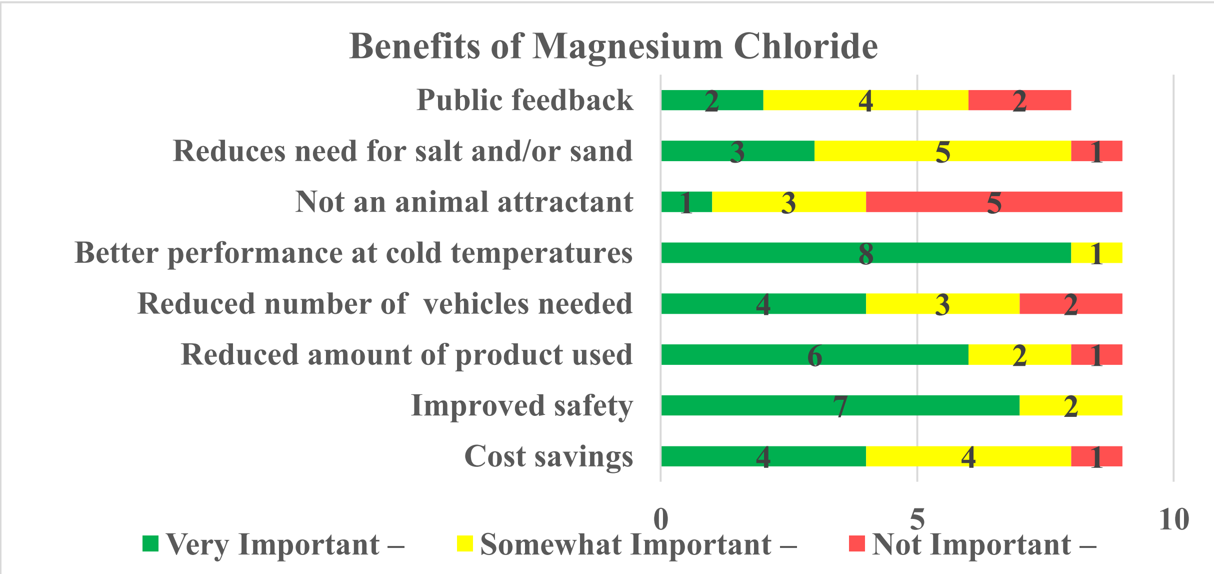

Figure 22: Benefits of Magnesium Chloride

The potential savings of using a Magnesium Chloride versus a straight salt brine was the next item respondents were asked to provide feedback on. The feedback received regarding this question is presented in Figure 23. Most (although not all) of $MgCl_2$ users indicated that the material provided a longer duration of black ice prevention. Some respondents also indicated a reduction in the number of treatment applications required during a storm was achieved, while only two indicated that vehicle refresh rates were lowered.

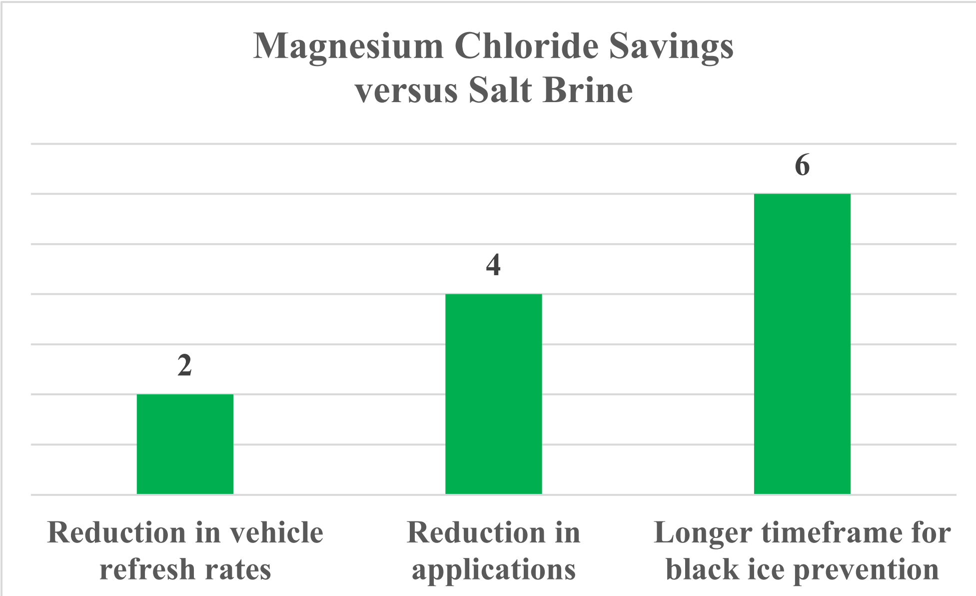

Figure 23: Potential savings of Magnesium Chloride versus salt brine

Calcium Chloride

Calcium Chloride ($CaCl_2$) was another Advanced practice material that was of interest to the work. A total of 9 respondents indicated that their agency used $CaCl_2$, while 4 agencies did not. Calcium Chloride can be used in different forms, and 4 respondents indicated that their agency used an inhibited liquid, 5 indicated an uninhibited liquid was used, 1 indicated an inhibited solid was used and 2 indicated an uninhibited solid form was used. Application rates were only provided by two respondents; the application rate of inhibited liquid used for prewetting salt was 8 gallons per ton, while the application rate for inhibited solid materials was 360 pounds per lane mile. Reported costs for each material were $1.00 to $1.21 per gallon for inhibited liquids, $0.80 to $1.09 per gallon for uninhibited liquids and $450 per ton for uninhibited solids. Information on the cost of inhibited solid materials was not provided by any respondent.

The equipment cited by respondents as being used to apply $CaCl_2$ was fairly standard and included pre-wetting systems, spreader trucks, saddle tanks on trucks spraying at the spinner, spray wands and bars, tank trucks and V-box spreaders. When asked where $CaCl_2$ was used, respondents indicated it was used when temperatures were below 10°F, systemwide depending on temperature, in stockpile treating of sand for gravel roads, and mixed with salt (granular and brine) for temperatures below 20°F. The use of $CaCl_2$ in prewetting was especially highlighted in the follow-up question, which asked if an applied this material was used in combination with other products (like pre-wetting). Seven respondents indicated that their agency used $CaCl_2$ in prewetting, while 1 agency indicated it did not.

Next, feedback was sought regarding the importance of different aspects related to $CaCl_2$ use. Feedback to this question is presented in Figure 24. As the figure illustrates, the majority of aspects that feedback was solicited on were cited as being very or somewhat important to respondents. Only 1 respondent indicated that pavement deterioration was not important, while 2 respondents indicated that difficulty in handling or applying the material was not important.

Collectively, the feedback received on the different aspects of $CaCl_2$ use indicates that agencies are aware of the issues associated with the material and recognize their importance.

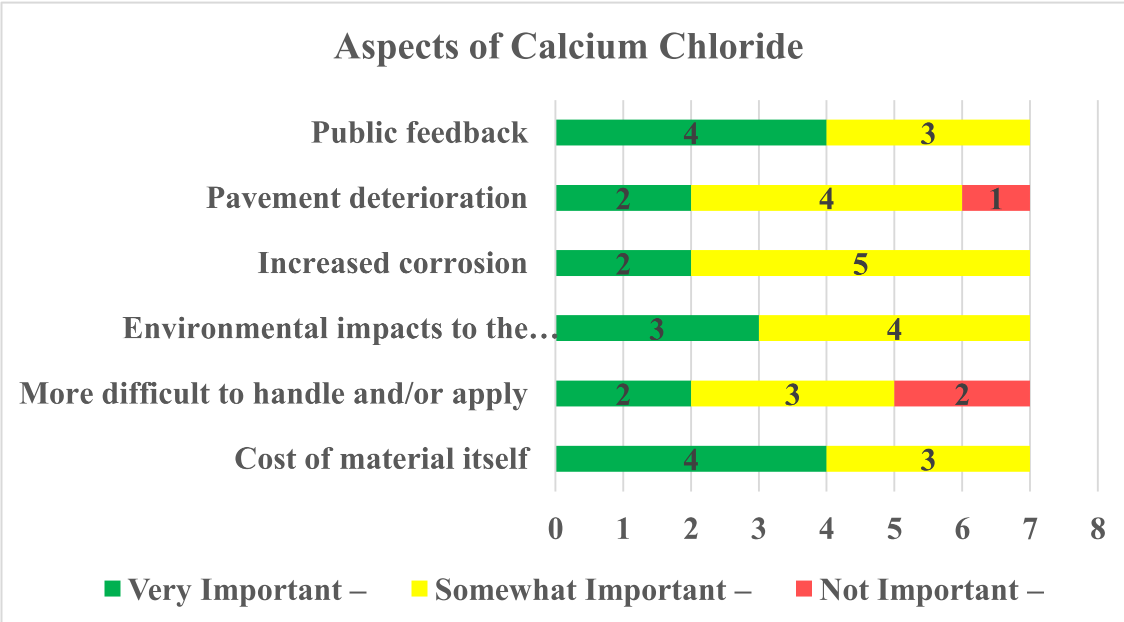

Figure 24: Importance of aspects for Calcium Chloride

A follow-up question asked respondents to indicate the importance of various benefits associated with $CaCl_2$. The results of this feedback are presented in Figure 25Figure 22. As indicated, respondents all agreed that the benefit of $CaCl_2$ having better cold temperature performance was a very important advantage. For other benefits, the results were generally mixed between the benefit being perceived as very or somewhat important. Reduction in the number of maintenance vehicles applying material was cited as not being important to 2 respondents, while the material not being an animal attractant was not important to 4 respondents.

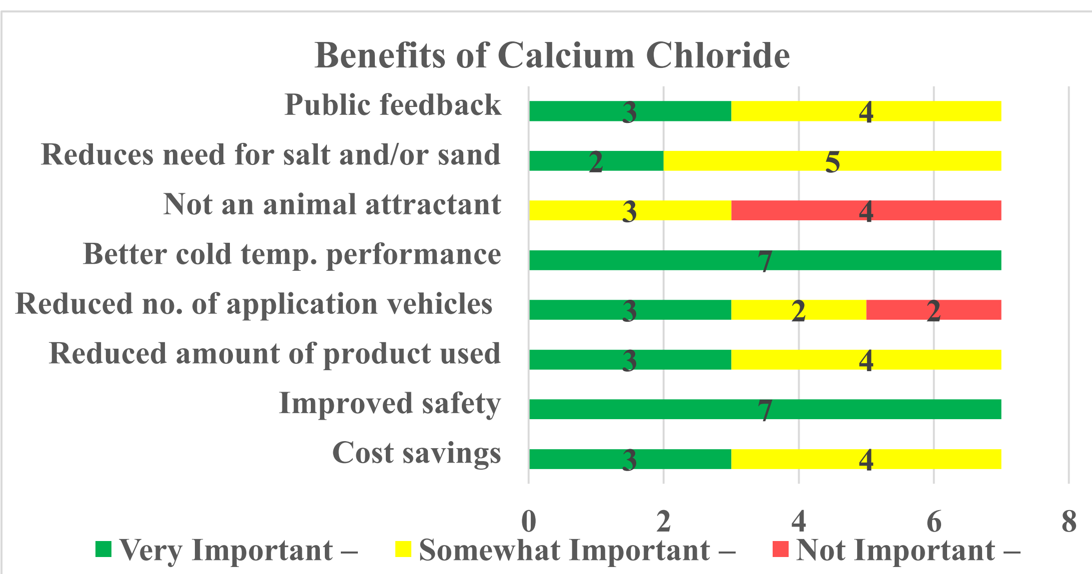

Figure 25: Benefits of Calcium Chloride

Blended Products

Blended products, specifically agricultural byproducts blended with de-icing and anti-icing chemicals, were the final Advanced practice material covered by the survey. Five respondents indicated that their agency used blended products, while 7 respondents indicated their agency did not use them. Only two respondents provided feedback on the types of blended products their agency used, which included an 80 percent salt brine/ 20 percent Ice B Gone mix and blended liquid $CaCl_2$ with forestry by-product [unnamed]. Four respondents indicated the product they used was inhibited (none indicated an uninhibited product was used). Specific application rates were not provided by any respondent, although one did note that the quantity of product used would vary depending on whether prewetting or pretreating was being performed. The prices reported for blended products ranged between $0.50 per gallon and $1.38 per gallon.

Respondents indicated that blended products were applied using a variety of equipment, including tankers, trailers, pretreating at the spinner, spray wands and bars, and plow trucks with saddle tanks. Blended products were cited as being used in a variety of ways, including all roads when temperatures were greater than 20°F, for stock pile treatment, as a pretreatment and retreatment on roads to prevent bonded precipitation. Three respondents indicated that their agency applied blended products in combination with other products, while 2 respondents indicated that their agency did not. One agency reported that one application of blended products reduced application of non-blended products by 50 percent. Information on estimates of the annual cost associated blended product operations (equipment, materials, labor, etc.) was not provided by any respondent.

Next, feedback was sought regarding the importance of different aspects related to blended product use. Feedback to this question is presented in Figure 26. As the figure illustrates, environmental impacts and the material cost were very or somewhat important aspects of blended products to all respondents. Pavement deterioration, increased corrosion and the handling and/or application of blended products were all rated similarly by respondents. Finally, public feedback was rated as being somewhat important by 3 respondents and very important by 2 respondents, indicating that listening to the feedback and needs of the public does receive consideration in using blended products.

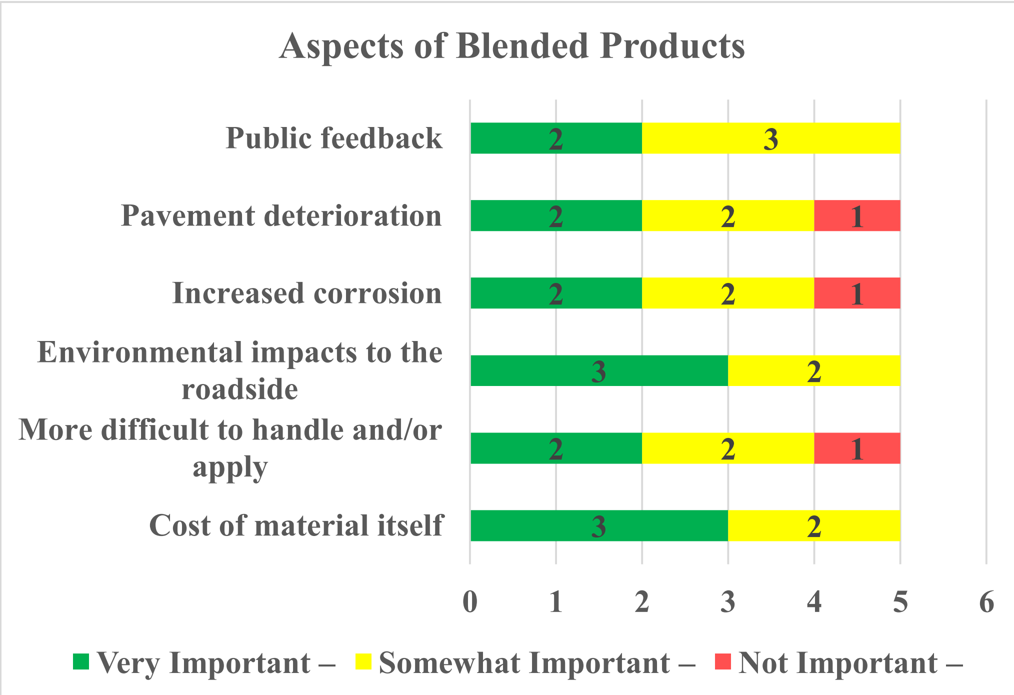

Figure 26: Importance of aspects for blended products

A follow-up question asked respondents to indicate the importance of various benefits associated with blended products. The results of this feedback are presented in Figure 27Figure 22. As indicated, respondents were largely positive regarding the improved cold temperature performance and safety offered by blended products. Reduced need for salt/sand or other materials, as well as longer lasting applications and cost reductions were also viewed favorably as benefits from blended products. Reduction in the number of maintenance vehicles applying material was cited as not being important to 1 respondents, while the material not being an animal attractant was not important to 2 respondents.

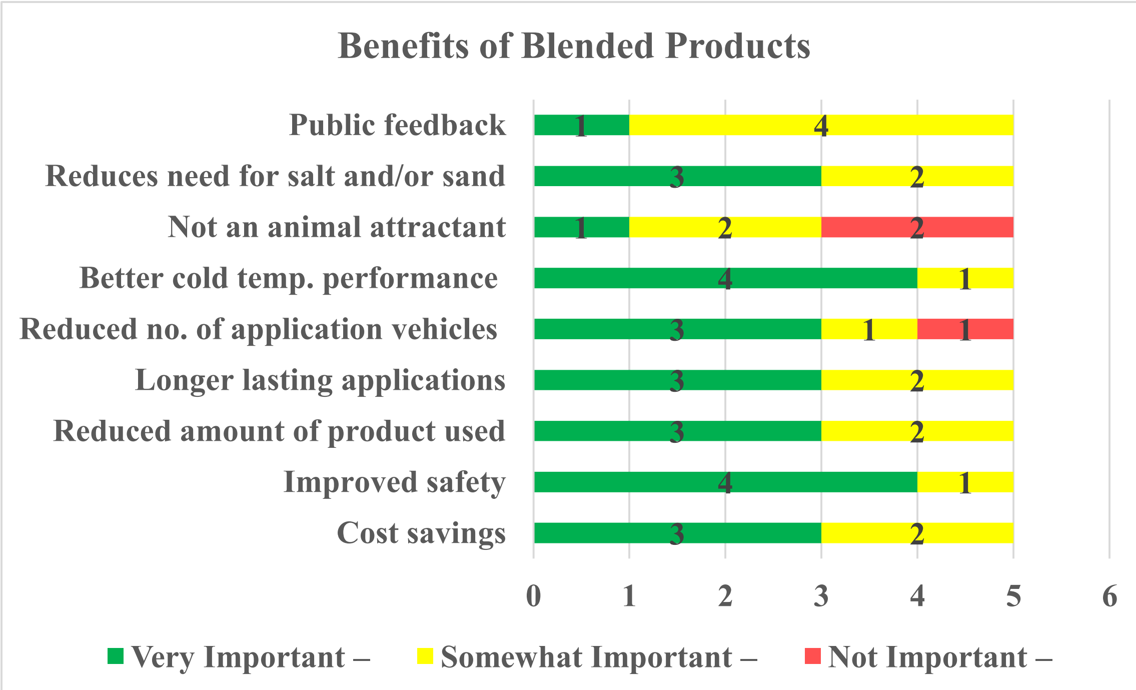

Figure 27: Benefits of blended products

Chemical Selection to Achieve LOS

The final section of the survey sought feedback from respondents on how their agency went about selecting different winter maintenance chemicals to achieve a targeted Level of Service. Unlike previous sections of the survey where a response of "No" to an initial screening question regarding one of the three maintenance practices would allow a respondent to skip over an entire section, questions in this section were posed to all participants. As a result, the responses received for this portion of the survey were higher than those in previous sections.

The initial question posed to respondents asked what factors went into their agency's selection of specific winter maintenance products. A total of 19 respondents answered this question, and the responses are presented in Figure 28. As the figure indicates, all respondents indicated that effectiveness of the material is a factor in its selection. Availability and cost were the next most frequently cited factors, which is reasonable given that these aspects play a role in the procurement process. Meeting LOS objectives and environmental impacts were each factors considered by 13 agencies, while public feedback and ease of use were considered by 10 agencies apiece. In summary, the results of this question illustrate that numerous factors are considered by agencies when selecting conducting product selection, some of which are considered more broadly than others.

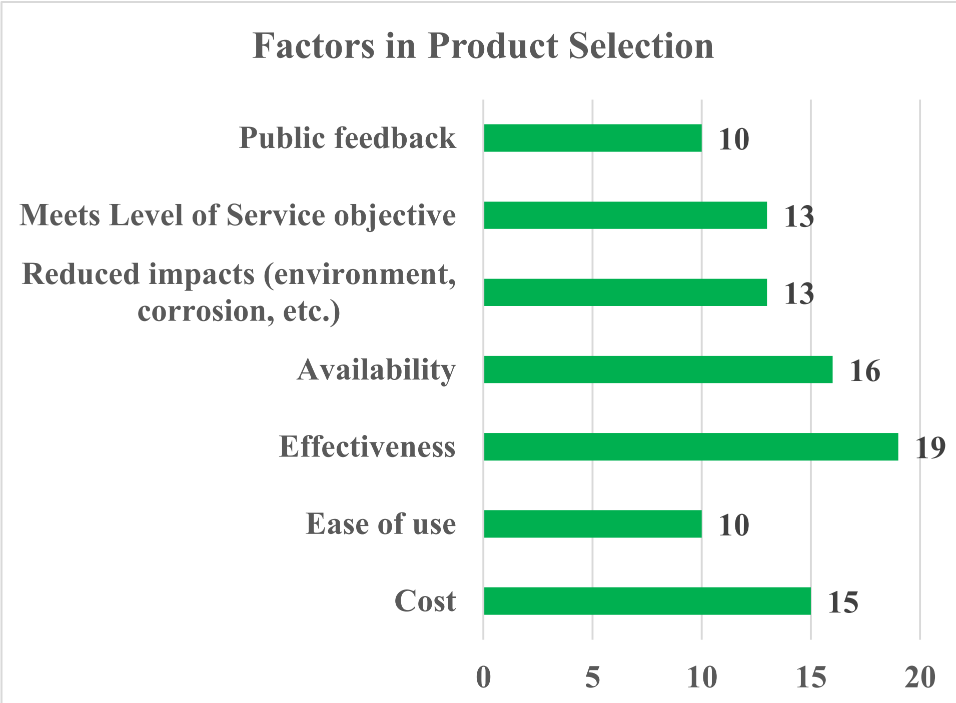

Figure 28: Factors in product selection

Next, respondents were asked if their agency modified its snow and ice control products selection to better meet a prescribed LOS. Twelve respondents indicated that their agency had modified product selection in order to meet LOS targets, while 7 respondents indicated that their agency had not made changes. Responses that indicated changes had not been made are not indicative of the previously discussed factors not being accounted for; rather, it is possible that the selection process already in place was appropriate in incorporating the factors that were important to that particular agency. In light of this potential, a follow-up question was posed that asked what products were used, what product the agency switched to, why the switch was made, and whether the switch has proven to be more effective. This was an open-ended question, and responses provided included:

- Used to just use 5% salt/sand. We are now pre wetting with 5/10 gallons per ton of salt brine or geo brine, and a direct app to the highways we have seen much less pack on the roads and far faster recoveries with the new practices.
- More salt brine applications.
- Continue to increase usage of salt brine. Continue to promote the practice of pre-wetting.
- We have gone to using more blended salt brine, we feel it is the best cost effective method we use.
- Agency only uses salt products. Timing and rates have been modified to achieve the desired LOS.
- We used a salt/sand combo of regular salt. When we switched to treated salt only we reduced our overall salt consumption by 20% and sand by 70% (sand is still used on gravel).
- Brine.

- We had been using regular salt and sand then switched to pre-wet inhibited salt. We now use less salt per season and have a dramatic reduction in rust.
- Main products are plain salt and treated salt.
- Addition of beet juice over the last several years.
- Switched from principally anti-skid mixed with salt to solid salt and salt brine usage. The switch has been very effective for both mobility during winter storms, accident reductions, reduced labor in spring clean-up, reduced winter-time broken windshield damage claims (none) and cost savings.

As many of these responses indicate, there has been a shift towards a greater use of salt brine, both in prewetting/pretreating applications. Many responses also referred to the use of various granular salt products (inhibited and uninhibited), which is in line with the results from the practices portion of the survey, where responses dropped off after the section of Intermediate practices. In several cases, material use was reduced compared to past practices when changes were made to achieve a given LOS.

The final survey question asked respondents whether their agency received any feedback (positive, negative, constructive) on any of the products used (e.g., rock salt, brine, $MgCL_2$, $CaCl_2$, blended products, pre-wet/pre-treated, or corrosion inhibited). Once again, this was an open-ended question, and the feedback received included:

- Negative feedback with sand-salt mix due to accumulation over the season, public perception is out of sight out of mind. Positive feedback with controlling costs for salt and overall winter maintenance.
- We have received less customer complaints with regards to vehicular corrosion after switching to corrosion inhibited salt brine from corrosion inhibited magnesium chloride.
- Prewetting and brine have been very positively received.
- The public feels salt brine is rusting their vehicles.
- All positive in how quickly we achieve our LOS
- The public likes salt and calcium. They do not like brine.
- Mostly negative in regards to vehicle corrosion and from reducing the amount of overall sand use.
- Some concern with ground water infiltration by chlorides. $MgCl_2$ for anti-icing causes slick conditions at times.
- Positive feedback.

As these responses illustrate, the feedback received by agencies was mixed. Some responses indicated that the public had concerns related to salt and corrosion (particularly with brine), while other responses indicated a favorable impression of salt use by the public. In cases where salt was an issue, it appears that the public was more inclined to see abrasives used, despite the potential for other types of vehicle damage to occur. In one instance, the respondent indicated that public complaints fell following the use of corrosion inhibitors, which is encouraging. Additional public concerns were related to chloride infiltration of groundwater. Finally, one respondent noted that use of $MgCl_2$ for anti-icing caused some slickness at times.

Follow-up Survey Results

Advanced Practices

Advanced winter maintenance practices were those that employed the selection and use of alternative chemicals, corrosion-inhibited liquids and/or treated or chemically enhanced solid chemicals to match performance with environmental conditions for anti-icing and deicing (in addition to Basic and Intermediate activities such as plowing and use of salt, salt brine and/or abrasives). The materials of interest to the survey included:

- Corrosion Inhibitors
- Corrosion Inhibited Salt Brine
- Magnesium Chloride – Solid
- Magnesium Chloride – Liquid
- Magnesium Chloride - Corrosion Inhibited Solid
- Magnesium Chloride - Corrosion Inhibited Liquid
- Calcium Chloride – Solid
- Calcium Chloride – Liquid
- Calcium Chloride - Corrosion Inhibited Solid
- Calcium Chloride - Corrosion Inhibited Liquid
- Blended Products - Agricultural byproducts blended with de-icing and anti-icing chemicals
- Blended Products - Corrosion Inhibited

In a survey focused entirely on obtaining information on these advanced practices, a total of 11 responses were received from 10 individual agencies. Among the respondents were 7 states and three municipalities.

Corrosion Inhibitors

Corrosion is a significant impact of winter maintenance operations, affecting the equipment and infrastructure of the agency itself as well as the vehicles of the general public. To address the issue of corrosion, agencies have begun to employ corrosion inhibitors in their winter maintenance operations. To understand the extent that corrosion inhibitors were employed, respondents were first asked if their agency used corrosion inhibitors with its winter maintenance products. Seven respondents (including four DOTs) indicated their agency used different corrosion inhibitors. Products/brands in use included:

- Aqua Salina products
- Beet Heet products
- Calcium Chloride with Boost
- Geomelt 55
- Geomelt S7
- Magnesium Chloride
- Ice B' Gone
- Magic Minus Zero
- Apex Meltdown Ingredient
- Freezgard CI Plus

- DowArmor
- Molasses

The approximate costs for these different materials were cited as follows:

- Calcium Chloride with Boost- $1.58 per gallon
- Aqua Salina- $1.01 per gallon
- Aqua Salina + IceBite- $1.29
- Beet Heet Concentrate- $1.67 per gallon
- Beet Heet Severe- $1.47 per gallon
- XO-Melt2- $1.17 per gallon
- Geomelt 55- $1.57 per gallon
- Geomelt S7- $1.33 per gallon
- Magnesium Chloride - $1.05 - $1.20 per gallon, $169.39 per ton
- Ice B' Gone - $1.40 - $1.50 per gallon
- Magic Minus Zero - $1.40 per gallon
- Apex Meltdown Ingredient - $0.73 per gallon
- Freezgard CI Plus – No price cited.
- DowArmor - $1.20 per gallon
- Molasses - $1.26 per gallon (mixed with Magnesium Chloride as a package)

Only two respondents (Maine and Ohio) provided further feedback regarding additional costs associated with corrosion inhibitors. Maine indicated that "Sometimes we get plugging of filters or segregation in the tanks. Sometimes the tanks have to be pumped out." Ohio indicated that "shipping costs for additional drops, demurrage and flat fees of deliveries under 2000 gallons" were incurred.

The Level of Service (LOS) achieved by products using corrosion inhibitors was difficult for respondents to determine, given that inhibitors are used in combination with other materials. Responses regarding LOS included:

- Not sure what can be attributed to the inhibitors.
- Assists in corrosion prevention on PCC streets and equipment.
- High Level of Service.
- We are able to achieve the desired level of service when materials are applied at the proper rate and time.

Similarly, no information was available from any respondent regarding observed or perceived reductions in crashes following the adoption of corrosion inhibitors.

The benefits of corrosion inhibitors as rated by respondents are presented in Figure 29. As the figure indicates, most respondents indicated that all of the listed benefits of inhibitors were very or somewhat important. However, two respondents indicated that corrosion protection for the general public's vehicles was not an important factor in corrosion inhibitor use.

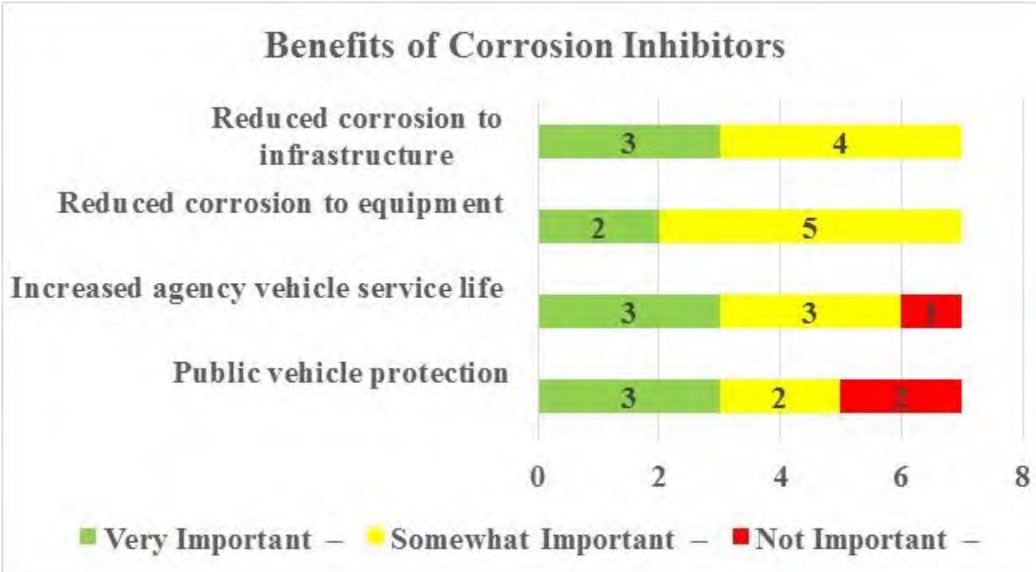

Figure 29: Benefits of corrosion inhibitors

Finally, additional thoughts provided by respondents related to corrosion inhibitors included:

- For the amount of corrosion reduction realized the additional costs do not justify the use. The base materials used for deicing are still corrosive enough that applying small volumes of liquids to offset the corrosiveness is somewhat trivial. While there is a "feel good" factor, in the field the results are minimal. For agency equipment we have seen much better success with pre-treatment of vehicles with new corrosion inhibitors and using salt neutralizers combined with frequent post storm cleaning.
- Use them for our magnesium chloride product, but not sure how much they really do in the environment. Most of the chlorides we use are from rock salt anyway.

Inhibited Salt Brine

Two respondents indicated that their agency used salt brine, both of which were municipalities. The limited responses for this material were expected, as a prior survey with 30 respondents found that only 6 agencies used inhibited salt brine. Cited application rates for this material ranged from 40 to 60 gallons per lane mile. Only one respondent provided a cost for the material, with that cost being $0.30 per gallon. Each respondent indicated that their agency produced its own salt brine. One respondent indicated that the estimated annual cost associated with corrosion inhibited salt brine operations at their agency (for aspects such as equipment, materials, labor, etc.) was $50,000.

Brine was applied using truck and trailer mounted spray systems and a 2000 gallon slide in unit with pencil nozzles. Corrosion inhibited salt brine was used on roads and bridges for a majority of storms and for bridge frost treatments by one agency, with the other using it for anti-icing and pre wetting of salt. Both respondents indicated that their agency had applied corrosion inhibited salt brine in combination with other products for activities such as prewetting. Only limited feedback was provided regarding the LOS achieved through the use of inhibited salt bring. One respondent indicated a "high" LOS was achieved, while the second indicated that the materials had a "great residual value, maybe some limited corrosion success".

Respondents were asked to characterize the importance of different aspects associated with inhibited brine use. The cost of the material itself was a very important aspect of corrosion inhibited salt brine for both respondents, while public feedback was a somewhat important aspect to each. Difficulty in handling the material was somewhat important to one respondent and not important to the other. Environmental impacts were very important to one respondent and not important to the other. Finally, pavement deterioration was cited as very important to one respondent and somewhat important to the other.

The benefits of inhibited brine use, including cost savings, safety improvement, reduced product use and reductions in salt and/or abrasive use were each rated as very important to one respondent and not important to the other. Both respondents indicated that a reduction in the number of applications was not an important benefit, while better performance at cold temperatures was an important benefit. Finally, public feedback was cited as being somewhat or not important to one respondent each, respectively. One respondent provided the additional comment that "the GeoMelt we use is really more beneficial for residual value and lower operating temperatures. While considered less corrosive, we really don't see a great deal of benefit with that aspect of the product".

<u>Magnesium Chloride</u>

Magnesium Chloride ($MgCl_2$) was cited as being used in some form by seven respondents. When broken down by type, one respondent used liquid $MgCl_2$ while six respondents used $MgCl_2$ as a corrosion inhibited liquid. The results to this matched those obtained in a general usage survey completed earlier, where only one respondent used $MgCl_2$ as a solid product and none used a $MgCl_2$ corrosion inhibited solid. The application rates used for $MgCl_2$ in different forms were as follows:

- Liquid $MgCl_2$
    - 1 gallon per lane mile dispersed with 200 lbs. of salt. (pre-wetting)
- Corrosion Inhibited Liquid $MgCl_2$
    - Direct application - 1-25 gallons per lane mile depending on temp.
    - Pre-wet application 4-8 gallons per ton of salt or sand or approximately 1-2 gallons per lane mile.
    - 8-10 gallons per ton to pretreat salt at the spinner.
    - 10 gallons per ton, prewetting.
    - 6-8 gallons per ton, prewetting.
    - 10 - 15 gallons for pre-wetting.
    - 25 - 35 gallons per lane mile for treatment.
    - 8-12 gallons per ton of salt, mostly a 75/25 blend. (pre-wetting)

The costs reported as being associated with the different forms of $MgCl_2$ were as follows:

- Liquid $MgCl_2$
    - $0.75/gallon
- Corrosion Inhibited Liquid $MgCl_2$
    - $1.05 - $1.20 per gallon depending on delivery site
    - $1.09 per gallon
    - $1.40 per gallon

- $1.26 per gallon
- Average cost is $169.39 per ton [Note that this state indicated a liquid was being used for prewetting and direct application, so it is not clear why a cost per ton was provided.]
- $1.26 per gallon.

Limited feedback was provided on the total estimated annual costs associated with Magnesium Chloride operations at each agency (equipment, materials, labor, etc.), and all feedback was provided for agencies using inhibited liquids. One respondent indicated that their agency used approximately 33,000 gallons of inhibited liquid per year. Two remaining respondents indicated that their material costs were $300,000 and $650,000 per year. Note that equipment and labor costs do not appear to be available or separately tracked.

Various equipment was reported as being used in applying the different forms of $MgCl_2$ previously indicated (all liquids). This equipment included:

- Saddle tanks, spraying units for older model trucks and built in onboard spraying system for newer models.
- Direct application - truck with 10 foot spray bar 1600-2500 gallon poly tank.
- Pre-wet application - sander chute by nozzle.
- Pretreat salt at the spinner.
- On board prewetting systems
- Stockpile blended to salt.
- De-icing trucks with mounted tanks and saddle tank on sanders.
- Saddle tanks with sprayers at the 3-6-9 o'clock positions in the chutes as the salt is dropping to the spinner for our conventional spreaders. We also us a Schmidt oatmeal ("slurry") spreader and anti ice with a slide in applicator.

The agency using straight $MgCl_2$ liquid indicated that the product was used with salt applications, with the liquid magnesium applied to the rock salt. Remaining applications of inhibited $MgCl_2$ liquids included:

- Typically whenever we make a salt application we apply the liquid magnesium to the rock salt.
- All road surfaces.
- Prewetting of salt at the spreader.
- Truck Spinner.
- It is used as a pre-treatment prior to storm events, used for pre-wetting with the application of anti-skid/salt materials and for ice removal during storm events.
- Mains, Submains, Hills, Residential streets and parking lots.

All six respondents indicated that their agency applied $MgCl_2$ in combination with other products (like pre-wetting). The LOS achieved by $MgCl_2$ products in all forms was not widely known. One respondent indicated that the use of inhibited $MgCl_2$ liquid produced a "high" LOS. Another respondent indicated that the LOS was "not certain, however it can be shown that the use of the magnesium will bring the roads to bare and wet conditions at a much faster rate". No information was available to or provided by any respondent on the number of applications needed for any form of Magnesium Chloride to achieve an LOS for a given condition versus another product.

Figure 30 presents the aspects of $MgCl_2$ used in both liquid forms. For inhibited liquids, the cost of the material was the greatest concern, albeit to three respondents. Pavement deterioration and environmental impacts were also a concern with inhibited liquids. Corrosion was a concern for uninhibited liquids, as one would expect. Environmental impacts and material cost were also a concern with uninhibited liquids, although as only one respondent selected these particular aspects. As only one agency cited the use of uninhibited $MgCl_2$ liquid, the benefits selected should be interpreted accordingly.

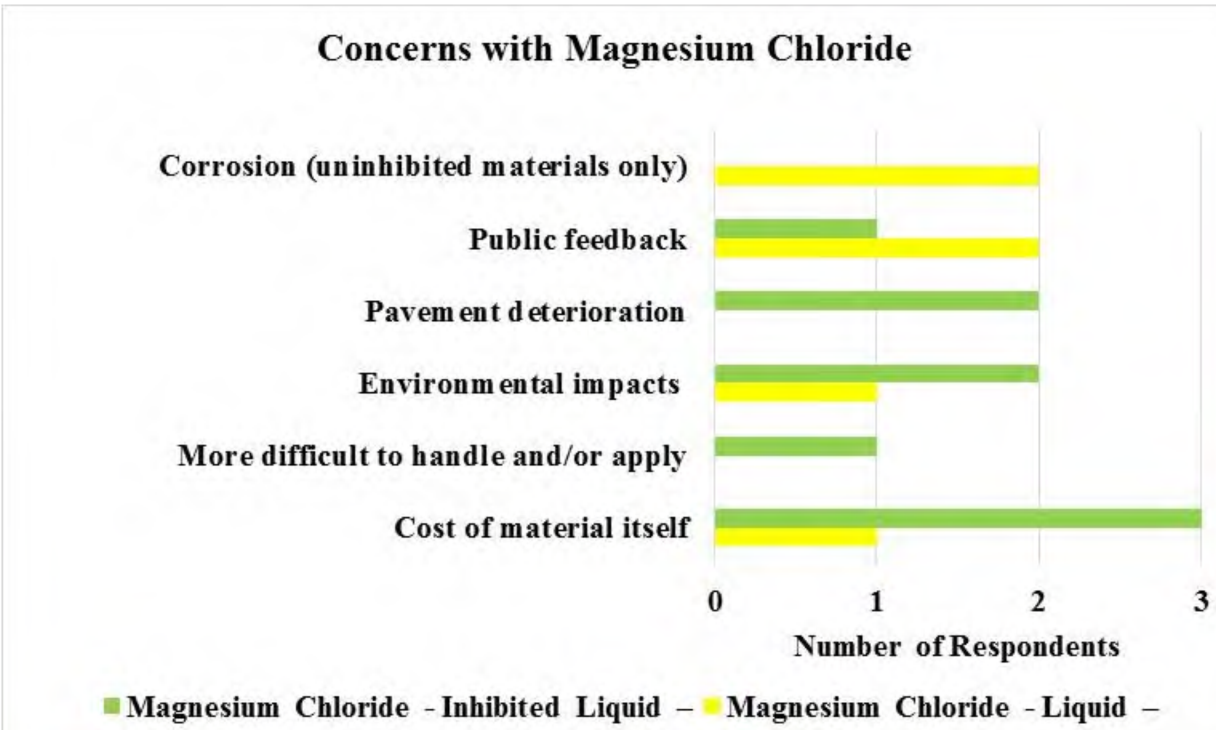

Figure 30: Concerns with Magnesium Chloride

Aside from not being an animal attractant, all cited benefits of $MgCl_2$ were selected by at least one respondent. The most frequently cited benefits were better cold temperature performance, reduced product use, improved safety and cost savings. Public feedback was also cited as a benefit of corrosion inhibited $MgCl_2$ liquid. Again, as only one agency cited the use of uninhibited $MgCl_2$ liquid, the benefits selected should be interpreted accordingly.

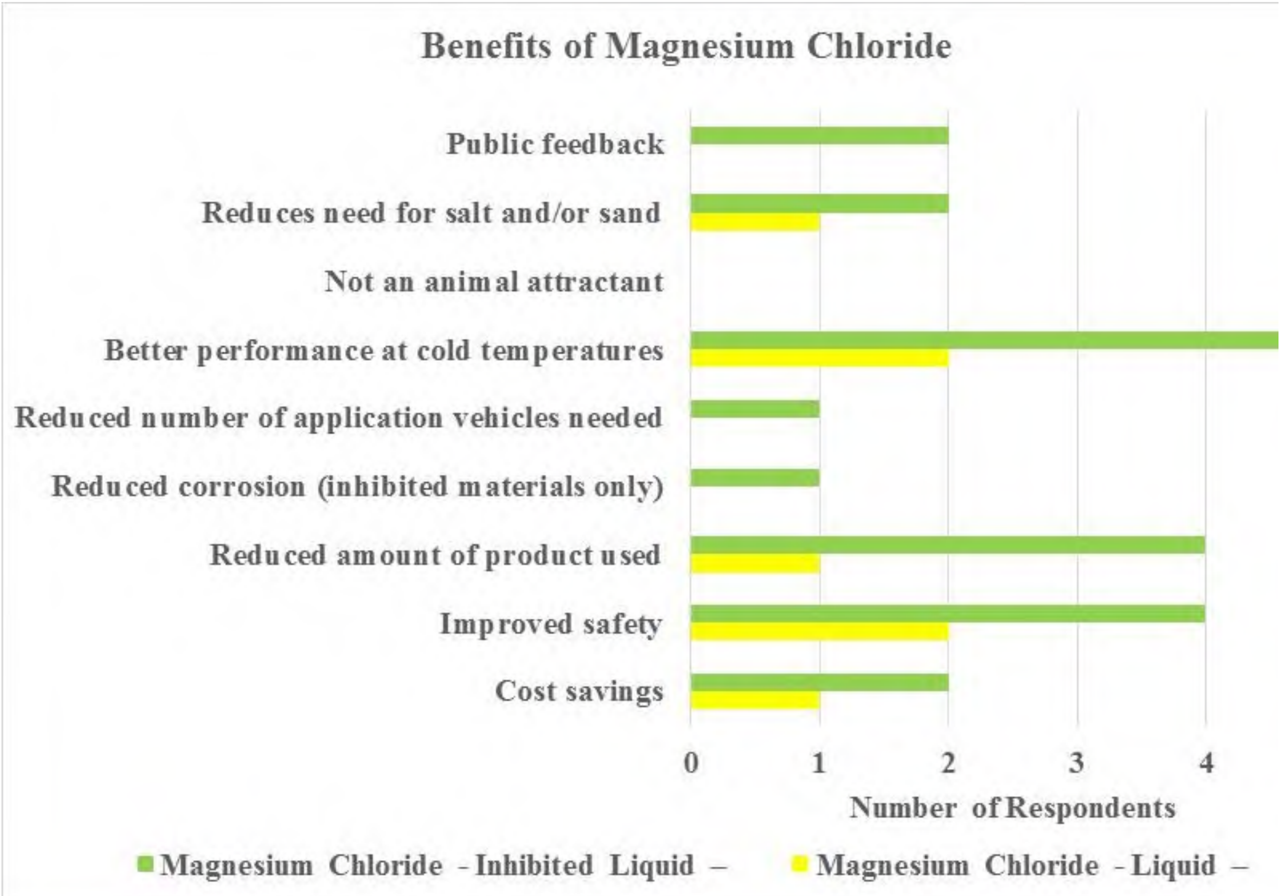

Figure 31: Benefits of Magnesium Chloride

One final comment was received regarding the use of inhibited $MgCl_2$ liquid. The respondent indicate that "we only have a few maintenance units (about 25%) that prefer to us magnesium chloride. Most prefer not to use it because of handling the material and if it is used wrong or at the wrong time it is not as forgiving as salt. We have not seen the cost benefit over using salt".

Calcium Chloride

Calcium Chloride ($CaCl_2$) in different forms (solids and liquids either uninhibited or corrosion inhibited) were used by four responding agencies. One agency used uninhibited $CaCl_2$ solid, three agencies used uninhibited $CaCl_2$ liquid and two agencies used corrosion inhibited $CaCl_2$ liquid. All three respondents indicated that their agency had used $CaCl_2$ in combination with other products (prewetting). Application rates for these materials were reported as follows:

- Solid $CaCl_2$
  - Data not provided
- Liquid $CaCl_2$
  - 30 gallons per lane mile to 300 gallons per lane mile. Never used straight, always in a blended liquid with brine or brine and beetheet. 80/20 blend, 20% Calcium Chloride. Application rate depends on the reason for use.

- 40 gallons per lane mile on roads for anti-icing. 20 - 35 gallons per ton for pre-wetting.
- We apply the mixture at 7 to 9 gallons of liquid per ton. We typically mix it with salt brine at a 10% solution of Calcium Chloride to 90% brine.
- Corrosion Inhibited Liquid $CaCl_2$
  - We apply the mixture at 7 to 9 gallons of liquid per ton.

The costs reported as being associated with the different forms of $CaCl_2$ were as follows:

- Solid $CaCl_2$
  - Data not provided
- Liquid $CaCl_2$
  - $0.55 per gallon
  - $0.65 per gallon
  - $0.69 per gallon
- Corrosion Inhibited Liquid $CaCl_2$
  - $1.58 per gallon

Equipment for applying solid materials was not reported. The equipment used to apply the liquid materials included "bulk 6000 gallon semi tankers, saddle tanks on salt trucks for pre-wetting" and "on board wetting tanks to pre-wet the salt with the Calcium Chloride brine solution at the spinner. Occasionally apply Calcium Chloride directly to the salt in the bed of the truck using an overhead shower system". Uses for the materials were as follows:

- Liquid $CaCl_2$
  - We use it as a brine enhancer during periods of extreme cold to pre-wet the salt at the spinner or to wet an entire load in the bed of the truck.
  - Pre-treating, pre-wetting, direct liquid application.
  - When pavement temperatures drop below 15 degrees we use it in lieu of salt brine for pre-wetting.
- Corrosion Inhibited Liquid $CaCl_2$
  - We use it as a brine enhancer during periods of extreme cold to pre-wet the salt at the spinner or to wet an entire load in the bed of the truck.
  - We use inhibited calcium chloride on new pavements.

Regarding the LOS achieved using $CaCl_2$, more generalized responses were provided. These included:

- LOS is very high but we never use straight calcium.
- We are able to achieve the desired level of service when materials are applied at the proper rate and time.
- Enhanced results when pavement temperatures go below 15 degrees.

None of the respondents had information available regarding the number of applications needed for form of Calcium Chloride to achieve an LOS for a given condition versus another product.

Estimates of the costs associated with $CaCl_2$ (equipment, materials, labor, etc.) were provided by two respondents. The total costs cited were $10,000 and $50,000, with the third respondent indicating these costs were unknown.

Regarding concerns with different aspects of $CaCl_2$, two respondents were concerned with the cost of uninhibited liquids and the potential for corrosion with it, while one respondent indicated concern with its environmental impacts to the roadside and pavement deterioration. For inhibited $CaCl_2$ liquid, two respondents were concerned with the cost of the material. The benefits of $CaCl_2$ cited by respondents included cost savings, reduced amount of product used, better cold temperature performance, reduced need for sand and salt, not serving as an animal attractant and improved safety for both uninhibited and inhibited liquids. Reduced corrosion was cited as a benefit of corrosion inhibited liquid. Additional thoughts provided on $CaCl_2$ included the following:

- Great tool during cold events. However with the inhibited material almost being double in cost, we only use it for newer pavements during the first year in lieu of salt.

<u>Blended Products</u>

Blended products, specifically agricultural byproducts blended with de-icing and anti-icing chemicals, were used by two respondents. One agency used an uninhibited product, while the other used an inhibited product. The types of products used and their respective costs were as follows:

- Uninhibited
  - GeoMelt - $1.20 per gallon
  - BioMelt - $1.20 per gallon
- Inhibited
  - Aqua Salina + IceBite- $1.29 per gallon
  - Beet Heet Concentrate- $1.67 per gallon
  - Beet Heet Severe- $1.47 per gallon
  - XO-Melt2- $1.17 per gallon
  - Geomelt 55- $1.57 per gallon
  - Geomelt S7- $1.33 per gallon

One respondent estimated the annual cost associated blended product operations (equipment, materials, labor, etc.) to be $50,000. Uninhibited products were applied at a rate of 40 gallons per lane mile, while inhibited products were applied "according to manufacturer recommendations". Application equipment included on board wetting systems, namely liquid tanks on trucks and trailers with sprayers.

Respondents indicated that blended products had been used for both blending with salt brine for anti-icing, pre-wetting and to deice roadways. In line with this, both respondents indicated that blended products have been applied in combination with other products (prewetting). One responded that their agency was able to achieve the desired level of service when materials are applied at the proper rate and time, while the other respondent noted that blended products provided increased residual value and lower operating temperatures. Information on the number of applications required to achieve a given LOS versus other products was not provided, but one respondent note that "for pre-treating roads, the blended material can last significantly longer than straight salt brine". In such cases, salt brine could last 1 to 3 days, while the blended product remains on the surface 2 to 3 times longer than that if there is not an immediate storm event.

Only the cost of the material itself was a concern associated with the use of blended products for both respondents. Cost savings, improved safety, reduced amount of product used, longer lasting applications, reduced number of application vehicles needed, better performance at cold temperatures, and reduced need for salt and/or sand were all cited benefits provided by blended products.

Chemical Selection to Achieve LOS

A final series of questions sought information from respondents on how their agency went about selecting different winter maintenance chemicals to achieve a targeted Level of Service. Ten respondents provided feedback on the factors used in deciding what snow and ice control products are used. Figure 32 presents the different factors cited as being important in selecting a particular product. As indicated, cost, effectiveness and availability were all important factors, as was the ability of a product to meet LOS objectives.

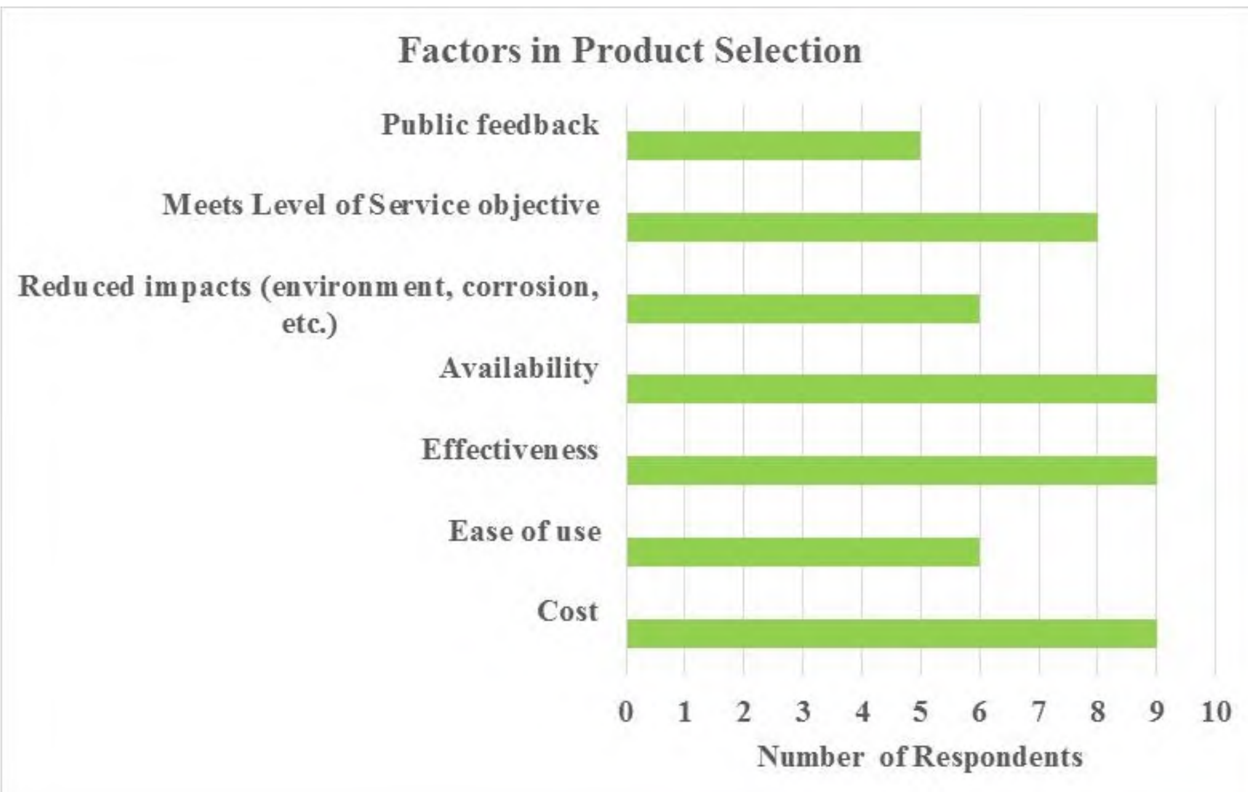

Figure 32: Factors in product selection

Six respondents indicated that their agency had modified its snow and ice control products selection to better meet the prescribed level of service, while four indicated that their agency had not done so. Respondents were also asked for additional feedback on what products were used, what product were switched to, why, and if the switch had proven to be more effective. Responses to these questions included:

- Trying organic blend decider in Chicago area. Feedback has been positive.

- We only have a few maintenance units that still use magnesium (approx. 25%). Most prefer not to use it because of handling the material and if it used wrong or at the wrong time it is not as forgiving as salt. We have over the past several years been switching more to salt brine
- Just the pretreating and pre wetting operations using salt brine and rock salt.
- We switched from a deicing approach, using vast amounts of winter sand, to more of an anti-icing approach back in 2001. The switch has been very effective in reducing cost, improving LOS, and saving money.
- Our District increased our salt content in the anti-skid / salt mixture from 0-30% to 50% (slurry) for this winter season to increase snow and ice removal effectiveness. It has proven to be more effective.
- We started with straight salt brine and moved toward blends. We typically always blend sugar beet based products with salt brine to improve residual performance, unless we have a high probability storm with warm pavement temperatures. Still utilize calcium chloride for pre-wetting at colder pavement temperatures and in our blends. With having a system where we can blend multiple products the ability to "mix for the storm" which creates added flexibility.
- Using liquids, none were used prior.

Regarding public feedback on any of the Advanced materials being used, respondents provided the following information:

- Negative feedback from the use of magnesium chloride due to corrosion concerns.
- Positive feed-back on salt brine usage since it leaves a residue that the public can see when it dries. Positive feed-back from the maintenance crews because the refreeze is easier to control.
- In recent years, people tend to object to any use of calcium or magnesium chloride, on the basis that those chemicals, and not rock salt, are causing corrosion of vehicles.
- Public just want bare roads.
- We have received positive feedback from the traveling public on the improved winter road conditions and less windshield damage due to flying rock.
- Positive feedback on the excellent LOS we are achieving. Our operation is based in a high service level community so expectations are high.
- Positive feedback
- We have received negative comments on the use of brine.